First Assessment of the Fish Populations Beneficial Use Impairment in the Toronto and Region Area of Concern

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Midwood, J.D., Blair, S.G., Boston, C.M., Brown, E., Croft-White, M.V., Francella, V., Gardner Costa, J., Liznick, K., Portiss, R., Smith-Cartwright, L., van der Lee, A., 2022. First assessment of the fish populations beneficial use impairment in the Toronto and Region Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3503: xvii + 283 p.

Fish populations in the Toronto and Region Area of Concern (Toronto AOC) have been assessed as impaired under beneficial use impairment (BUI) #3 (*Degradation of Fish and Wildlife Populations*). Here we use multiple lines of evidence to evaluate the three criteria listed under BUI#3. First, while a lack of evidence of impairment in pelagic prey fish is promising, nearshore fish community metrics were lower than regional reference areas and trends in metric values either showed no change or were largely declining, this indicates that native fish communities remain impaired. Next, populations of some species appear stable [e.g., Northern Pike (*Esox lucius*)], but other top predators are still rarely encountered [e.g., Walleye (*Sander vitreus*)] indicating that not all formerly abundant fish populations have been rehabilitated. Finally, the last criteria is complete given the availability of an integrated restoration priority tool for watershed management. While the overall status of BUI#3 was assessed as still being impaired, ongoing habitat creation and remediation efforts are underway that will hopefully support improvements to the remaining criteria. Recommendations on future monitoring actions and future analytics are presented that lay the foundation for a planned reassessment in 2025. Briefly these include: establishing regionally appropriate targets for the distinct ecotypes within the Toronto AOC, continued monitoring of sentinel sites both within and outside of the AOC, and a more holistic assessment of fish population health that focuses on population structure.

RÉSUMÉ

Midwood, J.D., Blair, S.G., Boston, C.M., Brown, E., Croft-White, M.V., Francella, V., Gardner Costa, J., Liznick, K., Portiss, R., Smith-Cartwright, L., van der Lee, A., 2022. First assessment of the fish populations beneficial use impairment in the Toronto and Region Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3503: xvii + 283 p.

Les populations de poissons du secteur préoccupant de la communauté urbaine de Toronto ont été évaluées comme étant altérées en vertu du critère d'altération d'utilisation bénéfique (AUB) n^o 3 (dégradation des populations de poissons et d'animaux sauvages). Nous utilisons ici plusieurs sources de données pour évaluer les trois critères énumérés dans l'AUB n^o 3. Premièrement, bien que l'absence de preuves d'une dégradation des poissons-proies pélagiques soit prometteuse, les paramètres de la communauté de poissons du littoral étaient inférieurs à ceux des zones de référence régionales, et les tendances des valeurs métriques n'ont montré aucun changement ou étaient largement en déclin, ce qui indique que les communautés de poissons indigènes demeurent altérées. Ensuite, certaines populations semblent stables (p. ex. le grand brochet [*Esox lucius*]), mais on rencontre encore rarement certains prédateurs au sommet de la chaîne alimentaire (p. ex. le doré jaune [*Sander vitreus*]), ce qui indique que toutes les populations de poissons autrefois abondantes n'ont pas été réhabilitées. Enfin, le dernier critère est considéré comme complet étant donné l'accès à un outil intégré de priorité de restauration pour la gestion des bassins versants. Bien que l'état général de l'AUB n^o 3 ait été évalué comme étant altéré, des efforts continus de création d'habitats et de restauration sont en cours, et ceux-ci devraient permettre d'améliorer les critères restants. Des recommandations sur les mesures de surveillance et analyses futures sont présentées, et servent de base à une réévaluation prévue en 2025. En résumé, ces recommandations comprennent l'établissement de cibles régionales appropriées pour les écotypes distincts dans le secteur préoccupant de la communauté urbaine de Toronto, la surveillance continue des sites sentinelles à l'intérieur et à l'extérieur du secteur préoccupant, ainsi qu'une évaluation plus globale de la santé des populations de poissons axée sur la structure des populations.

RATIONALE FOR BUI STATUS

Recommended Beneficial Use Impairment Status: Impaired

Several of lines of evidence were reviewed to assess the three criteria listed for fish component of beneficial use impairment (BUI) #3 – *Degradation of Fish and Wildlife Populations* in the Toronto and Region Area of Concern (AOC) (Table1). To evaluate Criteria FP-1, "ecosystem conditions within the AOC were supporting native fishes in a diverse and stable community structure that included top-level predators", long-term trends in fish community metrics analyzed from two main datasets. Comparison of these metrics to regional reference areas were completed using electrofishing data collected by the Toronto and Region Conservation Authority (TRCA) in section FP-1A and trap net data collected by the Ontario Ministry of Natural Resources and Forestry (OMNRF) in section FP-1B. Pelagic prey fish density and biomass were assessed using split-beam hydroacoustic surveys and mid-water trawling and compared to other areas within western Lake Ontario (section FP-1C). Last, acoustic telemetry was used to track movements of a subset of species within the central waterfront of the AOC to evaluate species-specific residency and general habitat conditions frequented by these species (section FP-1D). To evaluate whether formerly abundant fish populations are rehabilitated where locally depressed or extinct (Criteria FP-2), long-term trends in presence and catch of select top predators and non-native fishes were assessed again using the TRCA electrofishing dataset (section FP-2). Finally, to evaluate whether watershed plans are in place, the use of the integrated restoration priority (IRP) tool for watershed management is explored (section FP-3). The status of each criteria was assessed independently, but the overall recommendation related to the BUI status was informed by all three criteria.

Table 1. Summary of the evaluated status and rationale for this status for each of the three delisting criteria.

Delisting Criteria	Delisting Line of Evidence	Status	Rationale for BUI Status
FP–1 Restore aquatic ecosystem conditions capable of supporting native fishes in a more diverse and stable community structure that includes a top–level predator assemblage of native species (e.g. Northern Pike, Smallmouth Bass, and Walleye).	FP–1A – Fish Community Metrics (Electrofishing)	Impaired (unchanged)	The majority of metrics still indicate impairment in the fish community of the AOC, with declines in recent years. There is evidence for longer–term declines in total catch, and declines appear to be greater in native fishes more than non–native fishes. Relative to regionally similar areas, index of biotic integrity (IBI), species richness, proportion specialist biomass, and proportion piscivore biomass were all lower within the Toronto AOC
Specific Targets: - Biomass of specialist fish species should be greater than 40% - Biomass of piscivores should be greater than 20% total biomass	FP–1B – Fish Community Metrics and Population Trends (Trap Netting)	Impaired (unchanged)	Proportion piscivore biomass met targets in 2/8 years, but was below regionally similar areas; proportion specialist biomass was comparable to regionally similar areas, but below the restoration target IBI scores continue to be indicative of an impaired exposed embayment Relative to regionally similar areas, there were comparable catch rates of Largemotuh Bass and Northern Pike, but lower catches of Smallmouth Bass and Walleye
Overall status: Impaired	FP–1C – Pelagic Prey Fish	**Unimpaired**	No evidence for an impairment in forage fishes relative to the available regional comparison sites, particularly in the central waterfront, suggesting FP–1C is likely not impaired.
	FP–1D – Telemetry–Derived Residence in the Toronto and Region AOC	**Complete**	This section does not directly support BUI evaluations, but provides rationale for focusing on resident species in FP–2.
FP–2. Formerly abundant fish populations are rehabilitated where locally depressed or extinct. **Overall status: Impaired**	FP–2 – Trends in Populations of Top–Predators and Non-Native Fishes	Impaired (unchanged)	There were no increases in catch from (year-year) for native top predators in the Toronto AOC. During the same time period, there was no evidence for decreases in catch of non-native fishes. Northern Pike appear to be stable in most ecotypes and regions where they were found, but unchanged since AOC designation. Walleye and Smallmouth Bass are still rarely encountered lending evidence to the historical importance of the Don River and adjacent marshes for these species.

FP–3. Specific targets contained in watershed plans should be used. Where no plans exist they should be developed.	FP–3– Status of Watershed Plans	**Complete**	The Integrated Restoration Prioritization program supports watershed–based remediation and restorations strategies in the AOC. FP–3 should be considered complete.

Overall status: Impaired

AOC = Area of Concern

BUI = Beneficial Use Impairment

DFO = Department of Fisheries and Oceans

FP = Fish Population

NSCIN = nearshore community index netting

OMNRF = Ontario Ministry of Natural Resources and Forestry

TRCA = Toronto Region Conservation Authority

HISTORY OF THE FISH POPULATIONS BENEFICIAL USE IMPAIRMENT

Wetlands and nearshore freshwater embayments are vital to the sustainability of many ecosystem services provided by the Laurentian Great Lakes and offer economic benefits to more than eight million Canadians and 35 million Americans (GLRC 2005). As part of societal uses of those benefits, urban development within the Greater Toronto Area (GTA; population exceeding five million people) has led to a loss of over 600 hectares of wetland habitat (Whillans 1982). The loss of habitat area combined with degraded water and sediment quality resulted in the coastal area and upstream watersheds of the Toronto Region being listed as an Area of Concern (AOC) in 1987 (Figure 1). In the Toronto and Region AOC, two out of 14 BUIs are directly related to fish and include the Degradation of Fish and Wildlife Populations and the Degradation of Fish and Wildlife Habitat. In support of its AOC designation, a remedial action plan (RAP) was developed with the goal of delisting the Toronto and Region AOC and included various rehabilitation, naturalization, and habitat-creation projects that have been implemented (https://www.torontorap.ca) or are in the process of being implemented (e.g., Don River mouth) to address the BUIs related to fish. Prior to the delisting of the Toronto and Region AOC, these BUIs (among others) will need to be addressed.

Since the 1985 designation of Toronto and Region as an AOC, several planning documents have been developed to guide the de-listing of BUIs in the Toronto AOC. In 1989, a Stage 1 Environmental Conditions and Problem Definition report (Toronto RAP 1989) identified the nature and scope of issues related to water quality, fish, wildlife and habitats. In 1994, a Stage 2 strategy followed to address the identified problems (Toronto RAP 1994). The strategy laid out broad restoration targets and identified 53 key actions to restore the waters and habitats in the area. After the strategy was developed, implementation of remedial actions began.

In *Clean Waters, Clear Choices,* BUI #3 - Degradation of Fish and Wildlife Populations identified the following targets for waterfront fish communities:

1. Biomass of resident piscivores increased to 20%, and specialist fish to 40%
2. Formerly abundant fish populations are rehabilitated where locally depressed or extinct.
3. Proportion of native species is increased towards 100% of total fish community

Since the release of *Clean Water, Clear Choices*, six progress reports on the Toronto and Region RAP were released, the most recent being *Within Reach: 2015 Toronto and Region Remedial Action Plan Progress Report* (Kidd 2016). In this latest progress reports, targets were further refined to reflect the best available science and expert opinion. For instance, “Proportion of native species is increased towards 100% of total fish community” has been modified to better encompass the objective of the goal, which is that Toronto waters support a diverse and stable community that include native fish.

These target as listed in the 2015 progress report will be used for the current status assessment:

1. Restore aquatic ecosystem conditions capable of supporting native fishes in a more diverse and stable community structure that includes a top level predator assemblage of native species (e.g. Northern Pike [*Esox lucius*], Smallmouth Bass [*Micropterus dolomieu*], and Walleye [*Sander vitreus*]).
2. Formerly abundant fish populations are rehabilitated where locally depressed or extinct.
3. Specific targets contained in watershed plans should be used. Where no plans exist they should be developed.

BUI #3: Degradation of Fish and Wildlife Populations, is focused on fish populations since the wildlife population was never listed as impaired in the Toronto and Region AOC. Accordingly, the current report and delisting targets for ‘Degradation of Fish and Wildlife Populations’ are focused solely on fish. Toronto and Region RAP commissioned a report to ensure wildlife populations were considered, entitled “Evaluating the Status of Wildlife Habitat Loss and Degraded Wildlife Populations’ Beneficial Use Impairments in the Toronto and Region Area of Concern (TRCA 2018, https://torontorap.ca/resources/). Additionaly, recent works have evaluated the status of birds within the Toronto AOC watersheds (Cartwright et al. 2021) and freshwater turtles in the waterfront (Dupuis-Desormeaux et al. 2021).

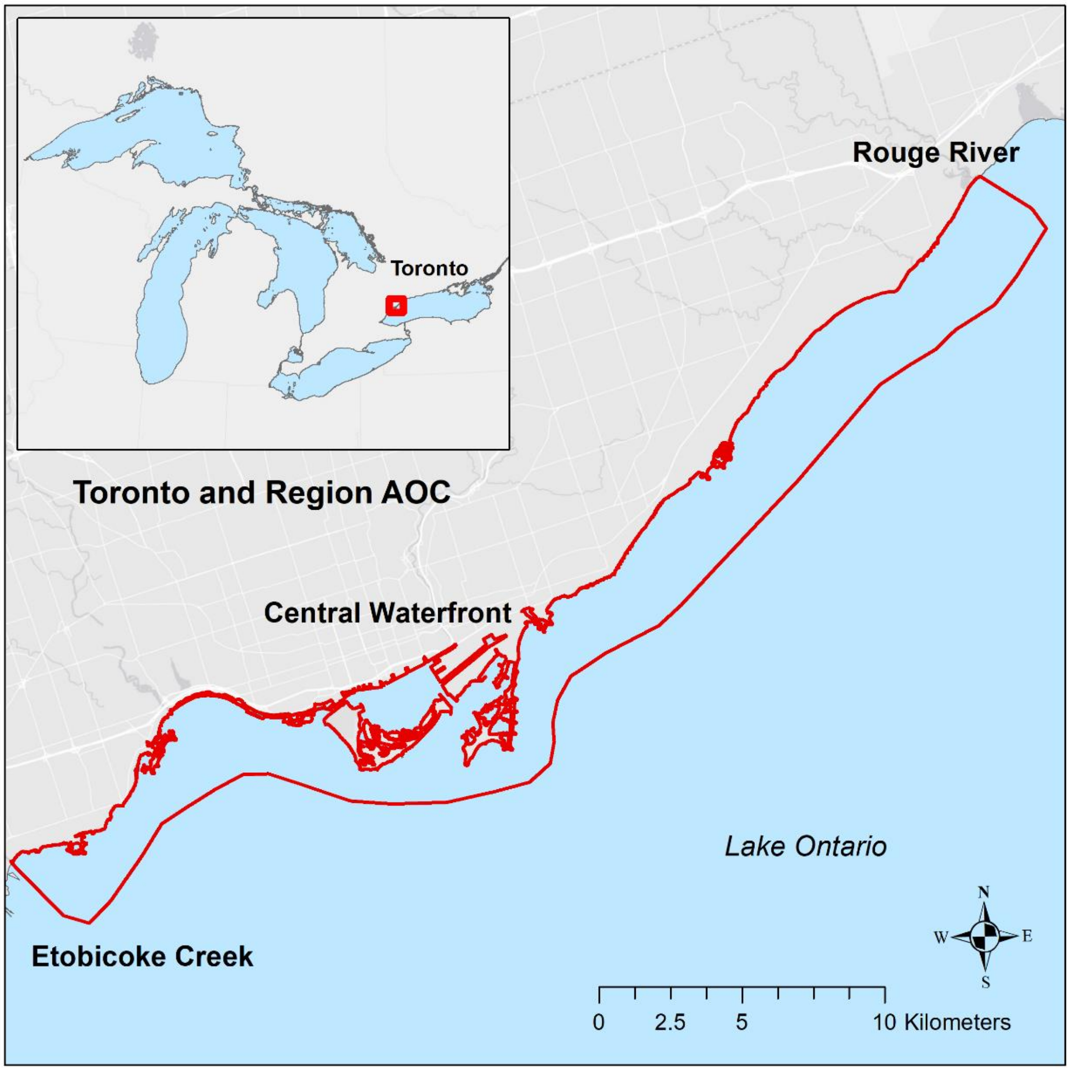

Figure 1. Full extent of the Toronto and Region Area of Concern (Toronto AOC). The red line shows boundary of the AOC with Etobicoke Creek in the west and the Rouge River in the east.

CRITERION FP-1: STABLE AND DIVERSE NATIVE FISH COMMUNITIES

Recommended Criteria Status: Impaired

Summary of Status of FP-1

Multiple lines of evidence were evaluated to assess this criterion, which focuses on establishing ecosystem conditions that can better support diverse and stable native fish communities. First, long-term trends in fish community metrics within the Toronto AOC were explored with limited evidence for improvements in the fish community and some concerning declines in catch of native species (section FP-1A). A subset of these metrics were then compared to regional reference areas, which similarly indicated continued impairment in the fish community (e.g., lower index of biotic integrity scores relative to similar regional sites; sections FP-1A and FP-1B). Shifting to more pelagic waters within the AOC, hydroacoustic surveys and mid-water trawling suggested that, while there was variability among open coast and more protected areas within the AOC, fish density and biomass were comparable to other similar ecotypes in western Lake Ontario (section FP-1C). Finally, eight different species were tagged and tracked using acoustic telemetry to determine their residence and habitat use within the central waterfront of the Toronto AOC (FP-1D). Results identify five species that are resident and thus more likely to respond to actions that are taken within the Toronto AOC, while others that are more migratory may respond more to regional or lake-wide conditions. Despite the positive findings for forage fishes, results from the current assessment of this criteria suggest that nearshore fish communities remain impaired. For many fish community metrics there was considerable variation among ecotypes (e.g., embayment and open coast) and regions, suggesting that future assessments should seek to establish distinct targets that are linked to the ecotype and regional conditions present within the AOC. Such targets have been established for some ecotypes and sampling methods (e.g., trap netting; Bowlby and Hoyle 2017), but should be developed for electrofishing-based data at all ecotypes and regions.

CRITERION FP-1A: FISH COMMUNITY METRICS (ELECTROFISHING) – ASSESSMENT OF TRENDS (1989 – 2018) AND REGIONAL DIFFERENCES IN LITTORAL FISH ASSEMBLAGES IN THE TORONTO AND REGION AREA OF CONCERN

Summary

Comparisons of fish community-based metrics within the Toronto and Region Area of Concern (Toronto AOC) to similar systems in Lake Ontario and temporal trends in these metrics within the Toronto AOC suggest that a majority of metrics continue to indicate impairment in the fish community. While overall indices of biological integrity scores were lower than predicted relative to similar regional sites, some ecotypes and regions within the Toronto AOC have in the past approached or exceeded these targets. Recent declines in the indices of biological integrity and other metrics have erased past gains. There is evidence for longer-term declines in total catch, which are concerning since they appear to be driven more by declines in native fishes than non-native fishes. Changes in environmental conditions (e.g., amount of available habitat, water temperature) may partially explain some of these changes, but additional analyses are required to confirm their influence. Finally, it is recommended that distinct targets for fish community-based metrics be developed for the dominant ecotypes (e.g., embayments, open coast, estuary/rivers, and slip) and sub-regions within the Toronto AOC to ensure future assessments are evaluated against appropriate reference values.

Key Messages

- Relative to regionally similar areas, index of biotic integrity (IBI), species richness, proportion specialist biomass, and proportion piscivore biomass were all lower within the Toronto AOC.
- Majority of fish community metrics indicate impairment in the fish community of the Toronto AOC, with declines in recent years.
- There is evidence for longer-term declines in total catch that are driven by declines in native fishes more than non-native fishes.
- The framework for a temporal assessment from Dietrich et al. (2008) (i.e., breaking trends down by ecotype and regions), is the most appropriate approach for the final assessment of BUI#3.
- The results from FP-1A suggest that criteria FP-1 should remain designated as “impaired”.

Remaining Concerns and Uncertainty

- The influence of environmental factors (e.g., water levels, water temperature, winter ice cover, etc.) on fish community metrics could not be explicitly assessed in the present works (see action #3 below).

- of the few reference areas that were sampled, effort varied across locations in terms of annual effort and the number of locations surveyed, making comparisons difficult (see monitoring suggestion #1 below).
- Several conditions (environmental and operational) likely contributed to fish community metric declines in 2012 – 2014; however, we could not determine which, if any, were the key drivers (see action #3 and monitoring suggestions #2 and #3 below).
- There are lag-times between when habitat remediation actions are completed and when fish species will respond; these lag-times will inherently be species-specific and it may not be possible to predict their duration (see monitoring suggestion #2 below).

Future Monitoring

1. Sentinel sites both within the Toronto AOC and in reference areas outside of the AOC should be established to better support fish community assessments in the future. These sites should be surveyed using a standardized, distance-based (e.g. 100 m) protocol over multiple seasons (spring, summer, and fall) every year. These sites will form the basis for temporal assessments of fish communities and provide consistency that is largely lacking in the present dataset. This does not prevent the inclusion of non-sentinel sites, rather sentinel sites would form the core of the dataset to complement data collected elsewhere within the Toronto AOC (see Future Monitoring Recommendations section for more specific details).
2. Monitoring of fish community metrics in all ecotypes should continue for a minimum of five years (possibly longer for some species) after the Don River revitalization project is complete and all habitat features are reconnected. This is necessary to capture the lag-time between habitat creation and population recovery.
3. Managers should document major changes to fish habitat supply (such as closing off an area to fish). If the project is intended to improve fish habitat and populations, ensure all habitat restoration areas are open and accessible to fish.

Recommended Actions

1. The RAP should consider establishing ecotype- and regional-specific targets for fish community metrics within the Toronto AOC. This may help to better align the noted variability in metric scores throughout the Toronto AOC with regional reference areas that have similar conditions.
2. Future assessments should explore trends in species evenness at ecotypes and regions with the index presented by Pielou (1966) or similar indices forming the basis for this analysis; this will provide guidance on whether the observed declines in total catch are driven by a few specific species or are reflective of a global shift in the abundance of all fishes across the lake.

3. Future temporal analyses should incorporate environmental factors, such as water levels, habitat area, summer temperatures, and winter conditions. This could identify potential drivers behind apparent trends (or lack of trends) and whether the drivers are elements that can be managed (e.g., habitat area) or not (e.g., water levels, climate).
4. Management actions geared at reducing the number of Common Carp in the system would help to increase the proportions of specialists and piscivores closer to established RAP targets. These actions will be most effective if coordinated regionally given that many of the tagged Common Carp were found to leave the system – suggesting a portion of the population is more regional rather than AOC-based.
5. Future analyses should explore temporal changes in the fish community using ordination to determine whether higher level changes in total catch and an absence of trends in species richness obscure changes in community composition [e.g., species replacement is keeping richness constant, but the species that are now dominant exist in higher total densities (e.g. Gizzard Shad)].

Background

Fish are sensitive to changes in environmental conditions and as such, changes in fish communities can be used as to inform the status of the overall health of aquatic ecosystems (Fausch et al. 1990). Based on this linkage, indices of biotic integrity (IBI) have been developed to describe fish community assemblages as a surrogate or indicator of aquatic ecosystem health (Karr 1981). In-line with this concept, the fish population criteria for the Toronto AOC are linked to having "*ecosystem conditions … capable of supporting native fishes in a diverse and stable community structure that includes top predators*" (Toronto RAP 2016). These criteria can thus partially be assessed by documenting the abundance and diversity of fishes, native fishes in particular, and the proportion of the community that is comprised of top predators [and their species-specific abundance – see section FP-2 (Fish Populations)]. Community stability is more challenging to determine, but metrics like the IBI, which integrate a variety of community components including richness, catch, and composition of different trophic and tolerance guilds (Minns et al. 1994), could serve as a surrogate for overall stability. Fausch et al. (1990) provides additional guidance on assumptions related to IBI and how fish communities could respond to degraded ecosystem conditions. Germane to the present discussion, evidence for improving ecosystem conditions in the Toronto AOC in the present section were evaluated using the following metrics: increases in native species, piscivores, and total catch, and decreases in non-native or degradation-tolerant species.

There are few protected embayments in western Lake Ontario and fewer still that provide warmwater fish habitat. This is largely due to shoreline topography, lake fetch, lake depth and prevailing winds. Most of the northwest shoreline of the lake provides habitat for coolwater fish, in part because this area is prone to significant upwelling of cold hypolimnetic water close to shore in the summer (Rao and Murthy, 2001). These upwelling events also penetrate into the central waterfront of the Toronto AOC (i.e., Inner and Outer Harbour and parts of the Toronto Islands and Tommy Thompson Park; Hlevca et al. 2015). As a result, the thermal characteristics of many of the embayments found in the central waterfront (see Murphy et al. 2011) and the fish community assemblages found therein (described in Bowlby and Hoyle 2017) are best characterized as exposed embayments, with only a small number providing temperatures suitable for warmwater fishes (Murphy et al. 2012). These more sheltered embayments within the Toronto AOC provide some of the scarcely available warmwater habitat in western Lake Ontario. Fish communities and derived fish community metrics (i.e., species richness, IBI, catch, etc.) for these more protected and warmer habitats will be naturally distinct relative to open coast and cooler habitats that predominate within the Toronto AOC (Randall and Minns 2002), as such conditions within the Toronto AOC should be assessed separately for different ecosystems or ecotypes.

Previously, fish community-based metrics within the Toronto AOC have been evaluated both in terms of their trends through time (Dietrich et al. 2008) and relative to other comparable systems (i.e., regional reference areas; Hoyle et al. 2018). Standardized time and space-based nearshore boat electrofishing data have been collected by the Toronto and Region Conservation Authority (TRCA) and Fisheries and Oceans Canada (DFO) to evaluate fish population criteria. There are a few specific targets for these criteria; the proportion of biomass comprised of piscivores should be greater than 0.20 and that of specialist fish species greater than 0.40 (Hoyle et al. 2018). Otherwise, a weight of evidence approach is necessary to assess the status of this BUI. Fish community-based metric values within the Toronto AOC will thus be deemed to have met their targets when they are comparable to regional reference areas and there is evidence for increasing trends in native species, piscivores, total catch and richness, and decreasing trends in non-native species.

To support the interpretation of trends in fish community-based metrics, readily available data on environmental conditions within the Toronto AOC and Lake Ontario were compiled. These included environmental parameters related to limnology (e.g., water temperature and water levels), and physical habitat (e.g., ice cover and total area of aquatic habitat). As ectotherms, most fish species have a narrow range of temperatures within which they can thrive and there is considerable variation among species in optimal temperature ranges (Somero 2005). Provided changes in thermal habitat are gradual, as is typical for diel and seasonal changes, and fall within a range of non-lethal temperature for fishes, individual fish are readily able to adapt. Despite this adaptation to gradual changes, fishes do exhibit thermal preferences and are generally grouped into cold, cool, and warmwater thermal guilds. When temperatures fall below or exceed their thermal preference, species will exhibit habitat selection away from or towards more suitable habitat (Peat et al. 2016). As such, temporal changes in temperature during sampling events can result in marked changes in the fish community assemblage that is captured.

A number of researchers have linked increases in Great Lakes water temperatures and decreases in ice cover to climate change (Austin and Colman, 2007; Magnuson et al., 2000; Mason et al., 2016). These changes in water temperature and ice cover can have an impact on fish populations. Farmer et al., (2015) found that shorter, warmer winters had a negative effect on Lake Erie Yellow Perch (*Perca flavescens*) with females that spawned after shorter, warmer winters producing smaller eggs that hatched at lower rates and had smaller larvae. Finstad et al., (2004) found that there was a lower metabolic cost to fish when they were under ice cover and the presence of ice cover can influence feeding, predation, and metabolism (Watz et al., 2013). Given these potential influences, it is possible that fish in Lake Ontario, and the Toronto AOC in particular, are influenced by changes in ice cover as well as water temperature.

Water level control on Lake Ontario began in 1958 in conjunction with the construction of the St. Lawrence seaway. The dams and locks that were built as part of the seaway allowed for the control of water leaving the lake. A number of factors influence Lake Ontario water level management including inflows from the watersheds related to snow melt and precipitation, inflows from Lake Erie via the Niagara River, flood control measures for downstream populations, as well as the need to maintain adequate water levels for shipping. All of these factors are assessed jointly between Canada and the United States and the water level is managed accordingly. Sustained low water levels have been found to negatively impact Great Lakes fish due to changes to and loss of habitat (Midwood and Chow-Fraser 2012; Fracz and Chow-Fraser 2013). In contrast, as water levels rise, newly flooded areas may provide additional forage, refuge, and nursery habitat provided sufficient upland natural habitat is available. The environmental conditions discussed thus far may act independently or in concert to influence fish community-based metrics both within the Toronto AOC and in Lake Ontario in general. Their incorporation into the assessment can provide important ecological context when interpreting apparent trends in metrics.

To support the assessment of BUI #3, the objectives of this section were to: 1) summarize comparisons made of fish community-based metrics within the Toronto AOC with those in other similar aquatic ecosystems in Lake Ontario (herein referred to as regional differences), 2) document temporal trends in fish community-based metrics within the Toronto AOC derived using TRCA boat electrofishing surveys, and 3) document temporal trends in environmental conditions that may contribute to observed variability in fish community-based metrics. Collectively, these works will help determine whether aquatic ecosystems within the Toronto AOC have improved since initial listing such that they are now better able to support native fishes and a diverse fish community. Some of the methods outlined here related to assessing temporal trends are also germane to section FP-2 since similar data preparation steps and model application and interpretation protocols were used for both sections.

Methods

Regional Differences

Hoyle et al. (2018) used boat electrofishing data to compare fish populations in the central waterfront of the Toronto AOC with other Lake Ontario embayments. While multiple embayments were surveyed and compared in this manuscript, Prince Edward

Bay, in eastern Lake Ontario, was similarly classified as an exposed embayment and was thus deemed to be the most appropriate regional reference for embayments in the Toronto AOC [also classified as an exposed embayment in Bowlby and Hoyle (2017) based on exposure and similar fish communities based on trap net data]. A comparison of catch and biomass between the Toronto AOC and this reference site was undertaken to provide guidance for delisting BUI #3.

Electrofishing surveys were conducted according to two different sampling protocols. DFO follows a standardized space-based protocol that samples 100 m transects at approximately 1.5 m water depths in nearshore habitats according to Brousseau et al. (2005). In contrast, TRCA follows a time-based protocol and samples for 1000 seconds; calibration equations were applied to the TRCA 1000 shock second data to convert it to the DFO 100 m equivalent (C.K. Minns, pers. comm.). Data were collected at night from 2006 to 2016 from July to October; the more limited year-range, relative to the time series analysis that follows was selected because it overlapped with concurrent trap netting efforts. More complete methods for data collection and analysis can be found in Hoyle et al. (2018).

Time Series/Trend Analysis
A temporal assessment by Dietrich et al. (2008) used electrofishing at 1000 shock second transects at fixed locations between mid-July and late August between 1989 and 2005 at embayment, estuary-river, and open coast ecotypes (see below for definitions). To interpret the data, seven metrics described by Fausch et al. (1990) that represented signs of environmental degradation were examined and included declines in overall catch, native species, piscivores, and specialists, and increases in the proportion of degradation tolerant species, generalists, and non-native species. The results of this temporal assessment are interpreted in the discussion and a comparison between conclusions derived from data up to 2005 relative to an additional 13 years of data is provided. For the present assessment, a statistical assessment of temporal trends was undertaken that incorporated these additional 13 years of data. The data preparation, statistical analysis, and related result sections that follow provide a high-level summary of this statistical evaluation of temporal trends. The development of a more formal document related to these works is planned and will be available for future assessments.

Data Preparation
TRCA has conducted boat electrofishing surveys within the Toronto AOC since 1989. Detailed methods on sampling are presented in Dietrich et al. (2008), but generally transects were run for approximately 1000 shock seconds and the first 20 individuals of fish species captured were counted and measured [total length (mm) and wet mass (g)], the remaining were batched and measured for wet mass (g). Some transects were shorter or longer than 1000 shock seconds and this variability was generally driven by the size of the area being sampled and/or the main purpose of the sampling event. For the analysis of temporal trends in fish community metrics, this large dataset (over 240,000 individual fish) was divided into subsets to focus on months with the most complete time series (to limit seasonal variation) and on sampling events that occurred

at night [based on likely higher richness and diversity (McKenna 2008) and catch (in wetland ecotypes – Midwood et al. 2016) during night surveys]. While these restrictions dropped a considerable number of viable records (i.e., no anticipated problem or error with these records), we elected to use the subset dataset to reduce the number of factors that could contribute to variability in catch among sampling events through time. July (records from 1989-2018 inclusive) and October (records from 1989-2017, but not 1996, 2000, or 2001) were found to have the most complete records. Night transects were selected based on the hour when they were noted to occur (July nights between 2100 h and 0500 h and October nights between 2000 h and 0700 h).

With the final dataset prepared, sites were then classified based on their ecotype and spatial location (Figure 2). Sampling sites covered a wide range of ecotypes (similar to what is presented in Dietrich et al. 2008) and each site was assigned as open coast (exposed to wind and wave action from Lake Ontario), embayment (protected areas, also includes wetlands), estuary and river (combined since there were insufficient replicates to treat estuary and river sites separately), or slips. Slips were grouped with embayments in the past (see Dietrich et al. 2008) but were separated here since they are deeper and surrounded by hardened shorelines. Ecotype assignments were made based on a combination of the site-type classifications available in the TRCA dataset, level of exposure to wind and wave action (i.e., weighted wind fetch, with mean values >5 km indicating open coast vs embayment), and a visual review of where sites were situated in Google Earth Pro (Mountain View, CA). There were considerably more sites in the open coast and embayment ecotypes relative to estuary and river and slips, therefore sites within these first two ecotypes were further broken down by their spatial location within the Toronto AOC (Figure 2b). Open coast was broken down into sites: west of the central waterfront (herein western), within the central waterfront (herein centralWF), west of Bluffer's Park (herein westbluffers), and east of Bluffer's Park (herein eastbluffers). Embayment sites were broken down into five regions: west of the central waterfront (herein otherwest), east of the central waterfront (herein othereast), within the Toronto Islands, within Tommy Thompson Park (herein TTP), and sites in the central waterfront but not within the Toronto Islands or TTP (herein centralWF). This sub-division into ecotypes and regions allowed for a determination of whether a specific region or regions (for open coasts and embayments) were driving any observed trends at the ecotype level.

Some July and October night electrofishing transects were run outside of the bounds of the Toronto AOC and these sites were extracted and analyzed separately as regional "reference" sites to provide an indication of whether observed trends within the Toronto AOC matched trends in sites proximate but outside of its boundary. There were insufficient sites in the reference group for October, too few for estuaries and rivers, and none for slips, therefore only reference data for open coast and embayment ecotypes in July were plotted. More formal statistical models for the open coast and embayment reference areas in July could not be completed due to insufficient replicates.

Fish community data for each electrofishing transect were aggregated into ten fish community-based metrics or indicators (Table 2). The IBI and $\mathrm{IBI}_{\mathrm{Adj}}$ were calculated (after Minns et al. 1994, but with a correction factor to convert from 1000 shock second transects to 100 m transects; C.K. Minns, pers. comm.). This IBI was developed for littoral areas in the lower Great Lakes and has been frequently applied to assess conditions in Great Lakes AOCs (Randall and Minns 2002; Brousseau et al. 2011; Boston et al. 2016; Hoyle et al. 2018). Additional metrics were partially selected based on Fausch et al. (1990), who, as noted, identified metrics and their likely response to environmental degradation. These included metrics that would be expected to decline with increasing degradation (e.g., total catch, native species richness). Total catch and richness were further split into native and non-native species, and total catch of native cyprinids to provide information on which, if any, of these sub-groups were contributing to observed higher-level trends. Finally, the proportion of total biomass that was comprised of piscivores (PPB) was also assessed since a proportion value of 0.20 has been set as a RAP target both for the Toronto AOC and in other Great Lake AOCs (Brousseau et al. 2004; Brousseau et al. 2011; Boston et al. 2016; Hoyle and Yuille 2016).

Statistical Analysis

All analyses were conducted in RStudio (R 3.6.0; R Development Core Team, 2019). Within the electrofishing dataset, there were differences each year in the number and location of transects within each ecotype and region. Further, it was expected that sites that were situated in proximity would have similar metric values (i.e., likely that there is spatial autocorrelation within the dataset). As a result, a Bayesian inference modelling approach was used [Integrated Nested Laplace Approximations (INLA), Rue et al., 2017], which includes methods to account for spatial-temporal autocorrelation (Lindgren et al. 2011). The INLA model produces a spatial field of correlated random effects projected over a mesh (Figure 3) constructed with built in INLA functions. The spatial correlation among sampling sites was represented with the Matérn correlation function, which is parameterized with the range parameter that describes the distance to which sampling sites are at least 10% correlated. A drawback to this approach is that the inclusion of a spatial random effect can increase the credible intervals in the model, therefore models were fit both with and without this random field and the resulting Deviance Information Criterion (DIC – an estimate of model fit; Spiegelhalter et al. 2002) values were compared and the model with the lowest DIC was generally selected. For most, but not all metrics (Table 3), the model with the spatial random field had better fit. All models were fit using the R-INLA package (http://www.r-inla.org) as well as support code and functions presented in Zuur et al. (2017) and Zuur and Ieno (2018).

Models were fit using the probability distribution most suited to the data. Count data (e.g., richness or catch) were modelled using either a Poisson or negative binomial distribution (negative binomial was used when there was evidence for over-dispersion in the Poisson model) and the IBI, IBI_{Adj}, and PPB, which have defined limits (0 to 100 for the indices and 0 to 1 for PPB), were rescaled using equation 1 (where N = the total number of samples) to a proportion that ranged from >0 to <1 and were then modelled using a beta distribution.

Equation 1

$$\frac{\left(\left(\frac{Metric}{100}\right) \times (N-1) + 0.5\right)}{N}$$

For some metrics, modifications were made to the base dataset to remove outliers (e.g., true catch values that were much higher than the rest of the dataset and were found to impair model fit) or ecotypes/regions with low total sample sizes or incomplete temporal records. Since the core objective of these works was to model trends in metrics through time, no covariates outside of the ecotype or region were included. Effort was incorporated into each model as an offset with sampling effort, measured in log-transformed shock seconds. In some instances, particularly when overall sample sizes were low (<100 transects), effort appeared to prevent an accurate prediction of temporal trends. In these instances (noted in Table 3) effort was removed from the model and the initial dataset was subset to limit the range of sampling effort from 900 – 1100 shock seconds.

Equation 2

$$y_{i,t} = Poisson(\lambda_{i,t}),$$

$$E(y_{i,t}^{01}) = \pi_{i,t}\ and\ var(y_{i,t}) = \lambda_{i,t},$$

$$log\left({}^{\lambda_{i,t}}\!/_{effort_{i,t}}\right) = Z_{i,t} + u_{t,j} + v_i$$

$$u_{t,j} = u_{t-1,j} + w_t, \qquad where\ w_t \sim N(0, \sigma_w^2),$$

$$v_i = \Phi v_i + s_i.$$

An example of the model formula based on count data is presented in Equation 2. In this example, count data at site *i* in year *t* was modelled with a Poisson distribution with mean λi,t. $Z_{i,t}$ represents all fixed effects (e.g. categorical variables ecotype or region and other covariates). The trend in time, $u_{t,j}$, was specific to each ecotype/regions, *j*, within the model and was modelled as a random walk function with noise term w_t. The spatial effect is represented by w_t with mean 0 and covariance matrix Σ.

As an alternative demonstration of how the model was implemented, an example of a generalized model formula in R notation is presented in equation 3 where: the first row includes the individual ecotypes or regions used in the model; the second row offsets the response values by the sampling effort (log-transformed); the third row incorporates year as a random effect modelled using a random-walk structure; the fourth row incorporates the spatial random effect; and the final row allows for differences in the apparent trend for each ecotype or region by year (rather than have a global trend applied to each ecotype or region). Once a model for each metric was selected and its fit was validated (described below), the mean temporal trend with credible intervals was plotted along with the raw data.

Equation 3

Metric ~ formula(-1 + Intercept + Ecotype/Region$_{i+1}$ + Ecotype/Region $_{i+2}$ +
Ecotype/Region $_{i+3}$ +
offset(log(Effort)) +
f(Year, model = "rw1") +
f(w, model = spde) +
f(Year, model = "rw1", replicate = as.numeric(Ecotype/Region))

A complete list of the models used for each metric at the ecotype and region levels and any associated adjustments made to improve model fit can be found in Table 3. Output from each model was validated using Pearson residuals for the model and a six-step process that is outlined in Table 4 and based on a workflow presented in Zuur et al. (2017) and Zuur and Ieno (2018). A variety of model parameters were recorded including: DIC (with and without the spatial term), the effective number of parameters, the mean, standard deviation, and 95% credible intervals for the posterior fixed effects, and the mean, standard deviation, and 95% credible intervals for the model hyperparameters. Only the DIC and effective parameters are presented in Table 3, but full model output is available in Appendix A.

Temporal trends derived using the INLA modelling approach were plotted and visually interpreted; yearly metric values with credible intervals that were distinct (i.e., did not overlap) were interpreted as representing a difference in the metric value between the two time periods. Given the large number of metrics, *post-hoc* analyses using contrasts were not undertaken, therefore apparent differences are described but not quantified.

Trends in Environmental Conditions

Environmental conditions that may influence the temporal trends in fish community metrics were explored and plotted through time. These included: water temperature, Lake Ontario ice cover (surrogate for over wintering conditions within the Toronto AOC), Lake Ontario water levels, and Toronto AOC-specific changes in area of aquatic habitat.

Water temperature:

To capture temporal trends in water temperature, the same modelling approach that was used for the assessment of temporal trends in fish community-based metrics was applied to water temperature data collected concurrently with electrofishing surveys in July and October. This included the incorporation of a spatial random field, with models using a Gaussian distribution and these models were applied at the ecotype level. Model fit was similarly evaluated and the output was plotted (mean temporal trend with credible interval) and visually interpreted.

Ice Cover:

Lake Ontario ice cover data from the National Oceanic and Atmospheric Administration (1973-2018) was used to plot: changes in time in maximum ice cover, duration of ice cover, last day of ice cover, and the number of days when ice cover was greater than 5%, 10%, and 20%. While this data set does not cover the lake at a resolution that can provide details on ice coverage in the Toronto AOC, lake-wide trends were assumed to be applicable to the Toronto AOC.

Water Level:

Historical Lake Ontario monthly mean water level data were compiled from the Canadian Hydrographic Service (http://www.tides.gc.ca/C&A/network_means-eng.html). July and October mean values were plotted from 1989 – 2018 as was the monthly rate of change in water level for the periods before and after the construction of the St. Lawrence seaway.

Aquatic Habitat:

A more formal assessment of habitat conditions within the Toronto AOC is underway related to BUI#14 (*Loss of fish and wildlife habitat*). For the present assessment, a simple plot of the cumulative gains and losses of the surface area of aquatic habitat within the Toronto AOC is presented.

Results

Regional Differences

Throughout the embayments surveyed in Lake Ontario, mean native species richness ranged from a low of 1.7 (Port Dalhousie and Frenchman's Bay) to a high of 7.9 in Upper Bay of Quinte, with values in the Toronto AOC of 2.9, well below the 5.6 observed in Prince Edward Bay (Table 5; Hoyle et al. 2018). The mean proportion piscivore biomass and proportion specialist biomass were similarly lower in the Toronto AOC (0.21 vs 0.45 and 0.28 and 0.33, respectively). IBI values ranged from 28.5 at Bronte Shore to 72.5 in the Upper Bay of Quinte, with an IBI of 45.1 in the Toronto AOC (below the mean of 66.6 at Prince Edward Bay). Within the Toronto AOC, IBI scores were found to be significantly greater in the Toronto Islands (50.8) compared to Tommy Thompson Park (40.2; see Hoyle et al. 2018 for complete results). The most abundant species captured during electrofishing surveys in the Toronto AOC were Alewife (*Alosa pseudoharengus*), Yellow Perch, Pumpkinseed (*Lepomis gibbosus*), Largemouth Bass (*Micropterus salmoides*), and Emerald Shiner (*Notropis atherinoides*) while the species with the highest biomass were Common Carp (*Cyprinus carpio*), Chinook Salmon (*Oncorhynchus tshawytscha*), Bowfin (*Amia calva*), Gizzard Shad (*Dorosoma cepedianum*), and Brown Bullhead (*Ameiurus nebulosus*).

Time Series/Trend Analysis

Trends in IBI and adjusted IBI scores and other metrics were examined in the Toronto AOC from 1989 – 2018. These trends were examined at the ecotype level (embayment, open coast, estuary/river, and slips) and regionally, using data collected in July and October; IBI and IBI_{Adj} were also examined globally (i.e., overall-all ecotypes combined). There were insufficient data collected prior to 2002 at slips to comment on trends before this period at this ecotype and generally limited data at the centralWF regions (both embayment and open coast ecotypes) also presented challenges.

IBI:

There were no changes in mean IBI scores from the beginning of the time series (1989) to the end (2018) during the July or October sampling periods at the global, ecotype, or regional level. However, there were noteworthy trends during the July time series. Globally, there were higher IBI scores between 1998 – 2006 compared to 2015 – 2018 (Figure 4). This trend was also seen in embayments at the ecotype-level but not at any of the other ecotypes suggesting that there was an improvement in IBI scores between 1998 – 2006 at embayments, but the trend did not continue after 2006 (Figure 5). At embayments in July, there appeared to be two primary periods of decline from the 1998 – 2006 peak, the first occurred from 2006 – 2008 and the second from 2013 – 2015 (Figure 5).

Mean IBI scores at embayments were generally higher in the Toronto Islands than at other embayments (e.g. TTP or otherwest) in July. With the exception of 2015 – 2018, mean IBI values at the Toronto Islands were between 60 – 70 (i.e., good), which is at or above IBI targets that have been used in the Bay of Quinte and Severn Sound (>60) and are currently in place for Hamilton Harbour (55 – 60). Mean IBI values at all regional embayments in October were also on average greater than 60. Among ecotypes, mean IBI scores were higher at embayments and estuary-river ecotypes than at open coast or slips (Figure 6). There were no changes in IBI scores over time at reference locations and IBI values were similar in the Toronto AOC relative to reference locations.

IBI_{Adj}:

Globally, there was no change in the mean IBI_{Adj} values at the start and end of the time series during the July or October sampling periods; however, there were some important changes to note during the time series. IBI_{Adj} scores between 2013 – 2015 and 2017 – 2018 were lower than the mean values between 2001 – 2006 and 2009 – 2012 (Figure 7). A similar trend was noted at the embayment, estuary/river, and open coast ecotypes (Figure 8); the data suggests that IBI_{Adj} scores between 2013 – 2015 and 2017 – 2018 are lower than what they were during multiple peaks between 1998 – 2012. In general, IBI_{Adj} values were higher at embayment and estuary/river sites than at open coast or slips ecotypes. The trend that was noted globally and at the ecotype level was also noted among embayment regions suggesting a declining trend (Figure 9); there was a peak in the mid-2000s, a low between 2013 – 2015, and to a lesser extent another low between 2017 – 2018. There were no trends at open coast regions in July nor during the fall sampling period at the ecotype or regional level. There were no changes in the IBI_{Adj} scores over time at the embayment or open coast reference locations, but mean IBI_{Adj} values were similar within the Toronto AOC relative to reference locations.

Total Catch and Species Richness

Total catch declined over time at embayment, estuary river, and open coast sites during July by approximately 50% with mean values in 2015 and 2017 – 2018 lower than what they were between 1989 and 2001 (Figure 10). At the regional level, a declining trend was noted at most regional embayments; however, these trends were not important regionally for either embayment or open coast regions in summer or fall largely due to large credible intervals. There was no change in catch over time at embayments or open coast habitats during the October sampling period. In general, catches were lower in the fall than during the summer. At reference locations in July, there were no apparent trends in total catch at embayments but there was a decline at open coast sites; mean total catch was lower between 2014 – 2018 than it was between 1998 – 2004 (Figure 11). A decline in total catch in embayments within the Toronto AOC but not at reference sites suggests that this may be a Toronto AOC-specific decline in total catch.

There were no changes in total species richness over time during July (Figure 12) or October at the ecotype or regional level or at reference locations. Total richness on average was higher in embayments and estuary/rivers (means ranged from 5 – 9) than at other ecotypes (means ranged from of 2 – 5) in both sampling periods. Mean species richness was similarly higher at reference embayments (8) than at open coast sites (6).

Proportion Piscivore Biomass (PPB)
For all PPB models, fit was found to be poor (Table 3) and results should therefore be interpreted with caution. There were a considerable number of zeroes in the dataset comprising 36% of the dataset in July and 26% in October. These zeroes could only be included in the ecotype models, and their absence in the embayment and open coast regional models artificially inflated fitted predicted PPB values. Overall challenges with model fit are presumed to be caused by the number of zeroes associated, generally low variance, and low values in the PPB metrics (e.g., mean ± standard deviation = 0.17 ± 0.19 in July and 0.32 ± 0.27 in October <0.2), which can impair prediction of values through time or among ecotypes/regions. With these caveats in mind, no changes over time in PPB were evident at the ecotype or regional level during July or October sampling periods. PPB, on average, was below healthy fish population target of a proportion of 0.2 at the ecotype level in July but increased in the fall (>0.2) at all ecotypes. PPB was also higher on average at embayments than open coast habitats both within the Toronto AOC and in reference areas; although mean PPB was high in 2018 at open coast reference locations (driven by Largemouth Bass and Smallmouth Bass captured just outside Frenchman’s Bay) compared to other years (Figure 13).

Native Cyprinid ─ Catch:
The mean catch of native cyprinids has declined over time at embayments, open coast, and estuary/river habitats during July (Figure 14) and at embayments in October. The mean catch of native cyprinids in July was lower between 2015 – 2018 than it was during other times at embayment (2003 – 2014), estuary/river (1994 – 1999 and 2004 – 2006), and open coast (2005 – 2007 and 2011 – 2013) ecotypes. At the regional level in July, the decline at open coast sites during the late 2000s was apparent at eastbluffers, westbluffers, and western sites (Figure 15). There was no clear trend at reference locations in the catch of native cyprinids at embayment or open coast habitats in July. The decline in mean catch of native cyprinids at embayments in October was similar to the July trends with low mean catch values in the most recent sampling years (2014 – 2018). In contrast to the July trends, however, similar lows were also evident earlier in

the time record (1989 – 1993; 2008 – 2009; Figure 16). Trends in October at other ecotypes were not detected.

Native Species ─ Catch and Richness:

There was a decline in the mean catch of native species at embayments over time in July. The mean catch from 2015 – 2018 was lower (approximately by half) than what it was between 1989 – 2000 (Figure 17). Similar declines were also evident at the other three ecotypes, although lower values were more apparent primarily in 2017 – 2018. No declines were evident at reference areas in July. While declining trends in mean total catch of native species were also present for most embayment and open coast regions (with lowest catch rates in the most recent 3 – 5 years), wide credible intervals limited our confidence to suggest a trend. In October, more recent catches (2014 – 2018) at the open coast ecotype were lower than at the start of the sampling record, but there were no trends for the other ecotypes. There were no trends in total catch of native fishes at reference areas in July.

There were no changes through time in total native species richness at the ecotype or regional levels in either July or October. Native species richness, however, was higher at embayments and estuary/rivers (mean generally between 5 – 8) than at open coast or slip ecotypes (mean generally between 2 – 5) in both months. At reference embayment and open coast habitats in July there was a decline in native species richness between 2000 – 2005; average native species richness has increased since then.

Non-native species:

Between 1989 and 2018 there was no change in non-native species total catch over time at the ecotype level during July or October; however, there was an important decline in the mid-2000s (2004 – 2005) that is lower than 1989 – 2000 period at embayment and open coast habitats (Figure 18). Catch of non-native fishes increases again throughout the latter half of the 2000s at these ecotypes. For the open coast regional and reference sites there is a suggestion a decline in non-native catch in 2018, but this trend cannot be confirmed without additional years of data. There were no important trends over time in the non-native species catch during October nor was there evidence for changes in non-native species richness over time at ecotypes in July or October (mean values ranging from 1 – 3 species).

Trends in Environmental Conditions

Water Temperature:

Mean water temperatures varied greatly during sampling for both July (low of 8.0°C at open coast in 1993 and high of 25.0°C at slips in 2013; Figure 19) and October (low of 7.5°C at estuary/rivers in 1993 and high of 17.5°C at embayments in 2016; Figure 20) both within and among ecotypes. In general, temperatures were cooler at open coast and slip sites relative to embayments and estuary/rivers. Annual high and low mean water temperature values were not always consistent among ecotypes. For example, in July, high mean water temperatures in embayments in 2013 (23.0°C) were followed by low values in 2014 (16.0°C), but similarly low values at open coast sites (11.0°C) were not apparent until 2015 (Figure 19). Longer-term trends (i.e., general increasing or decreasing temperatures) were not evident for any ecotype during either month.

Ice Cover:
Using National Oceanic and Atmospheric Administration's ice cover data we found a negative linear trend in the last day of ice coverage (p=0.05; Appendix B), suggesting that over time the ice on Lake Ontario is melting earlier. There was also a trend showing that the number of days where there was more than 5% ice coverage decreased significantly over the time period (p=0.03; Figure 21). The winters with longest periods of >5% ice cover that fell within the electrofishing data records occurred in 1993, 2012, and 2013. There were no trends in the maximum ice coverage, duration of ice coverage or the number of days when ice coverage was greater than 10% and 20% (Appendix B).

Water Level:
Between 1990 and 2016, mean July water level elevations in Lake Ontario generally fell between 74.8 and 75.2 m (above sea level; Figure 22). 2017 was a record-breaking year with the mean July water level reaching 75.8 m, the highest that it had been since record keeping began in 1918. The mean October water level recorded in 2017 were comparable to what was observed in 1993, but water levels in July 1993 were not notably higher. For both July and October, water levels were lowest in 2012, although similar lows were also observed in July in 1999. Within a year, water levels were generally lowest in December and highest in May and June (1959 – 2018) as shown in Appendix B. Year to year variation in water level was also higher in the spring (March – June) than at other times in the year.

On average, the rate of change of water levels was highest in April, which coincides with melting snowpack and increased precipitation. Figure 23 shows the rate of change for the period before water level management began (1918 – 1958) and after (1959 – 2018). Both periods were similar, with a peak in April. The rate of change in water levels for 2017 was greater than the average rates were already in January there was a substantial increase in the water levels over the previous month. This increasing trend continued into April and finally peaked in May. Control measures continued into the fall of 2017 in order to bring the water levels down to average levels.

Aquatic Habitat:
Significant losses in the surface area of aquatic habitat occurred in the late 1980's through to the late 1990's (Figure 24); however, there were similar gains (includes both habitat enhancement and habitat creation) during the same period as restoration projects were implemented. When functional gains (i.e., whether habitat enhancement or creation projects were accessible to fish) are incorporated, there was a decline in available habitat starting in 2012 at TTP when access to embayment D was restricted and continued through 2015 – 2016 with a loss of access to Cells 1 and 2. These functional habitat losses brought the total fish habitat area down to levels that were last seen prior to 2000 (Figure 24).

Discussion

Regional Differences

Relative to other embayments in Lake Ontario, IBI, species richness, and other fish community-based metric values in the Toronto AOC were similar to degraded sheltered embayments also found in western Lake Ontario (e.g., Hamilton Harbour, Frenchman's Bay) than comparatively healthy embayments in the Toronto AOC's eastern part of the basin. Hoyle et al. (2018) and Bowlby and Hoyle (2017) have suggested that given the observed high levels of exchange between protected habitats in the Toronto AOC and Lake Ontario as well as exposure to wind and wave action, the embayments in the Toronto AOC are best considered exposed embayments. As a result, the sole exposed embayment that was available as a regional reference for electrofishing data was Prince Edward Bay [additional sites were identified (e.g., Presqu'ile Bay), but electrofishing data from this site were not incorporated into the present assessment]; IBI, species richness, proportion specialist biomass, and the proportion piscivore biomass were all comparatively lower in the Toronto AOC. While PPB was lower in Toronto AOC embayment habitats, the mean value of 0.21 (range 0.15 – 0.46) meets the target of 0.20 set by the RAP, but with a considerable range both above and below the target. Ultimately PPB should consistently be at or above this target, but the authors of Hoyle et al. (2018) note that given the extent of development and disturbance within the Toronto AOC, it is promising to see PPB approaching and occasionally exceeding this target.

Of the ten species identified during the electrofishing surveys reported by Hoyle et al. (2018), two were generalist species (Common Carp and Brown Bullhead), three were piscivores (Bowfin, Chinook Salmon, and Largemouth Bass) and five were specialists (Alewife, Gizzard Shad, Emerald Shiner, Pumpkinseed, and Yellow Perch). The high proportion of generalist species biomass can be attributed to the catch of large bodied Common Carp. Of the three piscivorous fish, the non-native Chinook Salmon contributed almost 50% to the combined biomass. With only 0.28 proportion specialist biomass in the Toronto AOC, there is an indication that there are too many large bodied generalist fish such as the Common Carp. Management actions geared at reducing the number of Common Carp in the system (e.g., active removal, continued use of exclusion structures) would help to increase the proportions of specialist and piscivore and increase the likelihood of these metrics meeting the established RAP targets. Temporal trends in Common Carp catch are discussed in section FP-2.

Hoyle et al. (2018) found that a greater degree of exposure to Lake Ontario and higher fetch was associated with lower IBI scores, which is consistent with past comparisons among ecotypes (Randall and Minns 2002). By incorporating these factors into a predictive model, they concluded that the IBI scores calculated using electrofishing data were lower (45.1) in the Toronto AOC than expected (55.5). This indicates that there are still opportunities for improvement within the Toronto AOC as a whole, but the authors did note variability in IBI scores within the Toronto AOC (e.g., the Toronto Islands were higher than Tommy Thompson Park). Establishing ecotype- and regionally-specific targets within the Toronto AOC may therefore better align the noted variability in IBI and metric scores throughout the system with regional reference areas that are more targeted for local conditions.

Time Series/Trend Analysis:

There was little change in the overall fish community between 1989 and 2005, the fish community remained degraded and was continuing to degrade based on: a reduction in total catch, an increase in non-native species (although non-native fish catch was found to decline), an increase in generalist biomass, a decline in specialist biomass, and no change in the proportion of piscivore biomass or native species richness (Dietrich et al. (2008). For metrics that were also analyzed in the longer time record (1989 – 2018), many of these trends have continued. Total catch has continued to decline (50% reduction since 1989) while native species richness and the proportion of piscivore biomass have not changed (Table 6).

Declining trends reported in Dietrich et al. (2008) continued up to 2018 for the July sampling period. While a similar trend was not evident for the October dataset, total catch as a whole was lower in October, and there was no evidence for an increasing trend during this sampling period. For the two ecotypes with available reference data, the open coast sites did show a similar declining trend; however, total catch at embayment reference sites was stable suggesting that for this ecotype, declines are Toronto AOC-specific. Within embayments in the Toronto AOC, the greatest declines in total catch were observed in the Toronto Islands and Tommy Thompson Park. Despite the observed declines in total catch, there was no indication that species richness had changed during the same period. Species evenness was missing from the present assessment and would provide guidance on whether the declines in total catch were driven by a few specific species (this would manifest as a change in evenness and may indicate components of specific species life history are not being met) or were more reflective of a global shift in the abundance of all fishes that could be linked to regional changes in productivity (such as the introduction of aquatic invasive species). Future assessments should explore trends in species evenness at ecotypes and regions with the index presented by Pielou (1966) or similar indices forming the basis for this analysis.

Native species, native cyprinids, and non-native fish total catch were explored to identify which component of the fish community was driving declines in total catch. In contrast to Dietrich et al. (2008) who found evidence for declining trends in catch of non-native fishes, our expanded dataset shows no trend with the exception of a short decline in the mid-2000s and likely explains Dietrich et al. (2008) earlier findings. The cessation of this decline was likely driven by the invasion of Round Goby (*Neogobius melanostomus)*; they were first detected in 2003 but did not show marked increases in total catch until after 2005. Common Carp were the only other non-native species that is specifically addressed in section FP-2 and they showed a long-term declining trend only at estuary/river ecotypes in July. This suggests that the overall declines in total catch are not driven by changes in total catch of non-native fishes. For native species catch, the data from 1989 – 2005 showed an increasing trend at embayments starting in 2002; however, this trend did not continue, rather both native species in general and native cyprinids in particular exhibited declines in catch through to 2018. From an assessment perspective, these results negate some of the positive trends highlighted in Dietrich et al. (2008); however, at least for the non-native fishes, Round Goby catch at some embayments (e.g., Toronto Islands and Tommy Thompson Park) has shown a very recent decline that if maintained could put this trend back on a more desirable trajectory. Temporal trends in Round Goby catch are discussed in section FP-2.

Top predators are specifically mentioned in the delisting criteria for BUI#3 and their proportional contribution to overall biomass has been used as a means to assess whether there is a proper trophic balance within the Toronto AOC fish community. This is also one of the few metrics that has a specific target associated with it (proportion >0.20), however, presently for the Toronto AOC, mean values during July are below this threshold with no evidence for an increasing or decreasing trend through time. Mean values were higher at all ecotypes during the fall sampling period, which may be partially driven by top predators moving into nearshore areas (where they are more likely to be encountered with electrofishing gear). This shift could be driven by a variety of factors including: decreasing water temperatures in shallow waters, shifting occupancy in preparation for overwintering, or movements towards spawning beds for fall-spawning species (e.g., salmonids). Tracking of top predators on the Toronto Harbour acoustic telemetry array has documented some seasonal shifts in habitat use and reductions in home range in the fall (e.g., Bowfin; Midwood et al. 2018a) and through to the winter (e.g., Walleye and Largemouth Bass in Cell 2; Midwood et al. 2019a). Documenting the seasonal distribution of top predators within the Toronto AOC, both in terms of their habitat selection and their depth, would help determine whether lower than target PPB values in the summer are driven by top predators moving into cooler and deeper waters where they cannot be captured using electrofishing or whether PPB values above the target in the fall are driven by aggregations of top predators for overwintering or spawning. Without confirmation of any potential seasonally dependent sampling differences for top predators, an assessment of top predator contributions to the overall fish community using PPB alone is challenging.

A further complication is that top predators were infrequently captured, resulting in approximately 1/3 of sampling sites in July with zero PPB values. These zeros are true in the sense that they did not detect a piscivore in that transect, however, if a transect is deemed to be reflective of a larger area, these zeros likely do not reflect the presence of a top predator within an entire embayment (for example) at the time of sampling. Rather, these zeros reinforce the notion that top predators are naturally present in a lower density within a system than forage fishes. For the Toronto AOC, these zeroes drive down the mean PPB score for ecotypes and regions. In contrast, PPB values in less disturbed ecosystems (e.g., Presqu’ile Bay, Bay of Quinte) are well above the target proportion of 0.20, however it is unclear whether these PPB values are driven by a higher proportion of transects with top predators (possibly with similar biomass as the Toronto AOC) or a similar proportion of transects with top predators as the Toronto AOC but higher biomass. Both of these situations would yield the observed higher PPB values in these less disturbed areas, but each may suggest a different cause for the impairment in the Toronto AOC. If there is a higher proportion of top predators in transects outside the Toronto AOC, habitats where persistent zeroes are observed may not be conducive for top predators. In contrast, if transect proportions are similar, total catch of top predators is likely limiting this fish community-based metric. It is therefore recommended that a more comprehensive examination of the PPB metric in available electrofishing datasets in Lake Ontario reference areas be undertaken to provide some guidance on what is limiting this metric. In section FP-2, trends in catch of top predators are assessed on a species-specific basis to complement evaluations of PPB.

The IBI and IBI_{Adj} are an integration of a variety of community metrics and were specifically designed to use fish community assemblage information to assess the condition of aquatic ecosystems (Karr 1981). Given this connection to ecosystem conditions, it is not surprising that there was high variability among ecotypes and regions in mean IBI values since there is a substantial spatial gradient in both anthropogenic and natural disturbance within the Toronto AOC. Despite this variability, there was no evidence for a change in the IBI or IBI_{Adj} values from the start to the end of the sampling record (1989 – 2018). IBI_{Adj} values were generally lower than IBI values at Toronto AOC sampling locations, which is a function of species categorized as offshore and pelagic (e.g. Alewife, Gizzard Shad) being removed in the IBI_{Adj}. For the IBI, these species contribute to the IBI as a positive metric (i.e., specialists) despite the fact that they can be a non-native or degradation-tolerant species and when in high catch can have a disproportionate influence on the IBI; thus, their removal drops the overall score.

Among ecotypes, IBI and IBI_{Adj} scores were higher at embayments and estuary/rivers compared to open coast and slips. IBI scores in October were also higher than those observed in July, which is likely partially driven by higher PPB values during this season. Within ecotypes, embayments in the Toronto Islands and otherwest generally had higher IBI scores that until 2014, were above 55.5 (i.e., the IBI value that Hoyle et al. 2018 predicted given conditions in the Toronto AOC). Within embayments, gains in IBI scores observed in the early 2000s have since been lost during two specific time periods. The first decline occurred from 2006 – 2008, which coincides with the arrival and increase in catch of Round Goby while the second decline occurred from 2013 – 2015. The IBI values observed post-2015 at embayments were found to be lower than those seen from 1998 – 2006 and similar drops were also evident in IBI_{Adj} scores, suggesting the declines in IBI score were not driven by pelagic fishes. A similar pattern was also observed in IBI and IBI_{Adj} scores at the neighbouring Toronto AOC, Hamilton Harbour, which has been characterized as a protected embayment (Hoyle et al. 2018) with mean IBI scores that are generally lower than in Toronto. Despite habitat differences, in Hamilton there was similarly an increase in July and August IBI scores from 1997 – 2013 (except for 2002) followed by a decline from 2016 – 2019. As in Toronto, the decline in the composite IBI scores in Hamilton can be linked to declines in total and native species catch, but unlike Toronto, total native, Centrarchidae, and native cyprinid species richness were found to decline. These similar temporal patterns in IBI scores in spatially close (<50 km) but seemingly distinct (in terms of habitat conditions and anthropogenic stressors) embayments suggest that the drivers behind these declines may not be exclusively related to conditions within the Toronto AOC.

While the cause of the first, slower decline in IBI score cannot be confirmed, it may be partially linked to increases in Round Goby catch. The second decline is more complicated. Several of the environmental factors that were explored all appear to show marked changes just before the declines in IBI score that occurred from 2013 – 2015. The duration of ice cover (measured as days with >5% cover on Lake Ontario) was well above the long-term declining trend in the winters of 2012 and 2013 and the resulting summer water temperatures in 2014 were 7°C cooler than 2013. Water levels were at a record low in 2012 in both July (although similar to 1999) and October and throughout the cold winter of 2012. Finally, also in 2012, Embayment D was closed for remediation, resulting in a decline in the amount of available habitat within the system, a trend that has continued with the closure of Cell 2 for remediation in 2016 that also made Cell 1 inaccessible. This assessment cannot determine which factor (or combination of factors) was the driver behind the observed declines, therefore future works should incorporate these factors into the temporal models (i.e., INLA models) presented in this section since it will not only help explain the observed trends, but can also help provide a range of assessment targets under different future environmental conditions.

In past works, sites that were herein categorized as the slip ecotype have been treated as embayments (e.g., Spadina Quay in Dietrich et al. 2008). Given that slips were found to have lower IBI scores, total catch, and total species richness relative to embayments, their inclusion within this ecotype is inappropriate. Slips represent distinct habitat, with hardened vertical shorelines and deeper depths than more natural embayments. These depths (>4 m; see Veilleux et al. 2018) likely influence the efficacy of electrofishing at these sites, which may partially explain lower catch rates since boat electrofishing is typically only effective to 2.5 m depth and many protocols focus on the 1.5 m depth contour (see Brousseau et al. 2005). Furthermore, tracking using acoustic telemetry within four urban boat slips in the Toronto AOC found limited use of these slips throughout the year. The sole exception was for Northern Pike, which were found to frequent the Spadina, and to a lesser degree, Peter slips during the spring (Veilleux et al. 2018). This increase in the spring was hypothesized to be more a function of staging in or near these slips in preparation of using the Spadina wetland (which is accessed via the slip), rather than actual evidence for the use of slips as habitat. Collectively, this evidence supports the assessment of urban boat slips within the Toronto AOC as a distinct ecotype.

The objectives of this section were to compare fish community metrics within the Toronto AOC to similar systems in Lake Ontario, explore temporal trends in these metrics within the Toronto AOC, and document select environmental conditions during these time periods. Results suggest that a majority of metrics still indicate impairment in the fish community of the Toronto AOC (Table 6). While overall IBI scores were lower than predicted, some ecotypes and regions within the Toronto AOC have in the past approached or exceeded these targets (e.g., Toronto Islands in the mid-2000s), with declines occurring in recent years. There is evidence for longer-term declines in total catch, which are more concerning since they appear to be driven more by declines in native fishes than non-native fishes. For both the IBI and total catch, and the other fish-community metrics explored herein, more comprehensive models based on the TRCA electrofishing dataset should be developed that include available long-term environmental information such as water levels, water temperature, and ice cover. The influence of large-scale ecological events (e.g., invasion of Dreissenid mussels and Round Goby) should also be explored, since they have been found to influence fish communities and consequently derived metrics (Hoyle et al. 2012). This approach may identify causal mechanisms for these declines, some of which may well be more a function of regional processes (e.g., cold winters, water levels) rather than impaired conditions within the Toronto AOC. Additional fish community-based metrics should also be explored using this approach including those analyzed in Dietrich et al. 2008, but not in the present report (e.g., proportions of non-native fishes, generalists, and specialists, and the number of degradation tolerant species) as well as other fish groups (e.g., Centrarchidae) or species of interest not presently assessed in FP-2 (e.g., Yellow Perch [*Perca flavescens*]). Several of these were originally planned to be part of the trend analysis outlined herein but had to be dropped due to time constraints despite their clear relevance to the assessment.

Despite current community impairment, there is considerable opportunity for improvement, since the potential fish community gains from habitat enhancement efforts at Tommy Thompson Park have yet to be realized as many of these works are either still underway (e.g., Cell 2) or have yet to be fully connected back to the system (e.g., Embayment D). Additionally, the Don River revitalization project will yield a net gain in total aquatic habitat when it is completed in 2024 and this can only help to enhance fish abundance within the Toronto AOC. The Toronto AOC is located in, and was listed as a direct result of, the impacts from Canada’s largest urban area. Hoyle et al. (2018) emphasize that within this Toronto AOC, a certain base-level of degradation will chronically impact aquatic habitat and associated fish communities, and that fish community-based targets should reflect these conditions. Despite this, current and future plans for development in the Toronto AOC watershed will provide opportunities to improve habitat conditions for local species. Given current trends, now is a crucial time to protect existing habitats from infill or modification and implement ecosystem enhancement measures for vulnerable fish communities within the Toronto AOC. For future assessments of BUI#3, setting targets for fish community-based metrics that are appropriate and specific to the ecotype or region being assessed is essential in order to match the target with the optimal conditions that can be expected for each region and ecotype.

Tables and Figures

Table 2. Details on metrics evaluated for trends through time as well as their expected response should conditions in the system be improving through time. All metrics are calculated per unit of effort (i.e. transect sample). Individual species assignments as native, non-native, cyprinid, or piscivores can be found in Appendix C.

Metric	Metric Details	Expected Response
Index of Biotic Integrity (IBI)	Composite index made up of 12 metrics (8 positive and 4 negative) – see Minns et al. 1994	↑
Adjusted Index of Biotic Integrity (IBI_{Adj})	IBI adjusted for offshore fish species (exclusion) – see Minns et al. 1994	↑
Total Catch	Total number of individual fish	↑
Total Catch Native	Total number of native species individuals in the catch	↑
Total Catch Non-Native	Total number of non-native individuals in the catch	↓
Total Catch Native Cyprinid	Total number of individuals of native cyprinid species	↑
Species Richness	Total number of fish species in the catch	↑
Native Species Richness	Number of native species in the catch	↑
Non-Native Species Richness	Number of non-native species in the catch	↓
Proportion Piscivore Biomass (PPB)	Proportion of total biomass comprised of piscivores	↑

Table 3. Summary information on the trend-analysis models for the different ecotypes and regions by month. The type of distribution used to fit the model is presented as are any deviations from the standard formula(s), sample size used, Deviance Information Criterion (DIC; both with the spatial term in the model and without), effective number of parameters for the best model, any issues identified during model validation, and any notes related to model fit or dataset adjustments.

Metric	Ecotype	Month	Distribution	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
IBI	All	July	*Beta*	Full (no effort)	981	-2562	90.3	-2420	Passes tests	Drop zeros
	All	October	*Beta*	Full (no effort)	322	-798	27.8	-780	Passes tests	Drop zeros
	Embayment	July	*Beta*	Full (no effort)	562	-1556	58.1	-1460	Passes tests	Drop zeros
	Embayment	October	*Beta*	Full (no effort)	173	-459	10.4	-459	Passes tests	Drop zeros Poor fit
	Open Coast	July	*Beta*	Full (no effort)	212	-563	13.1	-560	Passes tests	Drop zeros Poor fit
	Open Coast	October	Model could not be fit – insufficient data							
IBI_{Adj}	All	July	*Beta*	Full (no effort)	948	-1124	83.9	-1011	Passes tests	Drop zeros
	All	October	*Beta*	Full (no effort)	316	-308	26.0	-241	Passes tests	Drop zeros
	Embayment	July	*Beta*	Full (no effort)	561	-750	54.4	-694	Passes tests	Drop zeros
	Embayment	October	*Beta*	Full (no effort)	173	-222	18.6	-222	Passes tests	Drop zeros
	Open Coast	July	*Beta*	Full (no effort)	210	-215	19.7	-217	Passes tests	Drop zeros
	Open Coast	October	Model could not be fit – insufficient data							
Total Catch	All	July	*Negative Binomial*	Full	983	10556	58.0	10651	Passes tests	Removed 5 transects with catch >400
	All	October	*Negative Binomial*	Full	327	3211	30.8	3219	Passes tests	Removed 1 transect with catch >400

Metric	Ecotype	Month	Distribution	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
	Embayment	July	*Negative Binomial*	Full	562	6222	28.7	6239	Passes tests	Removed 5 transects with catch >400
	Embayment	October	*Negative Binomial*	Full	171	1780	29.5	1810	Passes tests	Removed 5 transects with catch >375
	Open Coast	July	*Negative Binomial*	Full	214	2256	25.4	2255	Under-dispersed	
	Open Coast	October	*Negative Binomial*	Full	84	701	12.0	708	Lower residuals at western sites	Removed 1 transect with catch >700
	All	July	*Negative Binomial*	Full	994	9205	77.7	9393	Passes tests	
Total Catch Native	All	October	*Negative Binomial*	Full	325	2950	45.5	3572	Still over-dispersed	Removed 7 transect with catch >200
	Embayment	July	*Negative Binomial*	Full	565	5697	42.5	5742	Passes tests	Removed 72 transect with catch >450
	Embayment	October	*Poisson*	Full	171	2427	101.4	3590	Passes tests	Removed 5 transects with catch >240
	Open Coast	July	*Poisson*	Drop CentralWF	213	1869	84.7	2843	Passes tests	Removed low effort sites; Dropped 1 site with >200
	Open Coast	October	*Model could not be fit – insufficient data*							
Total Catch Non-Native	All	July	*Negative Binomial*	Full	991	9201	86.1	9319	Passes tests	Removed 1 transects with catch >450
	All	October	*Poisson*	Full	328	3502	140.0	4919	Passes tests	Removed 4 transects with catch >200

Metric	Ecotype	Month	Distribution	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
	Embayment	July	*Negative Binomial*	No Effort	480	4609	32.0	4617	Passes tests	Removed 3 transects with catch >425 Doesn't fit well for OtherEast
	Embayment	October	*Negative Binomial*	Drop CentralWF No Effort	127	991	9.1	1000	Poor model fit	Removed 3 transects with catch >200
	Open Coast	July	*Poisson*	Drop CentralWF No Effort No spatial term	190	1870	19.6	1870	Under-dispersed	Poor model fit
	Open Coast	October	Model could not be fit – insufficient data							
	All	July	*Negative Binomial*	Full	994	6120	75.7	6233	Passes tests	
Total Catch Native Cyprinid	All	October	*Poisson*	Full	327	3595	140.4	6472	Passes tests	Removed 5 transects with catch >200
	Embayment	July	*Poisson*	Full	557	6371	169.5	9251	Passes tests	Removed 7 transects with catch >150
	Embayment	October	*Poisson*	Full	150	1530	88.7	2948	Spatial residuals lower at islands and western sites	Removed 4 transects with catch >150
	Open Coast	July	*Poisson*	Drop CentralWF	204	1423	86.7	2408	Passes tests	
	Open Coast	October	*Poisson*	Drop CentralWF	76	323	40.3	497	Poor Fit - positive residuals in east bluffers	Removed one transect with catch >700
Spe	All	July	*Poisson*	Full	983	4691	76.6	4845	Passes tests	

Metric	Ecotype	Month	Distribution	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
	All	October	*Poisson*	Full	322	1597	39.3	1638	Passes tests	
	Embayment	July	*Poisson*	Full	565	2854	31.0	2897	Passes tests	
	Embayment	October	*Poisson*	Full	173	904	32.0	918	Passes tests	
	Open Coast	July	*Poisson*	Full	213	930	14.5	942	Passes tests	
	Open Coast	October	*Poisson*	Full	80	353	32.0	349	Passes tests	
Native Richness	All	July	*Poisson*	Full	994	4409	74.0	4577	Passes tests	
	All	October	*Poisson*	Full	332	1516	42.7	1543	Passes tests	
	Embayment	July	*Poisson*	Full	567	2753	33.4	2801	Passes tests	
	Embayment	October	*Poisson*	Drop CentralWF No spatial term	159	794	19.5	793	Passes tests	
	Open Coast	July	*Poisson*	Drop CentralWF	204	775	9.9	796	Passes tests	
	Open Coast	*October*	*Model could not be fit – insufficient data*							
Non-Native Richness	All	July	*Poisson*	Full	994	2958	24.5	2975	Passes tests	
	All	October	*Poisson*	Full	322	1001	12.1	998	Passes tests	Using spatial term despite slightly higher DIC
	Embayment	July	*Poisson*	No spatial term	567	1712	10.5	1712	Passes tests	
	Embayment	October	*Poisson*	No spatial term	176	525	5.5	524	Passes tests	
	Open Coast	July	*Poisson*	Drop CentralWF No spatial term	204	660	3.9	659	Passes tests	
	Open Coast	October	*Poisson*	No spatial term	85	262	3.9	262	Passes tests	
Prop. Pis	All	July	*Beta*	No Effort	981	-10771	32.5	-10733	Poor fit	Poor fit - limited range

Metric	Ecotype	Month	Distribution	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
	All	October	*Beta*	No Effort	328	-3045	13.9	-3018	Poor fit	Poor fit - limited range
	Embayment	July	*Beta*	No Effort	423	-905	15.2	-899	Poor fit	Drop Zeroes Poor fit - limited range
	Embayment	October	*Beta*	Drop CentralWF No Effort	146	-168	13.9	-160	Poor fit	Drop Zeroes Poor fit - limited range
	Open Coast	July	*Beta*	Drop CentralWF No Effort	125	-190.2	5.4	-190.5	Poor fit	Drop Zeroes Poor fit - limited range
	Open Coast	*October*	*Model could not be fit – insufficient data*							

Table 4. Steps for the assessment of model fit. These were evaluated for each model presented in this report. Models that did not pass all steps were occasionally included if there were no additional adjustments to the model that could be made to result in passing of these steps (e.g., if changing the distribution used from Poisson to Negative Binomial did not resolve over-dispersion). An overall assessment of model validation is presented for each model in Table 3.

Step	Method	Notes
1. Check for Over-dispersion	Assess whether the sum of squares residuals from the model fit is always higher than those of 1000 simulated datasets that have the same distribution and core parameters (e.g., Betas, mu, etc.). If model sum of squares is always higher, suggests over-dispersion. If not over-dispersed, model passes.	* some negative binomial models were found to still be over-dispersed, but it was unclear how to resolve this issue without adding in additional co-variates.
2. Plot Residuals vs Fitted	Assess whether there are any patterns in the residuals. If no pattern, model passes.	
3. Plot Fitted vs Observed	Assess how well the fitted values from the model match the observed data. If positive association between fitted and observed, model passes.	
4. Normality of Residuals	Visually assess whether the residuals have a normal distribution. If looks close to normal, model passes.	* interpretation of this component was less stringent based on suggestions by Zuur et al. (2017) that violations for this step were less important for successful model fit.
5. Plot Residuals by Ecotype or Region	Assess whether there is generally equal spread in the residuals for each ecotype or region in the model. If no evidence for larger or more restricted spread in residuals, model passes.	
6. Plot Residuals Spatially	Assess whether there is evidence for residual spatial autocorrelation in the residuals by mapping the residuals. If there is an even spread of positive and negative residuals throughout the study area, model passes.	

Table 5. Excerpt from Table 2 in Hoyle et al., (2018) showing metric values calculated from electrofishing data for the Toronto AOC and another exposed embayment in Lake Ontario, Prince Edward Bay. The Toronto AOC was sampled over 10 years with 200 samples and Prince Edward Bay was sampled over 2 years with 24 samples.

Metric	Toronto AOC	Prince Edward Bay	Remedial Action Plan Target
Index of Biological Integrity	45.1 (40.0-49.0)	66.6 (64.0-73.0)	No target
Native Species Richness	2.9	5.6	No target
Proportion Piscivore biomass	0.21	0.45	0.20
Proportion Specialist biomass	0.28	0.33	0.40

Table 6. The expected ecological responses for each metric that would suggest ecosystem improvements and the direction of the trends, where available, from 1989 – 2005 (from Dietrich et al. 2008) relative to the present work (1989 – 2018) are shown. Trends that deviate from the expected response are shown in red and no change is shown as an orange (↔).

Metric	**Expected Response**	**1989-2005**	**1989-2018**
IBI	↑	*NA*	↔
IBI_{Adj}	↑	*NA*	↔
Total catch	↑	↓	↓
Total species richness	↑	*NA*	↔
Catch native species	↑	*NA*	↓
Native species richness	↑	↔	↔
Catch cyprinids	↑	*NA*	↓
Catch non-native species	↓	*NA*	↔
Non-native richness	↓	*NA*	↔
Prop. non-native	↓	↓	*NA*
Prop. Piscivore biomass (PPB)	↑	↔	↔
Degradation tolerant species	↓	↓	*NA*
Prop. specialist biomass	↑	↓	*NA*
Prop. generalists	↑	↑	*NA*

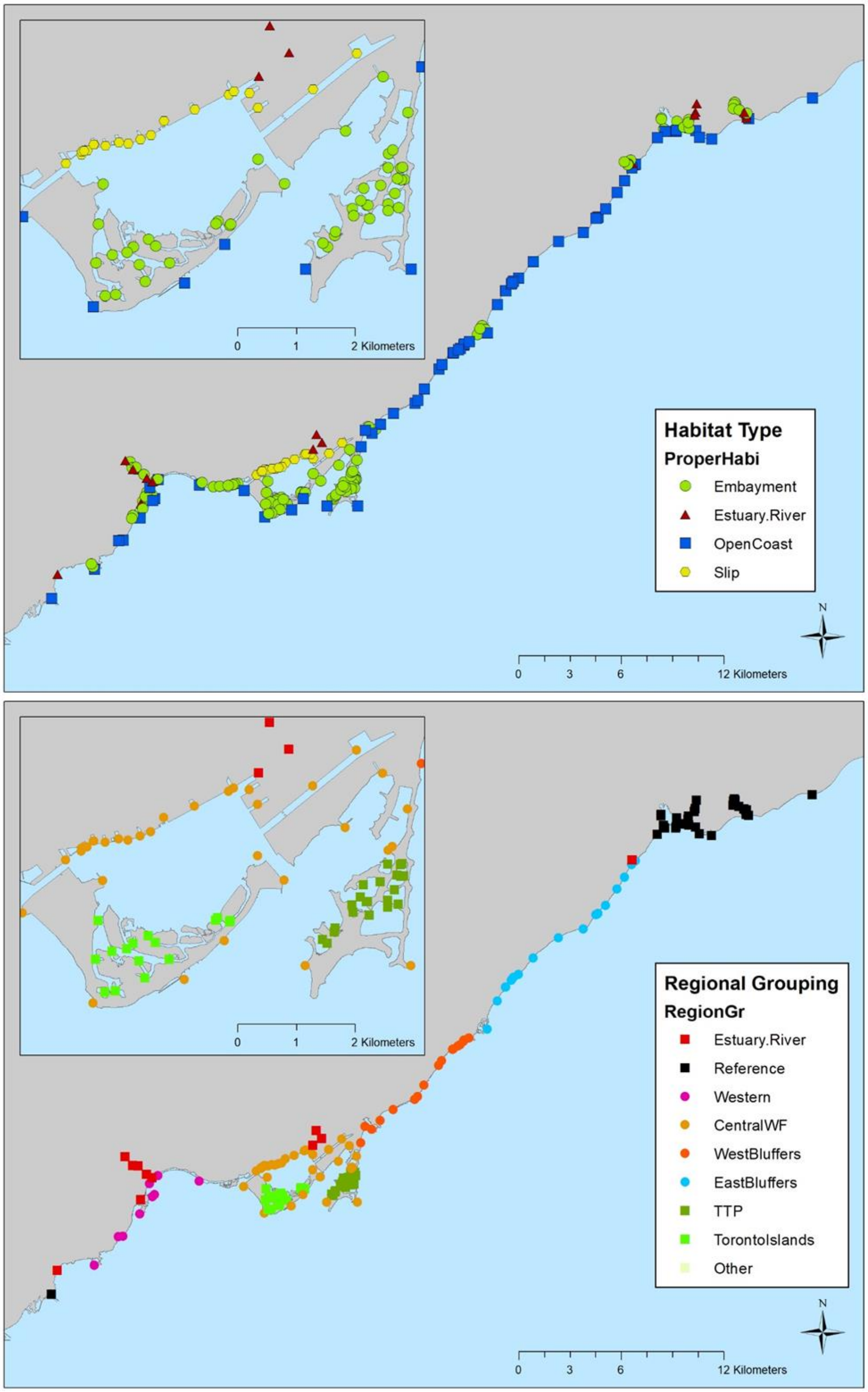

Figure 2. Location of transects within the Toronto AOC colour coded based on their assigned ecotype (top) and assigned region (bottom). Embayment regions included: TTP, Toronto Islands, centralWF, otherwest and othereast. Open coast regions included: western, centralWF, westbluffers, and eastbluffers.

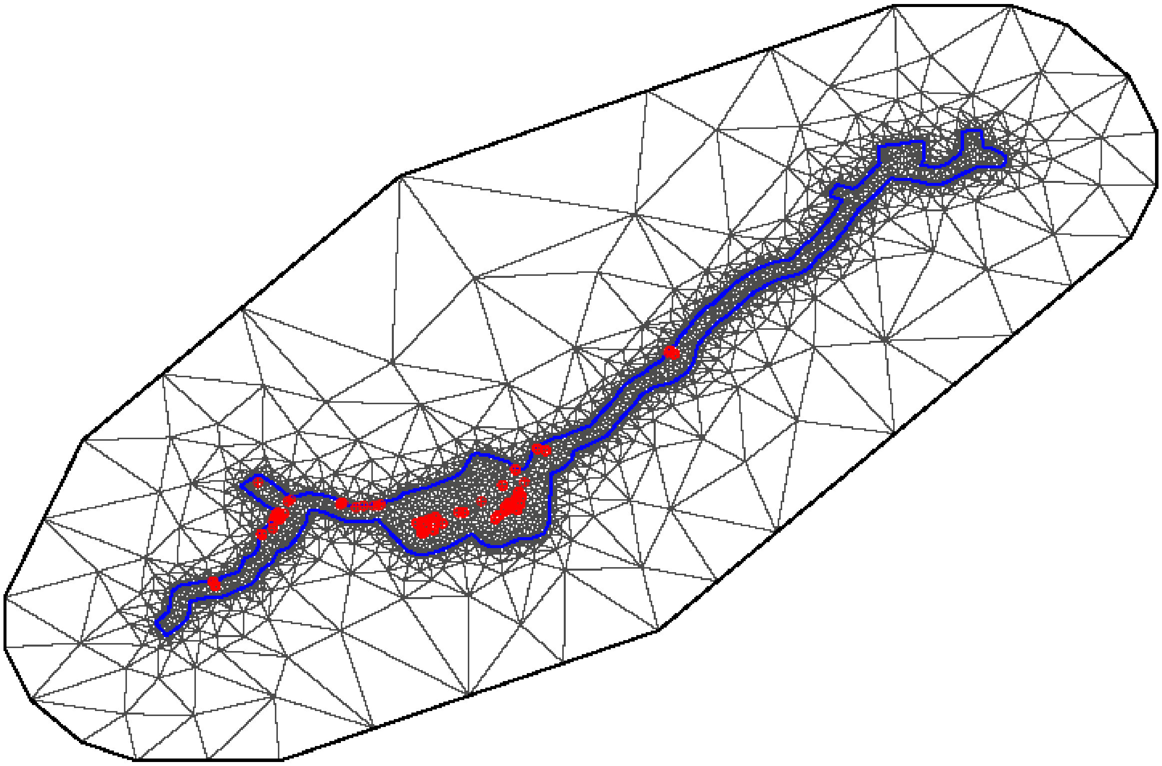

Figure 3. Example of the spatial mesh with 3375 vertices that was used to estimate the spatial random field for all Bayesian models. For the example, the red dots represent a subset of transects surveyed at embayments in July.

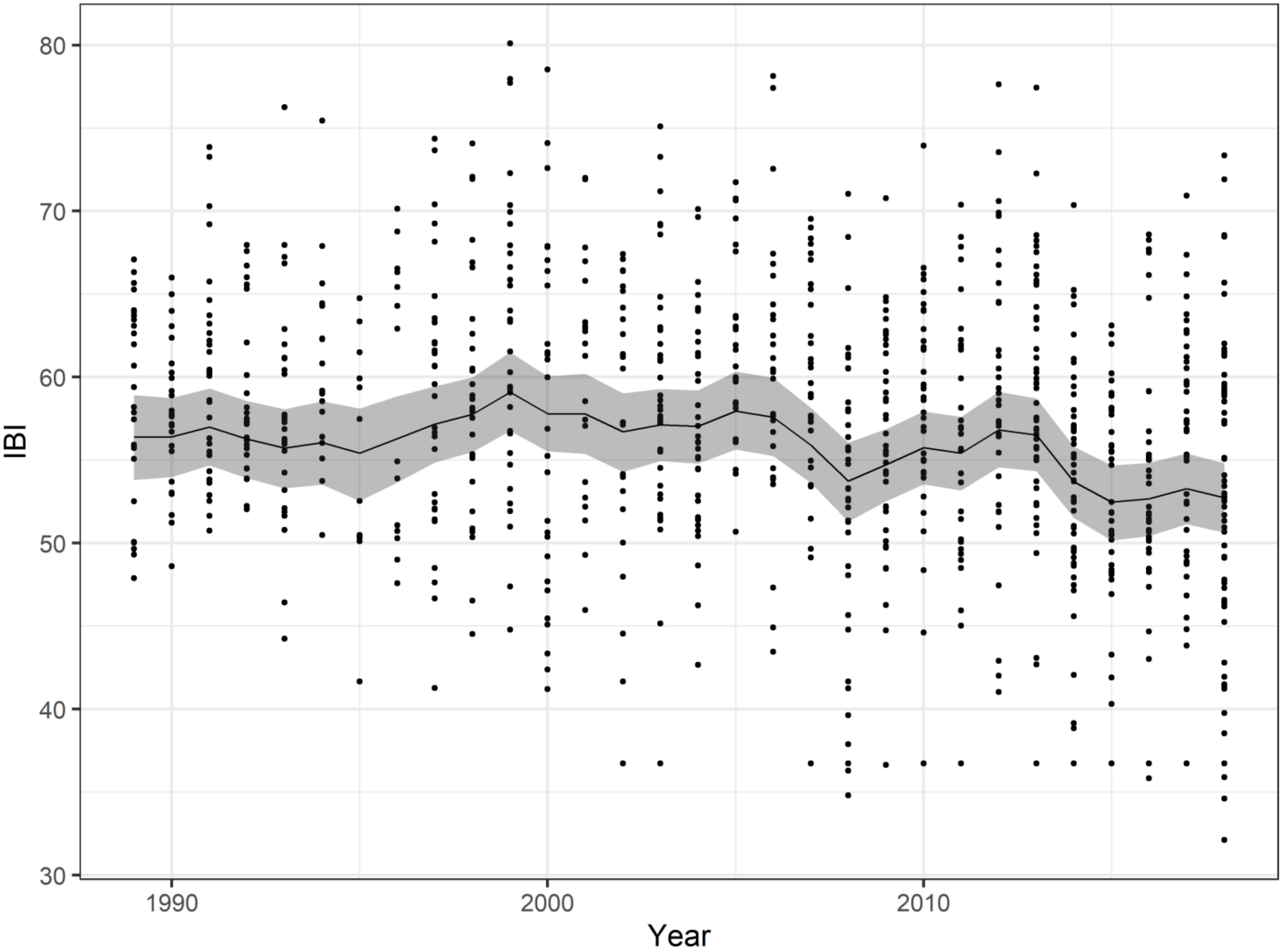

Figure 4. Global (all ecotypes) temporal trend in Index of Biological Integrity score. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

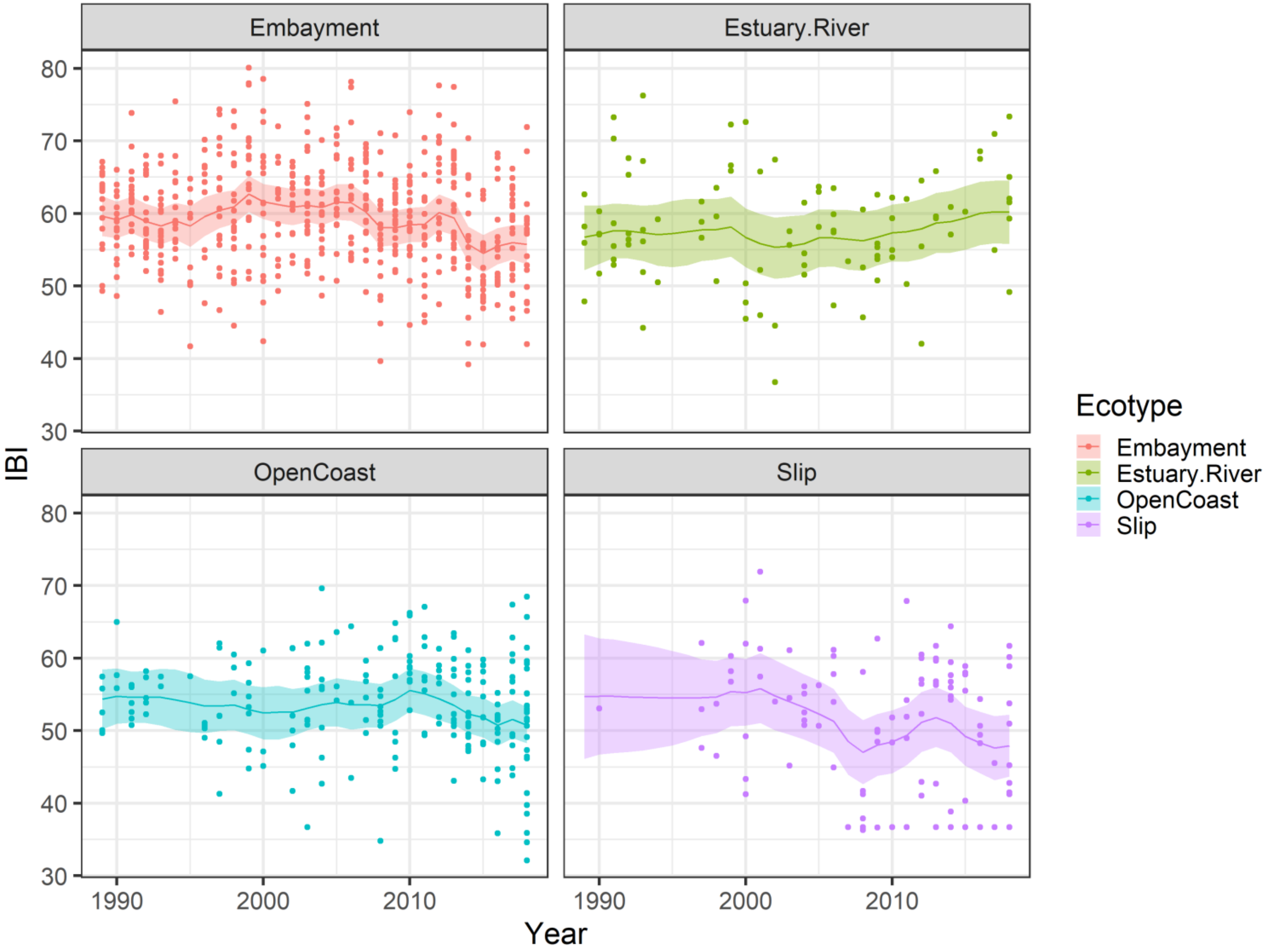

Figure 5. July trends in Index of Biological Integrity score at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

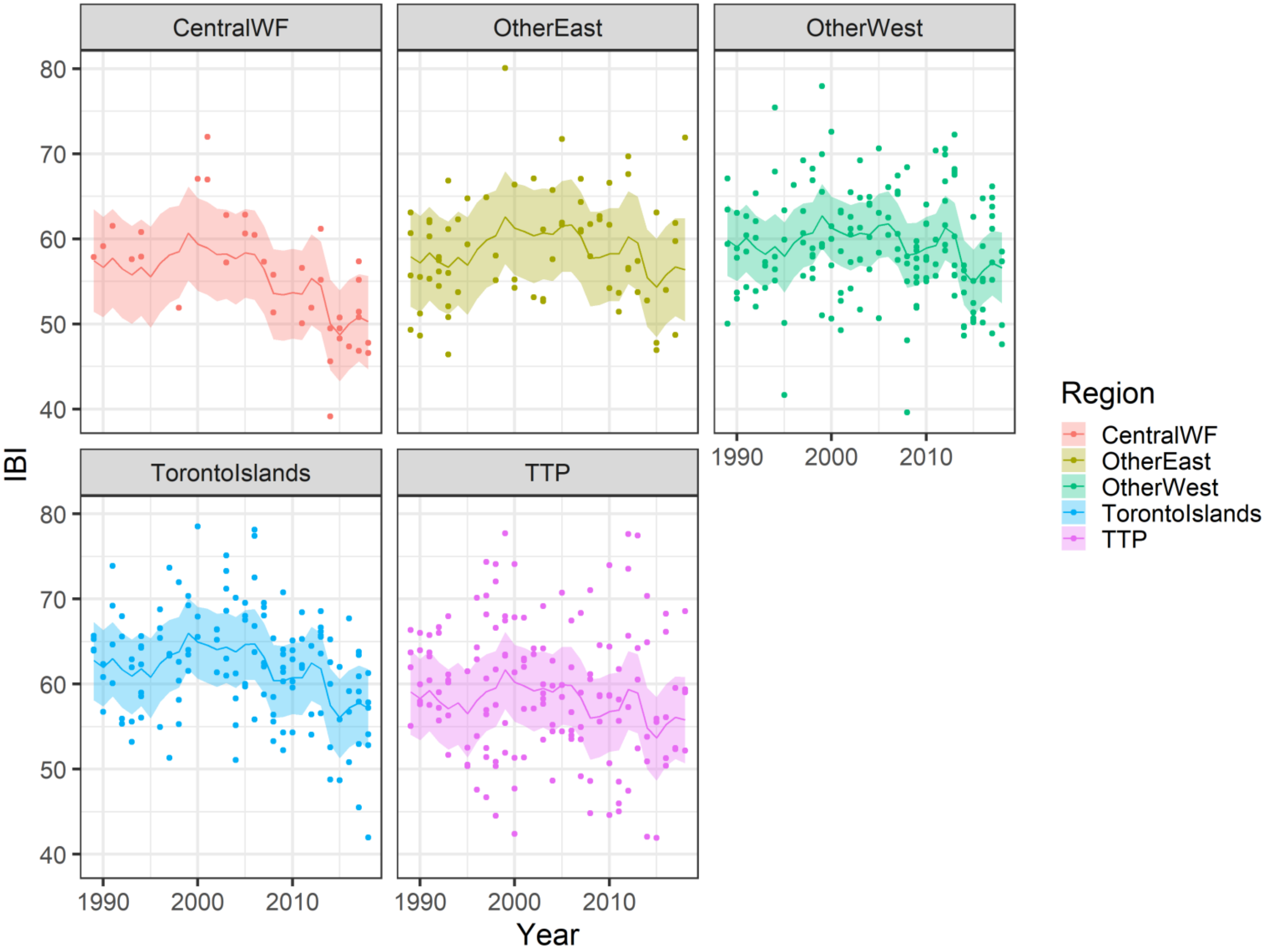

Figure 6. July trends in Index of Biological Integrity score at different embayment regions. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

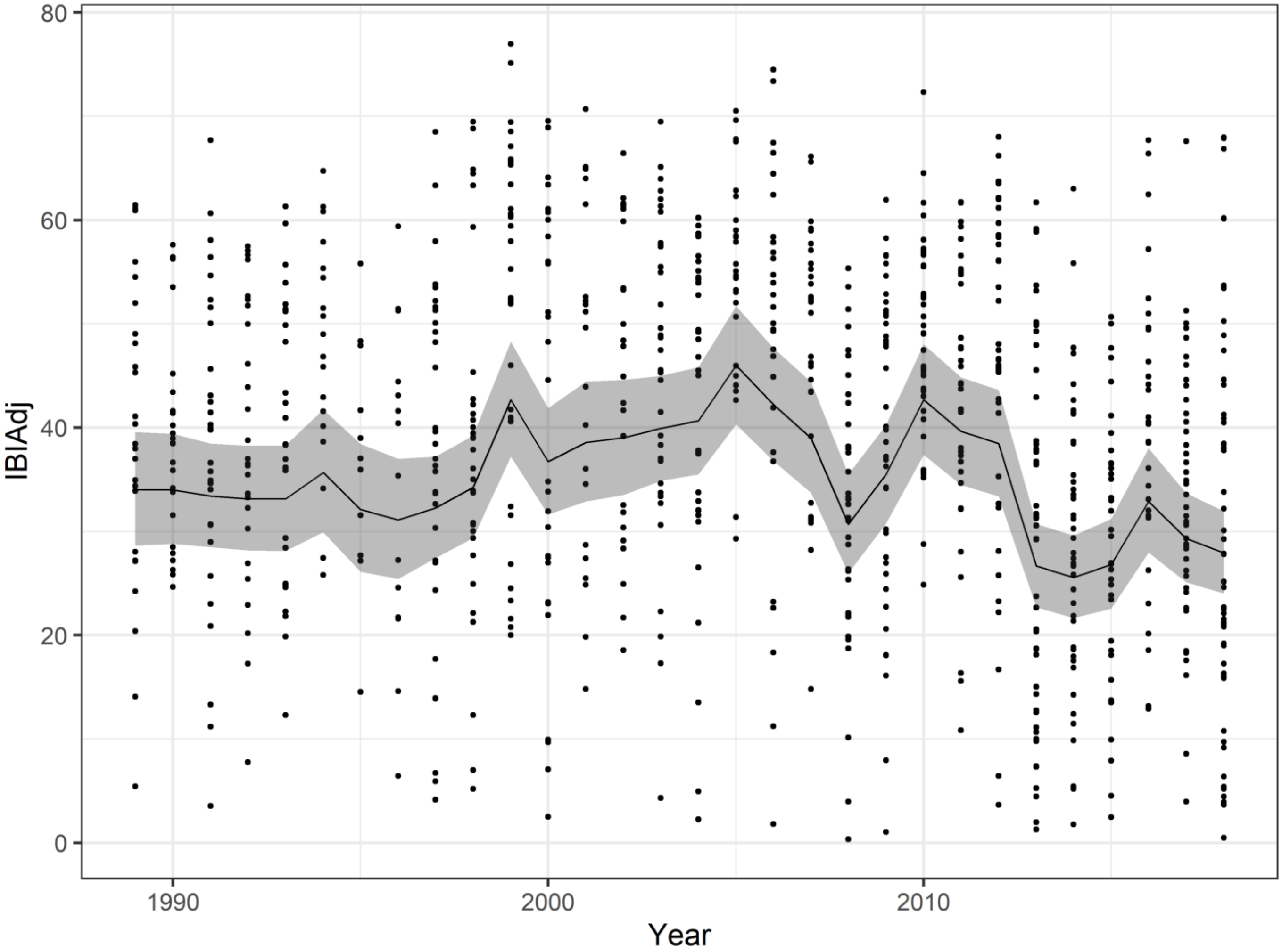

Figure 7. Global (all ecotypes) temporal trend in July Index of Biological Integrity (IBI_{Adj}) score. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 8. July trend in Index of Biological Integrity (IBIAdj) at the eco-type level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

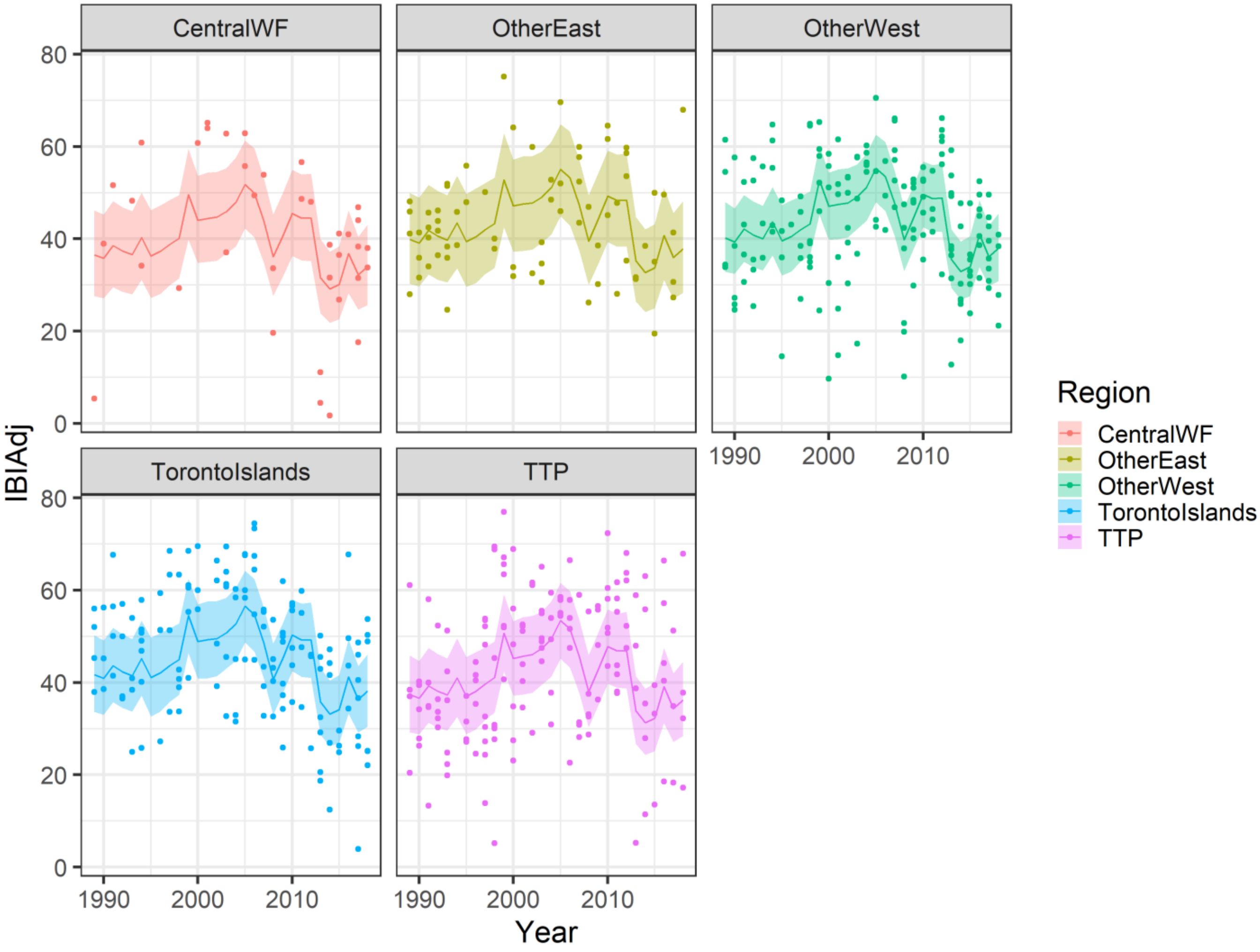

Figure 9. July trends in Index of Biological Integrity (IBI_{Adj}) at embayment regions. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

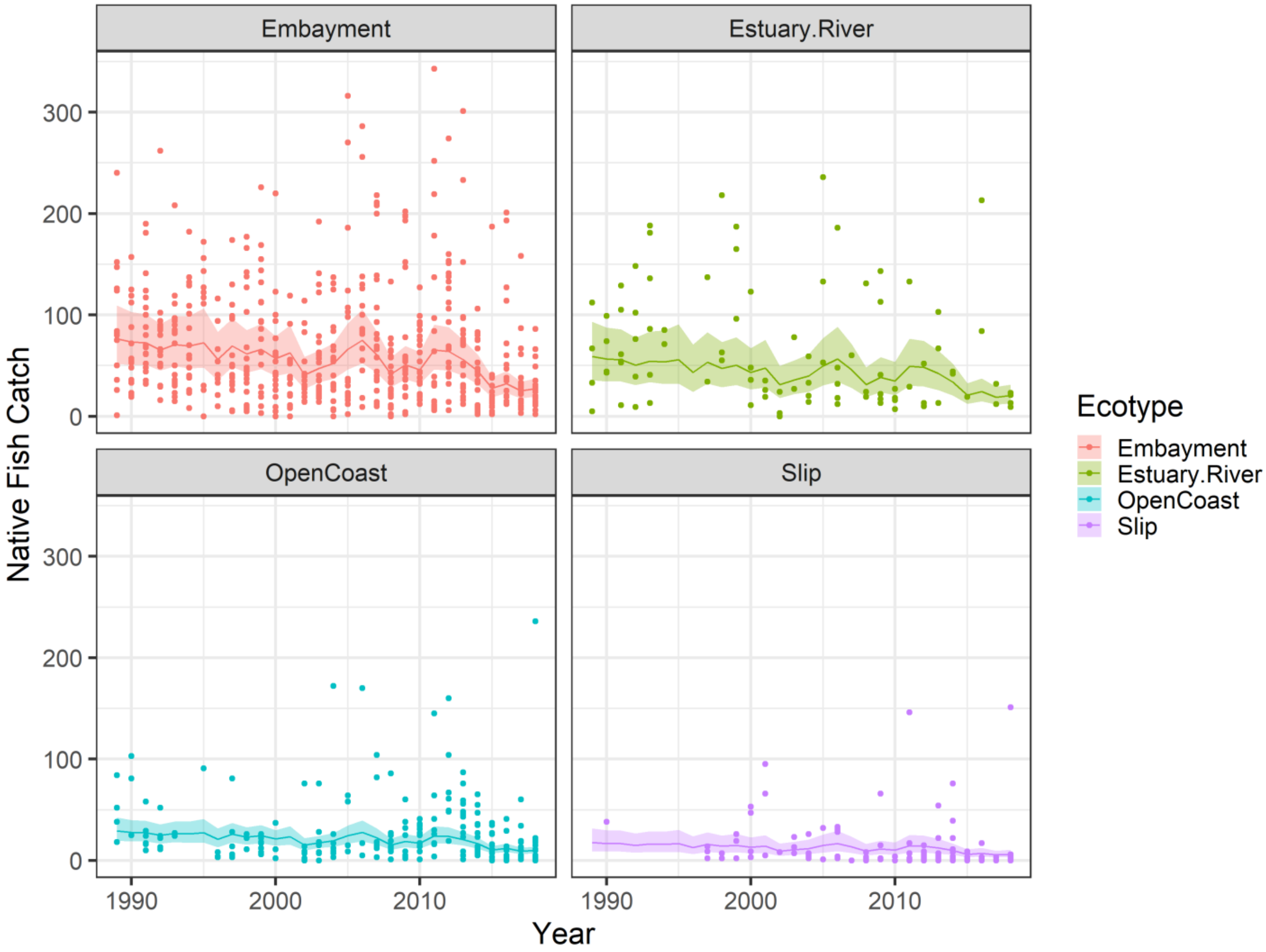

Figure 10. July trends in total catch among ecotypes. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

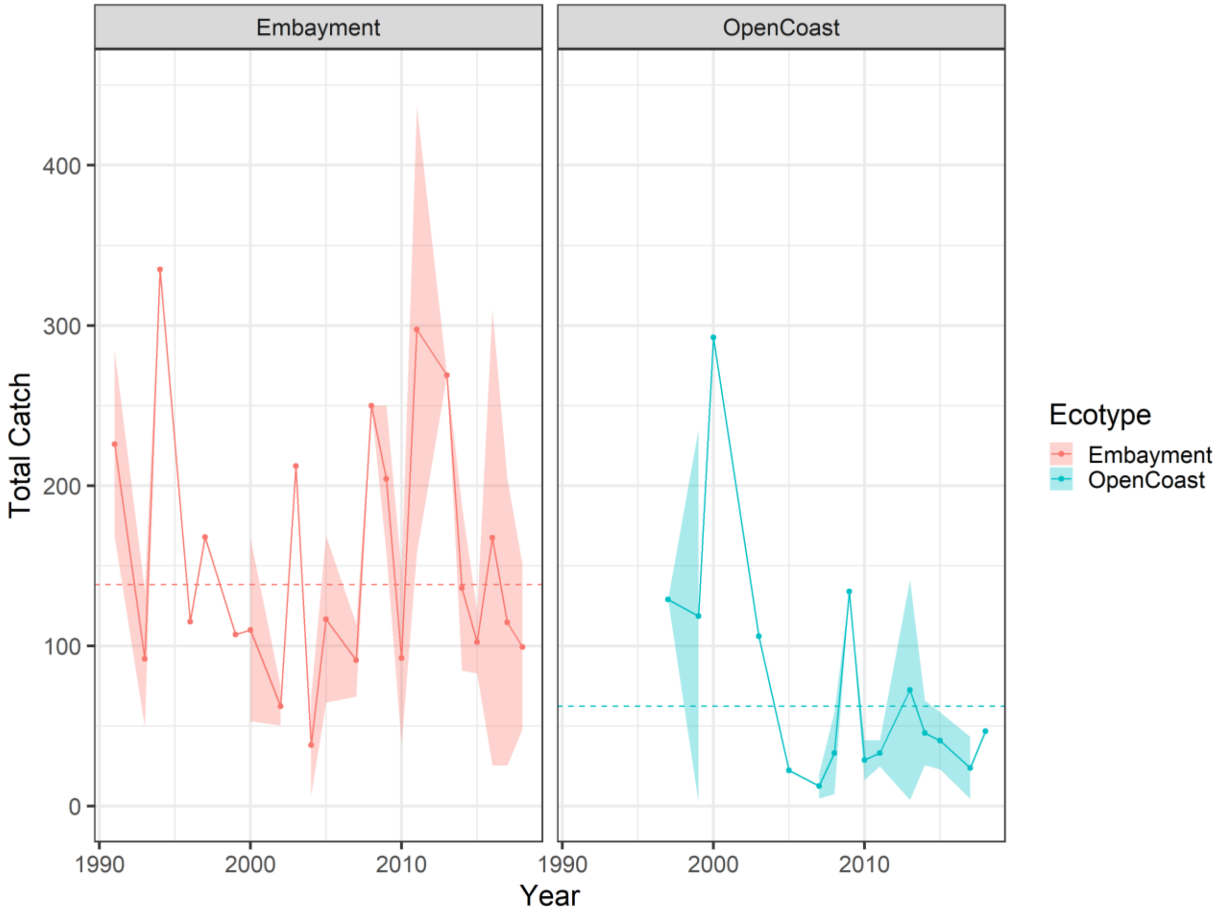

Figure 11. July total catch at reference areas for embayment and open coast ecotypes. Reference areas could not be modelled therefore annual values represent mean catch with shaded areas showing standard deviation (where possible).

Figure 12. Total species richness in July at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

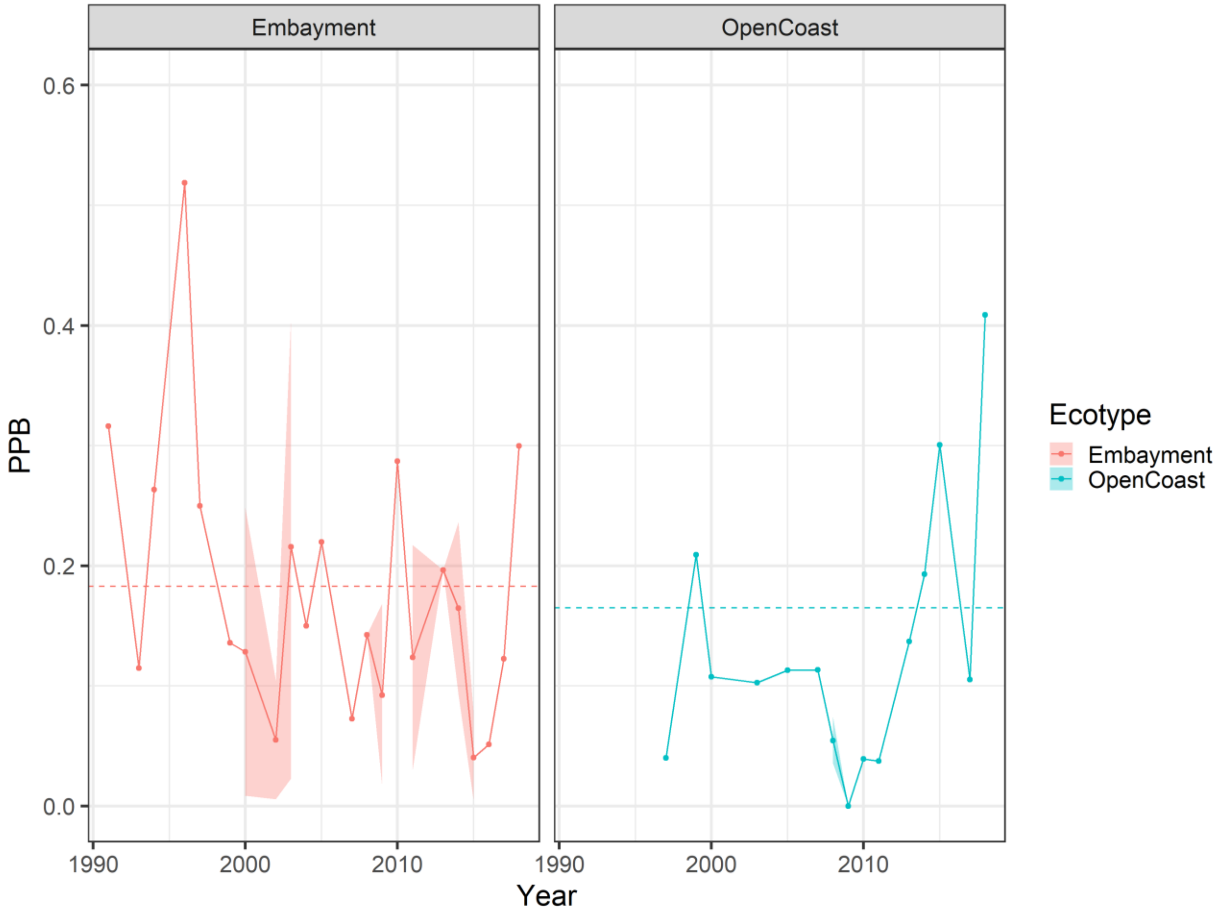

Figure 13. July proportion piscivore biomass (PPB) at reference areas for embayment and open coast ecotypes. Reference areas could not be modelled therefore annual values represent mean catch with shaded areas showing standard deviation (where possible).

Figure 14. July total catch of native cyprinids at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

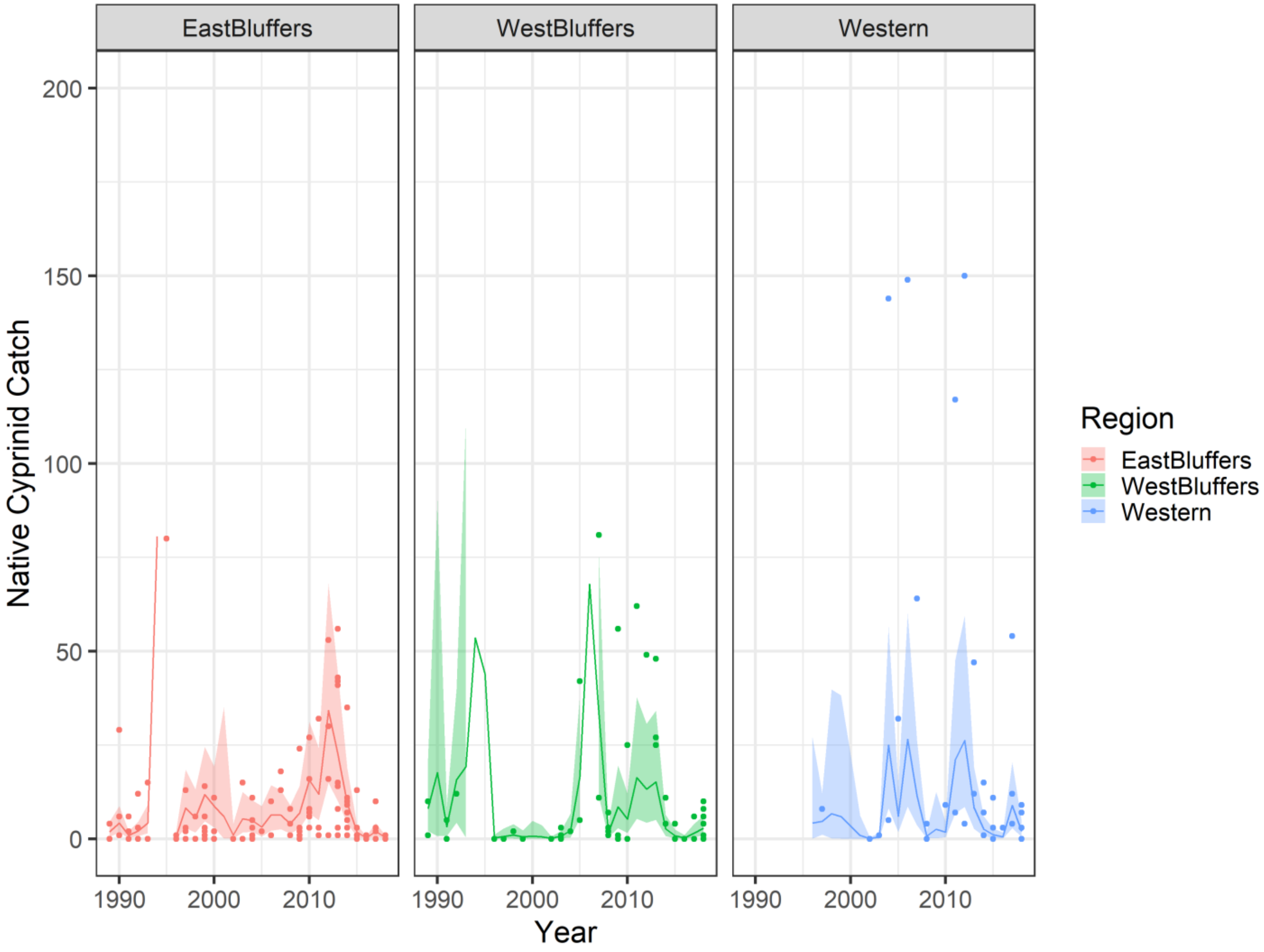

Figure 15. July total catch of native cyprinids at different open coast regions. There were insufficient data from the Central Waterfront open coast region for inclusion. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

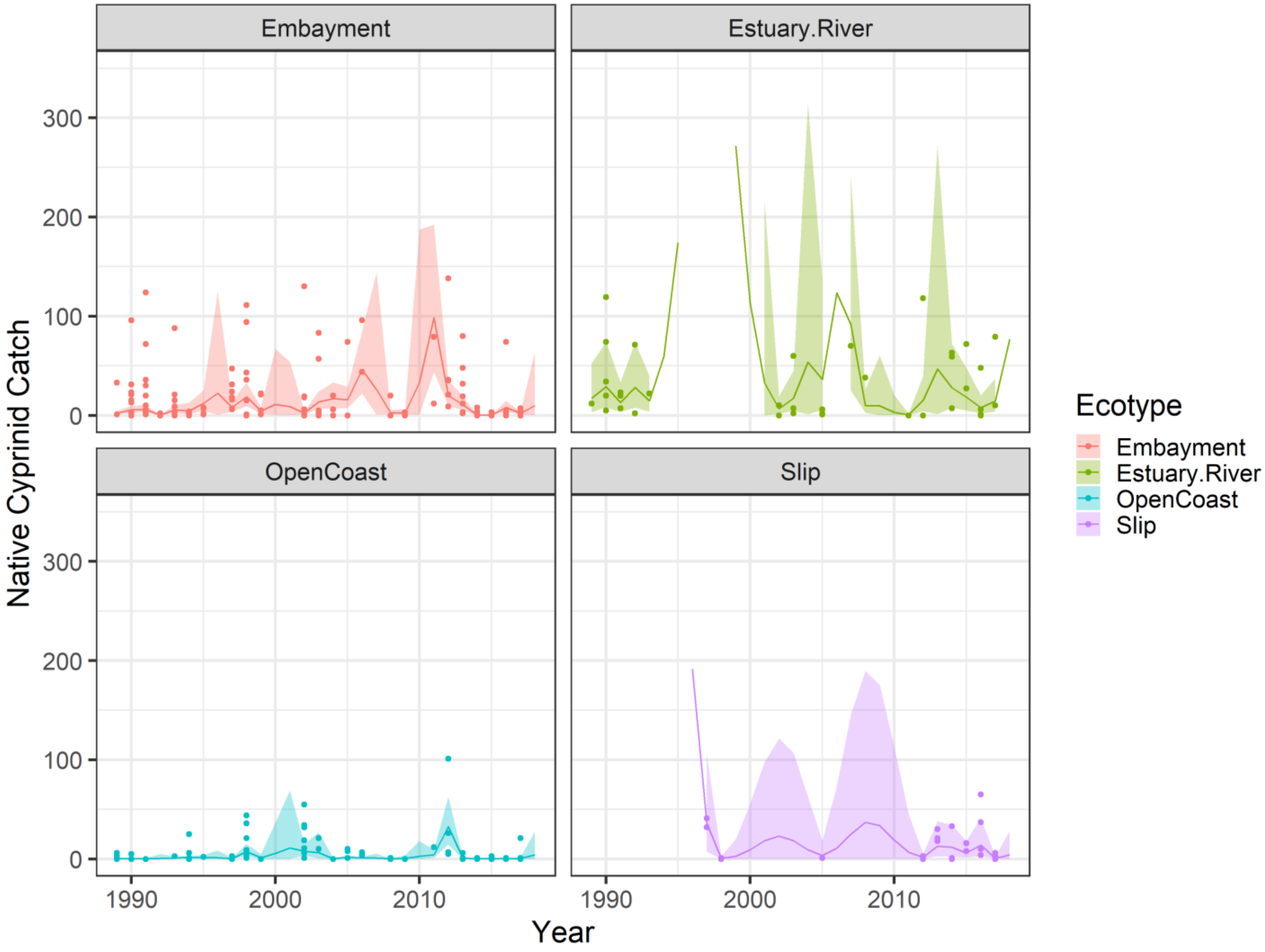

Figure 16. October total catch of native cyprinids at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

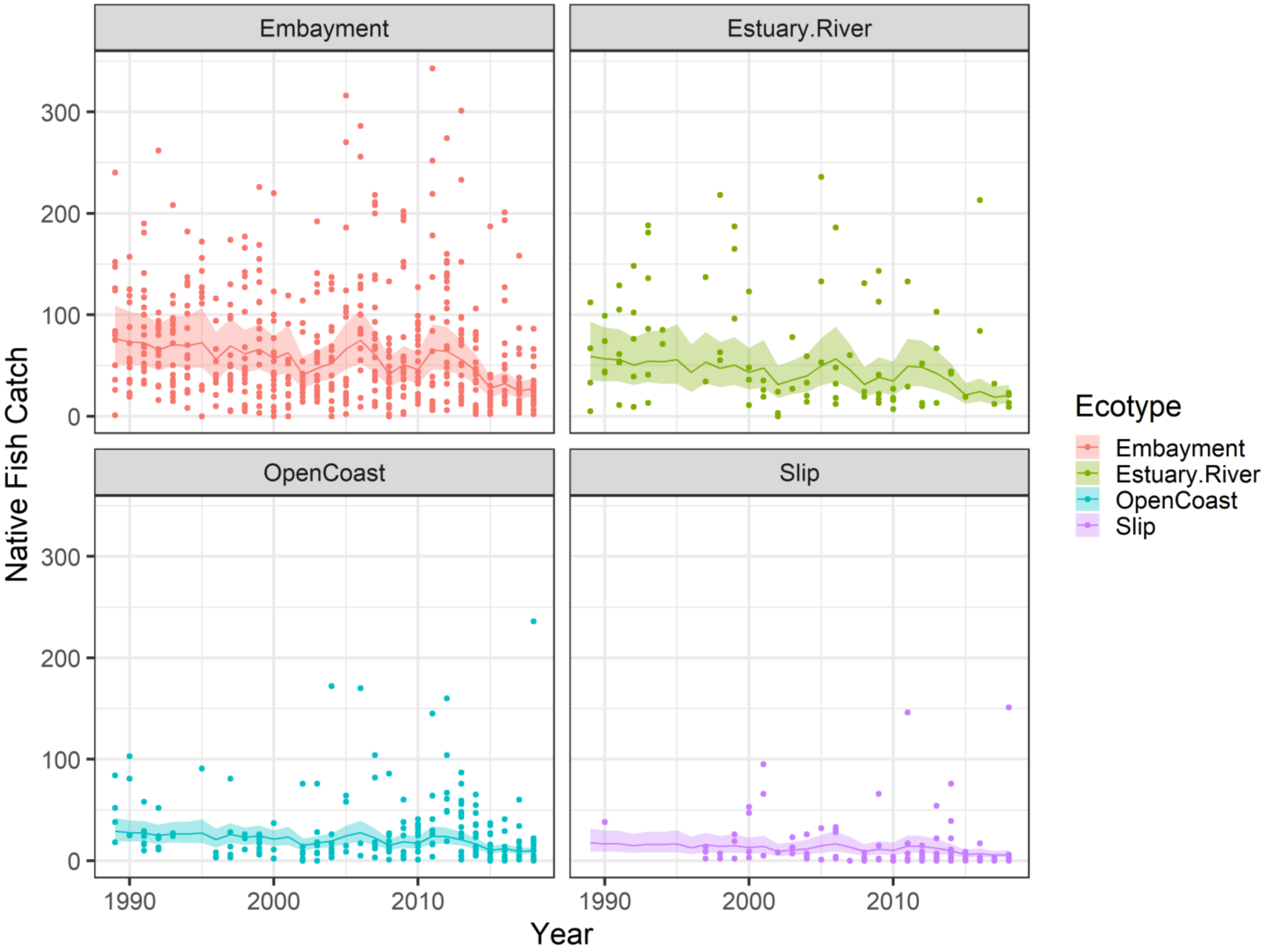

Figure 17. July total catch of native fishes at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 18. Total catch of non-native species in July at the ecotype-level. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 19. July water temperatures. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 20. October water temperatures. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

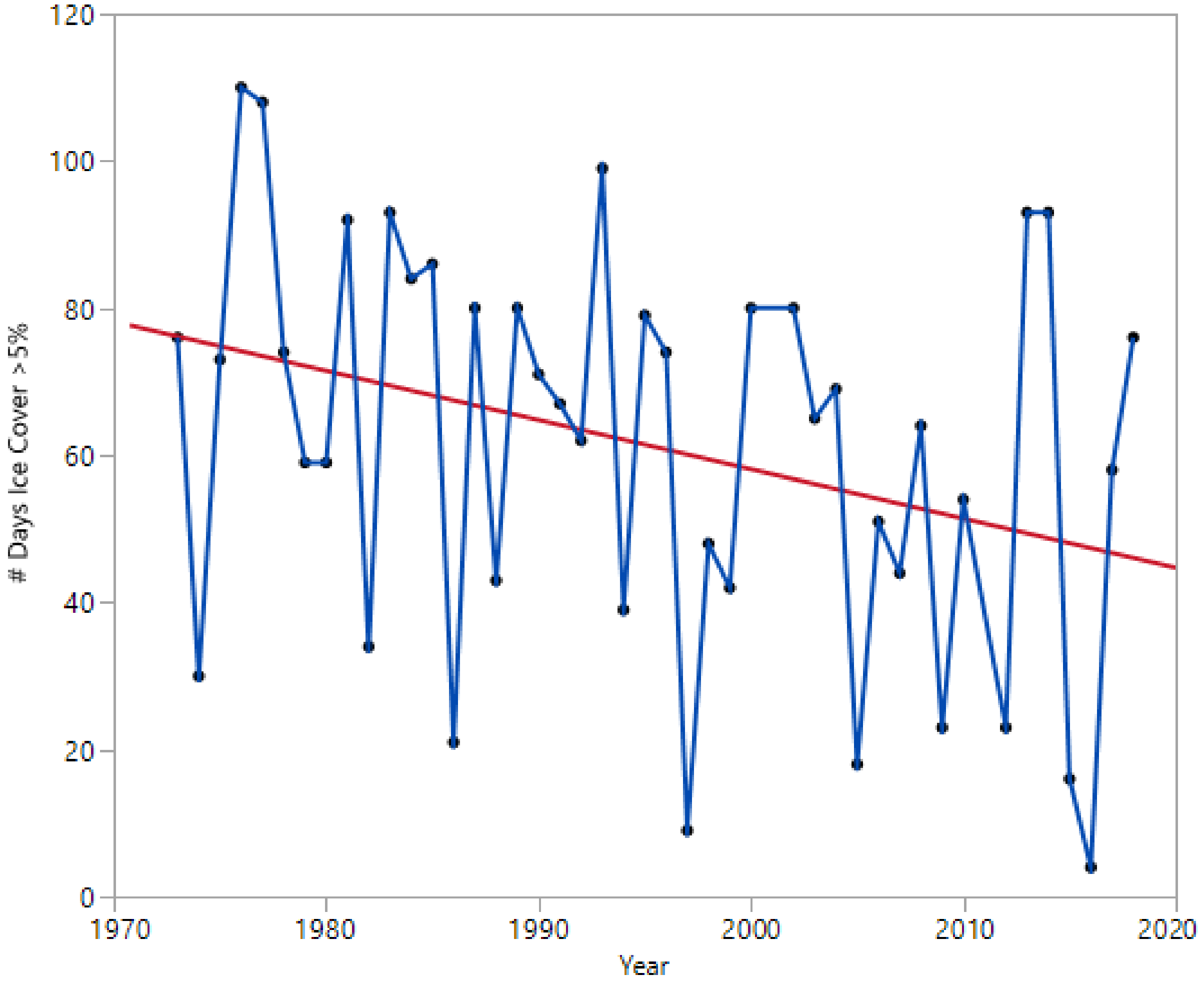

Figure 21. The number of days where the ice cover on Lake Ontario was greater than 5%. Data were compiled from mapping efforts by the National Oceanic and Atmospheric Administration. The red line represents a significant negative linear trend (p = 0.03).

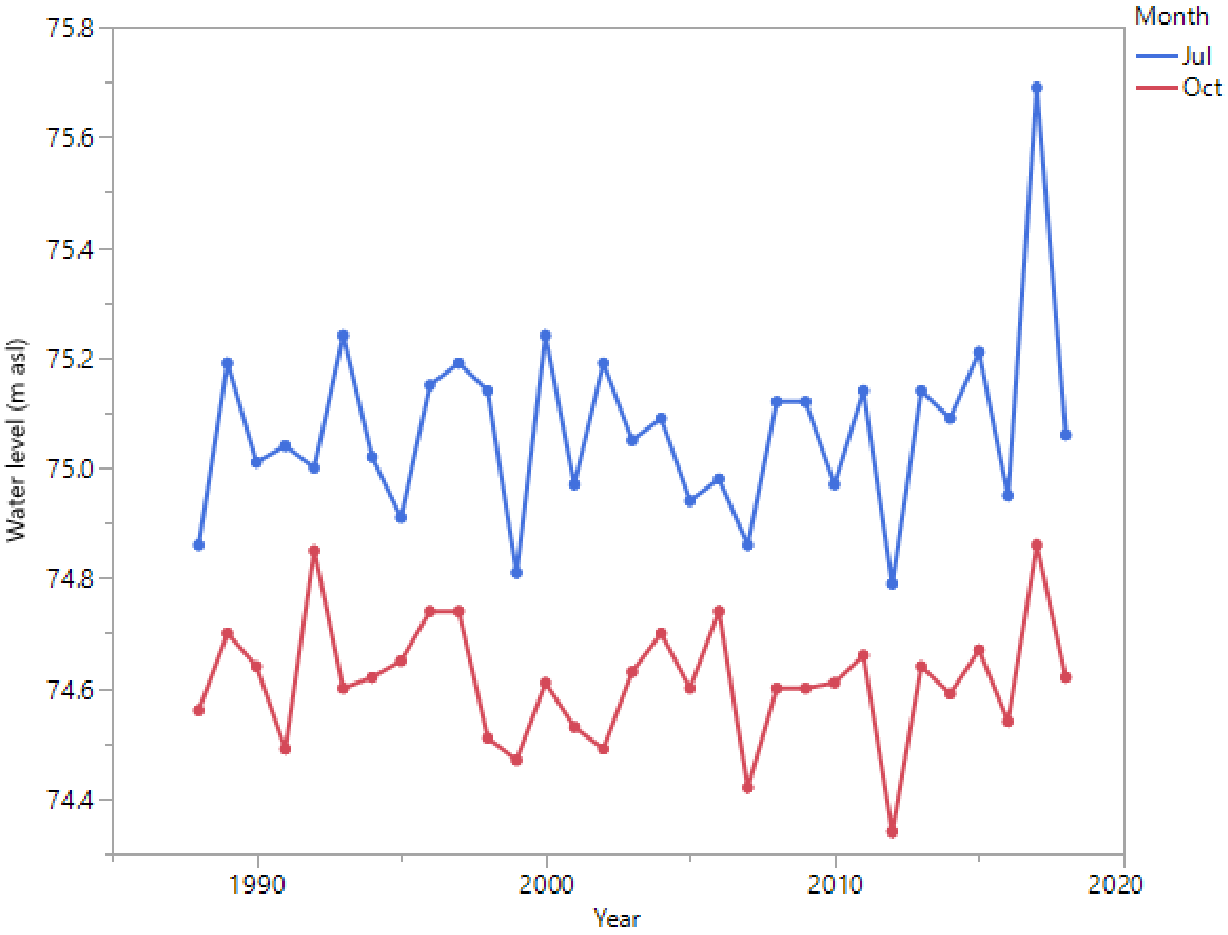

Figure 22. Annual mean water levels (m, above sea level) for July and October water levels in Lake Ontario. Data were compiled from the Canadian Hydrographic Service (http://www.tides.gc.ca/C&A/network_means-eng.html).

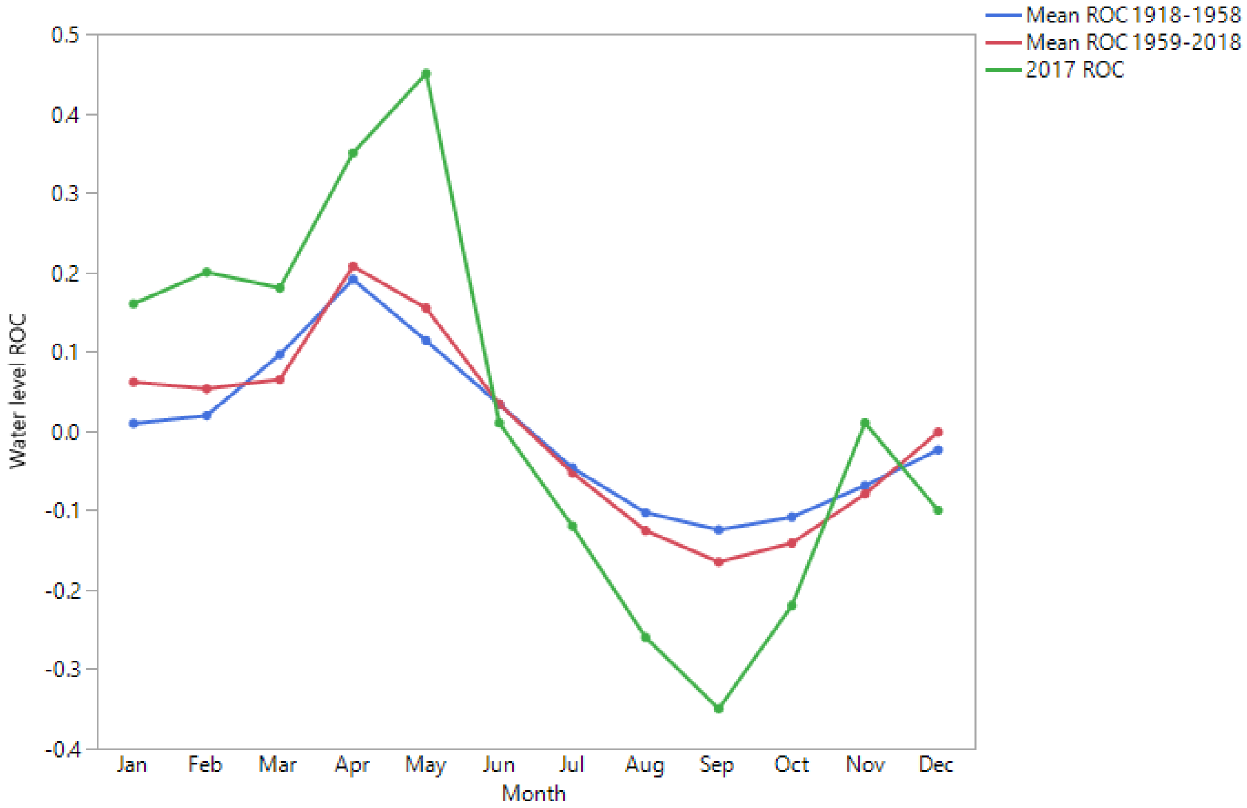

Figure 23. Monthly rate of change (ROC; m) in Lake Ontario water levels for the periods 1918 – 1958 and 1959 – 2018 as well as for just 2017. Data were compiled from the Canadian Hydrographic Service (http://www.tides.gc.ca/C&A/network_means-eng.html).

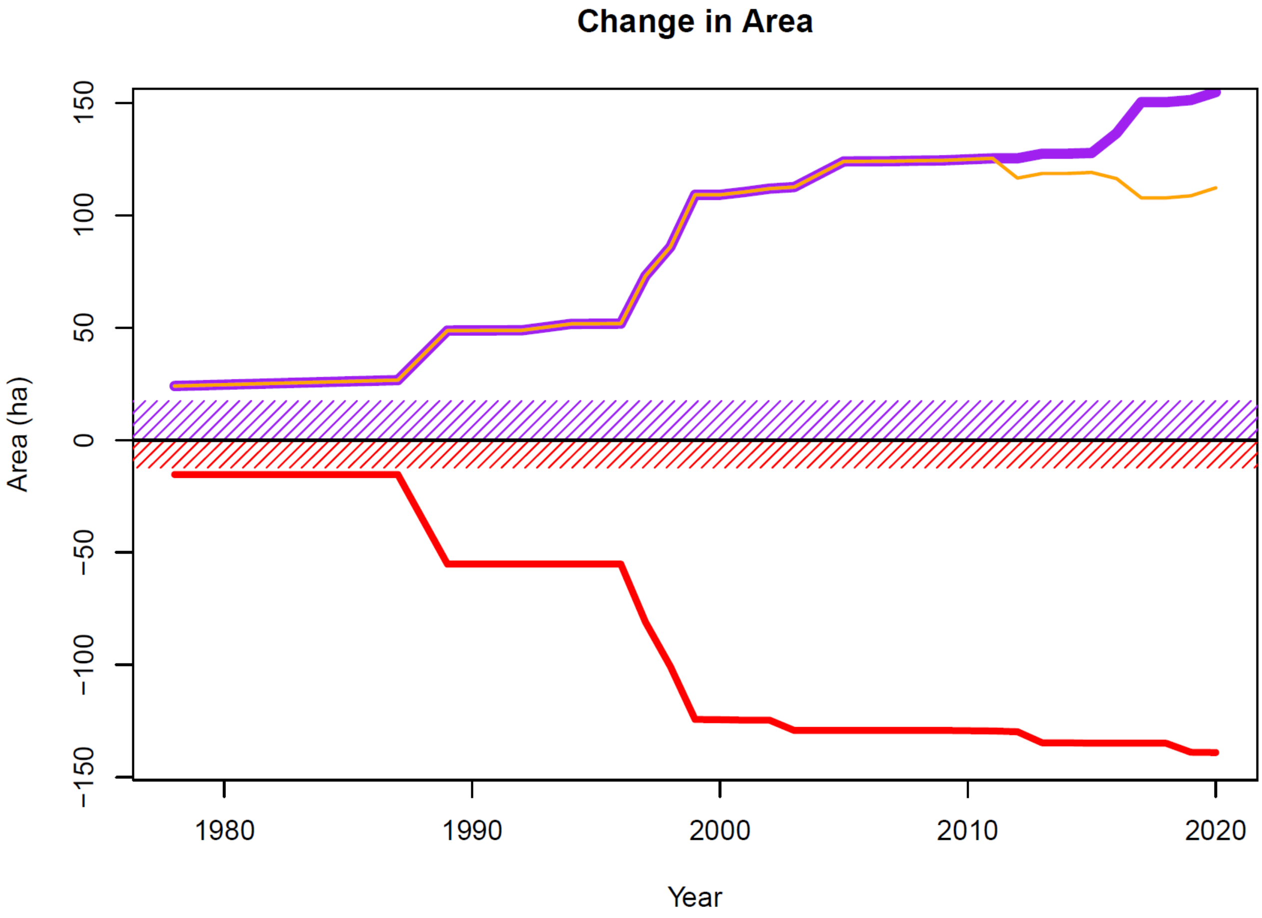

Figure 24. Cumulative surface area (ha) of modifications (purple) and infill (red) of fish habitat in the Toronto AOC from 1975 **–** 2020. The orange line represents functional availability of habitat for fish – some projects may have been completed, however, were taken offline for maintenance or inaccessible to fish after their recorded completion date. The coloured horizontal polygons represent area (ha) of modification and infill for projects without date information.

CRITERION FP-1B: NEARSHORE FISH COMMUNITY ASSESSMENT IN THE TORONTO AND REGION AREA OF CONCERN

Summary

An Ontario provincial standard fisheries assessment methodology known as nearshore fish community index netting (NSCIN) was used to assess the nearshore fish communities and ecosystem health in Lake Ontario / St. Lawrence River ecoregion (2006 – 2019), including the Toronto and Region Area of Concern (Toronto AOC) with remedial action plans (RAP) ongoing. An index of biological integrity (IBI) was developed based on the NSCIN survey to assess and compare the contemporary nearshore fish communities and ecosystem health among geographic areas as well as changes within embayments. The IBI was based on 11 metrics representing aspects of fish assemblage integrity, including: species richness, trophic structure, and abundance / biomass of species groups (e.g. piscivores). Toronto AOC IBI scores were classified as fair, remaining stable through the time series and below regionally similar areas. Sub-metrics, like the proportion piscivore and specialist biomass, remain below Toronto AOC target levels of 0.20 and 0.40, respectively. With early signs that Walleye stocking efforts in the Toronto AOC may be successful, stocking and ongoing sampling in alternating years continues.

Key Messages

- Relative to regionally similar areas, index of biotic integrity (IBI) scores were lower within the Toronto AOC; the scores continue to be indicative of an impaired exposed embayment.
- Proportion piscivore biomass (PPB) met target levels of >0.20 in two of the eight years sampled (2014 and 2019), but still below regionally similar areas.
- Proportion of total fish community biomass represented by specialist species (PSPE) was the same or higher than regionally similar areas, but still below the restoration target 0.40 in all years sampled.
- For top-predators, relative to other exposed embayments, there were similar catch rates of Largemouth Bass and Northern Pike, but lower catches of Smallmouth Bass and Walleye in the Toronto AOC; there is some evidence for lower catch of Largemouth Bass since 2012.
- Potential evidence for success from Walleye stocking in 2017 with the capture of five age-2 individuals in 2019 surveys.

Background

Toronto and Region is a Great Lakes AOC with multiple agencies engaged in a RAP. BUIs in the Toronto AOC include local fish populations (BUI#3) and are currently impaired. Historically, the Toronto waterfront had significant warmwater fish habitat associated with the Ashbridges Bay marsh. The historical resident fish community was dominated by cool and warmwater species of fish such as Northern Pike, Walleye, Largemouth Bass, Yellow Perch and Sunfish (Whillans, 1979). The Ashbridges Bay marsh area was filled in in the late 1800's to create what is known as the port lands. With the loss of this large coastal wetland, the remaining warmwater fish habitat would have been isolated to the lagoons within the Toronto Islands. Through the efforts of the RAP, habitat restoration activities have occurred and are still underway with the goal of restoring the fish community. The Ontario Ministry of Natural Resources and Forestry (OMNRF) conducts fish community sampling in designated AOCs (including the central waterfront of the Toronto AOC and other embayments) within a variety of nearshore habitat types (i.e. sheltered embayments, exposed embayments, transitional areas, and river reaches) to facilitate the comparison of fish community indices of ecosystem health in the Toronto AOC to relevant reference sites in the Lake Ontario / St. Lawrence River ecoregion. The objectives of the present section are to compare trap net-derived fish assemblage metrics from the Toronto AOC to regional reference areas and summarize species-specific trends in catch.

Methods

Ontario Nearshore Fish Community Index Netting (NSCIN) Methodology

The NSCIN protocol is a provincial standard fisheries assessment methodology that uses 6-foot trap nets set overnight and is designed to evaluate the relative abundance and other biological attributes of fish species that inhabit the littoral area (Stirling, 1999). Originally designed for application in Ontario Inland Lakes, this program has been implemented in the Lake Ontario / St. Lawrence River ecoregion by the Ontario Ministry of Natural Resources and Forestry for nearly two decades (OMNRF, 2020). The methodology allows for relative comparison of fisheries assessment benchmarks or targets among areas, trends through time, and can be sensitive enough to detect ecological change (Lester et al. 1996). As this is a passive, live-release methodology, a subsample of fish may also be selected for more detailed biological sampling (e.g., condition, age, maturity, diet), providing further insight into the status and health of the fish community.

As outlined in the NSCIN protocol (Stirling, 1999), field sampling occurs from August 1st to whenever the surface water temperature cools to 13 ^{o}C. Suitable trap net sites are chosen from randomly selected UTM grids that contain shorelines in the nearshore area. Although site selection varied annually, detailed grids for the Toronto AOC can be found in Brown (2019). Though the gear is suitable for a variety of nearshore habitat types, standard net setting criteria are required (e.g. water depth, orientation to shore, net separation distances) and it is not suitable for open-coastal areas. The number of trap net sites depends on the relative size of the area to be sampled and each trap net site is "fished" for approximately 24 hrs. For each trap net, fish species are identified and counted, and a subsample of fish are kept for detailed biological sampling (Brown, 2019). Minimum fish size captured with this gear is approximately 90 mm due to the 44 mm black polypropylene stretch mesh.

NSCIN was first initiated on the upper Bay of Quinte (Trenton to Deseronto), West Lake, and Weller's Bay in 2001, and was expanded to include the middle and lower reaches of the Bay of Quinte (Deseronto to Lake Ontario) in 2002. In 2006, the NSCIN program was expanded to include the Hamilton Harbour and Toronto AOCs thanks to partnerships developed with Fisheries and Oceans Canada and the Toronto and Region Conservation Authority (TRCA). NSCIN was further expanded to other Lake Ontario nearshore areas in subsequent years (Figure 25 and Table 7).

Fish Assemblage Metrics, IBI, and Restoration Targets

Using the NSCIN data collected from 2001-2013, fish assemblage metrics were selected and the trap net based IBI was developed (Hoyle and Yuille, 2016). The IBI used 10 of the 12 metrics described by Minns, et al. (1994) for fish assemblages in Great Lakes littoral areas using boat electrofishing. IBI classes can be described as follows: 0 – 20 very poor, 20 – 40 poor, 40 – 60 fair, 60 – 80 good, and 80 – 100 excellent ecosystem health. The number of intolerant species and the number of native cyprinids were not included as metrics, because of the inability of NSCIN trap nets to capture small fish (i.e., most cyprinids). The number of piscivore species was added as a metric to reflect habitat diversity and trophic function. The approach in which metrics were generated and IBI values calculated is described by Hoyle and Yuille (2016). Using this approach, fish assemblage metrics and IBI scores were generated using NSCIN data collected from all embayments sampled between 2006 and 2019.

The 11 metrics and IBI scores were evaluated in an effort to provide comparisons to relevant reference sites and to develop restoration targets for the nearshore fish population in the Hamilton Harbour and Toronto AOCs (Hoyle and Yuille, 2016; Bowlby and Hoyle, 2017; Hoyle et al. 2018). Through these studies, it was determined that the degree of exposure of an embayment to Lake Ontario influences fish species composition and abundance. The Central Waterfront of the Toronto AOC was classified as an exposed embayment and relevant reference sites were identified (i.e. Prince Edward Bay and Presqu'ile Bay). Restoration targets for the Toronto AOC were also identified; PPB > 20% and PSPE > 40%. For NSCIN sampling between 2006 – 2019 the 11 metrics and IBI scores for each embayment category (sheltered, exposed, transitional; Hoyle and Yuille 2016) were generated and compared to those in the Toronto AOC and compared between two time stanzas (2006 – 2012 and 2013 – 2019). PPB and PSPE within the AOC were also evaluated against restoration targets.

Results

The Toronto AOC has been sampled using the NSCIN protocol eight times since 2006 (2006, 2007, 2010, 2012, 2014, 2016, 2018, 2019) (Table 7). The Toronto AOC was classified as an exposed embayment (exposure index of 137.1), along with Prince Edward Bay and Presqu'ile Bay. All visits to the Toronto AOC occurred during the

NSCIN prescribed timing window (August – mid September) and an average of 24 sites were sampled each visit).

Species-specific abundance trends (mean catch per trap net) in the Toronto AOC are summarized in Table 8. The catch per unit effort ranged from 35 – 263 fish per trap net, with 2010 and 2012 representing the lowest and highest catches, respectively. In 2019, the most abundant species were Brown Bullhead, Alewife, Pumpkinseed, Rock Bass, and Common Carp. When compared to unimpaired embayments (Prince Edward Bay and Presqu'ile Bay), the catch in the Toronto AOC of species such as Walleye and Smallmouth Bass were depressed whereas Gizzard Shad and Brown Bullhead were elevated.

Fish assemblage metrics, IBI scores, and IBI classes for sheltered embayments, transitional areas, exposed embayments, and the Toronto AOC are shown in Table 9. During both time stanzas, IBI values were higher for sheltered embayments than for exposed embayments and transitional areas (Table 9). The Toronto AOC had one of the lowest IBI scores throughout the time series and remained in the "fair" IBI classification while the sheltered embayment reference sites were classified as "good" (Figure 26 and Figure 27). The proportion of total fish community biomass represented by piscivore species (PPB) in the Toronto AOC met target levels (>20%) two of the eight years sampled, though values still fell below comparable geographic areas (Figure 28 and Figure 29). Proportion of total fish community biomass represented by specialist species (PSPE) in the Toronto AOC was higher than comparable geographic areas though below the restoration target (>40%) in all years sampled with no clear trend (Figure 30 and Figure 31).

Discussion

Status of Toronto Nearshore Fish Community as Related to Restoration Targets

Through decades of studying the nearshore fish communities in the Lake Ontario / St. Lawrence River ecoregion, a better understanding of physical and environmental factors that influence fish community indicators of ecosystem health (i.e., IBI) has been achieved (e.g. Hoyle and Yuille, 2016; Bowlby and Hoyle, 2017; Hoyle et al. 2018). For example, through this body of knowledge, it is understood that the degree of exposure and effective fetch is related to IBI scores, with lower IBI scores related to exposed embayments and higher IBI scores related to sheltered embayments. Understanding how these underlying physical and environmental factors influence an IBI score can help to assess how anthropogenic impacts affect IBI beyond those factors. For example, temporal trends in IBI values for the Bay of Quinte are consistent with expectations based on ecosystem changes reflecting anthropogenic disturbances and remediation (Hoyle et al. 2012; Hoyle and Yuille, 2016). Comparing Toronto AOC IBI scores to unimpaired exposed embayments (i.e., embayments with similar underlying physical and environmental factors), we see that Toronto AOC IBI scores continue to be much lower and are indicative of an impaired embayment (e.g. between 2006 – 2019, IBI was 44 for the Toronto AOC and 65 for the other exposed embayments). That said, ongoing restoration efforts have the potential to increase IBI scores to unimpaired levels, particularly in the Toronto Islands area (Hoyle et al. 2012). As such, IBI scores in the Toronto AOC continue to play an important role in assessing the progress to restoration and delisting BUI#3.

Piscivore biomass positively contributes to and relates to ecosystem health. If the proportion of the total fish community comprised of piscivores is less than 0.20 (or 20%), this is associated with a degraded aquatic ecosystem (Bowlby and Hoyle 2017). As such, reaching and maintaining a PPB > 20% was selected for the Toronto AOC BUI#3 delisting criteria. In two of the eight years sampled, the PPB restoration target was met though not maintained. Piscivore restoration efforts (i.e., Walleye stocking) and ongoing habitat restoration efforts will serve to benefit piscivore species biomass, at the same time, decrease overabundant species, such as Common Carp (Bowlby and Hoyle, 2017).

A high diversity of specialist fish species is thought to represent a healthy and diverse aquatic habitat. A target of 0.40 (i.e., 40%) or greater for total fish community biomass represented by specialist species (PSPE) was selected as a restoration target for the Toronto AOC BUI#3. The proportion of specialist biomass in the Toronto AOC was below the 40% target in all eight years sampled, suggesting an impaired system, although the average was above that of both unimpaired reference embayments. The higher PSPE values in the Toronto AOC as compared to the unimpaired reference embayments may be explained by the higher catches of the native Gizzard Shad, a species indicative of degraded conditions, and the non-native specialists (i.e., Alewife and White Perch), which inflate the overall PSPE score.

Species-Specific Comparisons

Based on Principal Component Analysis, Bowlby and Hoyle (2017) found that the fish community in the Toronto AOC was significantly correlated with unimpaired exposed embayments like the North Channel, Lower Bay of Quinte, and Prince Edward Bay. While the sheltered embayment sites were dominated by Brown Bullhead, White Sucker, Rock Bass, and sunfishes, the more exposed sites were dominated by White Bass, Channel Catfish, Golden Shiner, Bluegill, White Perch and Black Crappie. When the fish community within the Toronto AOC was compared to other exposed embayments directly, it was found to have lower catches of Rock Bass, Smallmouth Bass and Walleye and more Gizzard Shad and Common Carp (Table 10). The catch of some top predators, notably Largemouth Bass and Northern Pike, was comparable to reference locations (Table 10), although for Largemouth Bass there was evidence of more recent declines in CPUE (starting after 2012; Table 8).

Walleye Restoration

Findings from the NSCIN surveys have historically shown very low abundance of Walleye in the Toronto AOC relative to comparable embayments such as Presqu’ile Bay. Walleye are predatory fish, and a healthy fish community should have a percentage of predators to balance the fish community (i.e. PPB > 20%). The Toronto AOC has historically been below this target. Stocking Walleye in the Toronto AOC not only supports efforts of the local RAP objectives to restore a healthy fish community, but it may also provide angling opportunities for urban anglers.

In April 2017 and 2019, the Lake Ontario Management Unit worked in conjunction with OMNRF’s White Lake Fish Culture Station to collect Bay of Quinte Walleye gametes (target of eight million eggs and 40 families) with the goal of stocking out 100,000 3-month old Walleye into the Central Waterfront of the Toronto AOC every other year (Ontario Ministry of Natural Resources and Forestry, 2020). In 2017, 1,080,000 swim up fry and 100,059 3-month old Walleye were stocked and in 2019, 100,000 3-month old Walleye were stocked (Table 11).

2019 was the first year Walleye from 2017 stocking efforts were likely to recruit into the trap net gear. A total of nine Walleye were detected in the Toronto AOC in 2019, five of which were age-2 (mean fork length: 402 mm) and presumably from the 2017 stocking event. Observations of the 2017 stocking event in the Toronto AOC suggests a positive outlook for this year class. These year classes will continue to be monitored in future trap net surveys.

Tables and Figures

Table 7. Sampling Information, exposure index (opening / surface area), and embayment classification of Lake Ontario Embayments sampled by OMNRF (2001 **–** 2006 not included). See Bowlby and Hoyle (2017) for a more detailed description of the exposure index as it related to the embayment classification.

Embayment	**Average Number of Sampling Sites**	**Number of Years Sampled**	**Years Sampled**	**Surface Area (km^2)**	**Opening**	**Exposure Index**	**Embayment Classification**
Toronto AOC	24	8	2006, 2007, 2010, 2012, 2014, 2016, 2018, 2019	14.3	1,960	137.1	Exposed
Prince Edward Bay	25	3	2009, 2013, 2017	101.9	9,247	90.7	Exposed
Presqu'ile Bay	14	2	2008, 2015	9.7	726	75.0	Exposed
Lower Bay of Quinte	11	3	2009, 2011, 2019	75.1	5,513	73.4	Transitional
North Channel	25	1	2009	130.2	5,939	45.6	Transitional
Hamilton Harbour	23	9	2006, 2008, 2010, 2012, 2014 -2016, 2018, 2019	21.0	88	4.2	Sheltered
West Lake	22	3	2007, 2013, 2017	19.1	27	1.4	Sheltered
East Lake	17	3	2007, 2013, 2017	11.6	21	1.8	Sheltered
Wellers Bay	24	2	2008, 2015	19.1	86	4.5	Sheltered
Upper Bay of Quinte	36	13	2007-2019	129.0	1,033	8.0	Sheltered
Middle Bay of Quinte	29	3	2009, 2011, 2019	62.7	884	14.1	Sheltered

Table 8. Species-specific abundance trends (mean catch per trap net) the Toronto and Region Area of Concern. Annual number of net sets, number of species, total catch, and total catch per net lift are also indicated.

Species	2006	2007	2010	2012	2014	2016	2018	2019
Longnose gar	0.17	-	-	0.04	0.17	0.08	0.04	0.08
Bowfin	0.33	0.08	0.46	0.42	0.13	0.54	0.25	0.79
Alewife	3.79	4.58	0.42	9.50	17.91	0.54	3.21	8.50
Gizzard Shad	2.71	0.42	0.04	1.08	0.35	4.04	0.83	0.42
Chinook salmon	0.08	-	-	-	-	-	-	-
Rainbow trout	-	-	0.04	-	-	0.08	0.04	0.04
Atlantic salmon	-	-	-	-	0.04	-	-	-
Brown trout	0.04	-	-	0.08	0.13	-	-	0.04
Northern Pike	1.17	0.83	1.38	1.25	1.00	1.50	0.88	0.75
Quillback	-	-	-	-	-	0.04	-	-
White sucker	4.17	3.83	2.29	1.13	1.17	2.58	0.46	0.79
Silver redhorse	-	-	-	-	0.04	-	-	-
Shorthead redhorse	0.04	-	-	-	-	-	-	-
Goldfish	0.04	-	0.04	-	-	0.25	-	-
Common carp	1.58	2.50	4.75	3.67	2.00	4.79	1.58	1.25
Brown Bullhead	32.63	14.79	8.42	198.00	71.65	160.38	29.79	48.17
Channel catfish	0.04	-	0.17	0.08	0.04	0.13	0.13	0.13
American eel	-	-	-	-	0.09	0.04	-	0.17
White perch	0.04	-	0.25	0.92	0.04	0.04	0.21	0.29
White bass	0.33	-	0.04	0.04	0.22	-	0.04	0.04
Rock bass	0.33	1.13	2.58	4.75	1.78	8.71	2.46	1.92
Pumpkinseed	7.29	16.29	7.67	12.75	2.48	15.92	10.75	7.38
Bluegill	0.54	3.96	1.13	2.04	0.87	1.46	0.83	0.83
Smallmouth bass	0.04	0.04	0.08	0.08	0.09	0.17	0.08	0.13
Largemouth bass	1.08	1.25	1.38	5.00	0.61	0.54	0.58	0.42
Black crappie	0.83	0.42	0.13	1.13	0.70	0.17	0.08	0.75
Yellow Perch	1.08	5.96	2.63	20.63	2.17	3.83	0.71	0.38
Walleye (Yellow pickerel)	0.38	0.08	-	-	0.09	0.33	-	0.38
Freshwater drum	1.08	1.29	0.83	0.63	0.83	0.75	0.29	0.42
Carassius auratus x Cyprinus carpio	-	-	-	-	-	-	-	0.13
Notropis hybrids	-	-	-	-	-	0.04	-	-
Number of net lifts	24	24	24	24	24	24	24	24
Number of species	24	16	20	20	24	24	20	24
Total catch	1,440	1,368	840	6,312	2,520	4,968	1,272	1,780
Total catch per net lift	60	57	35	263	105	207	53	74

Table 9. Mean raw metrics and IBIs (± standard deviation), and IBI class benchmarks for sheltered embayments, transitional areas, exposed embayments (excluding the Toronto and Region Area Of Concern (Toronto AOC)), 2006 **–** 2012 and 2013 **–** 2019.

		2006-2012				**2013-2019**			
Metric	**Description**	**Sheltered Embayments**	**Transitional Areas**	**Exposed Embayments**	**Toronto AOC**	**Sheltered Embayments**	**Transitional Areas**	**Exposed Embayments**	**Toronto AOC**
Species Richness									
SNAT	Number of native species	8 (3)	6 (3)	7 (2)	6 (2)	8 (3)	8 (4)	6 (2)	5 (3)
SNIN	Number of non-native species	1 (1)	0 (1)	1 (1)	1 (1)	1 (1)	1 (1)	0 (1)	1 (1)
SCEN	Number of centrarchid species	4 (2)	2 (2)	3 (1)	2 (2)	4 (2)	3 (2)	3 (1)	2 (1)
SPIS	Number of piscivore species	2 (1)	2 (1)	2 (1)	1 (1)	3 (1)	3 (1)	3 (1)	1 (1)
Trophic Structure									
PPIS	Percent piscivore biomass	27 (22)	30 (22)	33 (26)	16 (20)	30 (22)	59 (21)	53 (26)	21 (24)
PGEN	Percent generalist biomass	27 (29)	26 (28)	38 (27)	53 (29)	27 (28)	12 (17)	29 (25)	54 (31)
PSPE	Percent specialist biomass	46 (28)	44 (30)	29 (20)	31 (25)	43 (26)	29 (19)	18 (19)	26 (26)
Catch / biomass									
NNAT	Number of native individuals	179 (411)	42 (34)	95 (86)	96 (368)	198 (620)	59 (100)	60 (76)	100 (228)
BNAT	Biomass of natives	50 (106)	20 (16)	25 (22)	34 (95)	54 (143)	17 (10)	23 (22)	36 (88)
PNNI	Percent non-native numbers	10 (17)	2 (4)	12 (20)	18 (23)	12 (20)	13 (17)	2 (4)	26 (30)
PBNI	Percent non-native biomass	10 (15)	7 (16)	8 (16)	28 (26)	10 (15)	7 (9)	5 (11)	33 (31)
IBI	**Index of Biological Integrity**	**66 (15)**	**62 (12)**	**60 (11)**	**47 (14)**	**66 (13)**	**58 (13)**	**65 (10)**	**44 (14)**
IBI – class		**Good**	**Good**	**Good**	**Fair**	**Good**	**Fair**	**Good**	**Fair**

Table 10. Excerpt from Table 6.0 in Bowlby and Hoyle (2017) showing mean and standard deviation of catch of selected species in Toronto Harbour and exposed embayments of Lake Ontario. Change column indicates if Toronto and Region Area of Concern metric is within 1 standard deviation of exposed embayment.

	Thermal Regime	**Guild**	**Exposed Embayment**	**Toronto Harbour**	**Change**
Target Species					
Northern Pike	Cool	Piscivore	0.89 ±0.60	1.29	-
Rock bass	Cool	Piscivore	9.40 ±3.96	0.23	↓
Smallmouth Bass	Cool	Piscivore	1.39 ±0.96	0.05	↓
Largemouth Bass	Warm	Piscivore	1.11 ±1.01	1.95	-
Walleye	Cool	Piscivore	0.74 ±0.43	0.16	↓
Hyper-abundant Species					
Gizzard Shad	Cool	Specialist	0.02 ±0.03	57.38	↑
Common Carp	warm	Generalist	0.41 ±0.37	7.70	↑
Brown Bullhead	Warm	Generalist	28.28 ±28.26	2.24	-

Table 11. Chronology of Walleye (Bay of Quinte strain, White Lake Fish Culture Station) stocked into the Toronto and Region Area of Concern, 2017 **–** 2019.

Year	Month	Life-stage	Mean Weight (g)	Number of Fish
2017	May	Swim-up Fry	n/a	1,080,000
2017	July	3-months	0.5	100,059
2019	July	3-months	0.35	100,000

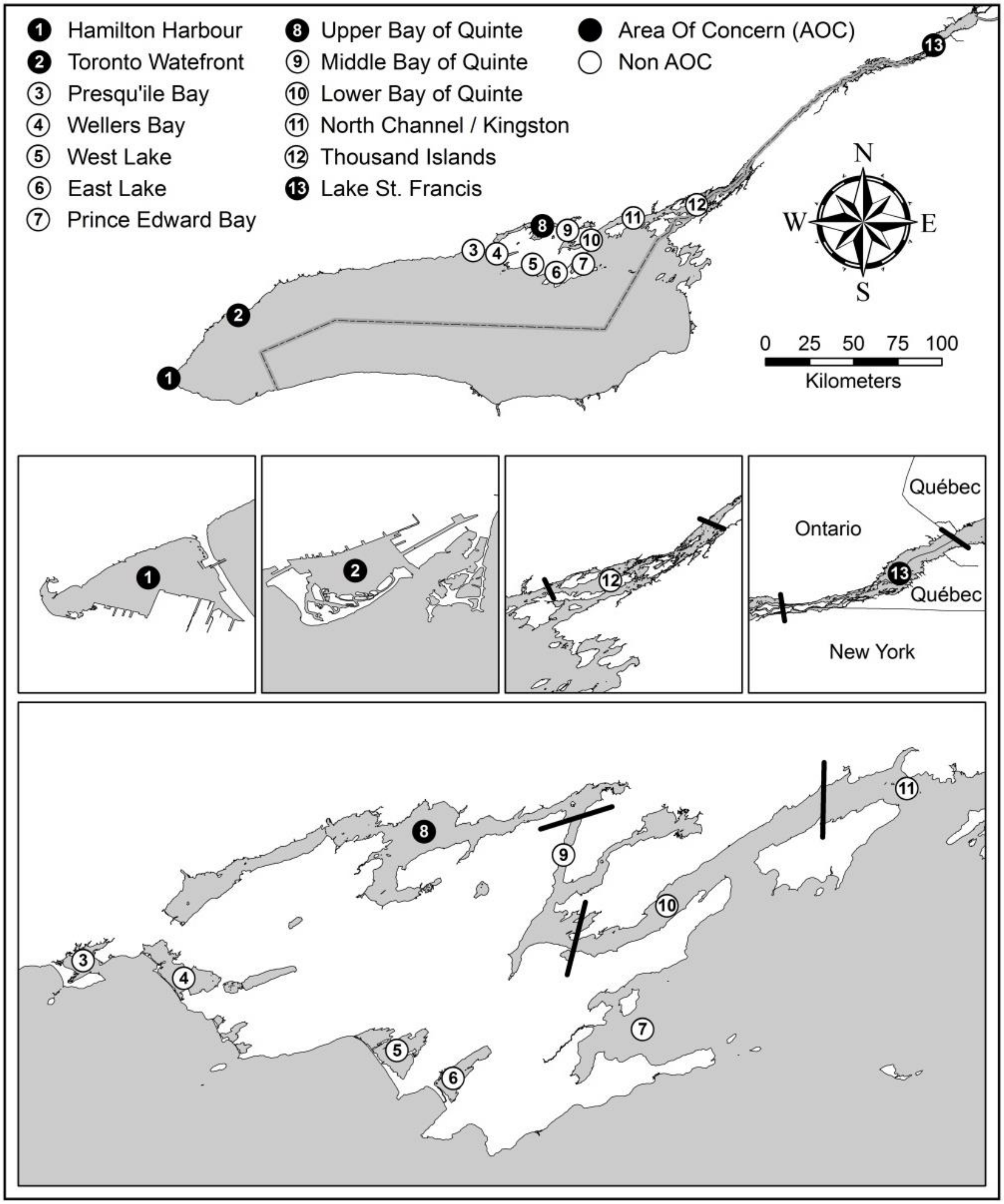

Figure 25. Map of Nearshore Community Index Netting sampling areas on Lake Ontario (n = 11) and St. Lawrence River (n = 2). Upper panel: Lake Ontario and the St. Lawrence River with filled circles indicating designated Great Lakes Areas of Concern (AOCs); middle panel: northeastern Lake Ontario and the Bay of Quinte sampling areas. Solid lines depict borders between upper, middle and lower Bay of Quinte, North Channel / Kingston, Thousand Islands, and Lake St. Francis (Hoyle and Yuille, 2016).

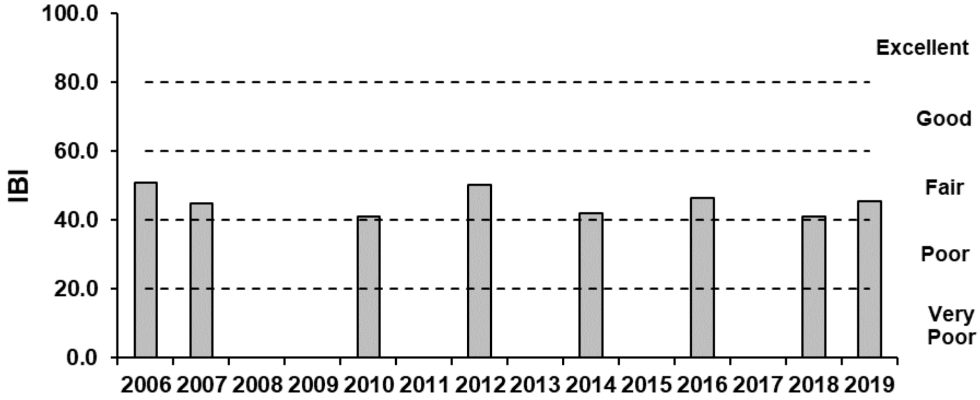

Figure 26. Index of biological integrity (IBI) values, as a measure of ecosystem health, in the nearshore trap net surveys in the Toronto and Region Area of Concern (2006 – 2019). IBI classes can be described as follows: 0 – 20 very poor, 40 – 60 fair, 60 – 80 good, and 80 – 100 excellent ecosystem health.

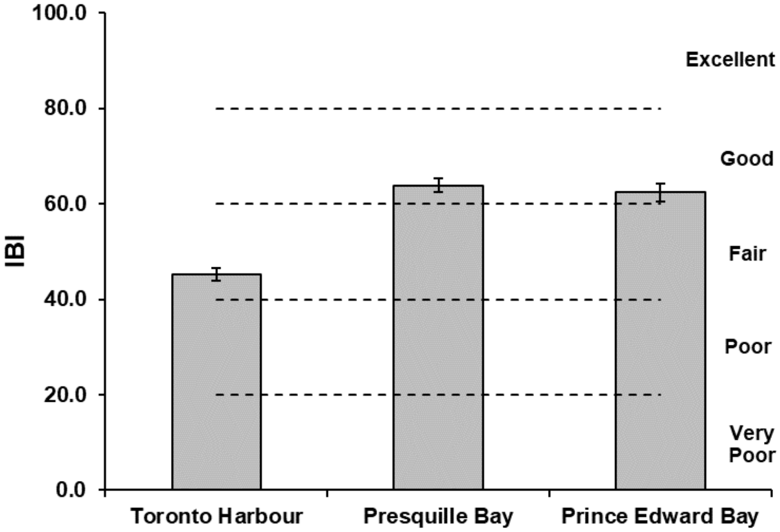

Figure 27. Index of biological integrity (IBI) values, as a measure of ecosystem health, in the nearshore trap net surveys in three exposed Lake Ontario embayments (2006-2019). IBI classes can be described as follows: 0 – 20 very poor, 40 – 60 fair, 60 – 80 good, and 80 – 100 excellent ecosystem health. Error bars are ± 2 standard error.

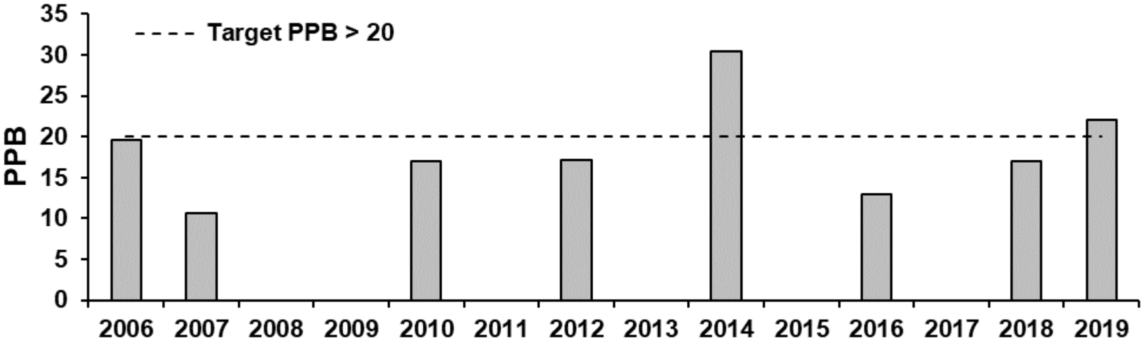

Figure 28. Percent of the total fish community represented by piscivore biomass (PPB) in the nearshore trap net surveys in the Toronto and Region Area of Concern (2006 – 2019). A PPB >20 is indicative of a balanced trophic structure and is the restoration target (delisting criteria) for the Toronto AOC. Piscivore species include Longnose Gar, Bowfin, Northern Pike, Smallmouth Bass, Largemouth Bass, and Walleye.

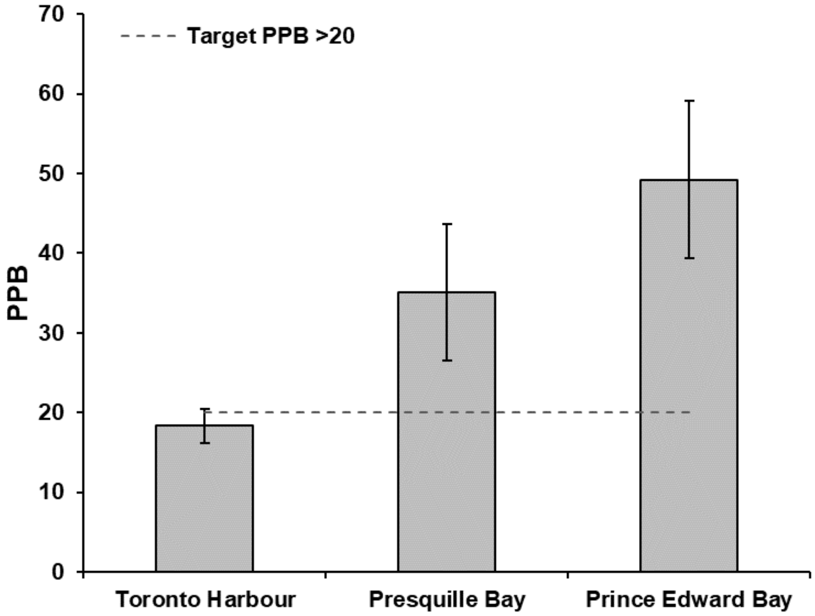

Figure 29. Percent of total fish community represented by piscivore biomass (PPB) in the nearshore trap net surveys in three exposed Lake Ontario embayments (2006 – 2019). A PPB >20 is indicative of a balanced trophic structure and is the restoration target (delisting criteria) for the Toronto and Region Area of Concern. Piscivore species include Longnose Gar, Bowfin, Northern Pike, Smallmouth Bass, Largemouth Bass, and Walleye. Error bars are ± 2 standard errors.

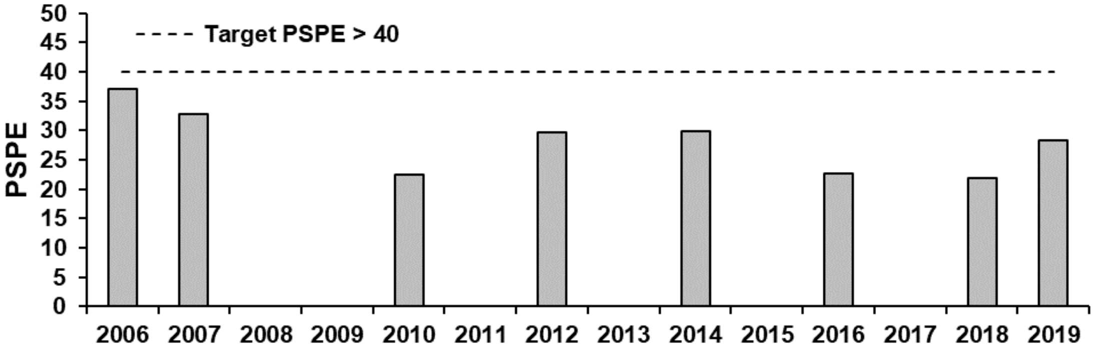

Figure 30. Percent of the total fish community biomass represented by specialist species (PSPE) in the nearshore trap net surveys in the Toronto and Region Area of Concern (2006 – 2019). A PSPE >40 is the restoration target (delisting criteria) for the Toronto and Region Area of Concern. Specialist species include White Sucker, Freshwater Drum, Pumpkinseed, Bluegill, Black Crappie, Rock Bass and Yellow Perch.

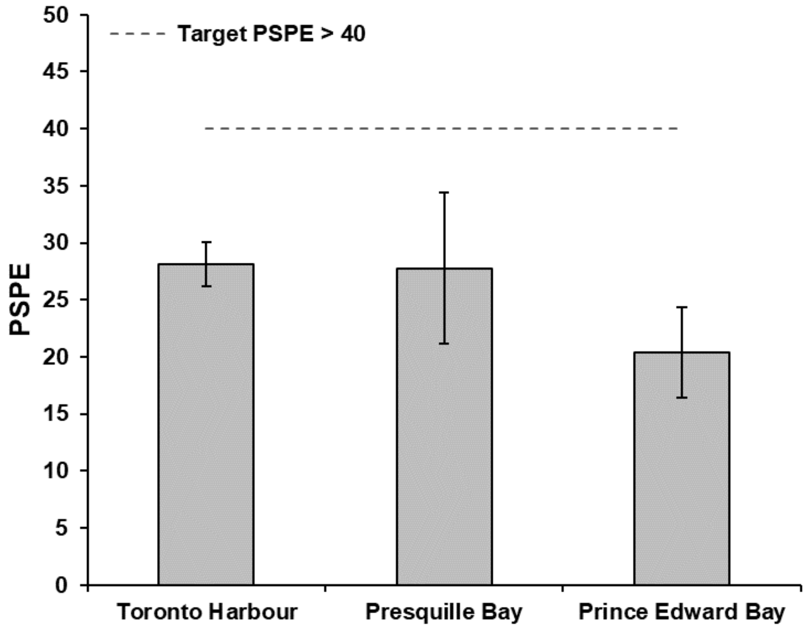

Figure 31. Percent of total fish community biomass represented by specialist species (PSPE) in the nearshore trap net surveys in three exposed Lake Ontario embayments (2006 – 2019). A PSPE >40 is the restoration target (delisting criteria) for the Toronto and Region Area Of Concern. Specialist species include White Sucker, Freshwater Drum, Pumpkinseed, Bluegill, Black Crappie, Rock Bass and Yellow Perch. Error bars are ± 2 standard errors.

CRITERION FP-1C: PELAGIC PREY FISH

Summary

Multi-year prey fish surveys from the lake conducted by OMNRF and other partners showed no differences in prey fish populations during DFO sample years. As such, we believe the patterns observed in the Toronto AOC and other regional reference areas were not confounded by the conditions of the lake during these sampling years. Four DFO hydroacoustic and trawling surveys were completed in 2009, 2010, 2016, and 2018. Although each study could not be compared for trends through time due to differences in sampling design, no apparent impairments of forage fish populations were observed in the Toronto AOC relative to the available regional reference sites. Differences within the Toronto AOC were observed, with generally higher density and biomass in waters adjacent to the central waterfront, but again lower values in the open coast areas of the Toronto AOC were consistent with the few open coast areas sampled concurrently in Lake Ontario. River mouths, as an ecotype, also appear to be distinct and to support higher fish densities that open coast areas and some more protected embayments. Consequently, river mouths and the central waterfront of the Toronto AOC are clearly important areas for forage fish and should be protected accordingly. Future studies should consider designs that allow for multi-year comparisons, but at the very least, additional sampling in more appropriate regional reference sites (open embayment sites in the Bay of Quinte) is needed to finalize the assessment of this sub-component of FP-1.

Key Messages

- No evidence for an impairment in forage fishes relative to the available regional comparison sites, particularly in the central waterfront, suggesting FP-1C is not impaired.
- Hydroacoustic surveys suggest the Toronto AOC (especially the central waterfront) is dominated by small bodied fishes, most likely Alewife.
- Open coast sites in Toronto AOC have low fish densities, consistent with surveys from the rest of Lake Ontario.
- River mouths and the central waterfront of the Toronto AOC are important areas for forage fish and should be protected accordingly.
- The results from FP-1C do not support the designation of criteria FP-1 as "impaired".

Remaining Concerns and Uncertainty

- Currently, there is a lack of appropriate reference sites for previous studies (see monitoring suggestions #1 and #2).
- Due to different sampling designs, previous studies did not allow for long term data comparisons.

- One of the core challenges of analyzing hydroacoustic data is the operational units used are artificially derived and subset from the overall transect. As a result, these sampling units tend to be spatially autocorrelated (see action #1).

Future Monitoring

1. For regional comparisons, Toronto AOC hydroacoustic surveys should be coordinated through lake-wide Coordinated Science and Monitoring Initiative works (Lake Ontario is slated for sampling in 2023) to leverage multi-jurisdictional sampling and put observed forage fish density and biomass in the Toronto AOC within the context of the lake.
2. Future studies should replicate the 2018 survey, to allow for multi-year comparisons (as was completed in 2018), with additional sampling in appropriate regional reference sites (likely Presqu’ile Bay).

Recommended Actions

1. Future analyses should explore alternative statistical approaches that can incorporate spatial autocorrelation [e.g., R-INLA (Integrated Nested Laplace Approximation)], and/or adjustments to the sampling design (e.g., shorter transects with more replicates); this will ensure these types of data are being analyzed in the most appropriate manner.
2. Studies to assess the importance of different ecotypes (river mouths, embayments, etc.) should be considered and could focus restoration activities to protect ecotypes that provide the most benefit to fish populations.
3. Future analyses should combine the 2018 hydroacousitc dataset with zooplankton information collected in the same survey to look for relationships between fish and zooplankton density in the Toronto AOC.

Background

A growing body of literature has documented diel horizontal migrations between littoral and limnetic waters by both top predators and forage species (see Muška et al. 2013). These movements are thought to occur because littoral waters offer better protection from predation while limnetic waters support better opportunities for growth (Gliwicz et al. 2006). Regardless of the causal mechanism, these types of movements occur regularly in freshwater and emphasize the importance of limnetic fishes as a source of forage for a subset of top predators. Most fish habitat losses in the Toronto and Region Area of Concern (Toronto AOC) have occurred in nearshore areas (e.g., wetlands). As a result, fish species that occupy the littoral zone have been the focus for monitoring and recovery efforts (see sections FP-1A/1B/FP-2 etc.). Fish tracking efforts in the Toronto AOC using acoustic telemetry have documented the regular use of limnetic waters by Walleye and adult Northern Pike (Midwood et al. 2019a), two species that are targets for population recovery. This suggests that these target species, and likely other top predators that are not presently being tracked (e.g., salmonids), feed on limnetic prey fishes. Including these limnetic forage fishes is therefore an important component of the assessment of fish populations in the Toronto AOC and efforts have been made to quantify the density and distribution of prey fishes in the Toronto AOC (DFO GLLFAS 2010, 2011, Midwood et al 2018b, J. Midwood, DFO, unpublished data) and in Lake Ontario as a whole (OMNRF 2017, Holden et al 2018).

The assessment of the status of limnetic forage fishes both within the Toronto AOC and relative to other areas in Lake Ontario informs BUI#3 FP-1 in two ways:

1) "*restore aquatic ecosystem conditions capable of supporting native fishes…that includes a top-level predator assemblage*" – evidence of an impaired forage fish community may influence top-level predators; and
2) *"…formerly abundant fish populations are rehabilitated where locally depressed…"* – evidence of lower than regional forage fish densities would suggest impairment.

This section details efforts to estimate the density, biomass, and distribution of prey fishes using hydroacoustics in the Toronto AOC. These studies are necessary for assessing the relative contribution of the nearshore and the relative importance of different habitats to overall production in the region. Our objectives are to determine if there are differences in prey fish density and biomass among sectors within the Toronto AOC and relative to areas outside the Toronto AOC. Sectors within the Toronto AOC can be further categorized into ecotypes, including: the embayments [protected; primarily the central waterfront]; open coast [exposed]; and river mouths to highlight important habitat features for future restoration work.

Methods

Several surveys of fishes in limnetic waters within the Toronto AOC and Lake Ontario have been completed by Fisheries and Oceans Canada. These surveys used split-beam hydroacoustics to develop estimates of fish density (#/ha or #/m^3) and biomass (kg/ha, g/m^3) in areas of interest, and were paired with bottom or mid-water trawling to determine the species assemblage and approximate size ranges for these species. The initial focus of these surveys was to compare density and biomass among sectors within the Toronto AOC (Midwood et al. 2018b), but surveys in 2018 were designed to support a comparison of density and biomass within the Toronto AOC to the open coast of Lake Ontario and the Hamilton Harbour AOC (unpublished DFO data). Surveys completed in late summer 2009 and 2010 used a different approach than later surveys and the results of the earlier surveys have not been analyzed fully. Results from these earlier surveys are presented to provide additional context to the results from the more spatially complete late summer 2016 survey; however, these studies have not been designed to provide an assessment of trends over time for prey fishes. Holden et al. (2018) provides a long-term dataset of prey fish trends for all of Lake Ontario and is used to provide lake-wide temporal trends in prey fish and place the AOC-specific surveys into a regional context. For all DFO-led hydroacoustics surveys, data were binned along a 50-m transect to yield Elementary Distance Sampling Units (EDSU) that were later treated as a sample (after Simmonds and MacLennan, 2005). For the 2009, 2010, and 2016 surveys, only daytime data are presented; therefore, prey fish were primarily detected in schools. In contrast, the regional surveys were undertaken at night so prey fish were more likely to be detected as single targets (which can yield more accurate estimates of density and biomass since there is no “shadow” effect; Guillard and Verges 2007). Temperature and dissolved oxygen profiles were typically collected for each survey transect to aid in the post-processing of the hydroacoustics data and to provide some information on local environmental conditions.

Within Toronto AOC differences

The primary objective of the within-Toronto AOC surveys was to compare forage fish biomass and density among limnetic waters throughout the Toronto AOC. This comparison can inform the identification of high productivity areas, which may be important for top predators and can also be used to identify differences among ecotypes within the Toronto AOC to ensure regional comparisons are applied appropriately. Each study year is interpreted independently from each other, since, as noted previously, the studies were not designed for comparisons of trends through time.

2009

Surveys were completed primarily during the day [some crepuscular (twighlight) and night surveys] from September 16 to October 2, 2009 using a BioSonics DTX 199 kHz split-beam echo-sounder system (6.3° X 6.3°). The study area was focused around the central waterfront (i.e., Inner and Outer harbour, Lake Ontario side of the Toronto Islands and Tommy Thompson Park) but extended into Ashbridges Bay and Humber Bay. Data were analyzed by Milne Technologies and are presented as mean density (#/ha) and biomass (kg/ha) for each analysis sector (DFO GLLFAS 2010). Benthic trawls were conducted concurrently with the hydroacoustic surveys.

2010

Similar to the 2009 surveys, works in 2010 occurred primarily during the day with some crepuscular and nighttime transect. These surveys also used a BioSonics DTX 199 kHz split-beam echo-sounder (6.3° X 6.3°) and were completed from September 14th – September 30th, 2010. The same areas as the 2009 survey were assessed, but the area surrounding the river mouth of Bronte Creek (outside of the Toronto AOC) was also included as a potential regional reference site. Data were analyzed by Milne Technologies and are presented as mean density (#/ha) and biomass (kg/ha) for each analysis sector (Leisti et al. unpublished). Benthic trawls were conducted concurrently with the hydroacoustic surveys.

2016

From September 6 – 22, 2016 daytime (08:00-19:00) surveys were undertaken throughout the Toronto AOC, including all sectors surveyed in 2009 and 2010 as well as additional sectors near the Rouge River and Etobicoke Creek. There was a slight change in the hydroacoustic unit that was employed with a slightly wider beam width than past surveys (BioSonics DTX 199 kHz split-beam echo-sounder, 6.9° X 6.9°). Separate analyses were completed for datasets with only schools, with only single targets (non-schooling fish), and with both school and non-schooling targets. A complete presentation of the works completed in 2016 can be found in Midwood et al. 2018b. Mid-water trawls were conducted concurrently with the hydroacoustic surveys.

Regional Comparison

2018

The primary objective of the 2018 surveys was to develop a dataset that would allow for a comparison of forage fish density and biomass between the Hamilton Harbour and Toronto AOCs as well as between these AOCs and more open limnetic waters of Lake Ontario. Surveys were completed at night (1 hour after sunset to 1 hour before sunrise) from September 10th to September 18th, 2018. A different split-beam hydroacoustic transducer was used [BioSonics DTX 120 kHz (7.7˚ X 7.7˚)] compared to past surveys and this was done in order to make these surveys comparable to the Lake Ontario prey fish assessments that are completed yearly by the Ontario Ministry of Natural Resources and Forestry. Analysis sectors in the Toronto and Hamilton Harbour AOCs were defined from past surveys (see Midwood et al. 2018b, 2019b) and new sectors were defined proximate to the mouth of the Credit River and for an open coast section located south west of this river. Within sampling sectors, transects were stratified across depth contours (6, 8, 10, 12, 16, 20-m), and midwater trawling was completed only for the 8-m contour sites because it was the only depth contour encountered across all sampling sectors. In addition, a Light-Optical Plankton Counter was towed concurrently with acoustics to capture zooplankton biomass and density in the Toronto AOC with an expected correlation between the presence of zooplankton and prey fishes, however, these data have not been processed at the time of writing this report.

Results

Within Toronto AOC Differences

2009

The highest density (approximately 1500 – 2250 fish/ha) and biomass (approximately 20 – 23 kg/ha) estimates were found in the Inner and Outer Harbour [INNH and OUTH/OUTI, (Table 12 for all site names for all surveys); Figure 32]. The eastern headlands (Ashbridges Bay) also had fairly high densities for schooling fish (approximately 1250 fish/ha), but this did not translate into high biomass of fish and therefore was likely driven by small-bodied fishes. The Humber Bay area had the lowest density and biomass estimates. With the exception of the Outer Harbour (OUTH and OUTI), the bulk of the biomass typically came from single targets. Eight species were captured in the benthic trawls, with Alewife (*Alosa pseudoharengus*) having the highest catch rates (driven by large numbers in Ashbridges Bay and the Outer Harbour). In contrast, catch in the Inner Harbour was dominated by Threespine Stickleback (*Gasterosteus aculeatus*) and Round Goby (Figure 33).

2010

The highest density (approximately 20000 fish/ha) and biomass (approximately 55 kg/ha) were found off the end of Tommy Thompson Park (Figure 34). Ashbridges Bay (Eastern Headlands in the report) also had high average density (approximately 3500 fish/ha) and biomass (approximately 26 kg/ha) relative to other areas surveyed in 2010, but there was a lot of variability within this site driven by high density and biomass estimates from EDSU that captured the same large school of fish that was detected off of Tommy Thompson Park (Leisti et al. unpublished). These schools were found to be sitting at the edge of the Toronto scarp in depths that are not available in most other sampling sectors (TTPK had well over double the mean sampling depth relative to other survey transects; Leisti et al. unpublished). Outer Harbour estimates were similar to those observed in 2009, but lower for the outer harbour islands and inner harbour. Bronte Harbour had comparable density and slightly higher biomass relative to the Outer Harbour, but well below those observed in the Tommy Thompson Park and Ashbridges Bay sectors.

For bottom trawling, the Inner Harbour had the highest average catch per trawl (~2000 fish) and this was dominated by Threespine Stickleback and to a lesser extent Round Goby. Similar species composition was observed in the Outer Harbour, albeit at lower numbers. For the remaining three sectors, Round Goby were still captured regularly, but Rainbow Smelt (*Osmerus mordax*) and Alewife also comprised between 10 and 65% of the total catch, respectively (Figure 35). No trawling was completed in TTPK.

2016

The hydroacoustic survey suggested that pelagic fishes were unequally distributed throughout the Toronto 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 (central waterfront is defined as the INNH, OUTH, OUTI; Figure 36). These values cannot be directly compared with surveys completed in 2009 and 2010, but the patterns are similar to the 2009 survey.

Most mid-water trawls occurred in 10 m of water or less and the most commonly encountered fishes were Alewife (primarily young of year), Round Goby, and to a lesser extent Threespine Stickleback, Brook Stickleback (*Culaea inconstans*), and Rainbow Smelt (Figure 37). Trawl catch per unit effort was highest at the Outer and Inner Harbour transects (0.01 – 0.07 $\#/m^2$) and orders of magnitude lower at transects outside of the central waterfront (<0.0005 $\#/m^2$) (Figure 38).

Regional Comparison

2018

Ten fish species were captured during the trawl survey, the most common species were Alewife (1749 total), followed by Rainbow Smelt, and Threespine Stickleback (which were only captured in Toronto's Inner Harbour). An Analysis of Variance (ANOVA) suggested significantly higher overall CPUE at 8-m mid-water trawls in Toronto (Inner Harbour and Outer Harbour) than either Hamilton or Lake Ontario and marginally so for Toronto Open Lake ($F_{(3)} = 6.8$, $p = 0.003$; Tukey Honestly Significant Difference (HSD) Toronto vs Hamilton/Lake Ontario, $p < 0.01$, Toronto vs Toronto Open Lake, $p = 0.08$, Hamilton/Lake Ontario vs Toronto Open Lake, $p > 0.96$;). Based on the mid-water trawling data, it is clear that inner parts of the Toronto AOC have significantly higher trawl CPUE than other regions as well as open lake portions of this Toronto AOC. These patterns were largely driven by higher catch of Alewife and Rainbow Smelt and are consistent with catches seen during the 2016 hydroacoustic surveys of the Toronto AOC (Midwood et al. 2018b). It is important to note, however, that the 2016 surveys were completed during the day which makes a direct comparison inappropriate and precludes comparisons to other areas surveyed in 2018 (all completed at night). This lack of intra- and inter-annual comparability was the major driver behind the application of a consistent approach in the 2018 survey.

There were 1070 EDSU collected across sampling sectors (sample areas: Lake Ontario, Hamilton Harbour AOC, and Toronto AOC), with similar effort across sectors (107 ± 28 EDSU). Fish were detected in significantly fewer EDSU in the Lake Ontario Open Coast (LK_OC), compared with either Toronto or Hamilton (Fisher's Exact, $p < 0.05$; Figure 39). There were significant differences in fish density and biomass among sectors for all depths [ANOVA $F_{(10)} = 15.8$ (density) $p<0.0001$, $F_{(10)}=21.1$ (biomass) $p < 0.0001$]. A post-hoc Tukey HSD test found that mean fish density was significantly higher from the other analysis sectors in the Toronto Inner Harbour (TO_IH), Toronto Outer Harbour (TO_OUTH), and Hamilton Harbour North East (HH_NE) (Figure 40). The open coast site, LK_OC had significantly lower fish density compared with all other analysis sectors. Fish biomass was highest in the Hamilton Harbour West (HH_W sector), and generally higher in Hamilton Harbour compared to Toronto AOC, and the open coast. Comparing hydroacoustic results from all depth contour transects showed a decrease in fish density and biomass with increasing distance from river mouths (Figure 41). Density distribution by size class was primarily in size classes 1 and 2 (< 82 mm, TL) and to a lesser extent 3 and 4 (82 – 250 mm, TL; Figure 42). Although not tested, Toronto Harbour sectors (TO_IH, TO_OH) seemed to be dominated by smaller fish (class 1 and 2). There was no clear dominance of any size class for estimates of biomass across all sites.

Given the stratification of depth contours for sampling transects for the survey, we wanted to highlight the importance of the nearshore area and so we also analyzed the data for fish density and biomass at only 8-m depth contours. These contour sites were available in all sampling sectors and captured nearshore distributions of fishes. There were significant differences in fish density and biomass among sectors for 8-m contours in the hydroacoustic survey [ANOVA $F_{(10)}=7.2$ (density) $p<0.0001$, $F_{(10)}=10.9$ (biomass) $p<0.0001$]. A post-hoc Tukey's HSD test found that mean fish density was highest in the Credit River (LK_CR) and Ashbridges Bay (TH_AB) and significantly different from the other analysis sectors (Figure 43). The open coast site, LK_OC had significantly lower fish density compared with other analysis sectors. The 8-m transects for Credit River and Ashbridges Bay were closest to their river mouth or outfall, respectively compared to the deeper contour transects.

Discussion

In all years of hydroacoustic sampling, the Inner and Outer Harbours of the Toronto AOC had greater fish densities than other sites, with the exception of 8-m transects within close proximity (i.e., less than 1.5 km) to river mouths or outfalls (only analyzed for 2018 data). Trawl data from each DFO sampling year are consistent with this trend, suggesting a non-random distribution of fish density and biomass within the Toronto AOC. These data highlight the importance of the central waterfront of the Toronto AOC for forage fishes as outlined in Midwoood et al. (2018b):

> "*while the entire region is affected by wind and wave action and upwellings of cold benthic water from Lake Ontario …, 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…*" p11.

Piecing together some common themes from the surveys discussed here, hydroacoustic results suggest that throughout the Toronto AOC: 1) the majority of small-bodied individuals school during the day (2009 – 2016 surveys), 2) schooling and non-schooling small-bodied fishes are most abundant in or near the central waterfront, 3) fish can be found in higher densities near river mouths compared the rest of the Toronto AOC (8-m transects only from the 2018 survey), and 4) the majority of large-bodied fishes encountered during the survey are also found in or adjacent to the central waterfront. The 2018 surveys were completed at night and did not capture schooling behaviour, but the estimates of fish density showed that more than 80% of the density in the central waterfront was made up of small bodied fishes (29 – 82 mm, total length).

Similar to the hydroacoustic results, mid-water trawling data suggest that throughout the Toronto AOC:

1) the areas proximate to the central waterfront of the Toronto AOC have significantly higher trawl CPUE than other regions as well as open lake portions,
2) the non-random distribution of fishes in the Toronto AOC is largely driven by higher catch of Alewife and Rainbow Smelt and is consistent among midwater trawl surveys for all years, and
3) the majority of Alewife captured in the trawls were young of year (based on data from 2016; Midwood et al. 2018b) and given the abundance of this species in the central waterfront for our surveys, it suggests that the central waterfront of the Toronto AOC provides important habitat for this species during their juvenile life stages.

Alewife and Rainbow Smelt are the two primary species of interest for Ontario Ministry of Natural Resources and Forestry (OMNRF) lake-wide prey fish surveys. Long-term hydroacoustic prey fish surveys from the OMNRF and New York State Department of Environmental Conservation have tracked the abundance of Alewife in the lake since the 1990s (Figure 42, Holden et al. 2018), and therefore provide a time series of Alewife abundance. These surveys were not conducted within the Toronto AOC but can provide insight into the state of the species lake-wide. During Toronto AOC sampling years (2009, 2010, 2016 and 2018) the lake-wide estimated Alewife populations were approximately the same. While the shifting sample design for each DFO survey has limited our ability to compare year to year, the OMNRF and New York State Department of Environmental Conservation trends give us confidence that the consistent patterns found in the DFO data are not confounded by lake-wide Alewife population fluctuations.

The greater densities of fish found near river mouths during our studies was an interesting finding. Although not well studied, river mouths are unique aquatic habitats utilized by fishes, which are typically heavily impacted in urban areas, such as in the Toronto AOC (Larson et al. 2013). Transects close to the mouth of the Credit River, outfall of Ashbridges Bay, and to a lesser extent, the mouth of Mimico Creek (Humber Bay) had greater densities of fish compared to deeper transects at these sites that were further offshore. Densities for the 8-m transects for Credit River and Ashbridges Bay were also greater than all other 8-m transects from the 2018 survey in the open coast, Toronto AOC, and Hamilton Harbour AOC. Specifically for Ashbridges Bay, the wastewater treatment plant outfall is located 1 km offshore, a new outfall is currently being built further offshore and may impact future fish density and biomass at this site. The findings for river mouths and outfalls should be explored further to verify the importance of river mouths and determine the causal mechanism behind increased fish densities. The results of such a study would solidify the importance of this habitat ecotype, determine the range of influence of these features out into the lake, and inform fish habitat managers on the relative importance of coastal waters adjacent to river mouths. In the context of the Toronto AOC, understanding and characterizing the function of different ecotypes within an AOC would allow for a focus on restoring or protecting ecotypes that would produce the most benefit for the least amount of effort. This research need is made more poignant by the undertaking of the Don Mouth Naturalization project – an initiative to reconnect the Don River to Lake Ontario by creating a naturalized Don River mouth. The $1.25 billion project will create 14 hectares of aquatic habitat and is expected to be complete by 2024. The Don River restoration project will provide an opportunity to measure the success of restoration efforts as well as characterize fish and fish habitat around a river mouth system.

Previous DFO reports suggested to merge the results of all past surveys of the Toronto AOC, however, this assessment exercise has uncovered the difficulty in merging hydroacoustic datasets that were not conducted with similar sample designs. The 2009, 2010, and 2016 surveys were completed during the day, which poses challenges for accurately estimating density and biomass and precludes comparisons to other areas surveyed at night in both 2016 (Hamilton Harbour) and 2018. As reported in Midwood et al (2018b),

> "*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 …. 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 …*" p7.

This underestimation of fish populations due to schooling behaviour and lack of intra- and inter-annual comparability was the major driver behind the application of a consistent approach in the 2018 survey. Future AOC surveys will follow the design of the 2018 survey to allow for inter-annual comparisons for future assessments. Currently, hydroacoustic data for portions of the Toronto AOC lack appropriate regional comparators. Hamilton Harbour, another AOC on Lake Ontario, was surveyed in 2018 since it was one of the few available non-open coast areas in western Lake Ontario. Hamilton Harbour, however, is a relatively protected, warmer, and eutrophic system that not only has higher productivity, but is also affected by seasonal hypoxia that has been found to influence the vertical and spatial distribution of pelagic fishes (see Midwood et al. 2019b). In contrast, the Toronto AOC is more open to the lake, cooler, and, depending on ecotype, oligotrophic or mesotrophic. Hamilton Harbour is therefore not an ideal comparison site and past efforts to compare fish communities in the Toronto AOC to other areas in Lake Ontario have identified exposed embayments (e.g., Presqu’ile Bay, South Bay; Bowlby and Hoyle 2017; Hoyle et al. 2018) as more appropriate comparators. Efforts were made in 2018 to reach these sites but were stymied by poor weather. If possible, future regional surveys should be planned to ensure the best possible comparison sites are surveyed. Integrating these efforts into future lake-wide Coordinated Science and Monitoring Initiative works (Lake Ontario is slated for sampling in 2023) would leverage multi-jurisdictional sampling and help place observed forage fish density and biomass in the Toronto AOC in a lake-wide context. Therefore, DFO and coordinators for the RAP should formalize a request to the Coordinated Science and Monitoring Initiative and the OMNRF to coordinate sampling and monitoring of forage fish for the next Lake Ontario intensive sampling year.

As noted previously, surveys undertaken in 2018 not only provided a regional comparison for conditions within the Toronto AOC but were also undertaken concurrent with sampling of the zooplankton community and measures of primary productivity. Future efforts to merge these two datasets should yield useful information for future fish population assessments as they will provide a potential explanation for the observed differences in forage fish density and biomass (both within the Toronto AOC and relative to other regions) and could yield predictive relationships of forage fish productivity under different lower trophic regimes. These types of relationships would provide a more formalized means of assessing whether there is evidence for impairment in prey fish productivity (i.e., if observed prey fish productivity is below what is predicted by lower trophic conditions it may suggest something other than their forage is limiting productivity).

Multi-year prey fish surveys from the lake conducted by OMNRF and other partners showed no differences in prey fish populations during DFO sample years. As such, we believe the patterns observed in the Toronto AOC and other regional reference areas were not confounded by the conditions of the lake during these sampling years. Four DFO hydroacoustic and trawling surveys were completed in 2009, 2010, 2016, and 2018. Although each study could not be compared for trends through time due to differences in sampling design, no apparent impairments of forage fish populations were observed in the Toronto AOC relative to the available regional reference sites. Differences within the Toronto AOC were observed, with generally higher density and biomass in waters adjacent to the central waterfront, but again lower values in the open coast areas of the Toronto AOC were consistent with the few open coast areas sampled concurrently in Lake Ontario. River mouths, as an ecotype, also appear to be distinct and to support higher fish densities that open coast areas and some more protected embayments. Consequently, river mouths and the central waterfront of the Toronto AOC are clearly important areas for forage fish and should be protected accordingly. Future studies should consider designs that allow for multi-year comparisons, but at the very least, additional sampling in more appropriate regional reference sites (open embayment sites in the Bay of Quinte) is needed to finalize the assessment of this sub-component of FP-1.

Specifically for criteria FP-1, a lack of evidence for an impairment in forage fishes relative to the available regional comparison sites, particularly in the central waterfront of the Toronto AOC suggests that any observed impairments to top-level predators are unlikely to be driven by a lack of limnetic foraging opportunities. Lower densities in the open coast ecotypes of the Toronto AOC are comparable to other parts of Lake Ontario, where surveys tracking populations since 2000 suggest low but stable Alewife populations. The influence from the forage fish community on top predator densities in this ecotype is therefore not expected to be different from other parts of the lake; rather, if top predators are found to be impaired in the open coast environment, other factors may be at play (e.g., loss or impairment of habitat, etc.). To our knowledge, forage fish were not explicitly identified as impaired in the Toronto AOC, therefore the hydroacoustic data can also be seen as an assessment of whether they are “locally depressed”. As noted previously, forage fish density and biomass within the Toronto AOC were comparable to other regional ecotypes, therefore we find no evidence of impairment at this time (barring the noted caveats of less than ideal regional reference areas for some ecotypes – exposed embayments).

Tables and Figures

Table 12. Site codes for each year of Hydroacoustics. Blank fields indicate samples were not taken in those sectors for that year. Sectors that are underlined are located in the Toronto and Region Area of Concern.

	2009	2010	2016	2018
Analysis Sector Name	**Sector Code**	**Sector Code**	**Sector Code**	**Sector Code**
Bluffers Park			BLUF	
Bronte North Harbour		BRNH		
Etobicoke			ETOB	
Hamilton Harbour North				HH_N
Hamilton Harbour North East				HH_NE
Hamilton Harbour South				HH_S
Hamilton Harbour South East				HH_SE
Hamilton Harbour West				HH_W
Humber Bay Offshore	HBOF	HBOF		
Lake Ontario Credit River				LK_CR
Lake Ontario Open Coast				LK_OC
Rouge River			ROGE	
Tommy Thompson Park	TTPK	TTPK	TTPK	
Toronto Eastern Headlands OR Ashbridges' Bay	TO_EHDL	TO_EHDL	TO_EHDL	TO_AB
Toronto Humber Bay Nearshore	TO_HBNR	TO_HBNR	TO_HBNR	TO_HB
Toronto Inner Harbour	TO_INNH	TO_INNH	TO_INNH	TO_IH
Toronto Outer Harbour	TO_OUTH	TO_OUTH	TO_OUTH	TO_OH
Toronto Outer Harbour (excludes an outlier in 2016)			OUTH.B	
Toronto Outer Islands	OUTI	OUTI	OUTI	

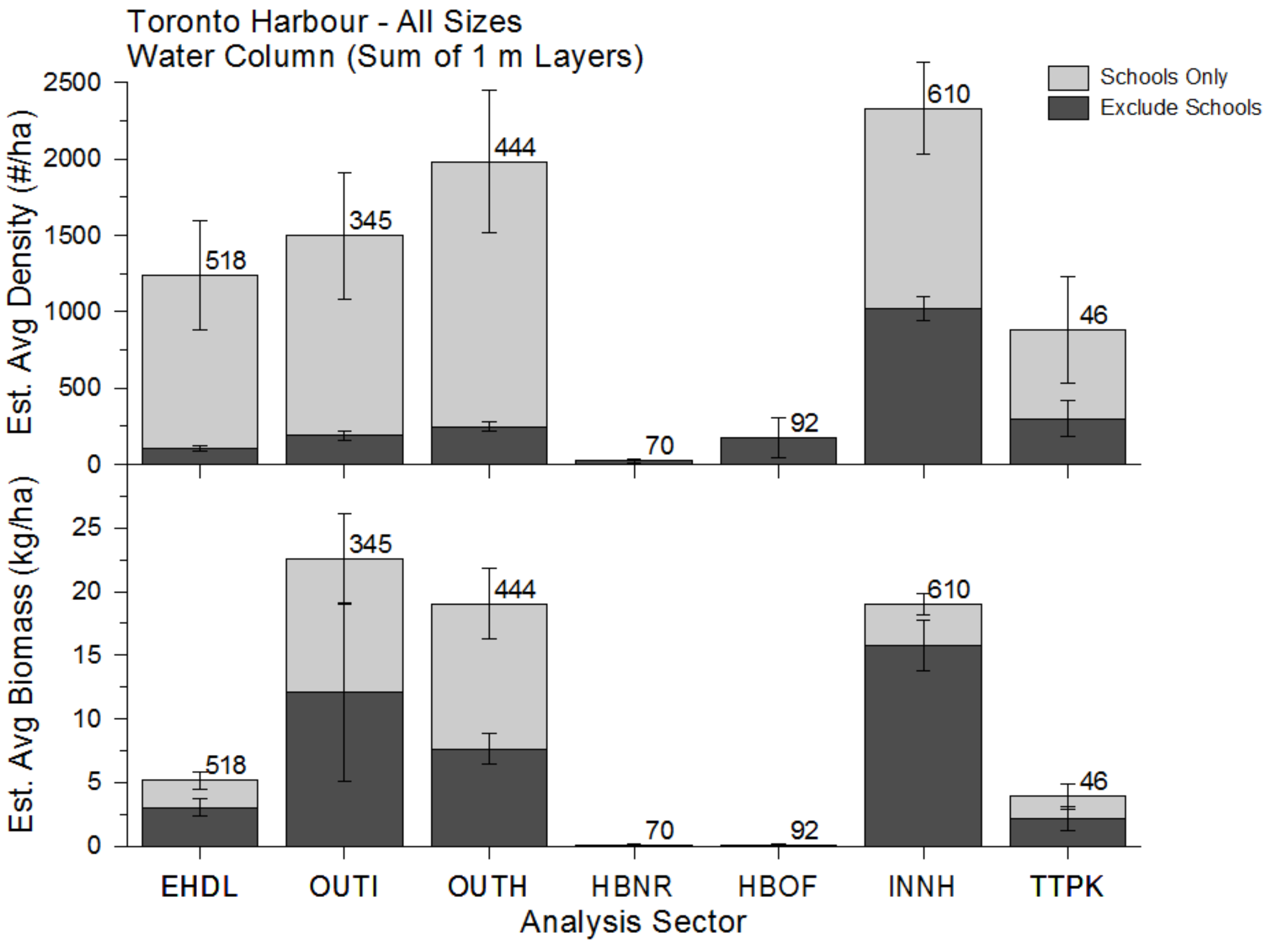

Figure 32. Taken from DFO GLLFAS 2010. The acoustic estimated average fish density (#/ha) (top panel) and average instantaneous biomass (kg/ha) (bottom panel) by analysis sector of the schooling (light shaded bar) and non-schooling (dark shaded bar) components of the Toronto Harbour fish community. Includes all fish sizes through the water column. Error bars are standard error of the mean. The numbers at the top of the bar indicate the number of 50-m Elementary Distance Sampling Units included in the estimate. Analysis sector codes can be found in Table 12.

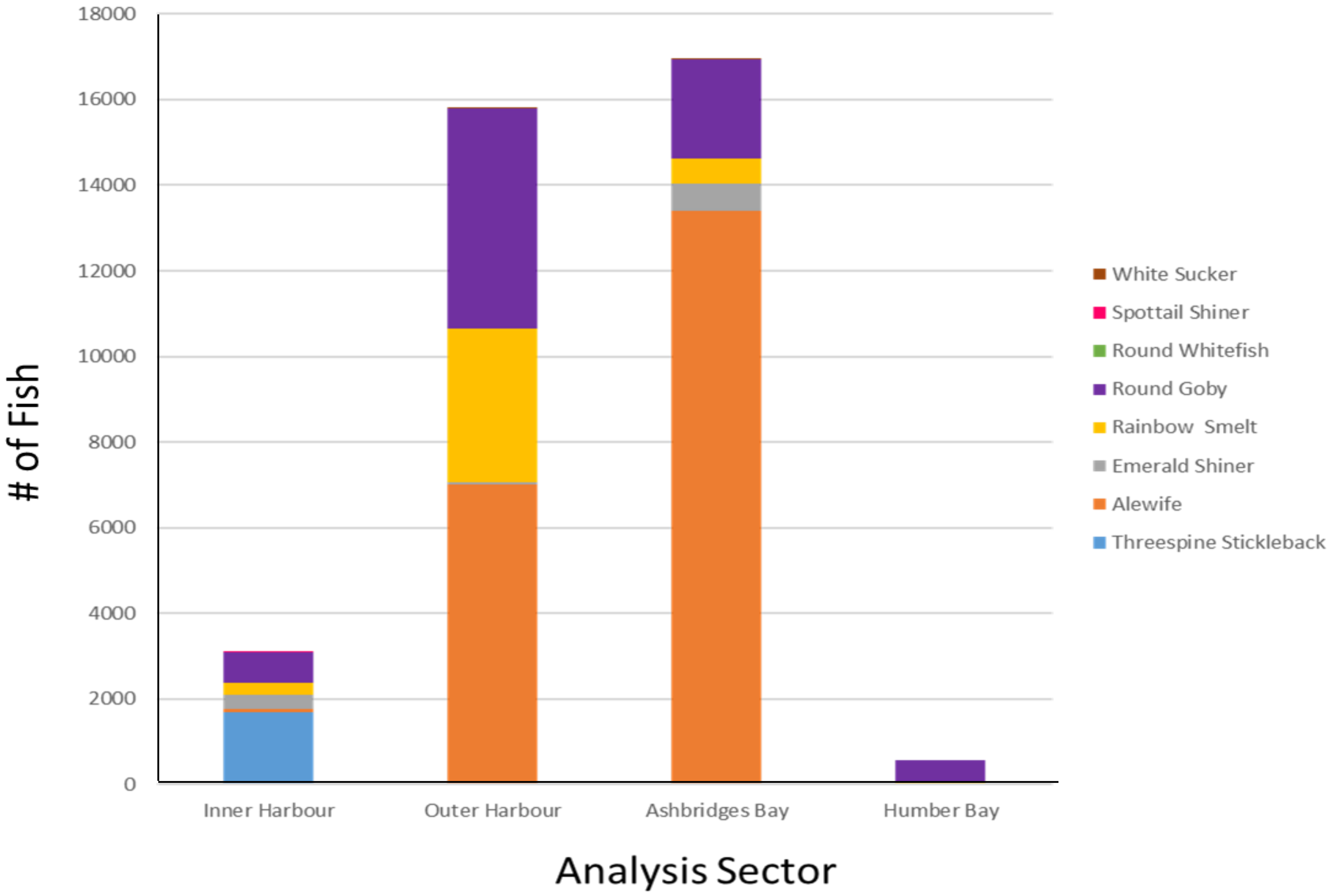

Figure 33. Catch of fishes in benthic trawls, for four sectors in 2009 in Toronto Harbour (DFO GLLFAS 2010).

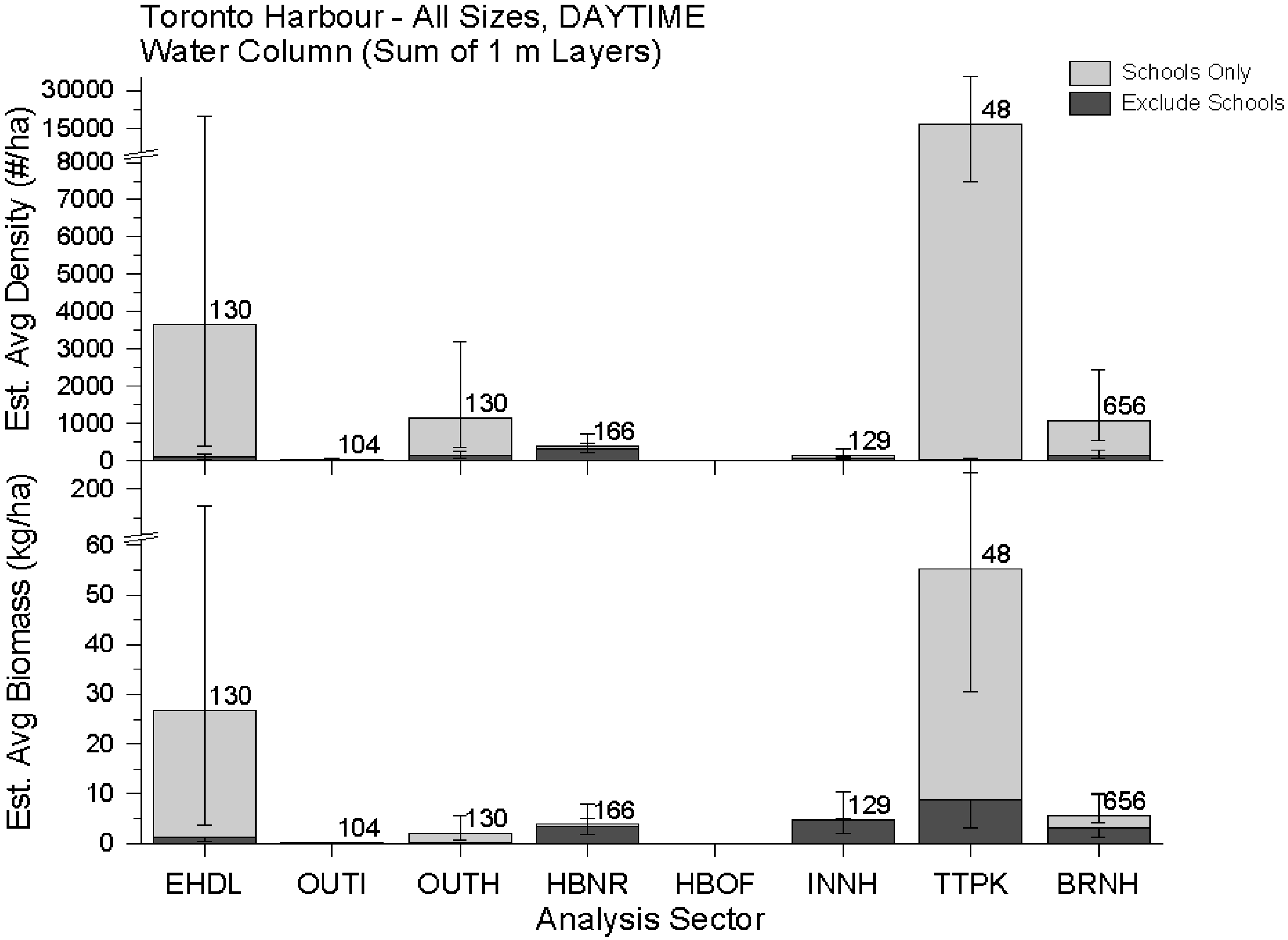

Figure 34. Taken from Leisti et al. (unpublished). The acoustic estimated average fish density (numbers/ha) (top panel) and average instantaneous biomass (kg/ha) (bottom panel) by analysis sector of the schooling (light shaded bar) and non-schooling (dark shaded bar) components of the Toronto and Bronte Harbour fish community. Includes all fish sizes through the water column from the daytime surveys. Error bars are bootstrapped 2.5% and 97.5% confidence intervals. The numbers at the top of the bar indicate the number of 50m Elementary Distance Sampling Units included in the estimate. See Table 12 for site code names.

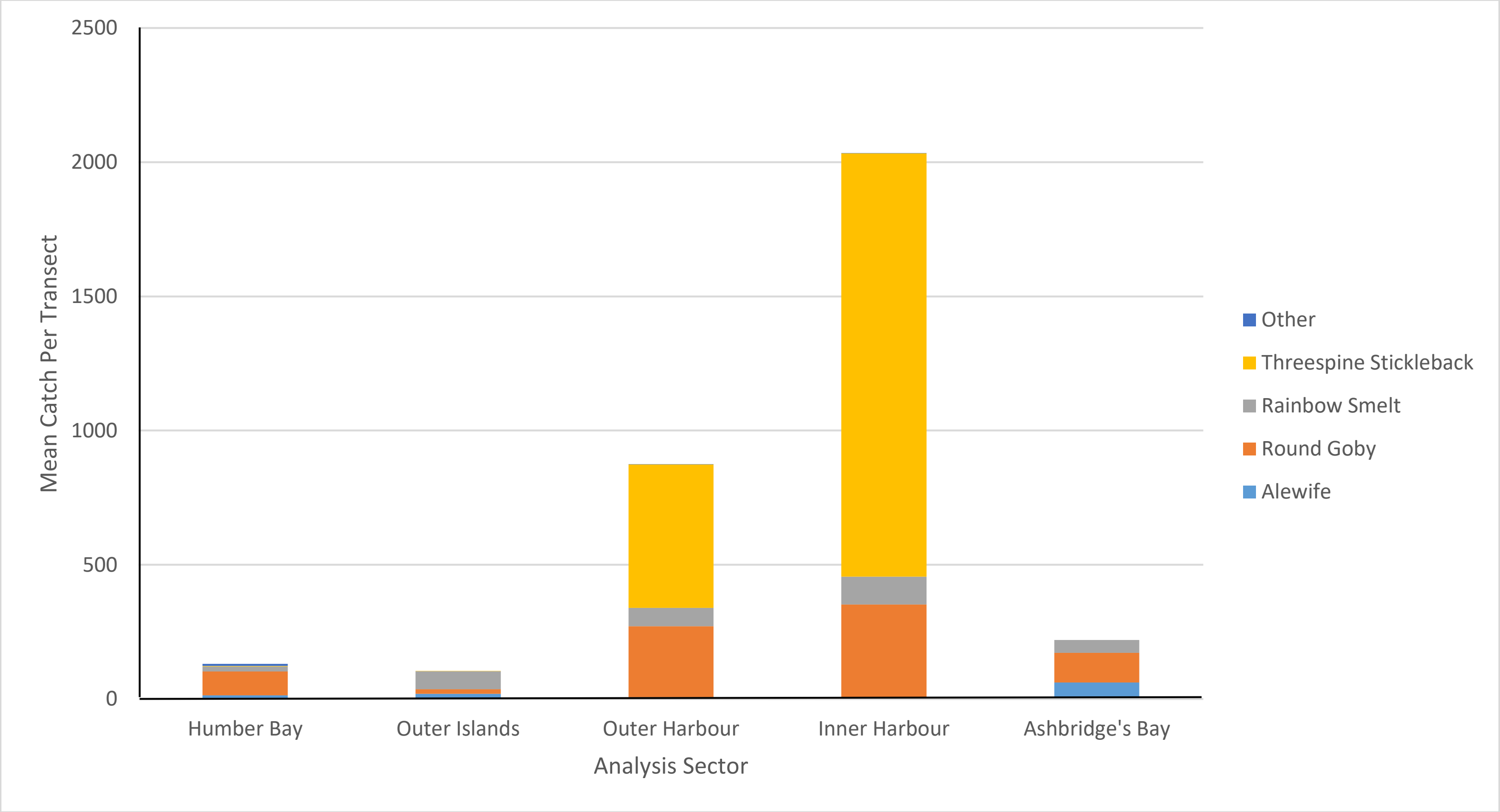

Figure 35. Mean catch per transect from the bottom trawl surveys. Effort was variable among sectors with 10 trawls in Humber Bay, six in both the Outer Islands and Outer Harbour, four in the Inner Harbour, and three in Ashbridges Bay. Trawls were not completed in Bronte Creek.

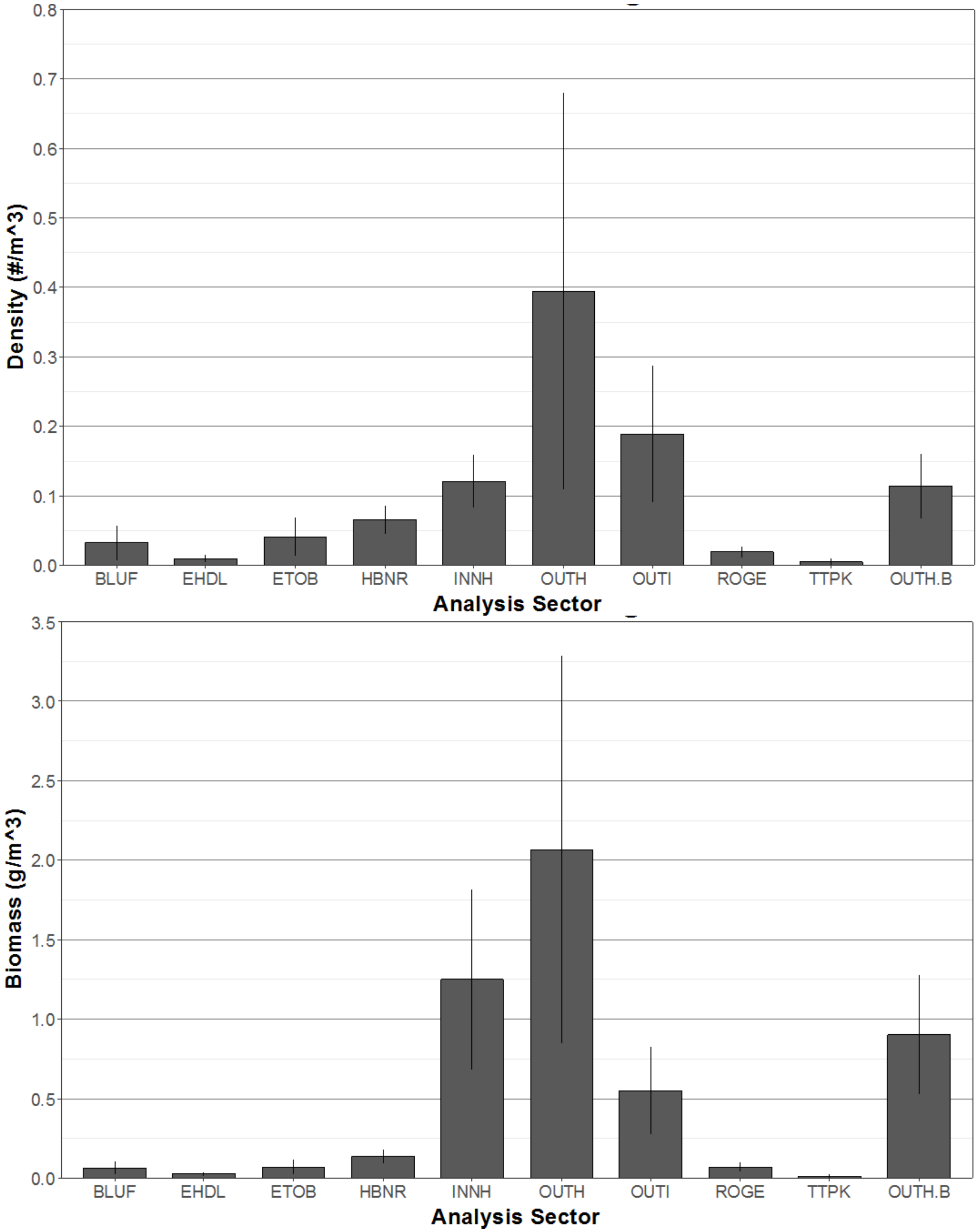

Figure 36. Mean total density and biomass (with standard error) for non-schooling fish and schools by analysis sector for Toronto AOC in 2016. See Table 12 for site code names.

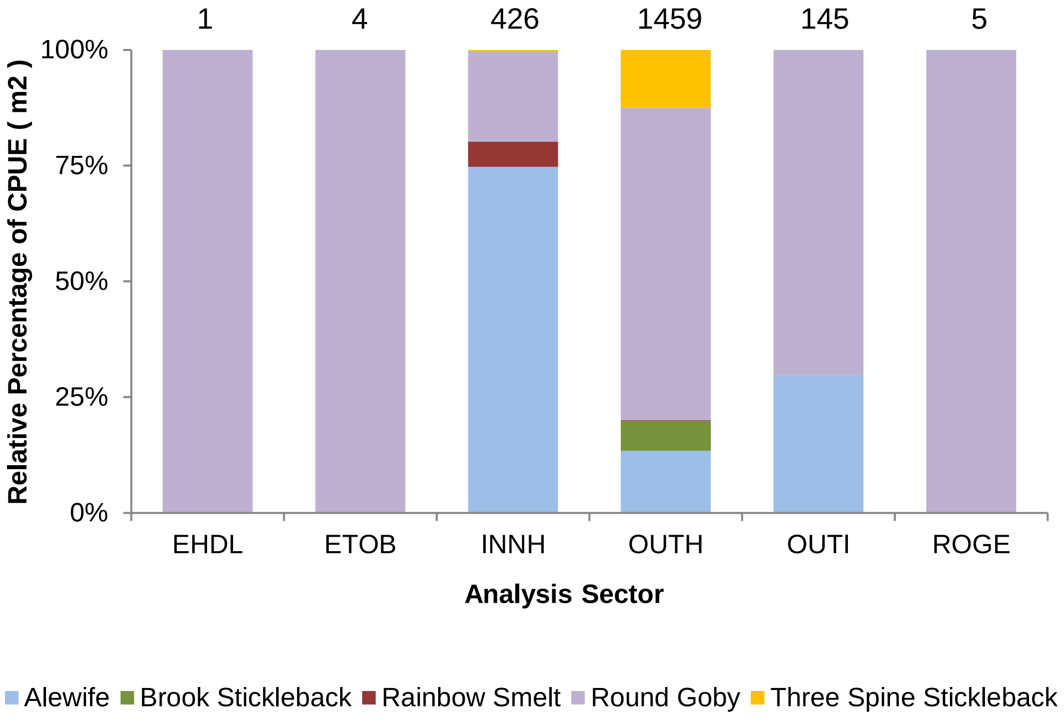

Figure 37. Relative percentage of catch per unit effort (CPUE) by species and analysis sector from mid-water trawling in Toronto Harbour in 2016. The numbers above each bar represent the total catch by sector. No fish were captured in BLUF, HBNR, and TTPK. See Table 12 for site code names.

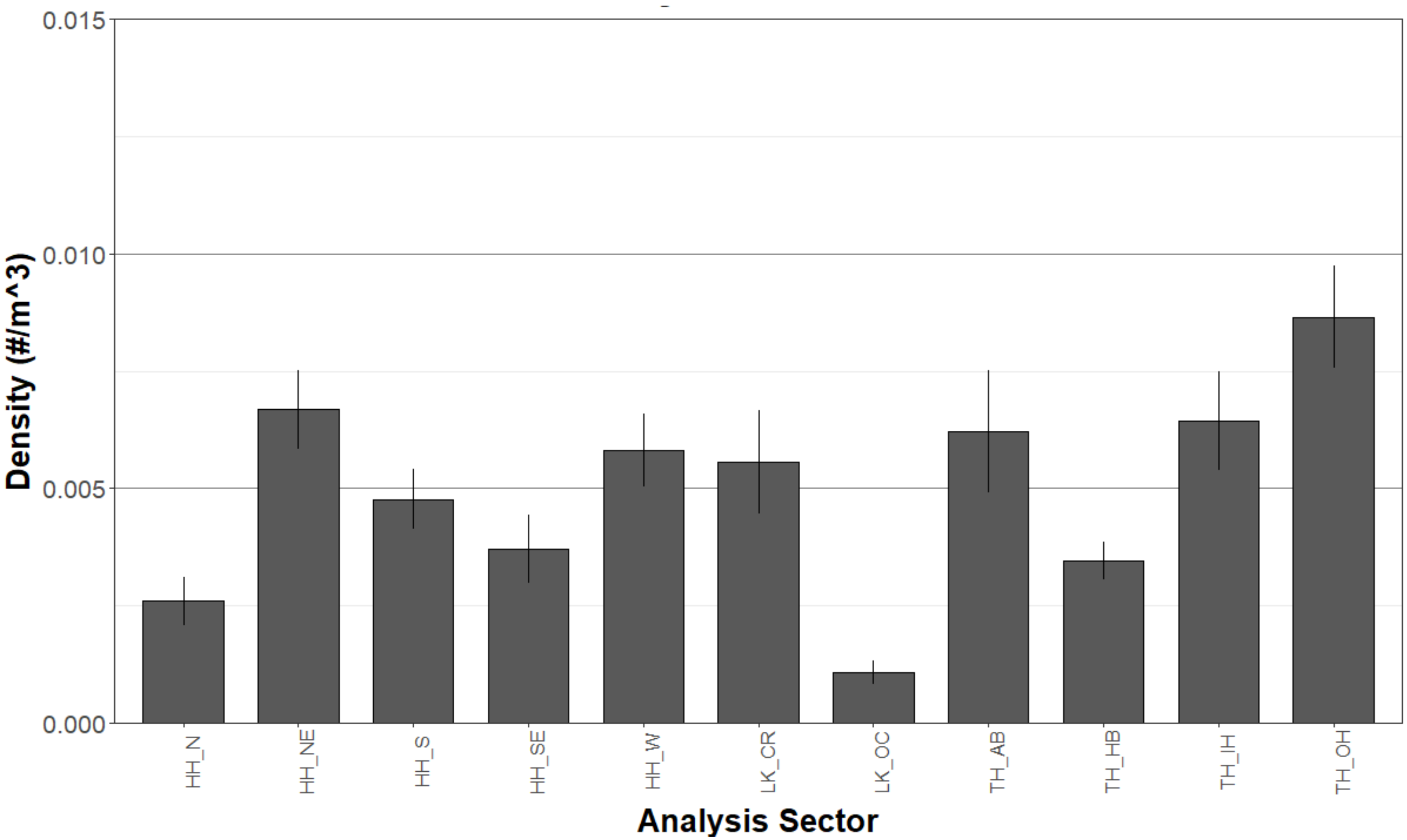

Figure 38. Estimates of fish density (#fish/m^3) based on the analysis of hydroacoustic pings in each analysis sector for fall 2018. See Table 12 for site code names.

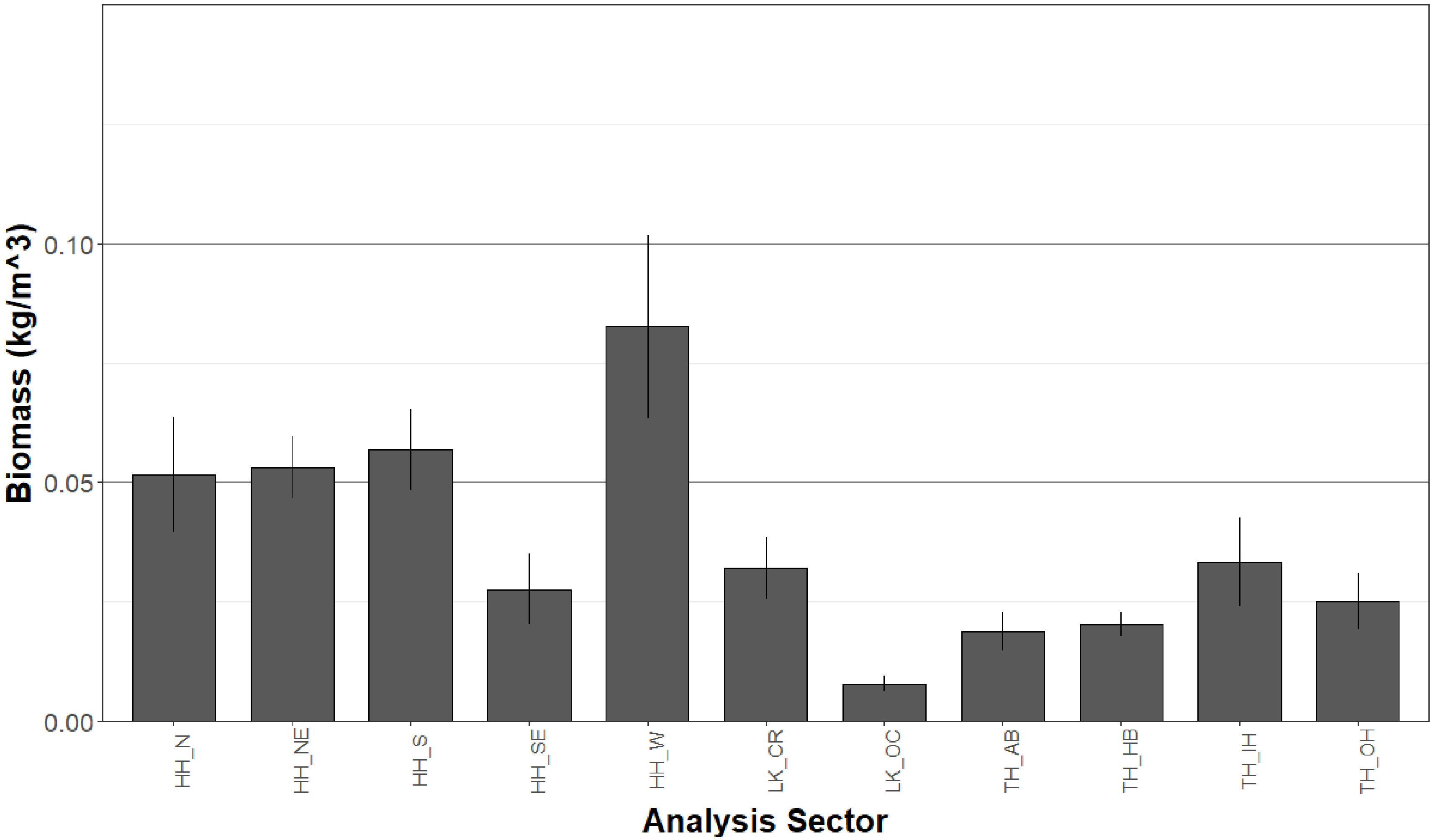

Figure 39. Estimates of fish biomass (kg/m^3) based on the analysis of hydroacoustic pings in each analysis sector for fall 2018. See Table 12 for site code names.

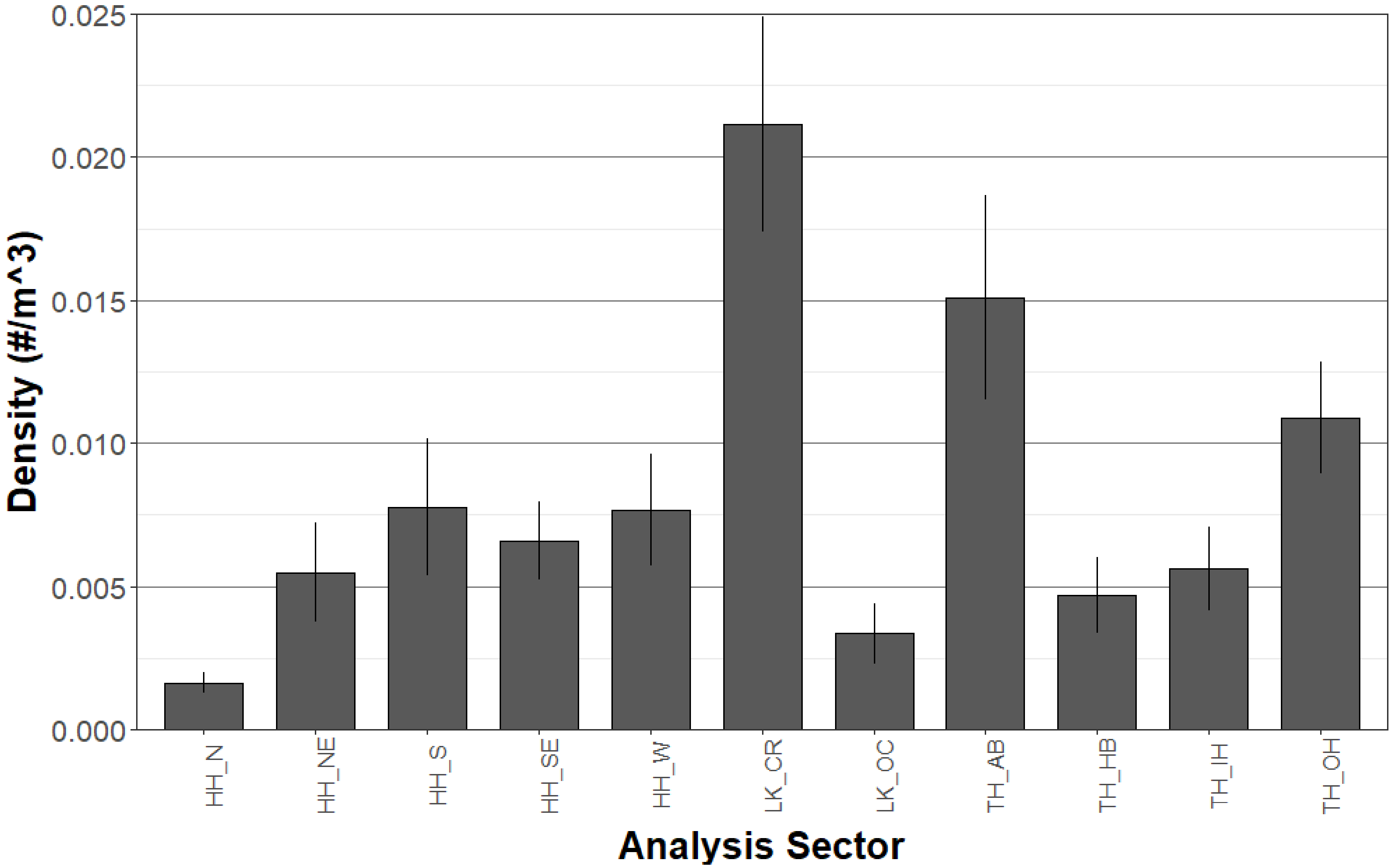

Figure 40. Estimates of fish density (#fish/m^3) based on the analysis of hydroacoustic pings in each analysis sector (8-m depth contours only) for fall 2018. See Table 12 for site code names.

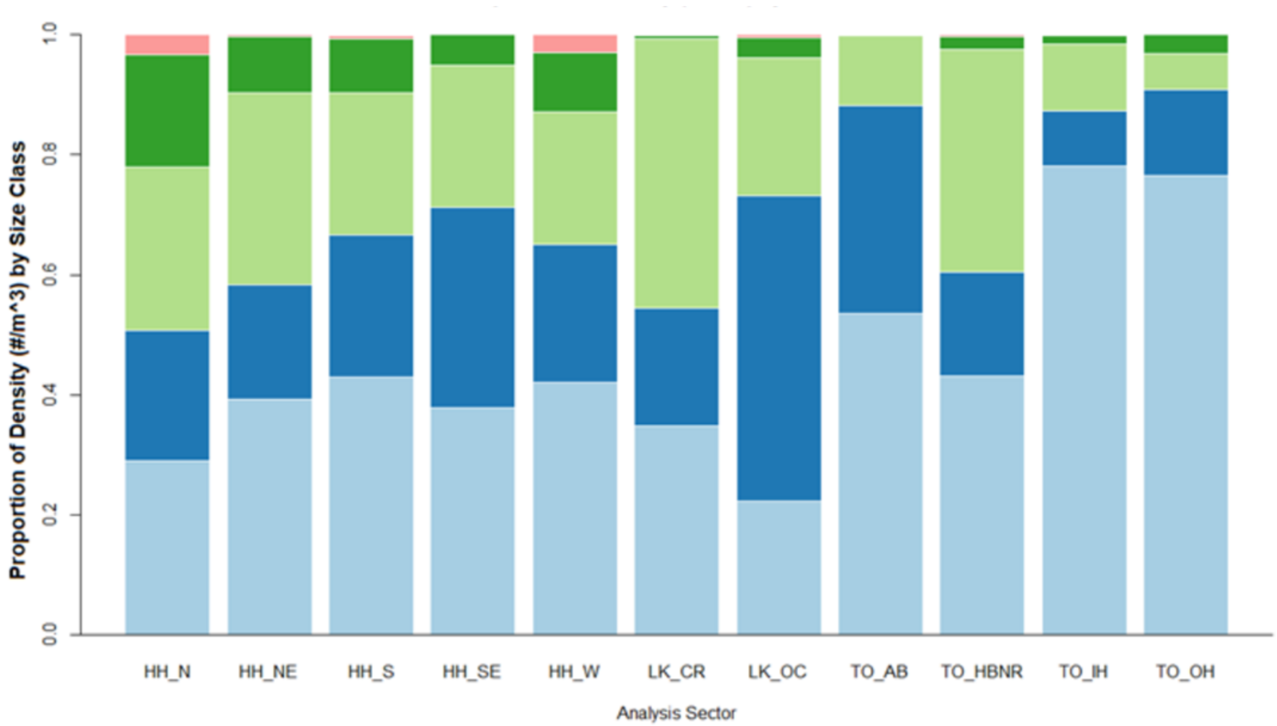

Figure 41. Proportion of density in each analysis sector by size class for fall 2018. Colours denote the mean values for each size class where: light blue = size class 1 (29 – 58 mm, Total Length; TL), dark blue = size class 2 (58 – 82 mm, TL), light green = size class 3 (82 – 130 mm, TL), dark green = 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). Analysis sectors names can be found in Table 12.

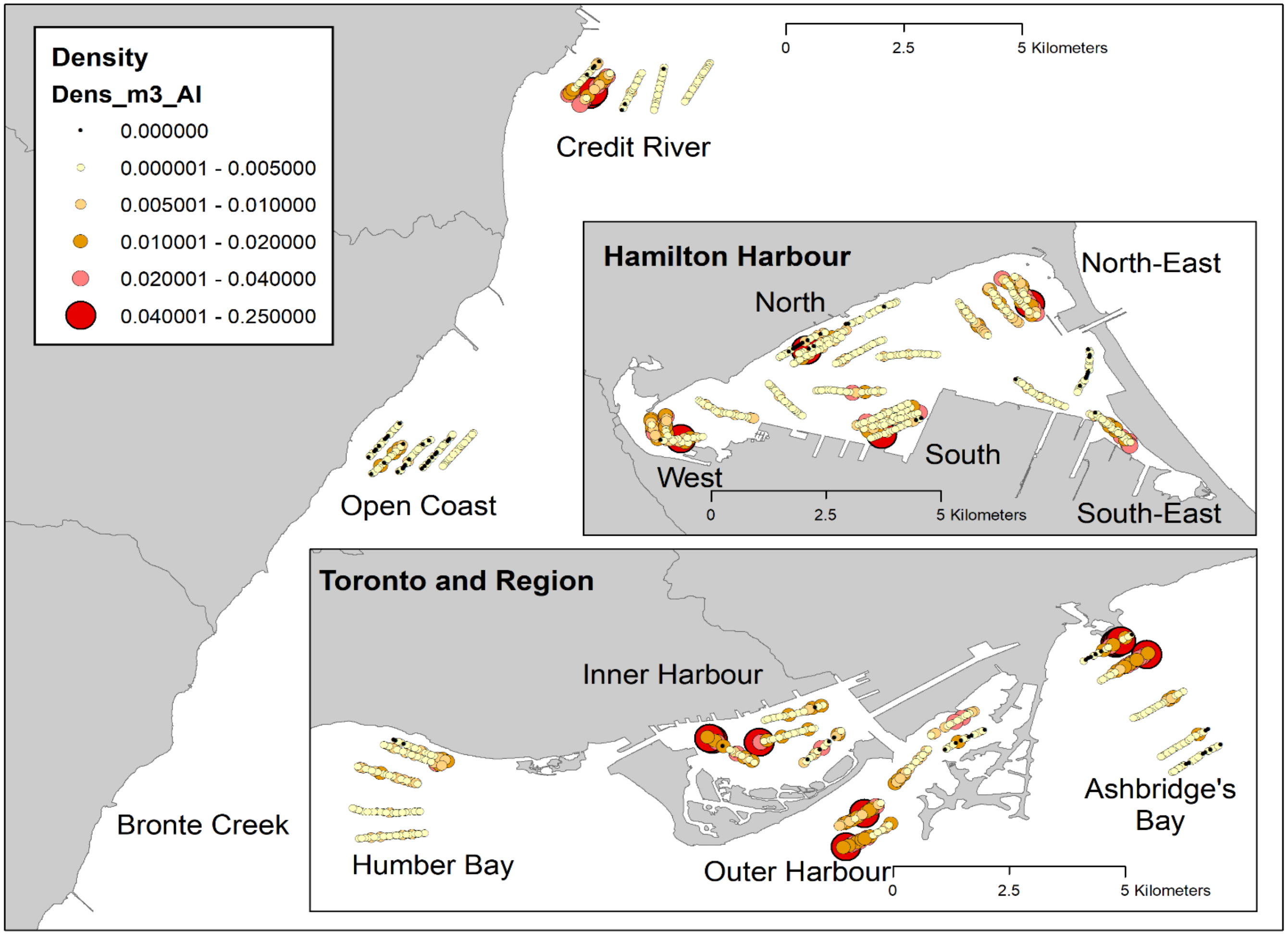

Figure 42. Estimates of fish density (density/m^3) for the 2018 Fisheries and Oceans Canada's hydroacoustic survey. Larger, darker circles denote greater density in a transect. The regions are presented in other figures and tables using alternate codes including: Hamilton Harbour (North = HH_N; North-East = HH_NE; West = HH_W; South = HH_S; and South-East = HH_SE), Toronto (Humber Bay = TH_HB or HBNR; Inner Harbour = TH_IH or INNH; Outer Harbour = TH_OH or OUTH; and Ashbridge's Bay = TH_AB or EHDL); and Lake Ontario (Open Coast = LK_OC; and Credit River = LK_CR).

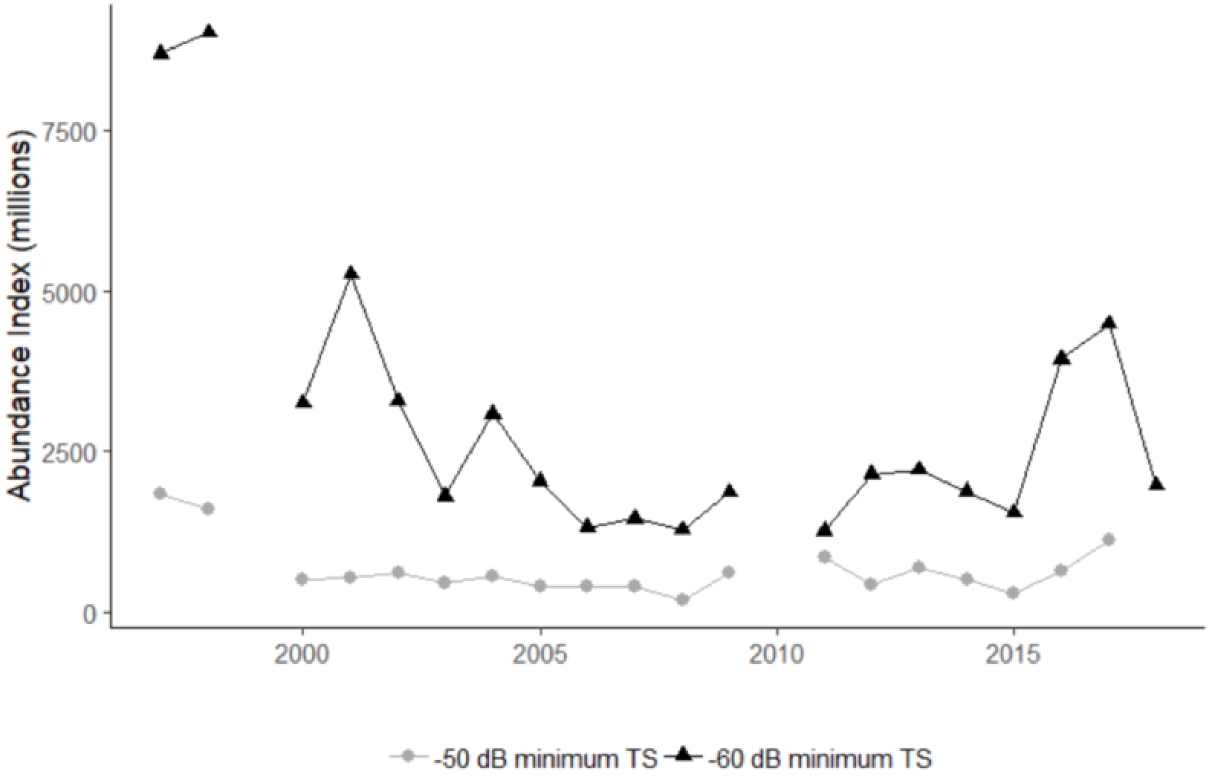

Figure 43. Abundance (in millions of fish) of yearling-and-older alewife [sic] in Lake Ontario from 1997 – 2018 based on hydroacoustic surveys using a –60 dB minimum target strength (triangle markers). Previous estimates based on a –50 dB minimum target strength threshold are included (circles) from 1997 to 2017. No hydroacoustic survey was conducted in 1999 and 2010. We have reproduced figure 9 (p.9) with permission from Holden et al. (2018).

CRITERION FP-1D: TELEMETRY-DERIVED RESIDENCE IN THE TORONTO AND REGION AREA OF CONCERN

Summary

Results from an assessment of fish residency within the central waterfront of the Toronto and Region (AOC) characterize different species as primarily resident [i.e., Largemouth Bass; Northern Pike; Bowfin; Brown Bullhead (*Ameiurus nebulosus*); Yellow Perch (*Perca flavescens*)] or migratory [i.e., Common Carp; Walleye; White Sucker (*Catostomus commersonii*); Midwood et al. 2019a]. In the context of the present assessment, encounter rates and total catch of species identified as primarily resident within the Toronto AOC are more likely to respond to changes in conditions within the Toronto AOC whereas these metrics for more migratory fishes may be more influenced by regional or lake-wide conditions. Interpretations of the trends in species catch as well as comparisons to regional catch rates should therefore incorporate these assignments of residence. With this in mind for section FP-2 (Fish Populations), population assessments for Northern Pike, Largemouth Bass, and Bowfin will likely respond more to actions taken within the Toronto AOC than Walleye, which are a more migratory top predator. This section does not directly support BUI evaluations, but provides rationale for focusing on resident species in FP-1A, and FP-2. Additional information on species-habitat use derived from the telemetry data are also presented to provide context in the interpretation of results for sections FP-1A, FP-1B, and FP-2.

Key Messages

- Largemouth Bass, Northern Pike, Bowfin, Brown Bullhead, and Yellow Perch are resident fish species in the AOC.
- Common Carp, Walleye, and White Sucker are non-resident (migratory) species in the AOC.
- Resident species are more likely to respond to changes in conditions within the AOC and the fish population assessment should focus on these species.
- Migratory fishes are likely more influenced by regional or lake-wide conditions. Common Carp, for example, should be managed from a regional level, not just within the AOC because they move in and out of the AOC throughout the year.
- Telemetry supports FP-1A and FP-2 and provides crucial information on species use of restored and created habitat (e.g. wetlands) and improvement of habitat supply (e.g. Don Mouth Naturalization).

Remaining Concerns and Uncertainty

- There were relatively few individual Bowfin, Brown Bullhead, Walleye, White Sucker, and Yellow Perch tagged, limiting our confidence in broad generalizations for these species.
- Due to their migratory behaviour Walleye populations may be more influenced by regional conditions rather than those within the Toronto AOC; consideration should be made on whether this species should be used for assessing AOC targets.

Future Monitoring

1. The benefits from ongoing telemetry tracking of species of interest within the AOC are clear (e.g., assessing pre/post remediation habitat use, identifying important habitat for species within the AOC, supporting management of Common Carp, supporting regional recovery of Walleye) therefore maintenance of the telemetry and tagging of species of interest should continue.

Recommended Actions

1. As more information on spatial ecology and habitat use become available through the collaborative acoustic telemetry projects in western Lake Ontario, effort should be to identify, enhance, or create potential spawning areas within the AOC.
2. Due to their migratory behaviour, recovery of Walleye within the Toronto AOC may be best achieved through larger-scale (regional rather than local) recovery strategies such as the stocking program currently led by OMNRF.
3. Local management measures for Common Carp should continue; however, active management of Common Carp within the AOC should be done in collaboration with other regional partners as a component of the Common Carp population is clearly migratory.

Background

An acoustic telemetry array has been deployed in the central waterfront of the Toronto and Region AOC (herein Toronto AOC) since 2010 (Figure 44) and during this time the movements and habitat use of over 650 individual fish representing eight different species have been tracked. From an assessment perspective, these efforts are designed to: 1) use tagged fishes as surrogates for the fish community response to evaluate the efficacy of restoration efforts within the Toronto AOC, 2) help refine the design and implementation of future restoration efforts based on actual fish usage (i.e., species-specific seasonal habitat use), and 3) develop a regionally specific area-based fish habitat management plan for the harbour that can link back to the Toronto Waterfront Aquatic Habitat Restoration Strategy (TRCA 2003). While much of the works related to the Toronto and Region acoustic telemetry project are more germane to the assessment of BUI#14 (Loss of Fish and Wildlife Habitat), for BUI#3 (Fish and Wildlife Populations) we have used the telemetry data to define species of interest as either resident or non-resident within the AOC. Population levels of resident fishes would be expected to track conditions within the AOC such that habitat enhancement or creation efforts and general improvements to ecological integrity should lead to an increase in the numbers of these fishes. In contrast, inter-annual changes in the populations of non-resident (or species where a subset of the population is non-resident) may be more influenced by lake-wide processes and ecological changes. From an assessment perspective, declining or increasing temporal trends for non-resident species, while still important and of interest within the Toronto AOC, may require additional exploration to confirm that these patterns are distinct from lake-wide patterns.

Analysis

Northern Pike, Largemouth Bass, Common Carp, Walleye, White Sucker, Brown Bullhead, Yellow Perch, and Bowfin were tagged, tracked, and had their movements analyzed for seasonal and central waterfront residency in Midwood et al. (2018a) for Bowfin, and Midwood et al. (2019a) for all other species (Table 13). Residency included both the timing and frequency of fish movements off the telemetry array into Lake Ontario. Fishes were deemed to be non-resident within the AOC if a subset of their population made regular movements outside of the central waterfront and were absent from the array during these movements for an extended period of time (weeks to months). Here we summarize the general patterns of movement from each paper for each species within the central waterfront of the Toronto AOC and assign each species as resident or non-resident. Some general discussion on the apparent habitat use of the eight tracked species are also provided for context, but should be interpreted with the following caveat from Midwood et al. (2019a):

> *"…estimates of individual and species residence … within a habitat type do not equate to an evaluation of "use" since the direct interaction of an individual with the physical and biological components of the habitat was not assessed. Rather, residence is more akin to habitat preference, as defined by Hall et al. (1997), since it is an evaluation of the disproportional use of an area by an individual or species relative to other available areas…"* p3

Results

Of the eight fish species that were tracked in the Toronto AOC, five can be categorized as resident (Northern Pike, Largemouth Bass, Brown Bullhead, Yellow Perch, and Bowfin) and three as non-resident (Common Carp, Walleye, and White Sucker). Northern Pike were overwhelmingly resident, with only 2 of 122 individuals leaving the harbour for any extended period of time (< 43 days); most of these movements occurred in the spring and fall. Northern Pike habitat preferences seemed to favour shallow and protected waters, with moderate-high temperatures and generally sparse submerged aquatic vegetation (SAV; although there are denser patches of vegetation around the margins of many of the embayments where they were detected). Extended movements out of the harbour by Largemouth Bass were infrequent, and only recorded for 8 of 111 individuals, and they primarily exited the harbour via the western gap. Largemouth Bass had high year-round residency in the Toronto Islands and generally remained in proximity to their tagging location with no evidence for regular movements between Tommy Thompson Park and the Toronto Islands. These fish were almost exclusively resident in shallow, sheltered areas with sparse to moderate SAV and moderate to high water temperatures.

While sample sizes for Brown Bullhead, Yellow Perch, and Bowfin were much lower than Northern Pike and Largemouth Bass, there was little evidence of these species moving out of the central waterfront with none of the 14 tagged Brown Bullhead leaving, only one of 16 Yellow Perch potentially leaving albeit for a very short duration (seven days), and one of the 10 Bowfin leaving via the western gap (it was later detected at Exhibition Place and therefore still within the AOC). From a habitat preference perspective, data on Brown Bullhead were only available for three seasons, but during this limited period they were almost exclusively detected in areas that were characterized as having high cover of SAV (> 50%), moderate to high benthic water temperatures during the stratified season (> 15°C), and moderate to low exposure (< 1000 m effective fetch). The greatest concentration of Yellow Perch movements was in and around the Outer Harbour, which is consistent with the majority of their detections being focused in and around their initial tagging location (Embayment C). Across all seasons, Yellow Perch frequented areas with shallow water depths (< 3.0 m), low levels of exposure to wind and wave action, and both dense and sparse SAV. In the spring and fall, deeper more open pelagic habitats (i.e., Cherry Beach) were also important. Finally, for Bowfin, there was definitive selection of shallow vegetated areas, which also tended to have warmer waters. Across all seasons, Bowfin were often associated with areas that had a higher percent coverage of SAV, though Bowfin exhibited variable levels of activity dependent on both the season and the individual’s size.

While in the harbour, Common Carp were primarily found in shallow, protected areas with variable levels of SAV cover; however, Common Carp showed extensive movements on the telemetry array. Twenty-three of the 57 tagged Common Carp left the harbour for extended periods of time. Nine of the 23 Common Carp with long-term data left the harbour completely, while 14 individuals made extended movements (> 7 days) outside of the harbour. Two of the 23 Common Carp were detected in the summer of 2015 on an acoustic telemetry array in the Hamilton Harbour AOC (approximately 60 km south west), and Common Carp tagged in Hamilton Harbour have recently been detected on the Toronto and Region array (P. Bzonek, University of Toronto, pers comm 2019). Similarly, radio and acoustic telemetry efforts in northern Lake Michigan have found that Common Carp make extensive movements among nearshore areas (in Brooks et al. 2017); home ranges in rivers have been estimated at over 200 km (linear home range; Stuart and Jones 2006); and, in contrast to their core spawning habitat, foraging areas have been found to be more than 3 times as large (Penne and Pierce 2008). Collectively, these results suggest that a subset of the population of Common Carp are non-resident in the Toronto AOC.

Eight of the 11 Walleye with long-term data made extensive forays out of the harbour (Figure 45). For five Walleye, these fish left the array in the summer of 2012 and did not return until April 2013 (an absence of over 290 days). Also, for five Walleye, these patterns occurred in multiple years, suggesting there may be annual cycles of residence within the AOC. One of the Walleye that was excluded from the residency analysis due to limited detections on the Toronto and Region array was subsequently detected in the summer of 2015 on the acoustic telemetry array in Hamilton Harbour. Walleye were found to prefer habitat with deeper water (> 3.0 m) and moderate to high levels of exposure and also move to shallow, heavily vegetated areas in the spring and fall (while in the harbour). Given the aforementioned movements, however, more pelagic habitats are also likely important for Walleye, but these types of preferences have yet to be documented for fish tagged on the Toronto and Region array. The characterization of Walleye as non-resident is further supported by evidence from other telemetry studies in the Great Lakes that have documented movements of up to 350 km by Walleye in Lake Huron (Hayden et al. 2014).

In terms of residency, three of eight White Suckers were detected making regular movements in and out of Toronto central waterfront and all three departed at different times and for different durations. Two more White Sucker moved out of the harbour on at least one occasion with one individual not returning. Elsewhere, there is evidence of large movements (up to 9.2 km) during the spawning season in rivers that further supports their assignment as non-resident (Doherty et al. 2010). From a habitat perspective, White Sucker were primarily concentrated around the open waters of the Outer Harbour and to a lesser extent the western gap. They frequented areas with a range of habitat conditions including: moderate to deep pelagic areas across a range of exposures, moderate exposed areas with dense SAV, and shallow protected areas with minimal vegetation. Given the movement of over half the tagged individuals outside of the harbour and no strong habitat preferences, we classified this species as non-resident, although we acknowledge the small sample size and lack of more definitive movement data. Additional White Sucker have been tagged both on the Toronto and Region and Hamilton Harbour arrays therefore future analysis can hopefully confirm their assignment as non-resident.

Discussion

The characterization of eight fish species as resident or non-resident within the Toronto AOC provides context to the interpretation of trends in their population, and also identifies the species that are most likely to benefit from habitat remediation or enhancement efforts. Resident species, like Northern Pike and

Largemouth Bass, should be the focus of restoration efforts since they are more likely to benefit from regional changes. These species also tend to be more dependent on littoral habitats (i.e., shallow, warmer, and with more vegetation), therefore their residence within the central waterfront is not surprising given the paucity of similar habitats in proximity. Frenchman’s Bay is likely the closest large embayment that provides similar habitat conditions and to reach this area resident fishes would need to traverse over 30 km of cool, exposed open water. This may result in some level of isolation of resident fish populations within the AOC, making their protection and recovery more important.

Movements outside of the central waterfront by non-resident fishes and the resulting detection of Common Carp and Walleye in Hamilton Harbour may be indicative of larger metapopulations of these species in the western portion of Lake Ontario. Recovery of Walleye within the Toronto AOC may therefore be best achieved through larger-scale recovery strategies and the current stocking strategy for Walleye, led by OMNRF, matches well with a regional approach. Walleye are being stocked into both the Hamilton Harbour and Toronto AOCs and Walleye stocked into Hamilton Harbour have been detected on the Toronto and Region array suggesting that this regional approach may help improve Walleye populations in all of western Lake Ontario, including the Toronto AOC. As more information on Walleye spatial ecology and habitat use become available through the collaborative acoustic telemetry projects in western Lake Ontario, effort can be made to identify, enhance or create potential spawning areas within the Toronto AOC. This would further help support regional recovery of populations of Walleye.

In contrast, Common Carp are a non-native species that are well known to negatively affect aquatic ecosystems (Weber and Brown 2009). Rather than recovery, active (i.e., removal) and passive (i.e., exclusion barriers) management of this species are the means available to try and reduce regional populations. Evidence of a lack of residence within the Toronto AOC poses a challenge for management of Common Carp since even if spawning and recruitment within the AOC can be limited, there will still be sources outside of the AOC that can bolster the local population. Similar to Walleye, a more regional and integrated approach to Common Carp management may be the best approach for reducing numbers within the Toronto AOC and other nearshore areas of western Lake Ontario. This suggestion does not preclude the need for local management measures (i.e., exclusion structures) since these will be important for maintaining habitat integrity within the AOC. Rather, active management of Common Carp within the AOC should be done in collaboration with other regional partners. Similar to Walleye, efforts are underway to track and document the timing and extent of movements of Common Carp in western Lake Ontario to support the development of a more regional management strategy.

As noted, more work focused on White Sucker is likely important to explore the extent of their movements in Lake Ontario and confirm their status as non-resident within the Toronto AOC. Similarly, more spatially expansive tracking of all fishes tagged in the AOC can confirm their assignment as resident or non-resident and help to determine the level of regional connectivity among littoral habitats. A western Lake Ontario telemetry array was deployed starting in 2017 and has expanded its spatial coverage to the present with a grid of receivers that now covers much of Lake Ontario west of Cobourg. Tagging of numerous fish species has continued not only in the Toronto AOC, but also in Hamilton Harbour, the Niagara River, Bay of Quinte, and the Kingston basin of eastern Lake Ontario. All of these works are part of a larger Great Lake-wide acoustic telemetry collaborative (Great Lakes Acoustic Telemetry Observation System; Krueger et al. 2017) that will help to address some of the remaining questions related to fish residency for the Toronto AOC and determine the potential role of habitats in the AOC for fishes tagged elsewhere in Lake Ontario.

Tables and Figures

Table 13. Total number of tagged fish species and the number of individuals that exited the central waterfront in the Toronto and Region Area Of Concern. Species were classified as either resident (most tagged individuals remained primarily in the harbour) or non-resident (many of the individuals for a tagged species moved in and out of the harbour). Data used to determine residency was taken from Midwood et al. (2018a) for Bowfin, and Midwood et al. (2019a) for all other species.

Species	# of fish that left Toronto Harbour Array	Total # of fish that were tagged	Resident or Non-resident
Bowfin	1	10	Resident
Brown Bullhead	0	14	Resident
Common Carp	23	57	Non-resident
Largemouth Bass	8	111	Resident
Northern Pike	2	122	Resident
Walleye	8	11	Non-resident
White Sucker	3	8	Non-resident
Yellow Perch	1	16	Resident

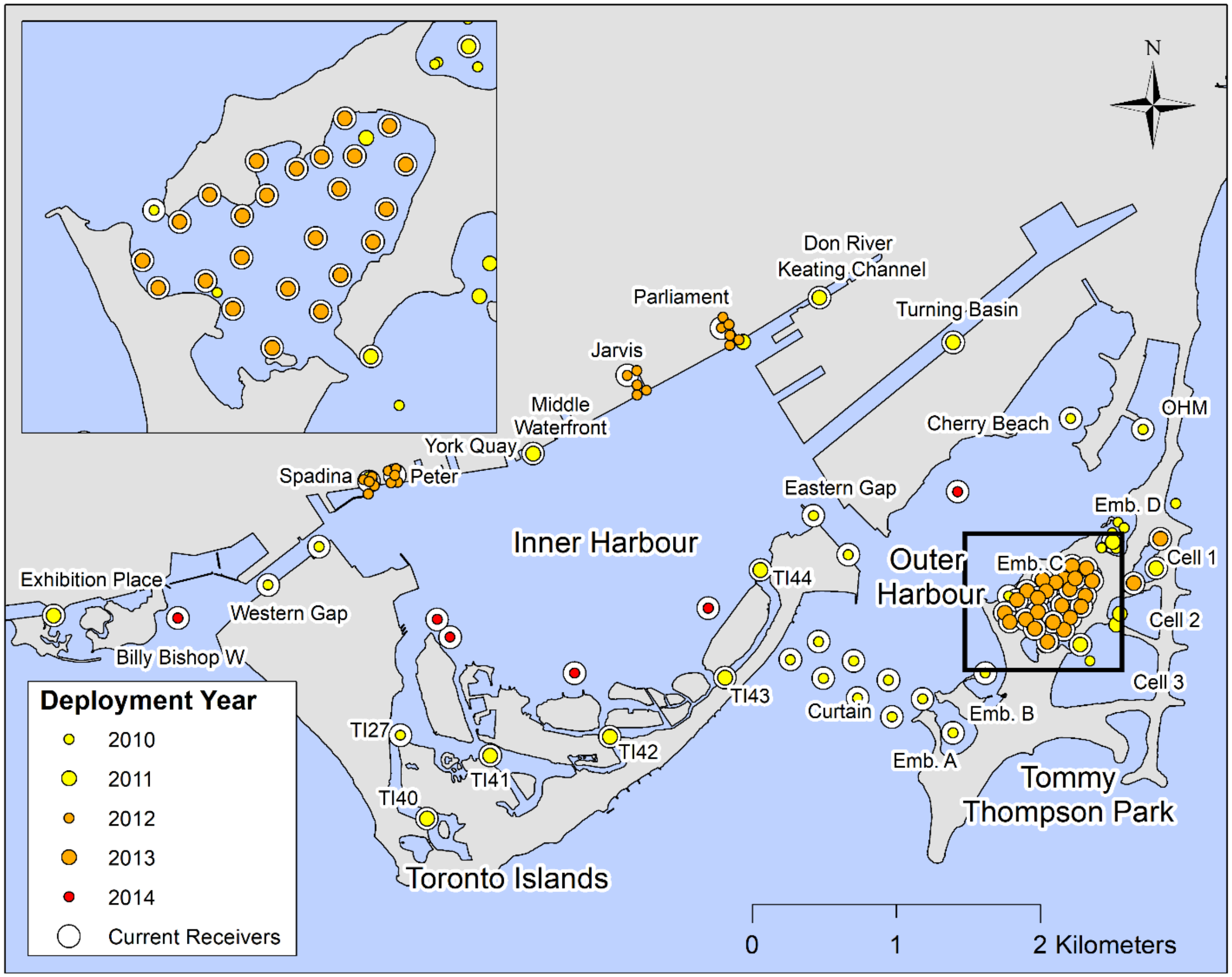

Figure 44. Location of receivers and their deployment year on the Toronto and Region array. Important regions are also labelled. See Table 2 in Midwood et al. (2019a) for information on receiver coordinates and receiver grouping.

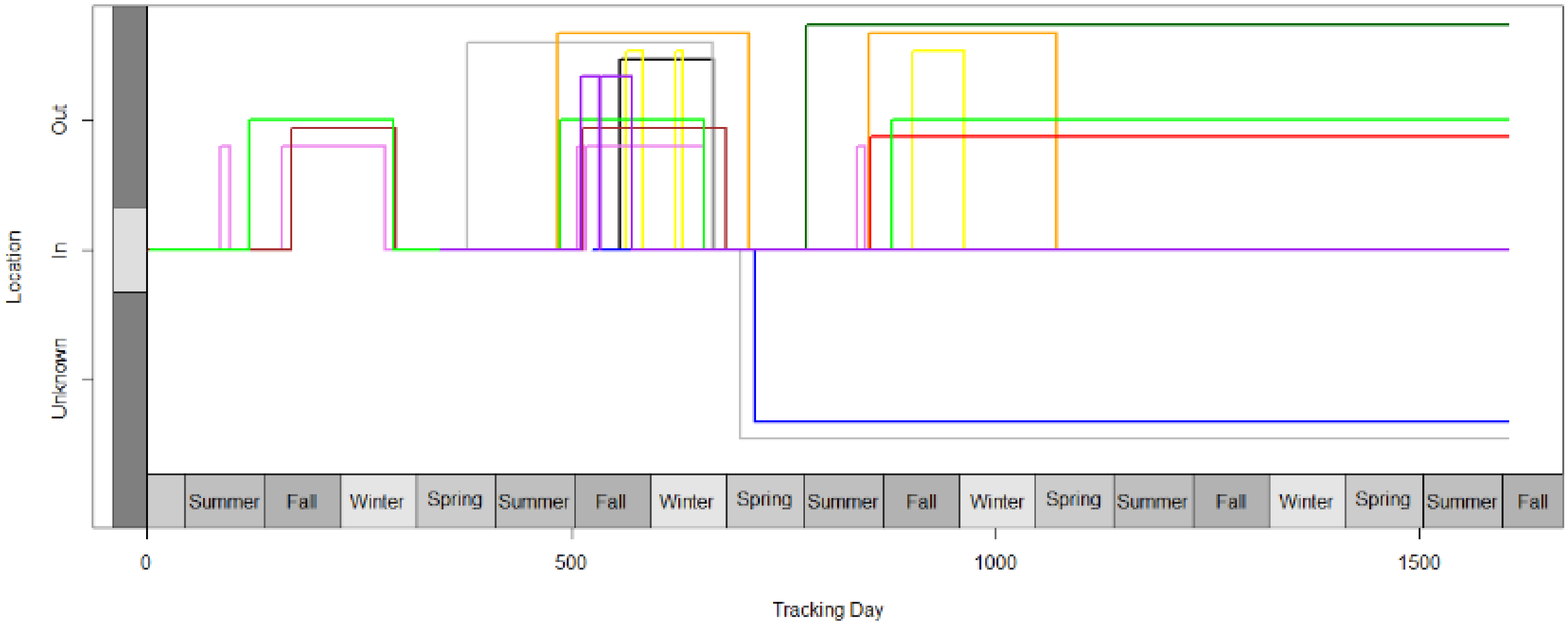

Figure 45. Evaluation of the general location of Walleye through time. “In” denotes time periods when an individual was detected within the Toronto and Regoion acoustic telemetry array and “out” times when they are confirmed to be outside of the array (detected passing through the western gap or the curtain). For the unknown location, the last detection of these individuals was within the harbour therefore their ultimate position is unclear. Two individuals (WALL472; WALL485) remained in the harbour for the duration of the study. For the remaining individuals, their movements are colour coded (Black = WALL423; Yellow = WALL504; Blue = WALL545 UNK; Dark Green = WALL560 Out; Grey = WALL601 UNK; Orange = WALL616; Violet = WALL635; Brown = WALL653; Red = WALL655 Out; Green = WALL676 Out; Purple = WALL703).

CRITERION FP-2: TRENDS IN POPULATIONS OF TOP PREDATORS AND NON NATIVE FISHES IN THE TORONTO AOC

Summary of Status of FP-2

Without specific catch targets for the species assessed in this section, we must presume that populations were locally depressed when the Toronto AOC was originally designated and surveys first began as documented in Whillans (1979). Given the noted lack of increasing catch for any of the native top predators assessed here and a lack of declining catch for the two non-native fishes, there is no other conclusion that can be made other than that formerly abundant fish populations remain locally depressed within the Toronto AOC. Prior to the next assessment, species-specific targets should be established for ecotypes and regions where they are found and these should be based on regional reference areas similar to the work presented in Bowlby and Hoyle (2017). As noted in this section, such targets have been developed for some species based on trap netting, but electrofishing-specific targets are required. The influence of temporally dynamic environmental conditions on trends in individual species has not been explicitly captured in the present assessment, but it is likely that factors such as water levels, summer temperatures, and winter conditions influence both capture efficacy and species catch. Incorporating these types of components into future trend analyses will provide a more accurate depiction of temporal trends in catch and also help environmental managers understand what actions should be taken to enhance species populations and, indeed, what the carrying capacity for individual species may be within the system.

Key Messages

- There were no increases in catch from 1989 – 2018 for native top predators in the Toronto AOC.
- Embayment ecotypes had the highest capture probability for all species (except Smallmouth Bass).
- Northern Pike appear to be stable in most ecotypes and regions where they were found.
- Sheltered regions within the Toronto Islands and Tommy Thompson Park embayments represent key habitat for Largemouth Bass.
- Walleye and Smallmouth Bass are rarely captured, lending evidence to the historical importance of the Don River and adjacent marshes for these species.
- Analyses for Bowfin should focus on summer catch trends due to limited catch in October; likely driven by smaller home ranges in the fall.
- Round Goby are found in all ecotypes, active management of this species is likely impractical
- Common Carp catch has remained stable over time at all ecotypes and regions.
- Based on these results, we recomme nd FP-2 remain designated as “impaired”

Remaining Concerns and Uncertainty

- For several species (e.g., Walleye, Smallmouth), insufficient catch during night surveys in July and October prevented modelling trends through time; a more detailed exploration of the Toronto and Region Conservation Authority (TRCA) electrofishing dataset and or alternative means for assessing populations may resolve this problem (see monitoring suggestion #2 and actions #1 and 4 below).
- It is unclear why Northern Pike are declining in some embayment regions (e.g., Toronto Islands) but not others; modeling trends through time that incorporate environmental factors may help resolve this uncertainty (see action #5 below).
- The focus of FP-2 was on the capture probability (presence) and catch of species of interest, but other elements such as age structure (size) and biomass are also important considerations since they are indicative of population fitness (see action #6 below).
- There are lag-times between when habitat remediation actions are completed and when fish species will respond; these lag-times will inherently be species-specific and it may not be possible to predict their duration (see monitoring suggestion #1 below).

Future Monitoring

1. Monitoring of warm-water piscivores in all ecotypes should continue for a minimum of five years (possibly longer for some species) after the Don River revitalization project is complete and all habitat features are reconnected. This is necessary to capture the lag-time between habitat creation and population recovery.
2. Given low catch of Smallmouth Bass, alternate gear types (e.g., gill nets, snorkel) and/or sampling times (e.g., daytime surveys) should be considered for the assessment of this species. A review of methods used in the literature to capture Smallmouth Bass may be sufficient.
3. Establishing and maintaining long-term monitoring at reference areas for each ecotype will help to determine if trends (or a lack thereof) within the Toronto AOC are related to Toronto AOC-specific conditions or a function of lake-wide or regional conditions (see Future Monitoring Recommendations section for more specific details).

Recommended Actions

1. Species-specific targets should be established for ecotypes and regions where they are found, and these targets should be based on regional reference areas [Bowlby and Hoyle (2017) have completed this for trap nets].
2. Options for managing Common Carp at a regional scale (western Lake Ontario) should be explored given documented movements. In support of these efforts the following actions should be taken: continue monitoring Common Carp within the

Toronto AOC to assess efficacy of management actions (e.g., exclusion structures); explore whether exclusion structures can be opened periodically to allow access to other species; and document extent and timing of Common Carp movements in western Lake Ontario.

3. Options for recovery of Walleye at a regional scale (western Lake Ontario) should be explored given documented movements. In support of these efforts, researchers should attempt to determine: 1) the extent of connectivity among major rivers and embayments within western Lake Ontario; 2) important movement corridors among these sites; 3) the timing and driver of movements; and 4) potential spawning locations (both within the Toronto AOC and in western Lake Ontario).
4. Future analyses should focus on a more holistic assessment of the TRCA electrofishing dataset. Specifically, these analyses should explore seasonal changes in catch for species of interest to determine what month/season is best used in their evaluation (i.e., when are they typically captured). There may be insufficient data for a formal trend-analysis, but it may support assessments of age structure and comparison of recent catch to regional reference areas.
5. Future temporal analyses should incorporate environmental factors, such as water levels, habitat area, summer temperatures, and winter conditions. This could identify potential drivers behind apparent trends (or lack of trends) and whether the drivers are elements that can be managed (e.g., habitat area) or not (e.g., water levels, climate).
6. Future analyses should consider age structure since the presence of juvenile fish indicates whether a population is self-sustaining. Analyses will need to be less restrictive with the data that are excluded (i.e., not only July/October night samples, as noted in action #4) to ensure there are sufficient data available for all species.
7. Future analyses should use the current electrofishing dataset to model the relationship between catch of species or community metrics and the capture probability and catch of Round Goby to determine if there is a quantifiable impact on these species or measures from their introduction.
8. Future analyses should assess trends in other species of interest (not just top-predators or non-native fishes) within the Toronto AOC. Assessment of prey species [e.g., Yellow Perch (*Perca flavescens*)] may help explain trends in top-predators and a larger number of species-specific trends could show how remediation actions may influence fish community composition (links to FP-1A).

Background

Top predators play important ecosystem roles as they regulate food web community structures through top-down interactions with lower trophic levels, down to planktonic communities (McQueen et al., 1989; Yoshida et al., 2003). Removal or declines in top predators can result in a trophic imbalance or cascade, completely altering food web dynamics (Pace et al., 1999) and leading to changes in nutrient levels and water quality (Carpenter et al., 2001). Embayments and river mouths/estuaries provide nursery habitat and shelter for many warm-water (e.g., Largemouth Bass) and cool-water (e.g., Northern Pike) predators from intense wind and wave action in open coasts (Dietrich et al., 2008). This is especially important in western Lake Ontario as there are few protected embayments remaining, and many of these are subjected to cold-water upwellings from Lake Ontario (Murphy et al., 2012; Hlevca et al., 2015). It is therefore important to monitor species-specific long-term trends in catch within the Toronto and Region Area Of Concern (Toronto AOC) to assess the status of top predators to limit declines in local populations, and provide management advice to support and sustain healthy fish community assemblages.

Piscivorous species known to occur in the Toronto AOC include Northern Pike, Walleye, Largemouth Bass, Smallmouth Bass, and Bowfin. Prior to listing as an AOC, populations of these species declined in and around the Toronto and Region due to a suite of human-induced activities including commercial fisheries, the destruction of wetland and riverine habitat, and the hardening of natural shorelines (Whillans, 1979). Nearly all of the historical marshes were lost in Toronto Bay, including the infilling of the Ashbridge’s Bay wetland (Whillans, 1982), which led to declines in many nearshore fishes, including Northern Pike, and more riverine species like Walleye and Smallmouth Bass (Whillans, 1979). These declines are one of the reasons that fish population delisting criteria explicitly state that “*formerly abundant fish populations are rehabilitated where locally depressed…*”. Top predators are also mentioned specifically as an integral component of a stable fish community structure, thus assessing the current status and recent trends for top predators are essential.

Given the cool- to cold-water conditions of open coast shorelines in western Lake Ontario, warm-water fish species rely on coastal vegetated wetlands for spawning, juvenile nursery habitat, and protection from intense wind and wave action. As a result of historical habitat loss, the Toronto Bay Initiative was developed to promote the restoration and creation of wetland habitats (Kidd, 1998). In addition to wetland remediation, shoreline hardening structures, such as groynes, revetments, and breakwaters, have been developed to prevent erosion in open coast environments, which can create artificial embayments and minimize nearshore sediment transport. Between 1989 and 2005, there was an apparent increase in native species biomass, as well as increased Walleye catch (Dietrich et al., 2008). Biomass of all native piscivores [Northern Pike, Smallmouth Bass, Largemouth Bass, Bowfin, Walleye, and Longnose Gar (*Lepisosteus osseus*)] varied among embayments, decreased in estuaries, and showed a slight increase in open coasts (Dietrich et al., 2008). Based on more recent fish community surveys, the Index of Biotic Integrity (IBI, a surrogate for overall aquatic ecosystem health; see Minns et al., 1994) for the Toronto AOC was lower than at other exposed embayments on Lake Ontario, however, values approached regional IBI targets set for the Toronto AOC, including in some years a healthy piscivore population (Hoyle et al., 2018 – see section FP-1A and FP-1B for more details).

The introduction of non-native species can impact aquatic ecosystems as they often lack natural predators, allowing them to become established rapidly and alter native fish community structure; AOCs with degraded fish populations and low numbers of top predators would be more susceptible to the impacts of non-native species than healthy ecosystems. Round Goby and Common Carp (both persist in the Toronto AOC and have disrupted food web dynamics within Lake Ontario through bottom-up trophic interactions. Established populations of Round Goby harm native fish species directly through predation on eggs and fry, as well as competition for benthic macroinvertebrates (Charlebois et al., 1997), including documented impacts on Lake Trout (*Salvelinus namaycush*) (Chotkowski and Marsden, 1999; Fitzsimons et al., 2009), numerous benthic species (French and Jude, 2001; Pennuto et al., 2010; Poos et al., 2010), and Smallmouth Bass (Steinhart et al., 2004a; Tufts et al. 2019) within the Great Lakes. The effects of Common Carp on freshwater fish communities has been well documented as they can alter aquatic ecosystems by reducing the amount of vegetated habitat (i.e., submerged aquatic vegetation) via consumption and increased turbidity via resuspension of sediments (Crowder and Painter, 1991). The high abundance of Common Carp in Lake Ontario may be preventing warm-water piscivores that rely on vegetated habitat from recovering (Bowlby and Hoyle, 2017). Thus, non-native species must be considered when assessing the trends in fish communities within the Toronto AOC.

The objectives of this section were similar to section FP-1A but with more of a focus on species-specific trends for top predators and select non-native fishes. Specifically, using the TRCA electrofishing dataset, temporal trends in the capture probability (probability of capturing that species in a transect) and catch of top predators (Northern Pike, Largemouth Bass, Smallmouth Bass, Walleye, and Bowfin) and non-native fishes (Round Goby and Common Carp) were modelled among ecotypes and within ecotype-regions. Where possible, trends within the Toronto AOC were compared to those for similar ecotypes that fell outside of the boundary of the Toronto AOC. The assessment of species-specific trends within the Toronto AOC will aid in determining whether formerly abundant fish populations are rehabilitated to support native fishes and a diverse fish community.

Methods

Data preparation and analysis for this section followed the same approach as the temporal trends analysis outlined in section FP-1A. Data preparation involved sub-setting the TRCA electrofishing dataset to include only sampling transect completed at night during July and October (2100 – 0500 h and 2000 – 0700 h, respectively). For each top predator or non-native species of interest, their presence/absence (used to derive capture probability) and catch at each transect was determined and used as the response metric for modelling. For the present analysis, no separation was made based on size classes within species, however, mean total length [mm] and mass [g] of captured fish are outlined in Tables 14 and 15.

As noted, temporal modelling followed methods outlined in section FP-1A, with the capture probability of a species using a Bernoulli distribution and catch modelled using either a Poisson or negative binomial distribution (the latter if there was evidence for over-dispersion in the residuals of the Poisson model). When possible, these models were developed at the ecotype-level (i.e., trends at the four core ecotypes: open coast, embayment, estuary/rivers, and slips) and sub-regions within open coast and embayment sites (see section FP-1A for descriptions of ecotypes and Figure 2 in that section for a map of those ecotypes). Since the core objective of these works was to model trends in species capture probability or catch through time, no covariates outside of the ecotype or region were included. All models were developed in RStudio (R 3.6.0; R Development Core Team, 2019) using the R-INLA package (http://www.r-inla.org) and additional support functions presented in Zuur et al. (2017) and Zuur and Ieno (2018). Details of each model can be found in Appendix D.

Temporal trends were plotted and visually interpreted with difference between years being identified when there was no overlap in the credible intervals between time periods. These apparent differences are described but were not quantified using *post-hoc* contrasts. Interpretation of species-specific summary data and the plots of temporal trends followed a standard process that included: 1) summary of whether there were sufficient data to complete the analyses; 2) description of apparent trends at the ecotype level (both July and October) and any differences between time periods; 3) description of apparent trends in embayment and open coast regions (both July and October) and any differences between time periods; 4) evaluation of the consistency in apparent trends at the ecotype and regional level; and 5) comparison of apparent trends within the Toronto AOC relative to available reference data (July only). When sufficient data were available, species-specific seasonal differences (July vs October) in capture probability and catch were compared among ecotypes and regions.

Results

Sampling effort and capture of species of interest were variable between months and among ecotypes and ecotype regions (Table 16). There were more sampling events in July (n=995), with a majority occurring in embayments (n = 567), followed by open coast (n = 215), slips (n = 118), and estuary/rivers (n = 95). Embayments were also the most frequently sampled ecotype in October (n = 176), followed by open coast (n = 85), estuary/rivers (n = 37), and slips (n = 34). Due to considerable variability in the capture of species of interest, analysis for each species for all combinations of month, ecotype, and ecotype region were not possible. Results are broken down by species and the models that were possible to run are interpreted. For a complete list of models that were analyzed and associated information on model fit and whether models passed validation see Table 17.

Bowfin

Bowfin were primarily captured at embayment sites (12% of embayment transects) with a single record from estuary/river sites, and none at open coast or slips during July

(Table 16). There was insufficient capture of Bowfin to conduct analyses for all ecotypes, among all regions, or during October. There were also insufficient data to conduct analyses on Bowfin catch. Therefore, only an embayment assessment of Bowfin capture probability in July at the Toronto Islands and TTP was undertaken. There were no quantifiable differences between these regions, nor was there evidence for temporal changes in Bowfin capture probability. At reference sites, Bowfin catch was considerably lower at open coast sites (close to zero) relative to embayment reference sites and there was no evidence for temporal changes in catch.

Largemouth Bass

Largemouth Bass were captured primarily at embayments, in both summer and fall, and were detected so infrequently at other ecotypes (e.g., 1% of open coast transects; 9% of estuary/rivers transects; 14% of slip transects in July) that trends in catch could not be evaluated for these ecotypes in either July or October (Table 16). The capture probability of Largemouth Bass in July was higher in embayments relative to other ecotypes. At embayments, capture probabilities peaked between 1998 – 2001 and were higher than the start of the data record (1989 – 1990) but have since declined back to these historical values (Figure 46).

Within embayments, catches were slightly higher (and predicted capture probability) in the fall. There were no apparent trends in the probability of catching Largemouth Bass among embayment regions; however, Largemouth Bass catch was highest at the Toronto Islands followed by Tommy Thompson Park relative to other embayment regions (Figure 47). At the Toronto Island sites, catch was highest from 2000 – 2014, peaking in 2005; catch declined after 2014 down to similar values documented at the beginning of the time series (Figure 47). At TPP, there was a smaller peak in catch in 2012, with numbers returning to those observed at the beginning of the time series afterwards. Catch of Largemouth Bass at open coast reference sites was typically lower than at embayment reference sites, but there was considerable inter-annual variability in catch at reference embayments.

Northern Pike

In July, Northern Pike were most frequently captured at embayments (43% of transects) followed by slips (27% of transects), estuary/rivers (15% of transects), and open coast sites (5% of transects) (Table 16). Similarly, in October, Northern Pike were captured at 60% of embayment transects, 29% of slip transects, and 6% of open coast transects, but they were more prevalent than in July at estuary/river transects (35%). There were sufficient data to conduct analyses at most ecotypes (except open coast) for both capture probability and catch; comparisons could also be made among embayments for July and October.

There was a decrease in Northern Pike capture probability in July 2005 across ecotypes with values recovering by 2008. Despite this variation, the capture probability of Northern Pike at the different ecotypes in July did not change between 1988 and 2018. There did not appear to be any changes in the probability of capturing a Northern Pike over time at most regional embayments during July, with the exception of the Toronto

Islands where Northern Pike capture probability was lower in 2013 – 2018 compared to 1989 – 1994 and 2010 (Figure 48). There were no differences in Northern Pike capture probability at the ecotype or regional embayment level during October between 1989 and 2018.

Northern Pike catch during July was lowest in estuary/river habitats compared to embayments and slips. Catch of Northern Pike in July did not change over time between 1988 and 2018 at any ecotype in July or October. At embayments in July, Northern Pike catch was lowest in the central waterfront and western regions. For most regions, there was no change in pike catch over time in either July or October. However, there was a decline in Northern Pike catch over time at the Toronto Islands in July; mean catch in 2017 – 2018 was lower compared to values from 1989 – 1997 (Figure 49).

There was no change over time in the capture probability Northern Pike at the ecotype level in July or October. Similarly, no differences were found in capture probability at regional embayments during October compared to July. Northern Pike catch was low at open coast reference sites (as was observed within the Toronto AOC), but they were commonly captured in embayment reference sites during July. In general, Northern Pike catch was similar at embayments in the Toronto AOC and reference areas. Catch at reference embayments also showed a similar declining temporal trend in Northern Pike catch that was observed in the Toronto Islands (Figure 50).

Smallmouth Bass

There were insufficient data to describe catch trends for Smallmouth Bass within the Toronto AOC, with capture of this species at less than 6% of embayment (primarily at the otherwest region) and slip transects in July. There were higher capture probabilities at estuary/rivers (22% of transects) and open coast (21% of transects; primarily east of Bluffers park), but no apparent trends in capture probability through time (Table 16). At reference sites, there was similarly no apparent trend in catch, but Smallmouth Bass were caught more often at open coast habitats compared to embayments (Figure 51).

Walleye

Walleye were rarely caught during electrofishing surveys; Walleye were captured at less than 6% of embayment and 4% of estuary/river transects, and none were captured at open coast or slips in July (Table 16). There were insufficient data to conduct a comparison at the ecotype or regional level in July or October. In July only, a model was fit to predict the capture probability for Walleye. Capture probability was low on average (typically less than a 1:10 chance of capturing a Walleye) and there was no change in capture probability between 1988 and 2018 despite a peak in 2005 (Figure 52). Walleye total catch was low at the embayment and open coast reference sites with only four individuals in total on record. These low catch numbers are consistent with the low capture probability Walleye in the Toronto AOC sites.

Round Goby

During July, Round Goby were captured more often at embayment (34%) and open coast transects (32%), compared to estuary/river (11%) and slips transects (2%; Table 16); similar patterns in capture probability were found during October surveys. There were sufficient data to conduct analyses on Round Goby capture probability at the ecotype level (except for slips) in July and October; however, analyses among regions for embayments and open coast ecotypes were only possible in July.

Round Goby were absent from the data record until 2003 when they appeared at all ecotypes during July and October. After 2003, the capture probability Round Goby during July was lower in estuary/river habitats compared to embayments and open coast (insufficient catch at slips, likely due to deeper depths). During October, the capture probability of Round Goby was similar at embayment and open coast habitats (could not be modelled for slips or estuary/rivers). Once established, there was no differences in capture probability at embayment or open coast ecotypes in October. In contrast, in July there was a reduction in the capture probability of Round Goby at all ecotypes in 2017 and 2018 compared to the peak observed in 2005 – 2016 (Figure 53). The capture probability of Round Goby at embayment and open coast ecotypes was higher in July compared to October. There were insufficient data to assess catch or capture probability y during October for estuary-river or slip ecotypes and at the regional level.

In terms of catch, once Round Goby became established in 2003 they were detected at all ecotypes during July; mean catch was higher at embayment and open coast ecotypes compared to estuary-rivers, however, turbidity at the riverine sites may have reduced catchability. Similar to the capture probability data, there was a decline in catch at all ecotypes in 2017 and 2018. At the end of the time series (2017 – 2018), mean catch of gobies at regional embayments during July were similar, but catch was higher during the first five years of invasion at the Toronto Islands and TTP (Figure 54). A similar pattern following initial invasion was also evident at open coast regional sites, but trends through time were more stable (i.e., no evidence for more recent declines in capture). Mean Round Goby catch was lower at embayment reference sites relative to open coast reference sites during July. Although the differences were small, this appeared to be the opposite when compared to the Toronto AOC sites, where catch was higher at embayment sites relative to open coast sites in July. In general, there seemed to be similar patterns of Round Goby catch between Toronto AOC sites and reference sites.

Common Carp

Common Carp were captured at 55% of embayment, 70% of estuary/river, 27% of open coast, and 27% of slip transects during July. The capture probability at estuary-river sites in October was considerably lower at 41%. The modelled capture probability for Common Carp during July and October was highest at estuary/river and embayment habitats compared to open coast and slips. There were no changes in capture probability over time at the ecotype or regional level in July or October. At embayments, capture probability was higher at TTP and the othereast region in July and at TTP and the Toronto Islands in October.

There was a decline in Common Carp catch at the estuary/river ecotype over time in July but not at any of the other ecotypes (Figure 55). Within this ecotype, mean catch was lower (<2.5 Common Carp per transect) from 2015 – 2018 than it was from 1989 – 2002 and 2008 – 2012 (2.5 – 5.0). In contrast, mean catch at other ecotypes was less than 2.0 for each year. There was no change in Common Carp catch over time at ecotypes in October, but mean catch was higher at embayments and estuary-river in October than at open coast or slips. On average, the catch at all ecotypes in October was <2 per transect. There was no change in Common Carp catch (1989 – 2018) at the regional embayment level in July or October, but mean catch was higher at othereast and TTP (2.0 – 2.5) in July than at other embayments (Figure 56) and highest at TTP in October. The mean catch of Common Carp was higher overall at reference embayments (~2.5) and open coast sites (~2.0) than at Toronto AOC embayments (~1.0) and open coast (<1.0) in July. The catch observed at reference embayments was comparable to mean catch at TTP and the othereast region.

Discussion

The loss of the historical marshes and river mouth habitat within the Toronto AOC is one of the driving factors of fish population declines in the Toronto AOC and its eventual listing as an AOC. Whillans (1979) identifies Northern Pike, Walleye, and Smallmouth Bass as species that declined during this period and, based on the present assessment, Northern Pike appear to be stable in most ecotypes and regions where they were found; however, Walleye and Smallmouth Bass are still rarely captured lending evidence to the historical importance of the Don River and adjacent marshes to these species. Where data were sufficient, embayment ecotypes had the highest capture probabilities for all species, except Smallmouth Bass, and warm-water top predators (e.g., Bowfin and Largemouth Bass) were almost exclusively captured in embayments. For all the species-specific trends assessed, there were few notable differences in capture probability or catch over time within ecotypes or regions. The few trends that were evident indicated a decline, which in some cases was beneficial (e.g., Common Carp at estuary/rivers), but more generally was counter to the objective of recovering formerly abundant fish populations (e.g., Northern Pike in the Toronto Islands). What follows includes some interpretation of species-specific trends in the context of environmental conditions during the survey period (1989 – 2018), and considerations for future sampling strategies and potential benefits from planned habitat creation and remediation works.

Species-Specific Trends

Bowfin were almost exclusively found in embayment ecotypes, with a clear preference for embayments in TPP and the Toronto Islands. This ecotype-preference is consistent with past acoustic telemetry studies of Bowfin that found they were most resident in shallow, warm, and protected habitats within the Toronto Islands and TPP (see section FP-1D and Midwood et al. 2018). While the acoustic work summarized in FP-1D did document some evidence for movements between these regions, tracked Bowfin were found to be largely resident within the central waterfront and is further confirmed by limited capture using electrofishing in embayments to the east and west of the central waterfront. As a warm-water piscivore, it is likely that coldwater intrusion from Lake Ontario into embayments outside of the central waterfront limit the suitability of these habitats for Bowfin. Furthermore, these western and eastern embayments are smaller and separated by larger expanses of cool Lake Ontario waters, which may act to isolate Bowfin compared to the larger network of embayments within TTP and the Toronto Islands. Finally, limited catch of Bowfin in October is likely driven by the observed reduction in home ranges during the fall as they prepare to overwinter. Trout pond in the Toronto Islands and Cell 2 in TTP have been identified as spawning and overwintering areas for this species (Midwood et al. 2018a). Given this reduction in range, tracking population trends for Bowfin is likely best done during the summer. While not often identified as important top predators since they are rarely targeted by anglers, Bowfin still play an important ecological role by exerting top-down control on lower trophic fishes, particularly in areas that are shallow, warm, and hypoxic during the summer and thus otherwise unsuitable for other top predators (Scarnecchia, 1992; Ashley and Rachels, 1999). Given these adaptations, Bowfin may be the first top predators to colonize newly created (e.g., planned Don River wetlands) or re-connected (e.g., Cells 1 and 2) habitats since these areas will all be shallow, protected, and consequently warm, which may limit their suitability during the summer for top predators like Northern Pike.

Similar to Bowfin, Largemouth Bass were predominantly captured at embayments; however, they were also occasionally found at estuary/rivers and slips. There was an apparent spike in catch of Largemouth Bass at the Toronto Islands between 2000 – 2014, peaking in approximately 2005. This more recent decline may be partially related to cooler water temperatures (lowest in 2014) and cold winters (2012 and 2013), but the temporary closure of embayment D (starting in 2012) and Cell 1 and 2 (starting in late 2015 into 2016) may also have contributed to catch at both TPP and the Toronto Islands remaining at low levels. Prior to its closure, Cell 2 in particular was identified as important habitat for Largemouth Bass, especially during the winter (Midwood et al. 2019a). A final determination of the driver(s) behind these declines cannot be made at this point, but given the importance of Largemouth Bass as warm-water top predators and the focus on warm-water habitat creation within the Toronto AOC, this deserves more attention in the future. Further stressing the importance of both the Toronto Islands and TTP for Largemouth Bass, they contained the highest proportions of sites where Largemouth Bass were captured (64% in July and 84% in October and 39% in July and 80% in October, respectively). For all other embayment sites Largemouth Bass were captured at < 25% of transects in July and < 41% in October. Similar to Bowfin, limited catch outside of the central waterfront of Largemouth Bass may suggest less suitable habitat in these embayments due to increased exposure to temperature fluctuations from Lake Ontario. Given their preference for warm, shallow vegetated habitat (Peat et al., 2016; Hoyle et al., 2018), these sheltered regions within the Toronto Islands and TTP embayments represent key habitat for Largemouth Bass. The planned creation of new wetlands as part of the Don River revitalization project should result in an increase in habitat suitable for Largemouth Bass, which may increase catch of this species within the central waterfront of the Toronto AOC.

The central waterfront of the Toronto AOC is an exposed embayment (Hoyle et al. 2018) that frequently experiences intrusions of cool lake water in the summer (Murphy et al. 2012). As a result, cool-water top predators like Northern Pike are likely well suited to these conditions. Generally stable populations were found within most ecotypes and regions, which is a positive indication that this species is able to complete its life history requirements within the Toronto AOC. Northern Pike were predominantly found at embayments, but were also frequently captured at slips and estuaries/rivers. Limited catch at open coast ecotypes is not surprising given that Northern Pike are generally considered ambush predators that are known to utilize aquatic vegetation (Pierce 2012), which is largely absent in open coast ecotypes within the Toronto AOC due to wind and wave exposure (Midwood et al. 2021). Their preference within the Toronto AOC for embayments has been previously documented, although there is some evidence for seasonal shifts into deeper waters in the fall and winter (Rous et al. 2017; Midwood et al. 2019a). Boat slip occupancy by Northern Pike has also been documented in the Toronto AOC, especially at slips in proximity to nearby spawning habitat (e.g., the Spadina wetland; Veilleux et al., 2018). Populations of Northern Pike in embayments were generally stable over time; however, there was a decline in Northern Pike capture probability and catch at the Toronto Islands.

From an catch perspective, Northern Pike trends at the Toronto Islands follow a similar pattern as the previously discussed declines in Largemouth Bass catch, starting in approximately 2012 and continuing through to 2018. While this may suggest conditions in the Toronto Islands region have deteriorated, there was also a decline in Northern Pike catch at reference embayments. The absence of a similar trend in other embayment regions within the Toronto AOC suggests that the driver of these declines is not ubiquitous across regions, but rather related to a common factor between the islands and regional reference embayments (which primarily occur in and around Frenchman’s Bay). As discussed, cold winters and the resulting cool summer water temperatures may be a partial driver for these declines, but more research is required to determine commonalities among the Toronto Islands and regional reference areas and potential buffering conditions in other embayment regions (and ecotypes) that may have prevented a similar decline. In general, Northern Pike are important top predators that are well suited to thermal conditions within the Toronto AOC, ensuring populations remain stable and, if possible, increasing should be a core goal for future habitat remediation and enhancement efforts. Determining the driver(s) of declines in some embayment regions but not others can provide guidance on habitat-related actions that may be undertaken to specifically support Northern Pike.

Smallmouth Bass were the only species assessed that were captured less frequently at embayments relative to other ecotypes, with capture probabilities of just over 0.20 at estuary rivers and open coast ecotypes. These ecotypes differences were similar in the Toronto AOC and reference areas, suggesting that these patterns are not specific to the Toronto AOC. A preference for open coast and estuary/river ecotypes is not surprising given their documented preference for cool, rocky habitats (Tufts et al., 2019); however, insufficient catch in the present assessment prevented a direct comparison among ecotypes or regions. Part of this data deficiency may be due to the depth limitations of electrofishing and the timing of Smallmouth Bass occurrence in these littoral habitats. Smallmouth Bass are more likely to occur in shallow water during the daytime and often reside in slightly deeper water at night (Emery, 1973), so nearshore electrofishing efforts may be more successful during calm sunny days rather than the night surveys used in the present assessment. It would therefore be prudent to explore the TRCA electrofishing dataset to determine if catch of Smallmouth Bass were higher during the day and, if so, use daytime data for future assessments of this species. Catch in general using electrofishing at open coast sites has been found to be inconsistent with highly variable catch rates and low diversity. Research currently underway is also finding that total catch and richness in open coast areas are linked to their proximity to nearshore features (e.g., marinas and large rivers), which are hypothesized to provide shelter for fishes during high winds or storm events (S. Blair, DFO, pers. comm.). Developing a better understanding of the factors dictating when and where fish may be using open coast habitats is essential for supporting accurate assessments of species that are reliant on this ecotype. Alternate gear types, such as gill nets, trawling, or snorkel/scuba surveys, are likely more effective at capturing fishes that use open coast habitats in general and Smallmouth Bass in deeper depths in particular; the efficacy of these approaches should be explored to support future assessments of open coast ecotypes within the Toronto AOC. Since a large proportion of the Toronto AOC (by area) is open coast habitat and there are numerous shoreline modification and enhancement projects planned and underway, it is essential that we understand the timing and magnitude of use of this ecotype. Identifying habitat enhancement or creation actions that will support Smallmouth Bass, which are likely the top predators in this ecotype for much of the year, will help recover this formally abundant fish and may help open coast fish populations by providing top-down control on non-native fishes like Round Goby. This type of work should be possible through a review of the available literature on this species and its habitat requirements paired with ongoing efforts to characterize habitat conditions throughout the AOC.

Walleye were captured only at embayment and estuary/river ecotypes and, consistent with other studies on Lake Ontario Walleye populations proximate to the Toronto AOC, catch of this species has remained relatively low over time (Bowlby and Hoyle, 2017; Hoyle et al., 2018). Given the lack of recovery of this historically abundant species, Walleye stocking efforts currently underway in western Lake Ontario may help to re-establish healthy regional populations (see Section FP-1B for details). These efforts include stocking of Walleye into Hamilton Harbour and Toronto Harbour in alternating years. In Hamilton, where these efforts started earlier, strong year classes of stocked Walleye have been observed (OMNRF, 2020); however, there is limited evidence for natural recruitment in Hamilton and it is unclear if these age-1 fish were from stocked Walleye or, albeit unlikely, a remnant natural population. Walleye are known to migrate long distances for spawning and foraging (Olson and Scidmore, 1962), therefore regional movement patterns of Walleye in Lake Ontario are important to consider when planning stocking locations and when assessing population levels within the Toronto AOC. Telemetry data from Hamilton Harbour found that some Walleye captured and tagged in Toronto migrated to Hamilton Harbour for spawning (Midwood et al. 2019a). This supports the notion that Walleye populations within the Toronto AOC are linked to regional populations and therefore limited catch within the Toronto AOC may therefore be more a function of low numbers in the western basin of Lake Ontario in general rather than a Toronto AOC-specific impairment (e.g., lack of habitat, or forage). Walleye recovery should therefore be a collaborative effort led by OMNRF and regional telemetry tracking projects currently underway can help determine: 1) the extent of connectivity among major rivers and embayments within the western basin; 2) important movement corridors among these sites; 3) potential spawning locations; and 4) the timing and driver of movements. These components can complement standardized assessment programs like those run by OMNRF (see section FP-1B) and TRCA (this section and section FP-1A) to support the development and implementation of a regional Walleye recovery program. Based on the success of establishing stocked Walleye in Hamilton Harbour, further exploration of spawning Walleye (both stocked and natural) in that system can be used to identify potential spawning habitats within the Toronto AOC that can be protected or enhanced. Historical records indicate that the Don River provided important spawning habitat for Toronto Bay Walleye (Whillans 1979) therefore, improvements to the Don River currently underway should increase opportunities for Walleye recovery in future.

Round Goby were predominantly captured at embayments and open coast sites, which is logical given their preference for coarse rocky substrate (Lynch and Mensinger, 2012). Round Goby capture probability also appeared to be slightly higher in embayment and open coast ecotypes during July compared to October, which may be driven by Round Goby migration patterns, moving from shallow nearshore habitats to deeper waters in the fall (Lynch and Mensinger, 2012; Blair et al., 2019). The rapid appearance of Round Goby in all ecotypes following 2003 was likely the result of natural and human-enhanced dispersal, such as bait bucket introductions, from their initial introduction in the St. Clair River (Charlebois et al., 1997). The sharp decline in Round Goby capture probability since 2017 may be more an artifact of record-high water levels in Lake Ontario decreasing electrofishing capture success rather than an actual decline in numbers. Round Goby are benthic and do not possess a swim bladder, therefore they do not float when shocked and can be challenging to net as depths increase. Round Goby were captured throughout the central waterfront of the Toronto AOC during trawling surveys (see FP-1C), and therefore other gear types, such as benthic trawling or minnow trapping, may provide better estimates of population trends for Round Goby and other benthic species within the Toronto AOC.

Upon their initial invasion, Round Goby were caught in higher numbers at the Toronto Islands and TTP before settling at locally stable levels at all ecoregions. Given their wide distribution throughout the Great Lakes, Round Goby are not unique to the Toronto AOC; however, they can cause potential issues for other species via competition and predation, which can lead to reductions in community metrics (e.g., IBI). Despite their potential negative effects, numerous native fish species have been found to shift to a Round Goby dominant-diet over time in several of the Great Lakes (Reyjol et al., 2010), including Smallmouth Bass (Brownscombe and Fox, 2013; Crane and Einhouse, 2016), Largemouth Bass (Nelson et al., 2017), Lake Trout (Dietrich et al., 2006; Rush et al., 2012; Colborne et al., 2016), and Walleye (Roseman et al., 2014). This diet shift has allowed native piscivores to take advantage of an abundant prey source, providing positive benefits that potentially outweigh the negative impacts to overall fish productivity in the Great Lakes. Furthermore, juvenile Smallmouth Bass in Lake Erie have exhibited much higher growth rates as a result of abundant Round Goby forage, leading to increased survival and an earlier age of maturity (Steinhart et al., 2004b; Nelson et al. 2017). The ubiquitous presence of Round Goby in Lake Ontario ecotypes makes active management of this species impractical. Their capture probability and catch is therefore most relevant from a fish population assessment perspective in the context of: 1) how they may negatively affect native species through competition or predation; 2) how they may benefit some species by providing a readily available forage base; and 3) how they may influence fish community metrics (i.e., IBI, non-native catch) that are being used to assess conditions and trends (see section FP-1A and FP-1B). For all of these components, the TRCA electrofishing dataset can be used to model the relationship between catch of species or community metrics and the capture probability and catch of Round Goby to determine if there is a quantifiable impact from their introduction. Also, for the final component, a research project planned for the Hamilton Harbour AOC is going to explore how active management (i.e., removal or reduction in numbers) of aquatic invasive fishes would change the reported IBI scores. Results from that project can help better understand the potential influence of the invasion of Round Goby on IBI scores, which is thought to be a driver behind declines in IBI score in the Toronto AOC (see section FP-1A).

Common Carp were captured at all ecotypes, but primarily embayments and estuary/rivers. Catch of Common Carp has remained relative stable over time at ecotypes and regions; however, there was a decline in catch at estuary-river sites during July. Given their generalist foraging strategy and absence of predators once they reach maturity, Common Carp continue to thrive within the Toronto AOC. Their well-documented habitat altering activities related to removal of aquatic vegetation and increased turbidity may be impairing habitat for warm-water littoral fish species (Bowlby and Hoyle, 2017). Indeed, the prolonged closure of areas like Embayment D and Cells 1 and 2 is partially linked to the need to have aquatic vegetation well established in these sites so it can better resist Common Carp activity. Historic removal of Common Carp from Cootes Paradise Marsh produced bottom-up restorative effects on wetland habitat, including improved water clarity, macrophyte growth, and planktivore populations (Lougheed et al., 2004). This has led to the incorporation of exclusion structures into the design of embayment creation or restoration projects throughout the Toronto AOC in an effort to improve wetland quality and fish nursery habitat for native warm-water species. Since many of these works are currently underway or have been completed only recently, it is likely too soon to look for any response from these barriers on local Common Carp populations. An added complication for Toronto AOC-specific management of Common Carp populations are the documented large-scale movements by Common Carp, with individuals tagged within the Toronto AOC detected in Hamilton Harbour and the Welland Canal (Midwood et al. 2019a, Midwood, unpublished data). As discussed in FP-1D, a lack of residence by a subset of Common Carp within the Toronto AOC is suggestive of a regional (i.e., western Lake Ontario) population of Common Carp. Confirmation of this hypothesis would suggest that Toronto AOC-specific actions designed to prevent access of adult Common Carp to nearshore areas are essential, but may not yield the desired declines in catch of this species. Rather, Common Carp need to be managed not only within the Toronto AOC, but also at spawning hotspots throughout western Lake Ontario.

While the primary sources of fish community information within the Toronto AOC are handled through TRCA electrofishing and OMNRF trap netting efforts, other works have documented the presence of species not typically captured during these efforts. To assess the impacts of an extension and replacement of the existing outfall to the Ashbridges Bay Treatment Plant (east of Toronto Harbour) on potential Round Whitefish (*Prosopium cylindraceum*) and Lake Trout (*Salvelinus namaycush*) spawning habitat, gill net surveys were conducted in November of 2015 and May and June of 2016 by Hatch Environmental. The gill nets consisted of panels of monofilament mesh, with sizes ranging from 38 mm to 152 mm, which were assembled as one net, referred to as a "gang". Round Whitefish (n = 64, Fish/hr = 0.17, Fish/net/hr = 0.0058), Lake Trout (n = 18, Fish/hr = 0.047, Fish/net/hr = 0.0016), White Sucker (*Catostomus commersonii*; n = 19, Fish/hr = 0.050, Fish/net/hr = 0.0017) and Walleye (n = 1, Fish/hr = 0.0027, Fish/net/hr = 0.000091) were captured in fall 2015, with the majority of Round Whitefish and Lake Trout in spawning condition. Two-thirds of the Lake Trout and Round Whitefish captured in the fall were male, but additional information on age or year class were not reported. A total of 29 nets were set in the fall and they were in the water for 376.8 hrs. In the spring of 2016, catch was dominated by Alewife (*Alosa pseudoharengus*; n = 223, Fish/hr = 0.42, Fish/net/hr = 0.015), with some Lake Trout (n = 26, Fish/hr = 0.049, Fish/net/hr = 0.0017), Round Whitefish (n = 4, Fish/hr = 0.0075, Fish/net/hr = 0.00027), Lake Sturgeon (*Acipenser fulvescens*; n = 1, Fish/hr = 0.0019, Fish/net/hr = 0.000067) and Round Goby (n = 1, Fish/hr = 0.0019, Fish/net/hr = 0.000067). Two thirds of the recorded Alewife were female, and there were roughly equal numbers of male and female Lake Trout (note: a large proportion of the Alewife did not have the sex recorded and two thirds of the Lake Trout had the sex listed as unknown). The majority of Lake Trout and Round Whitefish in the fall were noted to be in spawning condition. A total of 28 nets were set in the spring and they were in the water for 530.9 hrs. Although Alewife generally spawn later in June and July, those captured in the spring were checked for gonad maturity and the majority were considered to be "developing" indicating that they would be in spawning condition that season. Capture of a Lake Sturgeon was notable since they are considered to be a threatened species provincially and the last time a Lake Sturgeon was caught in the Toronto waterfront was in 1927. The Lake Sturgeon caught in 2016 did not appear to be in spawning condition but may have been transiting between known spawning populations (Niagara river, Bay of Quinte, and Thousand Islands). While these data are only representative of some limited sampling events they do provide a snapshot of components of the open coast fish community in Lake Ontario adjacent to the central waterfront. Indeed, later season (e.g., November) sampling within the Toronto AOC is rarely undertaken, but based on these findings, could yield complementary information on native species habitat use in ecotypes within the Toronto AOC.

Summary, Caveats, and Recommendations

In the present analysis of temporal trends in top predator and select non-native fishes capture probability and catch, it was not possible to break down the analysis into different size classes (i.e., by total length) due to time constraints and, for less frequently captured species, low sample sizes. This type of analysis is, however, important for understanding the health and status of populations within the Toronto AOC since age structure is an important indicator of population fitness (Minns et al. 1996). Assessing the capture probability and catch of juvenile individuals for top predators in the Toronto AOC will provide further evidence that populations are stable and/or self-sustaining and can identify important nursery habitats that may be distinct from adults. Indeed, telemetry-based analysis found more restricted areas of residence for juvenile Northern Pike and Largemouth Bass relative to adults (Midwood et al. 2019a). Pairing this information with catches in electrofishing and trap net surveys can confirm the location of important habitats, provide an indication of the size of future year classes, and the condition of individuals within these populations. In contrast, the absence of juveniles would suggest that spawning is not occurring within the Toronto AOC (i.e., these species may be more migratory and spawning elsewhere) or that recent spawning attempts have been unsuccessful. The TRCA electrofishing dataset can and should be mined for this type of information since it will provide a more complete assessment of population status for species of interest within the Toronto AOC. Specifically, an exploration of the dataset may identify different time periods (e.g., months, seasons, day vs night) when species of interest are more commonly captured relative to the July and October night surveys used in the present assessment. While there may be insufficient data to complete the statistical analysis used herein, comparisons of recent age structure and catch relative to regional reference areas would still be informative.

Habitat availability is likely the main limitation for warm-water piscivores in the Toronto AOC since, as outlined in Murphy et al. (2012), many of the embayments in the system experience intrusions of cold-water from Lake Ontario and thus would be better considered cool-water habitat. As outlined in section FP-1A, there has also been a decrease in the surface area of embayment habitats within the Toronto AOC that started in approximately 2012. This decrease will be temporary as remediation actions are undertaken in Embayment D and Cells 1 and 2 at TTP, but in the meantime this reduction is likely partially to blame for a lack of increasing trends for warm-water (e.g., Bowfin and Largemouth Bass) and cool-water (e.g., Northern Pike) piscivores and highlights the importance of habitat restoration for these species. Warm-water piscivores like Bowfin and Largemouth Bass may benefit from the planned creation of three new embayments as part of the Don River revitalization project, which should complement potential increases in their catch from the re-connection of currently disconnected habitats (Cells and Embayment D). For all species and in all ecotypes there will be a lag-time between habitat creation and re-connection and a population-level response. Continued monitoring is therefore necessary to document any increases in catch of top predators as well as the duration of the lag-time. The latter component will be beneficial for informing the assessment of future habitat remediation projects since species-specific lag-times in response to management actions are largely unknown and can be challenging to predict (Nilsson et al. 2017).

As discussed in section FP-1A, a lack of reference areas outside of the Toronto AOC for slips and limited temporal replicates for all other ecotypes prevented the inclusion of reference areas in the models. Establishing and maintaining long-term monitoring at reference areas for each ecotype will help to determine if trends within the Toronto AOC are related to Toronto AOC-specific conditions or a function of lake-wide or regional conditions. While the available reference data for embayment and open coast ecotypes were useful in interpreting Toronto AOC catch, a more comprehensive reference dataset would increase confidence in these interpretations and help determine if there have been improvements in Toronto AOC conditions. Exploration of existing datasets from other similar regions within Lake Ontario [e.g., Fisheries and Oceans Canada (DFO) electrofishing dataset] could also help to establish specific targets for the top predators of interest. A similar approach was taken by Bowlby and Hoyle (2017) using trap net data and it was clear that catch of Bowfin, Smallmouth Bass, and Walleye within the Toronto AOC was lower than other Lake Ontario embayments, while Largemouth Bass catch was similar and Northern Pike catch was higher. Setting catch-goals using this type of approach for electrofishing is essential but requires either the application of the TRCA electrofishing protocol at appropriate references locations within Lake Ontario or a correction factor between this protocol and others for reference areas that have been sampled historically. Some combination of these two options would also work, but it is essential that: 1) reference areas are selected to match the conditions within the Toronto AOC; 2) reference areas for all of the four ecotypes assessed here are surveyed, and 3) the validity of comparing catch from the TRCA protocol and any alternate protocols (e.g., DFO; Brousseau et al. 2005) has been assessed.

The primary objective of this section was to document the trends in top predators and non-native fishes in the Toronto AOC, which will help determine if there was evidence for recovery of species that were formally abundant within the Toronto AOC. Only one of the three species identified by Whillans (1979) as having declined due to historical habitat losses was found to be captured regularly with Northern Pike generally showing stable catch numbers. An absence of increasing trends in any of the native species assessed in the current section is concerning, but there is room for optimism given the habitat creation efforts underway for the Don River revitalization project and impending re-connection of temporarily disconnected habitat in Tommy Thompson Park. Some recommendations for future species-specific assessments within the Toronto AOC were identified, including a need for consistent sampling in reference areas, the establishment of species-specific catch targets, and adjustments to the timing or for sampling for some species of interest (e.g., Smallmouth Bass). The works presented here provide an update on current trends in top predators and select non-native fishes and lay the foundation for future assessments. More holistic recommendations on sampling strategies to support the assessment of fish populations are presented in the Future Monitoring or Actions Required section.

Tables and Figures

Table 14. Total catch, mean total length and mass with standard deviation (SD), and ranges for each species during July night electrofishing transect sampling. Data are broken down by location [e.g., within the Area of Concern (AOC) or in a reference area (Ref)], ecotype, and region. For abbreviated region names: Central waterfront (CentralWF), Tommy Thompson Park (TTP).

Species	Location	Ecotype	Region	Total Catch	Length ± SD (mm)	Length Range (mm)	Mass ± SD (g)	Mass Range (g)
Bowfin	AOC	Embayment	centralWF	0				
	AOC	Embayment	othereast	8	475±62	368-536	1326±517	628-2100
	AOC	Embayment	otherwest	2	455±25	437-472	1275±389	1000-1550
	AOC	Embayment	Toronto Islands	70	534±183	105-762	2223±1308	12-5200
	AOC	Embayment	TTP	20	523±142	157-645	2034±1051	53-4000
	AOC	Estuary.River		1	620		2800	
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	0				
	AOC	OpenCoast	westbluffers	0				
	AOC	OpenCoast	western	0				
	AOC	Slip		0				
	Ref	Embayment		45	560±120	126-700	2126±1031	24-4000
	Ref	OpenCoast		1	695		3400	
Common Carp	AOC	Embayment	centralWF	40	777±80	520-950	7645±2835	2300-16000
	AOC	Embayment	othereast	186	667±192	135-910	5585±3512	12-15000
	AOC	Embayment	otherwest	156	761±111	211-1020	7315±2881	180-14400
	AOC	Embayment	Toronto Islands	110	716±109	70-905	6337±2596	700-14250
	AOC	Embayment	TTP	297	702±148	120-917	5815±3323	26-18000
	AOC	Estuary.River		275	684±147	50-980	5813±3285	2-17000
	AOC	OpenCoast	centralWF	4	761±46	695-792	7263±1324	5400-8500
	AOC	OpenCoast	eastbluffers	44	734±64	565-825	5921±1718	2450-9500
	AOC	OpenCoast	westbluffers	19	749±73	569-860	6500±2122	2800-10900
	AOC	OpenCoast	western	21	754±53	652-840	6657±1682	3000-10600
	AOC	Slip		41	760±91	560-952	9771±3158	3000-16000
	Ref	Embayment		156	582±165	56-954	3666±2568	3-17400
	Ref	OpenCoast		89	704±131	62-890	5522±2219	3-12000
Largemouth Bass	AOC	Embayment	centralWF	11	149±98	43-320	127±205	1-600
	AOC	Embayment	othereast	23	96±60	43-260	42±96	2-409
	AOC	Embayment	otherwest	122	153±63	41-418	87±156	1-1182
	AOC	Embayment	Toronto Islands	1235	87±68	22-534	46±211	0.6-2890

Species	Location	Ecotype	Region	Total Catch	Length ± SD (mm)	Length Range (mm)	Mass ± SD (g)	Mass Range (g)
	AOC	Embayment	TTP	240	130±108	7-505	149±385	1-2250
	AOC	Estuary.River		13	217±71	140-398	214±259	42-969
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	1	49		1	
	AOC	OpenCoast	westbluffers	1	48		1	
	AOC	OpenCoast	western	1	132		29	
	AOC	Slip		19	176±145	35-529	196±388	1-1400
	Ref	Embayment		349	159±113	32-456	202±378	1-1750
	Ref	OpenCoast		15	354±103	56-492	961±643	3-2400
Northern Pike	AOC	Embayment	centralWF	9	588±200	180-863	1988±2018	29-6010
	AOC	Embayment	othereast	77	493±233	52-1000	1237±1259	3-5000
	AOC	Embayment	otherwest	78	601±211	74-1000	1931±1668	2-7400
	AOC	Embayment	Toronto Islands	188	470±229	12-944	1176±1250	3-6500
	AOC	Embayment	TTP	161	554±170	65-930	1574±1426	1-6500
	AOC	Estuary.River		28	602±208	161-930	1865±1664	21-6500
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	7	747±189	482-933	3218±1769	875-5100
	AOC	OpenCoast	westbluffers	2	788±294	580-996	3825±3217	1550-6100
	AOC	OpenCoast	western	1	619		1500	
	AOC	Slip		63	666±188	57-915	2516±1669	1-6650
	Ref	Embayment		64	550±200	100-853	1503±1121	6-4600
	Ref	OpenCoast		2	709±265	521-896	2940±2913	880-5000
Round Goby	AOC	Embayment	centralWF	44	85±25	39-126	12±8	1-30
	AOC	Embayment	othereast	88	82±22	40-190	11±18	1-146
	AOC	Embayment	otherwest	736	79±23	28-171	8±9	0.5-118
	AOC	Embayment	Toronto Islands	244	72±18	17-141	6±6	1-40
	AOC	Embayment	TTP	528	72±19	19-178	5±6	1-42
	AOC	Estuary.River		40	66±17	27-104	4±4	1-14
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	198	85±27	10-173	12±14	1-99
	AOC	OpenCoast	westbluffers	58	70±27	37-151	7±11	0.5-52
	AOC	OpenCoast	western	42	82±27	34-150	10±12	1-54
	AOC	Slip		2	113±46	80-145	41±45	9-73
	Ref	Embayment		36	73±13	51-118	6±4	1-23
	Ref	OpenCoast		43	80±23	42-165	9±11	1-62
Small mouth Bass	AOC	Embayment	centralWF	1	274		300	
	AOC	Embayment	othereast	3	222±140	93-371	370±509	19-953
	AOC	Embayment	otherwest	48	195±95	81-455	221±386	5-1550

Species	Location	Ecotype	Region	Total Catch	Length ± SD (mm)	Length Range (mm)	Mass ± SD (g)	Mass Range (g)
	AOC	Embayment	Toronto Islands	3	256±61	186-302	356±261	99-620
	AOC	Embayment	TTP	5	306±96	144-390	531±314	41-854
	AOC	Estuary.River		164	222±83	67-462	221±243	5-1280
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	282	209±57	75-628	167±193	6-2000
	AOC	OpenCoast	westbluffers	2	122±93	56-187	45±61	2-88
	AOC	OpenCoast	western	16	190±30	114-236	127±65	24-262
	AOC	Slip		1	40		1	
	Ref	Embayment		19	255±102	121-401	342±340	26-948
	Ref	OpenCoast		153	307±114	60-510	668±616	2-2400
Walleye	AOC	Embayment	centralWF	0				
	AOC	Embayment	othereast	9	298±57	186-361	278±129	59-488
	AOC	Embayment	otherwest	17	483±144	219-695	1608±1229	93-4150
	AOC	Embayment	Toronto Islands	11	462±195	176-668	1746±1474	32-3750
	AOC	Embayment	TTP	12	473±151	333-785	1760±1699	281-5700
	AOC	Estuary.River		8	285±61	194-380	239±134	65-458
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	0				
	AOC	OpenCoast	westbluffers	0				
	AOC	OpenCoast	western	0				
	AOC	Slip		0				
	Ref	Embayment		2	699±52	662-736	3450±778	2900-4000
	Ref	OpenCoast		2	732±73	680-783	3756±274	3562-3950

Table 15. Total catch, mean total length and mass with standard deviation (SD), and ranges for each species during October night electrofishing transect sampling. Data are broken down by location [e.g., within the Area of Concern (AOC) or in a reference area (Ref)], ecotype, and ecotype region. For abbreviated region names: Central waterfront (CentralWF), Tommy Thompson Park (TTP).

Species	Location	Ecotype	Region	Total Catch	Length ± SD (mm)	Length Range (mm)	Mass ± SD (g)	Mass Range (g)
Bowfin	AOC	Embayment	centralWF	0				
	AOC	Embayment	othereast	0				
	AOC	Embayment	otherwest	0				
	AOC	Embayment	Toronto Islands	6	445±226	205-674	1472±1474	80-3300
	AOC	Embayment	TTP	5	238±187	125-570	473±965	25-2200
	AOC	Estuary.River		1	224		106	
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	1	650		5000	
	AOC	OpenCoast	westbluffers	0				
	AOC	OpenCoast	western	0				
	AOC	Slip		0				
	Ref	Embayment		2	544±204	400-688	2052±2048	603-3500
	Ref	OpenCoast		0				
Common Carp	AOC	Embayment	centralWF	5	706±51	644-765	6620±2035	4200-8200
	AOC	Embayment	othereast	32	767±112	215-865	7817±2481	150-12000
	AOC	Embayment	otherwest	55	496±273	80-941	4116±4145	8-18750
	AOC	Embayment	Toronto Islands	70	587±202	140-895	4648±3177	47-133000
	AOC	Embayment	TTP	100	561±243	55-925	4816±3735	3-17000
	AOC	Estuary.River		63	495±243	95-910	3854±4110	11-14500
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	17	621±109	406-770	4114±2419	110-8250
	AOC	OpenCoast	westbluffers	0				
	AOC	OpenCoast	western	6	642±108	466-750	5025±2539	2050-8200
	AOC	Slip		16	704±64	520-824	6966±2399	2800-11800
	Ref	Embayment		23	528±139	241-745	2787±1864	255-8000
	Ref	OpenCoast		13	649±96	485-810	4231±2029	1685-8000
Largemouth Bass	AOC	Embayment	centralWF	68	140±70	56-460	98±271	2-2100
	AOC	Embayment	othereast	15	132±43	73-213	51±64	3-198
	AOC	Embayment	otherwest	116	156±62	14-390	80±150	2-1020
	AOC	Embayment	Toronto Islands	399	127±85	34-542	97±293	1-2500
	AOC	Embayment	TTP	414	131±51	45-430	59±151	1-1800
	AOC	Estuary.River		7	106±26	74-145	20±14	5-49
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	0				

Species	Location	Ecotype	Region	Total Catch	Length ± SD (mm)	Length Range (mm)	Mass ± SD (g)	Mass Range (g)
	AOC	OpenCoast	westbluffers	1	88		10	
	AOC	OpenCoast	western	3	185±44	150-234	89±68	36-165
	AOC	Slip		24	117±38	78-230	29±33	5-157
	Ref	Embayment		135	155±70	57-400	103±175	1-1300
	Ref	OpenCoast		6	214±50	145-287	319±347	37-805
Northern Pike	AOC	Embayment	centralWF	28	260±89	160-644	159±308	22-1700
	AOC	Embayment	othereast	27	494±238	125-855	1362±1404	9-4200
	AOC	Embayment	otherwest	39	561±246	195-918	1910±1791	43-5400
	AOC	Embayment	Toronto Islands	198	380±186	132-975	718±1058	14-5600
	AOC	Embayment	TTP	143	362±206	128-1020	725±1328	13-6500
	AOC	Estuary.River		27	411±185	210-915	782±1274	40-5750
	AOC	OpenCoast	centralWF	1	885		6200	
	AOC	OpenCoast	eastbluffers	1	710		2000	
	AOC	OpenCoast	westbluffers	0				
	AOC	OpenCoast	western	4	596±336	245-898	2600±2891	89-6000
	AOC	Slip		23	569±220	152-997	1766±1843	17-6900
	Ref	Embayment		6	531±224	359-945	1399±2041	230-5500
	Ref	OpenCoast		4	796±96	706-921	3763±1523	2650-6000
Round Goby	AOC	Embayment	centralWF	49	91±26	30-148	16±13	1-52
	AOC	Embayment	othereast	9	116±15	86-132	28±11	10-42
	AOC	Embayment	otherwest	81	92±24	43-155	15±14	1-89
	AOC	Embayment	Toronto Islands	4	83±30	38-101	11±7	1-16
	AOC	Embayment	TTP	72	80±19	30-146	10±8	1-57
	AOC	Estuary.River		1	45		3	
	AOC	OpenCoast	centralWF	1	75		4	
	AOC	OpenCoast	eastbluffers	8	104±27	70-154	21±18	9-62
	AOC	OpenCoast	westbluffers	2	73±3	71-75	5±3	3-7
	AOC	OpenCoast	western	28	103±19	75-150	19±12	4-54
	AOC	Slip		7	96±30	55-146	17±17	4-50
	Ref	Embayment		5	87±4	80-90	8±2	6-11
	Ref	OpenCoast		1	89		10	
Smallmouth Bass	AOC	Embayment	centralWF	0				
	AOC	Embayment	othereast	0				
	AOC	Embayment	otherwest	17	158±60	88-348	103±174	12-750
	AOC	Embayment	Toronto Islands	11	110±40	75.5-151.5	30±29	5-60
	AOC	Embayment	TTP	1	83		23	
	AOC	Estuary.River		3	151±23	126-172	48±16	29-60
	AOC	OpenCoast	centralWF	0				

Species	**Location**	**Ecotype**	**Region**	**Total Catch**	**Length ± SD (mm)**	**Length Range (mm)**	**Mass ± SD (g)**	**Mass Range (g)**
	AOC	OpenCoast	eastbluffers	6	286±25	265-331	355±121	260-589
	AOC	OpenCoast	westbluffers	6	180±55	95-265	114±99	16-300
	AOC	OpenCoast	western	25	268±102	130-480	444±587	14-2200
	AOC	Slip		0				
	Ref	Embayment		0				
	Ref	OpenCoast		25	268±102	130-480		
Walleye	AOC	Embayment	centralWF	0				
	AOC	Embayment	othereast	1	341		420	
	AOC	Embayment	otherwest	4	291±224	150-625	724±1351	30-2750
	AOC	Embayment	Toronto Islands	0				
	AOC	Embayment	TTP	0				
	AOC	Estuary.River		5	353±91	194-422	442±216	65-615
	AOC	OpenCoast	centralWF	0				
	AOC	OpenCoast	eastbluffers	2	597±332	362-832	2500±2828	500-4500
	AOC	OpenCoast	westbluffers	1	184		54	
	AOC	OpenCoast	western	2	742±13	733-751	6250±354	6000-6500
	AOC	Slip		0				
	Ref	Embayment		0				
	Ref	OpenCoast		0				

Table 16. Numbers of samples (electrofishing transects) where each species was detected. These are broken down by location [e.g., within the Area of Concern (AOC) or in a reference area (Ref)], ecotype, and region. Totals are also provided for all embayments, all open coast sites, and all AOC-sites by month (July or October). For abbreviated region names: Central waterfront (CentralWF), Tommy Thompson Park (TTP).

Month	**Location**	**Ecotype**	**Region**	**Bowfin**	**Largemouth Bass**	**Northern Pike**	**Round Goby**	**Smallmouth Bass**	**Walleye**	**Common Carp**	**Total Samples**
July	AOC	Embayment	centralWF	0	9	8	15	1	0	19	38
	AOC	Embayment	othereast	5	8	34	17	3	4	49	72
	AOC	Embayment	otherwest	2	41	53	69	23	14	77	167
	AOC	Embayment	Toronto Islands	46	87	83	41	3	6	61	137
	AOC	Embayment	TTP	13	60	66	51	4	7	106	153
	AOC	Embayment	*Total*	66	205	244	193	34	31	312	567
	AOC	Estuary.River		1	9	14	10	21	4	66	95
	AOC	Open Coast	centralWF	0	0	0	0	0	0	4	10
	AOC	Open Coast	eastbluffers	0	1	7	40	39	0	31	120
	AOC	Open Coast	westbluffers	0	1	2	13	2	0	15	52
	AOC	Open Coast	western	0	1	1	16	5	0	9	33
	AOC	Open Coast	*Total*	0	3	10	69	46	0	59	215
	AOC	Slip		0	16	32	2	1	0	18	118
	AOC		**Total**	67	233	300	274	102	35	455	995
	Ref	Embayment	*Total*	22	34	23	15	8	1	43	61
	Ref	Open Coast	*Total*	1	7	2	8	26	2	26	43
October	AOC	Embayment	centralWF	0	7	4	13	0	0	3	17
	AOC	Embayment	othereast	0	8	12	4	0	1	9	28
	AOC	Embayment	otherwest	0	18	15	14	8	3	21	45
	AOC	Embayment	Toronto Islands	6	31	31	2	2	0	26	36

Month	Location	Ecotype	Region	Bowfin	Largemouth Bass	Northern Pike	Round Goby	Smallmouth Bass	Walleye	Common Carp	Total Samples
	AOC	Embayment	TTP	3	40	40	15	1	0	35	50
	AOC	Embayment	*Total*	9	104	102	48	11	4	94	176
	AOC	Estuary.River		1	5	13	1	3	2	15	37
	AOC	Open Coast	centralWF	0	0	1	1	0	0	0	8
	AOC	Open Coast	eastbluffers	1	0	1	0	1	2	11	48
	AOC	Open Coast	westbluffers	0	1	0	2	0	1	0	14
	AOC	Open Coast	western	0	3	3	7	4	1	4	15
	AOC	Open Coast	*Total*	1	4	5	10	5	4	15	85
	AOC	Slip		0	8	10	4	0	0	7	34
	AOC		**Total**	11	121	130	63	19	10	131	332

Table 17. Summary information on the trend-analysis models for the different ecotypes and regions by month. All presence/absence (P/A) type models were fit using a binomial distribution while all catch type models were fit using a Poisson distribution. The deviations from the standard formula(s), sample size used, Deviance Information Criterion (DIC; both with the spatial term in the model and without), effective number of parameters for the best model, any issues identified during model validation, and any notes related to model fit or dataset adjustments are presented. No catch models were fit for Bowfin, Smallmouth Bass, and Walleye because of insufficient data.

Species	Type	Ecotype	Month	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
Bowfin	P/A	All	July	Model could not be fit – insufficient data						
Bowfin	P/A	All	October	Model could not be fit – insufficient data						
Bowfin	P/A	Embayment	July	Drop CentralWF Drop OtherEast Drop OtherWest	290	251	9.8	260	Passes Tests	
Bowfin	P/A	Embayment	October	Model could not be fit – insufficient data						
Bowfin	P/A	Open Coast	July	Model could not be fit – insufficient data						
Bowfin	P/A	Open Coast	October	Model could not be fit – insufficient data						
Common Carp	P/A	All	July	Full	995	1224	33.1	1253	Passes tests	
Common Carp	P/A	All	October	No spatial term	332	2168	4.2	417	Passes tests	
Common Carp	P/A	Embayment	July	Full	567	747	16.2	752	Passes tests	
Common Carp	P/A	Embayment	October	Full	176	224	9.2	225	Passes tests	
Common Carp	P/A	Open Coast	July	Model could not be fit – insufficient data						
Common Carp	P/A	Open Coast	October	Model could not be fit – insufficient data						
Common Carp	Catch	All	July	Full	995	2832	96.8	3132	Passes tests	
Common Carp	Catch	All	October	Full	332	839	70	976	Passes tests	
Common Carp	Catch	Embayment	July	Full	567	1848	48.3	1931	Passes tests	
Common Carp	Catch	Embayment	October	Full	176	533	48	551	Passes tests	
Common Carp	Catch	Open Coast	July	Model could not be fit – insufficient data						
Common Carp	Catch	Open Coast	October	Model could not be fit – insufficient data						
Largemouth Bass	P/A	All	July	Drop OpenCoast	780	739.8	43.9	862	Passes tests	
Largemouth Bass	P/A	All	October	Drop Estuary.River Drop OpenCoast Drop Slips	176	198.6	43.9	241.8	Passes tests	
Largemouth Bass	P/A	Embayment	July	Full	567	594	40.2	621	Passes tests	

Species	Type	Ecotype	Month	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
Largemouth Bass	P/A	Embayment	October	Drop Central WF	159	172	12.4	182	Passes tests	
Largemouth Bass	P/A	Open Coast	July	Model could not be fit – insufficient data						
Largemouth Bass	P/A	Open Coast	October	Model could not be fit – insufficient data						
Largemouth Bass	Catch	All	July	Model could not be fit – insufficient data						
Largemouth Bass	Catch	All	October	Model could not be fit – insufficient data						
Largemouth Bass	Catch	Embayment	July	Full	567	2238	111.3	3442	Passes tests	
Largemouth Bass	Catch	Embayment	October	Drop CentralWF	159	789	70.4	1184	Passes tests	
Largemouth Bass	Catch	Open Coast	July	Model could not be fit – insufficient data						
Largemouth Bass	Catch	Open Coast	October	Model could not be fit – insufficient data						
Northern Pike	P/A	All	July	Drop OpenCoast	780	862	52.4	981	Passes tests	
Northern Pike	P/A	All	October	Drop OpenCoast	247	281	19.3	334	Passes tests	
Northern Pike	P/A	Embayment	July	Full	567	637	10.2	703	Passes tests	
Northern Pike	P/A	Embayment	October	Drop CentralWF	159	177	10.2	180	Passes tests	
Northern Pike	P/A	Open Coast	July	Model could not be fit – insufficient data						
Northern Pike	P/A	Open Coast	October	Model could not be fit – insufficient data						
Northern Pike	Catch	All	July	Drop OpenCoast	780	1648	81.6	1920	Passes tests	
Northern Pike	Catch	All	October	Drop OpenCoast	247	809	65.6	1059	Passes tests	
Northern Pike	Catch	Embayment	July	Full	567	1309	67.9	1427	Passes tests	
Northern Pike	Catch	Embayment	October	Drop CentralWF	159	593	45.6	644	Passes tests	
Northern Pike	Catch	Open Coast	July	Model could not be fit – insufficient data						
Northern Pike	Catch	Open Coast	October	Model could not be fit – insufficient data						
Smallmouth Bass	P/A	All	July	Drop Slips	877	251	15.6	583	Passes tests	
Smallmouth Bass	P/A	All	October	Model could not be fit – insufficient data						
Smallmouth Bass	P/A	Embayment	July	Model could not be fit – insufficient data						
Smallmouth Bass	P/A	Embayment	October	Model could not be fit – insufficient data						
Smallmouth Bass	P/A	Open Coast	July	Model could not be fit – insufficient data						
Smallmouth Bass	P/A	Open Coast	October	Model could not be fit – insufficient data						
Round Goby	P/A	All	July	Drop Slips	877	Can't estimate DIC			Passes tests	No pre-2003 data

Species	Type	Ecotype	Month	Formula	Sample Size	DIC	Effective # Parameters	DIC (without)	Model Validation	Notes
Round Goby	P/A	All	October	Drop Slips Drop Estuary.River	261	Can't estimate DIC			Passes tests	No pre-2003 data
Round Goby	P/A	Embayment	July	Full	877	Can't estimate DIC			Passes tests	No pre-2003 data
Round Goby	P/A	Embayment	October	Model could not be fit – insufficient data						
Round Goby	P/A	Open Coast	July	Drop CentralWF	215	Can't estimate	Can't estimate	Can't estimate	Passes tests	
Round Goby	P/A	Open Coast	October	Model could not be fit – insufficient data						
Round Goby	Catch	All	July	Drop Slips	877	3239	99.7	4506	Passes tests	
Round Goby	Catch	All	October	Model could not be fit – insufficient data						
Round Goby	Catch	Embayment	July	Full	567	1975	92.9	2729	Passes tests	
Round Goby	Catch	Embayment	October	Model could not be fit – insufficient data						
Round Goby	Catch	Open Coast	July	Drop CentralWF	205	501	46.9	554	Passes tests	
Round Goby	Catch	Open Coast	October	Model could not be fit – insufficient data						
Walleye	P/A	All	July	Drop Estuary.River Drop OpenCoast Drop Slips	567	221	11.3	237	Passes tests	
Walleye	P/A	All	October	Model could not be fit – insufficient data						
Walleye	P/A	Embayment	July	Model could not be fit – insufficient data						
Walleye	P/A	Embayment	October	Model could not be fit – insufficient data						
Walleye	P/A	Open Coast	July	Model could not be fit – insufficient data						
Walleye	P/A	Open Coast	October	Model could not be fit – insufficient data						

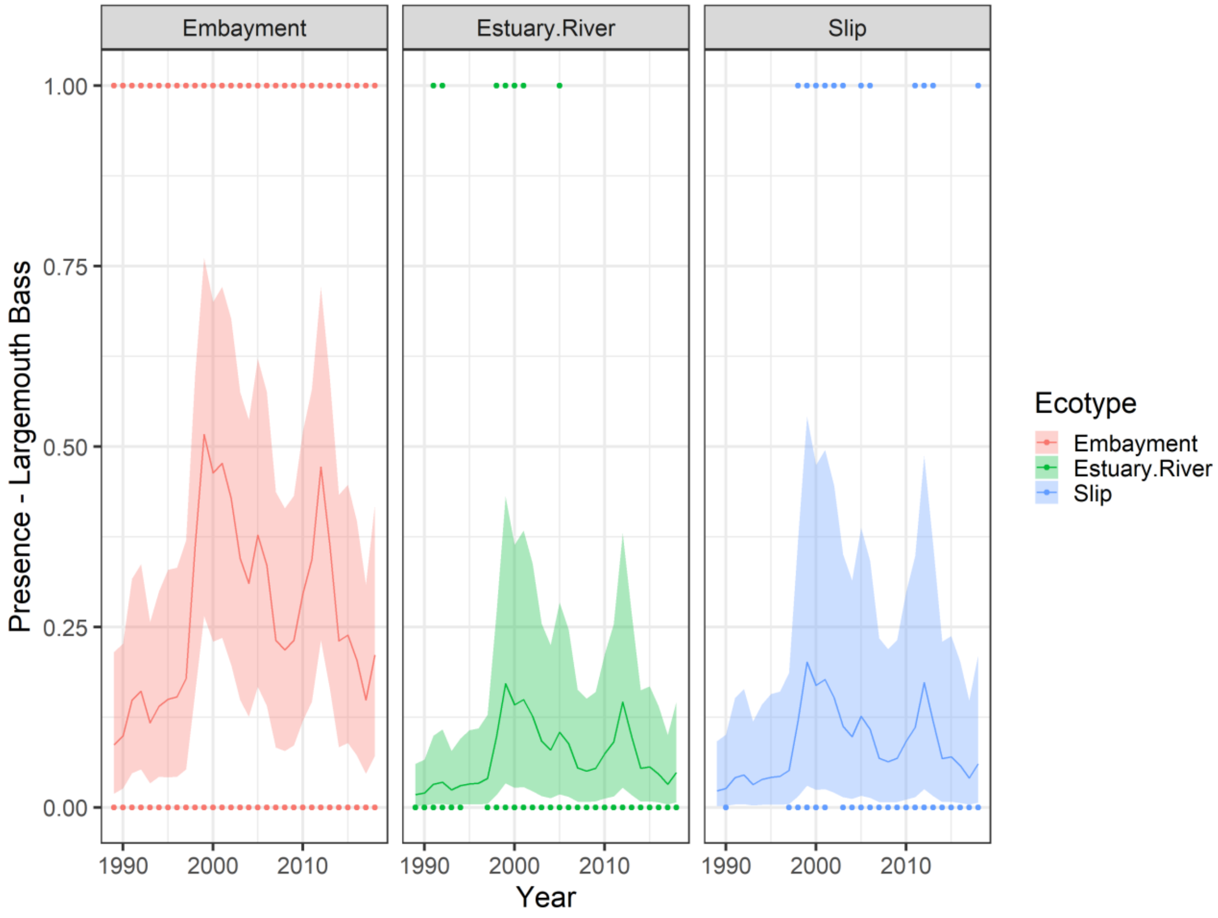

Figure 46. Capture probability of Largemouth Bass at ecotypes in July. There were insufficient records at the open coast ecotype for their inclusion in the model. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

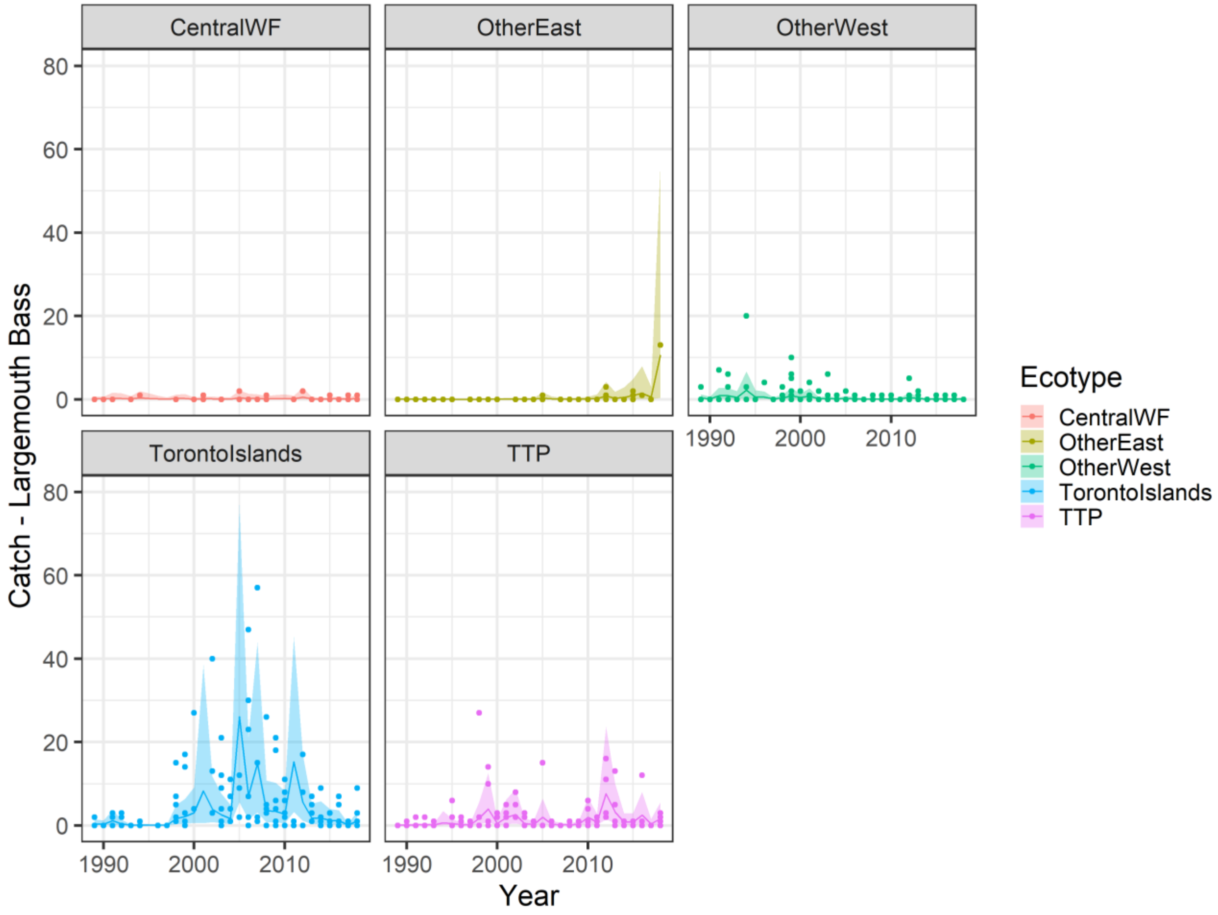

Figure 47. Total catch of Largemouth Bass at embayments in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

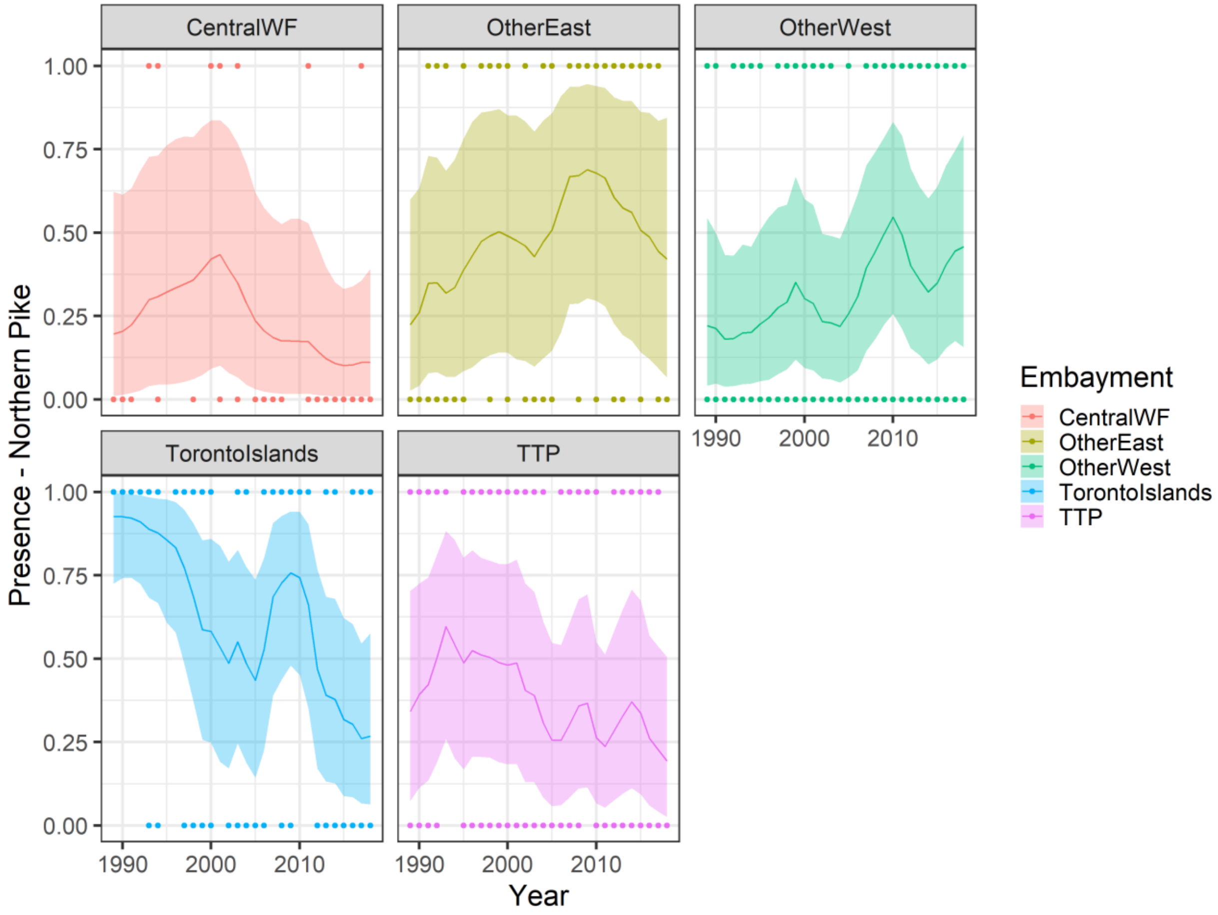

Figure 48. Northern Pike capture probability at embayment regions in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

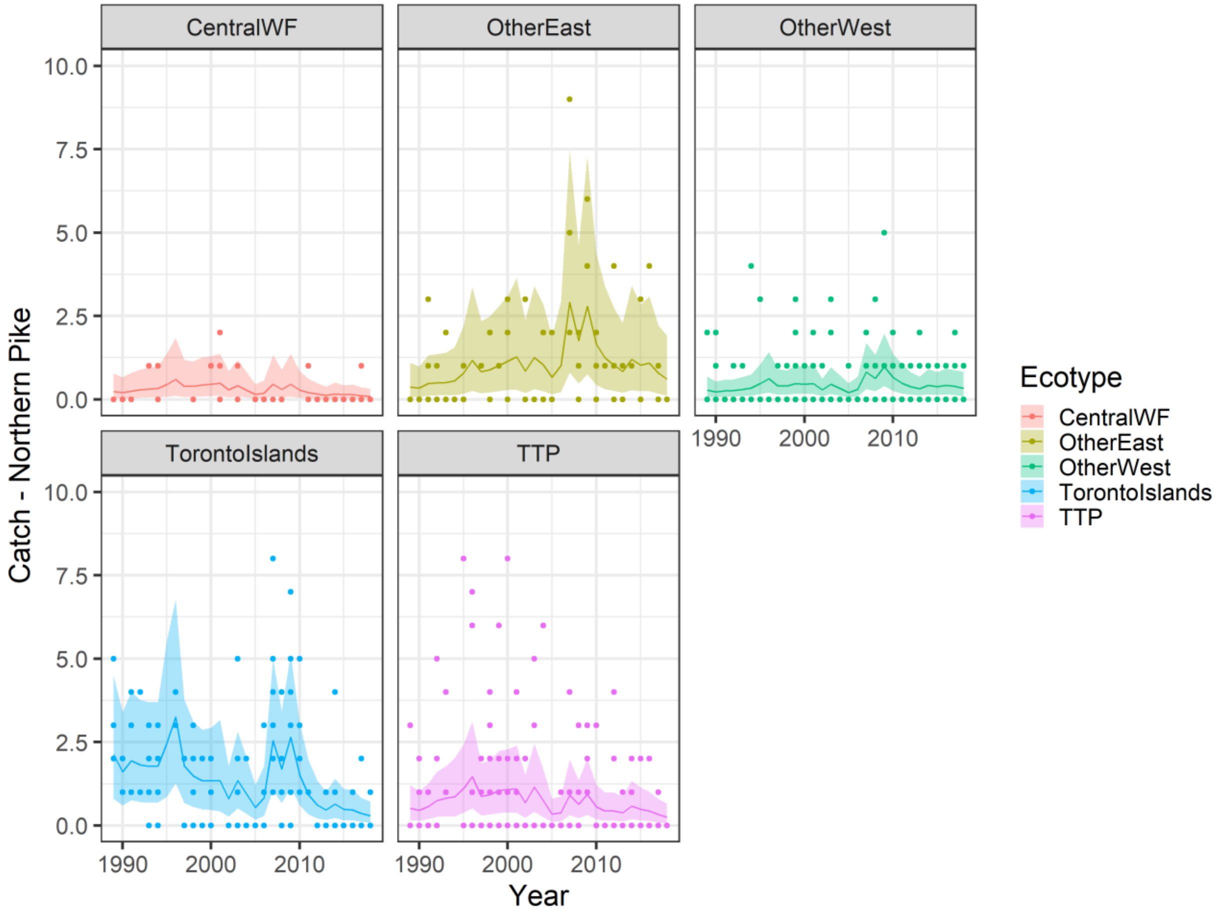

Figure 49. Northern Pike catch within embayment regions in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

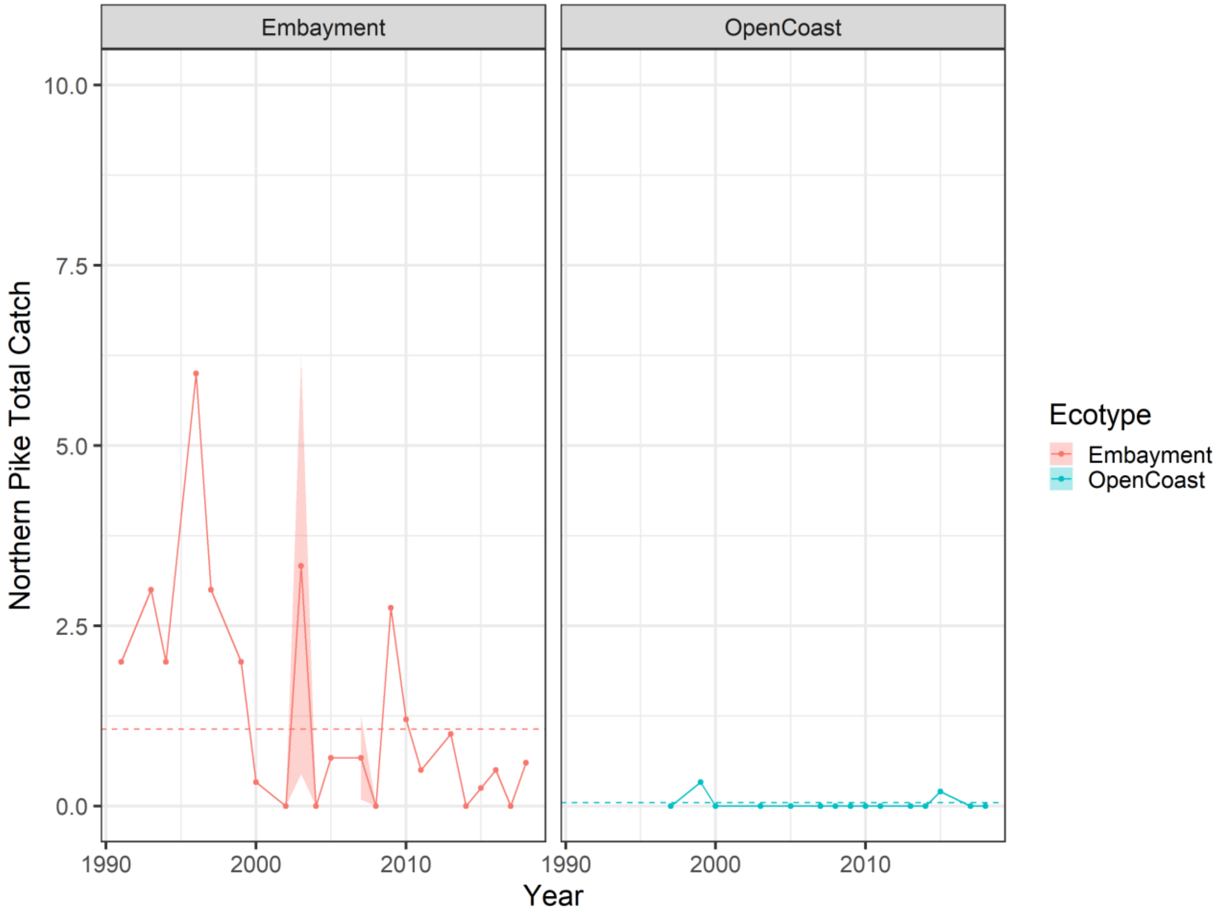

Figure 50. Northern Pike catch at embayment and open coast ecotypes in reference areas outside of the Area of Concern. Reference areas could not be modelled therefore annual values represent mean catch with shaded areas showing standard deviation (where possible).

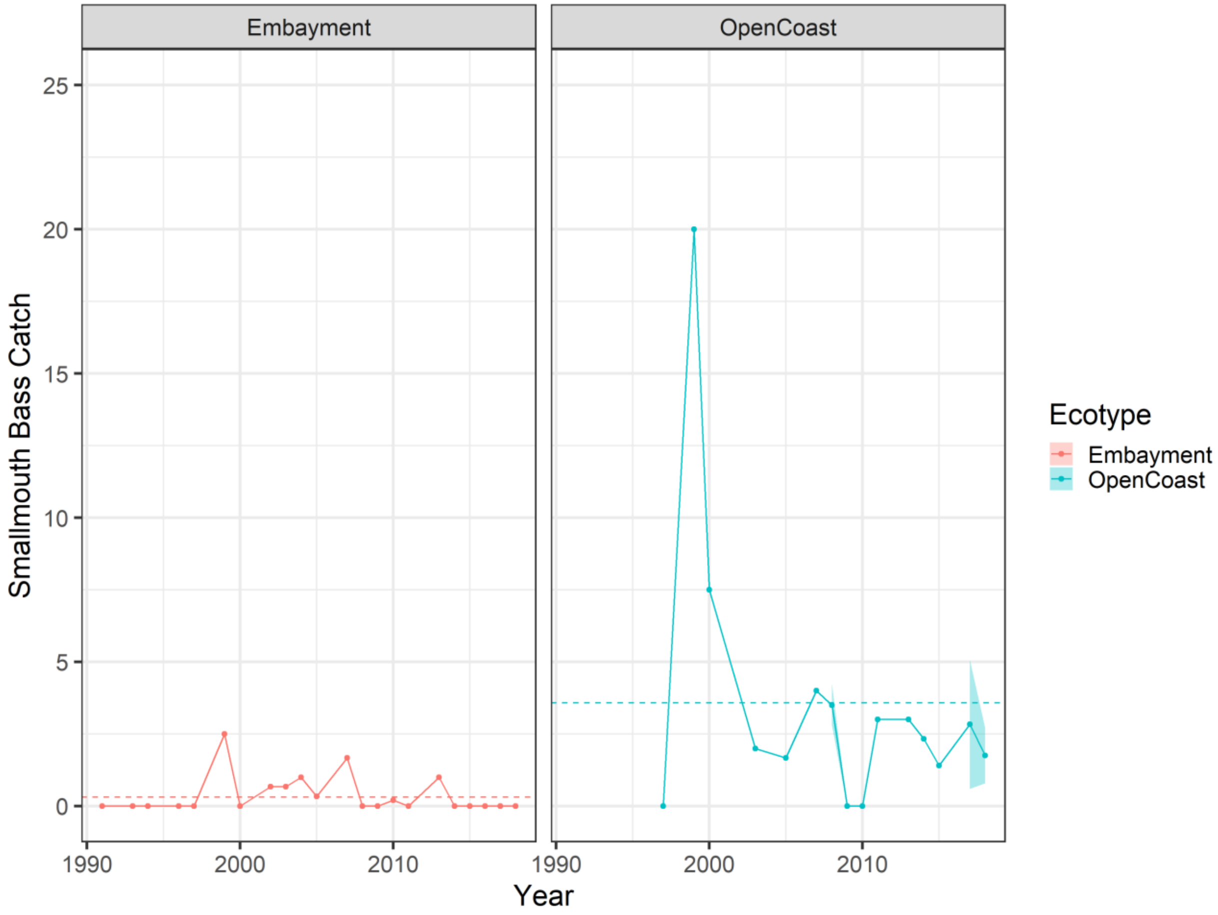

Figure 51. Smallmouth Bass catch within ecotypes in reference areas outside of the Area Of Concern. Reference areas could not be modelled therefore annual values represent mean catch with shaded areas showing standard deviation (where possible).

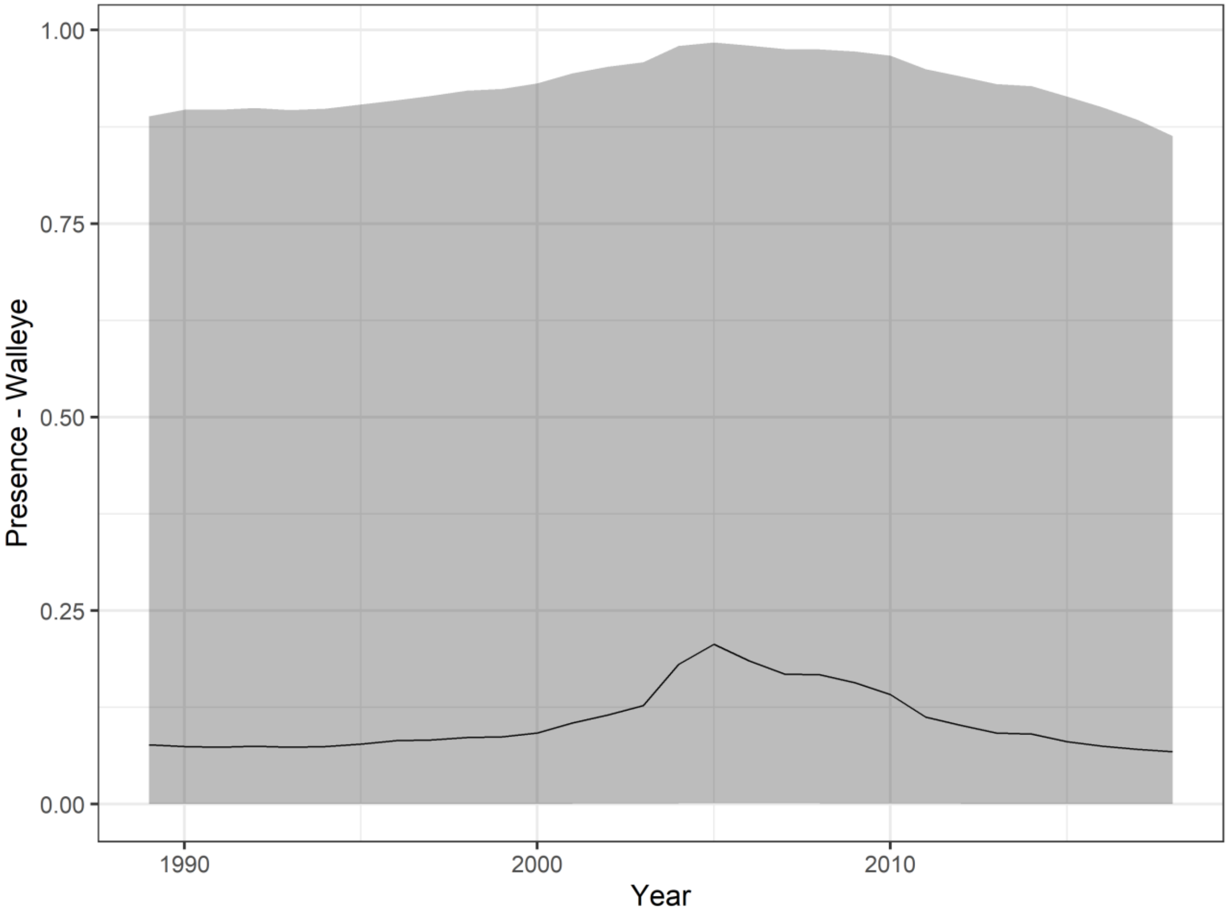

Figure 52. Capture probability of Walleye at embayment sites in July. There were insufficient data for the open coast, estuary/river, and slips ecotypes to allow models to be fit. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

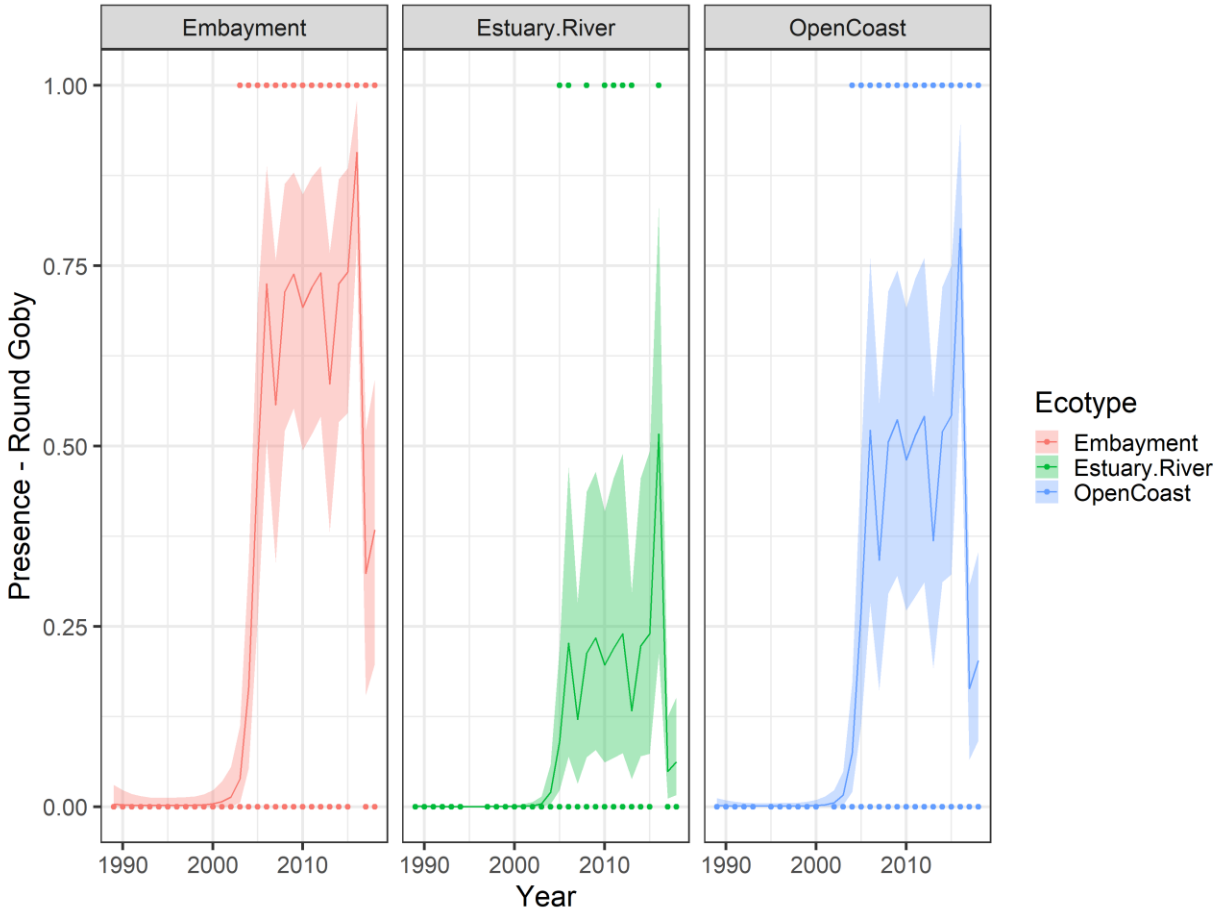

Figure 53. Capture probability of Round Goby at ecotypes in July. There was insufficient catch at slips to allow models to be fit. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

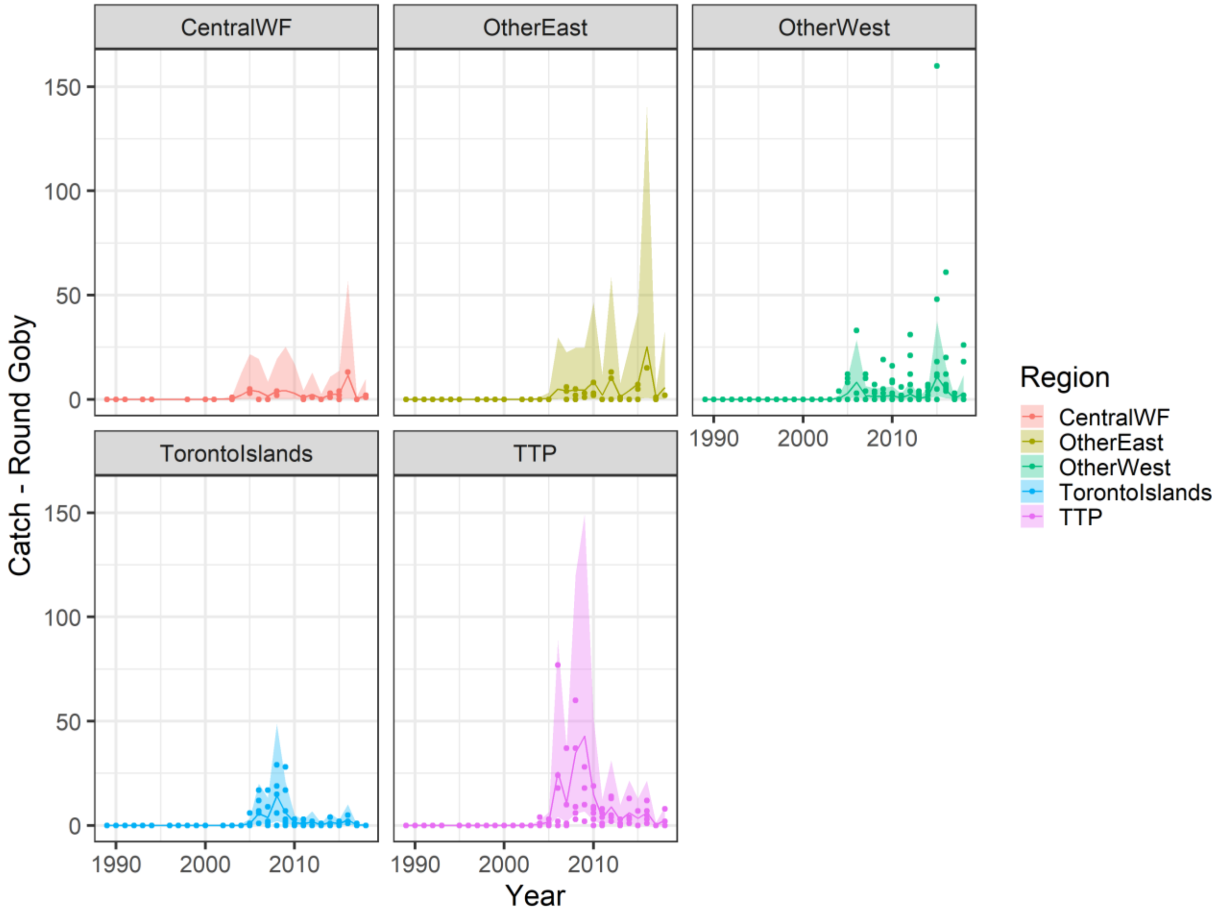

Figure 54. Total catch of Round Goby at embayment regions in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods Total catch of Round Goby at embayment regions in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 55. Common Carp catch at ecotypes in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

Figure 56. Common Carp catch at embayment regions in July. Solid line indicates the modelled mean value through time while the shaded area represents the 95% credible intervals. Two time periods were interpreted as being distinct if their credible intervals did not overlap.

CRITERION FP-3: WATERSHED MANAGEMENT

Summary of Status of FP-3

While watershed-specific fisheries management plans are being implemented by the Toronto and Region Conservation Authority, the Integrated Restoration Prioritization (IRP) program can still be used to guide watershed-based remediation and restoration efforts within the Toronto and Region Area of Concern (AOC). Additional information on the IRP and how it will be implemented within the AOC can be found in the report on the assessment of BUI #14 (Fish and Wildlife Habitat; Toronto RAP 2016). The potential trajectory of fish-community responses to restoration actions is indirectly outlined in Wallace et al. (2013), which documented the current differences in fish community assemblage among Toronto AOC watersheds along a gradient of anthropogenic disturbance (used road density as a surrogate). In general, removal of barriers to fish passage, improvements in water quality, and a reduction of stream temperature should result in increases in species richness. With the Integrated Restoration Prioritization program in place, the final criteria for this BUI is largely resolved. One potential point to stress, which is no doubt already understood by those managing the IRP program, is to focus on maintaining or adding forest cover within the sub-watersheds rather than limiting the expansion of impervious surfaces. Such a trade-off has been found to better protect or improve the hydrological properties of streams (Booth et al. 2002); this should not be interpreted as a recommendation for more impervious surfaces, rather that positive trends in forest cover are more likely to manifest in improvements in streams than static or small declines in impervious surface cover.

Key Messages

- The Integrated Restoration Prioritization (IRP) program supports watershed-based remediation and restorations strategies in the Toronto AOC (thus meeting the FP-3 criteria)
- For fish populations, IRP efforts should focus on removal of barriers to fish passage, improvements in water quality, and a reduction of stream temperature to increase species richness.
- Adding and tracking changes in forest cover will likely have a greater impact on protecting or improving hydrological properties of streams than limiting impervious surfaces.
- FP-3 should be considered complete.

Recommended Actions

1. For fish populations, Integrated Restoration Prioritization efforts should focus on removal of barriers to fish passage, improvements in water quality, and a reduction of stream temperature to increase species richness.
2. The Integrated Restoration Prioritization tool should continue to be used and any restoration techniques should be updated or refined based on updated science recommendations.

Background

The delisting criteria for FP-3 (fish populations) states that specific targets contained in the watershed plans should be used and where no plans exist they should be developed. The TRCA is no longer creating watershed management plans with specific fish-targets but instead has developed a multidisciplinary Integrated Restoration Prioritization (IRP) program to highlight areas for future restoration in the jurisdiction. One of the goals of the IRP is that it will identify areas for restoration that will have the greatest impact on delisting BUI # 3, Degradation of Fish and Wildlife Populations. A series of GIS exercises using natural cover scores, hydrology scores, aquatic scores and Terrestrial Natural Heritage scores were used to create a map of the jurisdiction. The aquatic scores were based on water temperature, instream barriers and water quality indicators. Streams with barriers to fish passage, and online ponds would benefit from restoration efforts that would remove barriers and improve connectivity between stream reaches. Warmwater streams with little riparian cover and poor water quality would benefit from planting native species in the riparian corridors.

Wallace et al. (2013) found streams in the TRCA jurisdiction exhibit characteristics of the urban stream syndrome, including flashier hydrographs, higher nutrients and contaminants, changes to channel morphology, reduced species richness and a prevalence of tolerant species. Road density was used as a surrogate for urbanization because it is a measure that can be easily calculated and is readily understood by the general public. Species sensitive to urban development were found in areas with low road density and as road density increased the species richness decreased leaving only the species most tolerant to urban development at the sites with the highest road density.

In the absence of fisheries management plans both the IRP and Wallace et al (2013) can be used to; 1) identify areas that would benefit most from restoration and 2) pinpoint what type of restoration will have the greatest impact on improving fish populations in the Toronto AOC.

Methods

Wallace et al. (2013) sampled fish at 133 stream sites across nine watersheds in TRCA's jurisdiction, over a nine year period. A number of landscape level variables were calculated including stream order, road density and natural cover

(% forest, % wetland, % meadow). Species richness, % tolerant fish, Simpson's Diversity Index (SDI) and Index of Biotic Integrity (IBI) were calculated from the fish data. Habitat variables were calculated including stream flashiness. Correspondence analysis was used to look at the relationship between the species and the sites they were found at and canonical correspondence analysis was used to look at the relationship among species, site and a series of environmental variables. See Wallace et al. (2013) for complete details on study methods and analysis.

Results

Correspondence Analysis was used to look for relationships in the fish community data. They found that there was a distinct thermal gradient with warmwater fish grouped together and coldwater fish grouped together, as well as a fish sensitivity gradient with the more sensitive species grouped together (see Figure 2 in Wallace et al. 2013). Sites with coldwater sensitive fishes were found in the upper reaches of the Duffins Creek, Humber River and Rouge River watersheds. Sites dominated by warmwater tolerant fish species were in the more urbanized Don River, Mimico Creek and Highland river watersheds.

Fish metrics such as richness, SDI, and IBI decreased with increasing road density while the abundance of tolerant fish species increased with increasing road density. The fish community structure was strongly influenced by water temperature and percent forest cover, stream order and road density. Sites with road density of 11 – 13 km/km^2 only had four native fish species present: Blacknose Dace (*Rhinichthys atratulus*), Longnose Dace (*Rhinichthys cataractae*), Creek Chub (*Semotilus atromaculatus*), and White Sucker (see Figure 4 in Wallace et al. 2013). Coldwater fish species like the American Brook Lamprey (*Lampetra planeri*), Brook Trout (*Salvelinus fontinalis*), and Northern Hog Sucker (*Hypentelium nigricans*) were only found in areas with road density less than 3 km/km^2.

Discussion

The IRP was used to identify and map areas where improvements in water temperature, instream barriers, and water quality would have the greatest positive impact on fish in the jurisdiction. The relationship between stream water temperature and urbanization has been well established (Paul and Meyer 2001) and was found to hold true in GTA streams (Wallace et al. 2013). Urban streams generally have warmer water due to the lack of riparian vegetation, decreased amount of cold water entering the stream (decreased groundwater recharge) and increased amount of warm storm water entering the streams after flowing over impervious surfaces, or being detained in shallow storm water management facilities.

Road density is an excellent surrogate for urbanization but is a poor measure of restoration efforts. Even in areas where significant restoration has occurred, it is unlikely that road density would decrease as part of the restoration efforts. But with this in mind it is important to note that percent forest cover was highly related to road density and may be a better measure of restoration efforts. Booth et al. (2002) advised that maintaining or adding forest cover would have a greater impact on protecting or improving hydrological properties of streams than limiting impervious surfaces. The connectivity of the impervious surfaces to the streams was found to be more of an indicator of taxa loss than impervious surface area (Walsh 2004).

Areas with a high percentage of forest cover and low road density had fewer tolerant fish species and more sensitive fish species. Blacknose Dace, Longnose Dace, Creek Chub and White Sucker were ubiquitous in the jurisdiction and were the only fish species remaining at the highest road density. They owe their success to their adaptability to changing hydrological conditions and food sources. Removal of barriers to fish passage, improvements in water quality, and the reduction in stream temperature should result in increases in species richness.

Recommendations for future tracking of fish populations

Another source for tracking changes in fish communities in the watershed is through the implementation of a new watershed planning process for the jurisdiction in 2019 – 2020. Watershed plans are required to be updated every 10 years and should assess past changes, the current status and potential future changes in several key variables including the Water Resources System, the Natural Heritage System, water quality, natural hazards and climate change resiliency. Several indicators have been established in the new watershed planning process related to fish populations and habitat including: groundwater recharge/discharge, riparian cover, habitat connectivity (i.e. barrier removal) and aquatic health (fish IBI) within the Water Resources section, natural cover in the Natural Heritage System section, and stormwater management within the Natural Hazards section.

FUTURE MONITORING RECOMMENDATIONS

In their seminal paper, Fausch et al. (1990) identify a simple but critical question related to assessing biological integrity, “What should fish communities look like in this *region?*“. Given the variety of aquatic ecosystems in the Toronto AOC including rivers, wetlands, and high energy shorelines (among others) and range of anthropogenic disturbances from highly modified urban boat slips to comparatively more natural vegetated areas, there is no single answer to this question for the Toronto AOC. While many of the metrics assessed in previous works and the present document are not meeting appropriate regional reference targets nor are they trending in a direction that would indicate improvement, the observed variability in metric scores within the Toronto AOC both among and within ecotypes suggests that targets for assessment criteria may be best set separately for different ecotypes and regions. A key component of setting these targets and evaluating them against observed conditions within the Toronto AOC is ensuring sufficient and appropriate data are collected to guide comparisons between thresholds and conditions within the Toronto AOC. Below, we present a three-tiered monitoring approach that will require some minor adjustments to current practices but should ensure sufficient information is collected for future assessments. The first component deals with the establishment of sentinel sampling sites within the Toronto AOC, the second with identifying regional reference areas within Lake Ontario that have similar physical conditions (e.g., exposure), and the last with continued sampling in areas with long-term data records. An essential part of each of these steps is a review of information contained within existing datasets since this may reduce the need for additional sampling. Where possible, we identify suggestions that are deemed to be essential, those that are recommended, and those that are non-essential.

Sentinel Sites

Within the Toronto AOC, it is recommended that between 5 – 10 sentinel sites (transects) be established for each ecotype-region (final number will be dependent on size of the region and available historical data). To help control for the observed differences in fish community metrics among ecotypes, it is important to ensure the sentinel sites fall within a distinct ecotype (i.e., transect does not span multiple ecotypes). Sentinel sites should be selected from transects that are regularly sampled as part of the TRCA electrofishing monitoring program. These sites should be sampled every year in summer (July – August) and fall (October – November) and, if possible, spring (April – May; Table 18) following the TRCA-DFO hybrid protocol discussed below. The benefit of establishing and maintaining sentinel sites is consistent sampling effort within an ecotype-region, which will ensure sufficient data are available for analysis during future assessments. An added benefit is that these sentinel-sites can also serve as control sites when evaluating habitat creation or remediation projects since they will capture the natural background variability in fish community metrics and species catch before, during, and after an intervention. The establishment of sentinel sites does not preclude the inclusion of other sites in future monitoring or analysis, rather sentinel sites would form the core of the dataset to complement data collected elsewhere within the Toronto AOC.

Regional Reference Sites

For all sections, data were limited for regionally appropriate reference sites. Regional reference sites are required for each ecotype so that targets for fish community metrics and species-specific catches within the Toronto AOC can be properly developed and evaluated. Reference locations outside of the Toronto AOC should be selected at ecotypes that are considered physically similar to ecotypes within the AOC (e.g., exposed embayments and open coast). Data from these sites should be used to establish targets for fish community metrics and species-specific catch and biomass. There are several electrofishing datasets available to inform FP-1A and FP-2 that were not used in the present assessment because these data were not collected as consistently through time as they were in the Toronto AOC, had limited replicates, and/or used a distance-based rather than time-based sampling approach (Table 19). Despite these caveats, these data are still relevant and have been used to set targets for IBI scores (Hoyle et al. 2018) and for specific species (Bowlby and Hoyle 2017) in the Toronto and Bay of Quinte AOCs and other Lake Ontario embayments. Exploring datasets maintained by DFO and OMNRF to determine the number of physically similar sites with existing data (e.g., Prince Edward Bay and Presqu’ile Bay) is an important first step since it will determine whether there is sufficient information to establish the necessary targets and, if not, which ecotypes require additional sampling. The reference sites that were available for sections FP-1A and FP-2 (e.g., embayment and open coast sites that were mostly situated in or proximate to Frenchman’s Bay) can also be incorporated to support target development, and if possible, should be sampled regularly (i.e., similar sampling approach and schedule as sentinel sites) to provide additional information on lake-wide temporal trends.

Temporal Reference Sites

Data from “out-of-type" systems (e.g., protected embayments) can also be informative, particularly from sites that are proximate to the Toronto AOC. These datasets can help with the interpretation of local vs. lake-wide drivers of change within fish communities. For example, while Hamilton Harbour is important as a regional comparator, it is considered a protected rather than exposed embayment and therefore not ideal as a physically similar reference area from which to establish metric or species targets. Despite these differences, the long-term dataset from Hamilton Harbour was useful in the present assessment when interpreting trends in IBI scores since both AOCs have seen declines in IBI score starting in approximately 2016 (suggestive of lake-wide rather than AOC-specific driver). The datasets highlighted in Table 20 should be examined to compare trends in fish community metrics or individual species at locations outside of the Toronto AOC. Continued data collection at these locations is important to support the interpretation of trends both within the Toronto AOC and throughout Lake Ontario.

Monitoring Recommendations

In support of future assessments, it is important to collect consistent data using standardized protocols both within the Toronto AOC by ecotype (e.g., embayment, open coast, estuary/river, slips) and region (e.g., Toronto Islands, Central Waterfront) as well as at appropriate reference locations outside the AOC by ecotype and region. As discussed, monitoring for FP1 and FP2 should be carried out within the Toronto AOC (Table 18), at regional reference sites (Table 19), and at sites with existing long-term datasets (Table 20). The monitoring recommendations outlined below complement the past and ongoing efforts to monitor fish populations within the Toronto AOC and will help form the basis for temporal assessments of fish communities and the establishment of AOC-specific fish community metric and species-specific targets.

1. Sentinel sites should be selected (5-10 transects per ecotype-region) within the Toronto AOC and should continue to be monitored following the TRCA time based 1000 second electrofishing protocol (see Table 18).
2. At each ecotype-region, 5 – 10 electrofishing samples should be collected using DFO’s standardized, distance-based protocol (e.g., 100 m at 1.5 water depth; Brousseau et al. 2005) over multiple seasons (spring, summer, and fall) on either an annual or biannual basis. The 100 m transects can be collected as the first 100 m of a TRCA 1000 second transect.
3. Where possible, transects should be adjusted to compensate for water levels to ensure consistent sampling in approximately 1.5 m of water.
4. When possible, water quality parameters should be collected at each transect (e.g., conductivity, temperature, Secchi depth, turbidity, etc.)
5. Selected sentinel sites should fall completely within a single ecotype (as opposed to spanning multiple ecotypes).
6. It is not recommended that slips be monitored using electrofishing in future as they are too deep to sample efficiently with this gear; it is more appropriate to evaluate their importance as fish habitat using other means (e.g., acoustic telemetry, netting, underwater cameras).
7. Where possible, regional reference sites outside of the Toronto AOC (Table 19) should be monitored during the same time frame as the within-AOC data (i.e., every year or other year) following the same DFO standardized distance-based protocol (e.g., 100 m at 1.5 water depth) at 5 – 10 transects (Brousseau et al. 2005) over multiple seasons (spring, summer, and fall).
8. Monitoring at reference locations should be split among agencies to share the workload.
9. Attempts should be made to coordinate the timing of the OMNRF’s trap net surveys with electrofishing sampling so these complementary datasets are collected during the same year.
10. Monitoring of fish community metrics in all ecotype-regions should continue for a minimum of five years (possibly longer for some species) after the Don River revitalization project is complete and all habitat features are reconnected. This is necessary to capture the lag-time between habitat creation and population recovery.

Managers should document major changes to fish habitat supply, such as closing off an area to fish during habitat remediation or blockages caused by beaver. If the project is intended to improve fish habitat and populations, it is essential that all habitat restoration areas are open and accessible to fish as soon as the remediation actions allow.

Tables and Figures

Table 18. Ecotypes and regions where it is recommended to establish sentinel sites for future monitoring within the Toronto and Region Area of Concern. Specific sentinel sites should be selected by ecotype and region; it is important to select sentinel sites that fall within one distinct ecotype as opposed to those that may span multiple ecotypes. Cells are colour-coded based on their importance to future assessments. The present table uses a proposed reduction in the number of regions for the Embayment and Open Coast ecotypes. For Embayments, the Other Embayment region combines the OtherEast, OtherWest, and CentralWF regions used throughout the present report. For Open Coast, East and West Bluffer regions are cominbed into an Eastern region and the CentralWF and Western region are combined into a Western region.

		Future Monitoring		
Ecotype	**Region**	Spring	Summer	Fall
Embayment	Toronto Islands	🟦	🟨	🟨
	Tommy Thompson Park	🟦	🟨	🟨
	Other Embayment	🟦	🟨	🟨
Open Coast	Western	🟦	🟨	🟨
	Eastern	🟦	🟨	🟨
Estuaries/River Mouth	Humber River	🟦	🟨	🟨
	Don River	🟦	🟨	🟨
	Rouge River/Marsh	🟦	🟨	🟨
Slips	Central WF	🟥	🟥	🟥

Essential 🟨
Recommended 🟦
Non-Essential 🟥

Table 19. Proposed regional reference sites for the Toronto and Region Area of Concern including past monitoring and future monitoring by agency. Rows that are italicized indicate out-of-type ecotypes (e.g., shelter embayments); however, these locations may still provide useful comparators given their regional proximity (e.g., Hamilton Harbour) or less degraded conditions (e.g., Upper Bay of Quinte). The "x" in the Past Monitoring columns denotes when sampling was completed.

				Past Monitoring			Future Monitoring			
Gear	**Ecotype**	**Location**	**Years Sampled**	**Spring**	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**	**Monitoring Agency**
Electrofishing	EMB-EX	Prince Edward Bay	2001, 2009, 2011		x		🟥	🟨	🟦	DFO/OMNRF
		Presqu'ile Bay	2018		x		🟥	🟨	🟦	DFO/OMNRF
		Frenchman's Bay	1992 -2019		x	x	🟥	🟨	🟦	TRCA
	EMB-SH	*Hamilton Harbour*	*2006, 2008, 2010, 2012, 2013, 2016, 2018, 2019*	*x*	*x*	*x*	🟥	🟨	🟦	*DFO*
		Bay of Quinte	*2007, 2011, 2015, 2017*	*x*	*x*	*x*	🟥	🟨	🟦	*OMNRF*
	OC	Bronte	1994-2018	x	x	x	🟥	🟨	🟦	DFO
		Pickering			x	x	🟥	🟨	🟦	TRCA
		Cobourg	2018		x		🟥	🟨	🟦	DFO/OMNRF
		Presqu'ile	2017, 2018		x		🟥	🟨	🟦	DFO/OMNRF
		Prince Edward Bay	2011		x	x	🟥	🟨	🟦	DFO/OMNRF
	RM	Black River	2011	x	x	x	🟥	🟦	🟦	DFO/OMNRF
		Bronte	1994, 1998, 1999, 2008, 2009, 2010, 2013, 2018				🟥	🟦	🟦	DFO/OMNRF
Trap nets (NSCIN)	EMB-EX	Prince Edward Bay	2009, 2013, 2017		x			🟨		OMNRF
		Presqu'ile Bay	2008, 2015		x			🟨		OMNRF
	EMB-SH	*Hamilton Harbour*	*2006-2019*		*x*			🟨		*OMNRF/DFO*
		Bay of Quinte	*2001-2019*		*x*			🟨		*OMNRF*

Essential	🟨
Recommended	🟦
Non-Essential	🟥

Ecotypes are denoted as: EMB = Embayment (EX = exposed, SH = sheltered), OC = Open Coast, RM = Estuary/River Mouth).
TRCA = Toronto Region Conservation Authority
DFO = Fisheries and Oceans Canada
OMNRF = Ontario Ministry of Natural Resources and Forestry
NSCIN = Nearshore community index netting

Table 20. Electrofishing time series data available to support trends over time comparisons. The “x” in the Seasons columns denotes when sampling was completed and the “x” in the Stanzas columns denotes whether sampling occurred in each ecological stanza (as defined by Hoyle et al. 2012).

				Seasons			Stanzas		
Ecotype	**Location**	**Monitoring Agency**	**Years sampled**	**Spring**	**Summer**	**Fall**	**Pre-Dreissena**	**Dreissena**	**Post-Round Goby**
EMB	Frenchman’s Bay	TRCA	1992 -2019		x	x		x	x
	Hamilton Harbour1988-1996	DFO	1988, 1990, 1992, 1994, 1995, 1996	x	x		x	x	
	Hamilton Harbour 1997-2019	DFO	1997, 1998, 2002, 2006, 2008, 2010, 2012, 2013, 2016, 2018, 2019	x	x	x		x	x
	Upper Bay of Quinte*	DFO	1989, 1990, 1999, 2001, 2007, 2009, 2011, 2015, 2017,	x	x	x	x	x	x
OC	Pickering (Frenchman’s Bay)	TRCA	1998-2019					x	x
	Bronte*	DFO	1994, 1998, 1999, 2008, 2009, 2010, 2013, 2018	x	x	x		x	x
	Prince Edward Bay*	DFO	1998, 1999, 2000, 2001, 2009, 2011	x	x	x		x	x
RM	Black River*	DFO	1998, 1999, 2000, 2001, 2011	x	x	x		x	x

* indicates where seasonal data may not be available in each year.
Ecotypes are denoted as: EMB = Embayment, OC = Open Coast, RM = Estuary/River Mouth)
TRCA = Toronto Region Conservation Authority
DFO = Fisheries and Oceans Canada

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REFERENCES

Ashley, K.W., and Rachels, R.T. 1999. Food habits of bowfin in the Black and Lumber Rivers, North Carolina. North Carolina. Proc. Ann. Conf. Southeast. Assoc. Fish and Wildl. Agencies 53: 50–6.

Austin, J.A., and Colman, S.M. 2007. Lake Superior summer water temperatures are increasing more rapidly than regional temperatures: A positive ice-albedo feedback. Geophys. Res. Lett. 34: 1–5. https://doi.org/10.1029/2006GL029021

Blair, S.G., May, C., Morrison, B., and Fox, M.G. 2019. Seasonal migration and fine-scale movement of invasive round goby (Neogobius melanostomus) in a Great Lakes tributary. Ecol. Freshw. Fish 28(2): 200–208.

Booth, D. B., Hartley, D., and Jackson, R. 2002. Forest cover, impervious surface area, and the mitigation of stormwater impacts. J. Am. Water Resour. Ass. 38: 835–845.

Boston, C.M., Randall, R.G., Hoyle, J.A., Mossman, J.L., and Bowlby, J.N., 2016. The fish community of Hamilton Harbour, Lake Ontario: Status, stressors, and remediation over 25 years. Aquat. Ecosyst. Heal. Manag. 19(2): 206-218.

Bowlby, J.N., and Hoyle, J.A., 2017. Developing restoration targets for nearshore fish populations in two Areas of Concern in Lake Ontario. Aquat. Ecosyst. Health Manag. 20(3): 241–251.

Brooks, J.L., Doka, S.E., Gorsky, D., Gustavson, K., Hondorp, D., Iserman, D., Midwood, J.D., Pratt, T., Rous, A., Withers, J., Krueger, C.C., and Cooke, S.J. 2017. Use of fish telemetry in rehabilitation planning, management, and monitoring of Areas of Concern in the Laurentian Great Lakes. J. Great Lakes Res. 60(6): 1139-1154.

Brousseau, C.M., Randall, R.G., and Clark, M.G. 2004. Comparison of Severn Sound fish assemblages in Hog Bay and Penetang Bay, 1990 and 2002, using two indices of productive capacity. Can. Manuscr. Rep. Fish. Aquat. Sci. 2686: vii+ 45 p.

Brousseau, C.M., Randall, R.G., and Clark, M.G., 2005. Protocol for boat electrofishing in near shore areas of the lower Great Lakes: transect and point survey methods for collecting fish and habitat data, 1988 to 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2702: xi+ 89 p.

Brousseau, C.M., Randall, R.G., Hoyle, J.A., and Minns, C.K. 2011. Fish community indices of ecosystem health: How does the Bay of Quinte compare to other coastal sites in Lake Ontario? Aquat. Ecosyst. Health Manag. 14(1): 75-84.

Brown, E., 2019. Toronto Waterfront Nearshore Community Index Netting Protocol 2019. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario, Canada.

Brownscombe, J. W., and Fox, M. G. 2013. Living at the edge of the front; reduced predation risk to invasive round goby in a Great Lakes tributary. Hydrobiologia 707(1): 199–208.

Carpenter, S. R., Cole, J. J., Hodgson, J. R., Kitchell, J. F., Pace, M. L., Bade, D., Cottingham, K.L, Essington, T.E., Houser, J.N., and Schindler, D. E. 2001.

Trophic cascades, nutrients, and lake productivity: Whole-lake experiments. Ecol. Monogr. 71(2): 163–186.

Cartwright, L.A., Hayes, S., Tozer, D.C., Clayton, D., Burns, M., Lewis, D., Gaetz, N., Shrestha, N. 2021. Assessing terrestrial wildlife populations in the Toronto and Region Area of Concern. J. Great Lakes Res. 47(2): 273-282.

Charlebois, P. M., Marsden, J. E., Goettel, R. G., Wolfe, R. K., Jude, D. J., and Rudnika, S. 1997. The round goby, *Neogobius melanostomus* (Pallas), a review of European and North American literature Zion, IL: Illinois-Indiana Sea Grant Program and Illinois

Chotkowski, M. A., and Marsden, J. E. 1999. Round goby and mottled sculpin predation on lake trout eggs and fry: Field predictions from laboratory experiments. J. Great Lakes Res. 25(1): 26–35.

Colborne, S. F., Rush, S. A., Paterson, G., Johnson, T. B., Lantry, B. F., and Fisk, A. T. 2016. Estimates of lake trout (Salvelinus namaycush) diet in Lake Ontario using two and three isotope mixing models. J. Great Lakes Res. 42(3): 695–702.

Crane, D. P., and Einhouse, D. W. 2016. Changes in growth and diet of smallmouth bass following invasion of Lake Erie by the round goby. J. Great Lakes Res. 42(2): 405–412.

Crowder, A., and Painter, D. S. 1991. Submerged macrophytes in Lake Ontario: Current knowledge, importance, threats to stability, and needed studies. Can. J. Fish. Aquat. Sci. 48(8): 1539–1545.

DFO GLLFAS (Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences). 2010. 2009 Toronto Harbour hydroacoustic survey report: methodology and summary of results. Report prepared by Milne Technologies. 57 pgs.

DFO GLLFAS (Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences). 2011. 2010 Toronto and Bronte Harbour hydroacoustic survey report: methodology and summary of results. Report prepared by Milne Technologies. 69 pgs.

Dietrich, J.P., Morrison, B.J. and Hoyle, J.A. 2006. Alternative ecological pathways in the eastern Lake Ontario food web—round goby in the diet of lake trout. J. Great Lakes Res. 32(2): 395-400.

Dietrich, J.P., Hennyey, A.M., Portiss, R., MacPherson, G., Montgomery, K., and Morrison, B.J. 2008. The fish communities of the Toronto waterfront: summary and assessment 1989-2005. Report prepared for the Toronto and Region Remedial Action Plan. 42 p.

Doherty, C.A., Curry, R.A., and Munkittrick, K.R. 2010. Spatial and temporal movements of white sucker: implications for use as a sentinel species. Trans. Am. Fish. Soc. 139(6): 1818-1827.

Dupuis-Desormeaux, M., McDonald, K., Moro, D., Reid, T., Agnew, C., Johnson, R. and MacDonald, S.E., 2021. A snapshot of the distribution and demographics of freshwater turtles along Toronto’s Lake Ontario coastal wetlands. J. Great Lakes Res. 47(2): 283-294.

Emery, A. R. 1973. Preliminary comparisons of day and night habits of freshwater fish in Ontario lakes. J. Fish. Res. Board Can. 30(6): 761–774.

Farmer, T.M., Marschall, E.A., Dabrowski, K., and Ludsin, S.A., 2015. Short winters threaten temperate fish populations. Nat. Commun. 6: 1-10

Fausch, K.D., Lyons, J.O.H.N., Karr, J.R. and Angermeier, P.L., 1990. Fish communities as indicators of environmental degradation. American fisheries society symposium. 8: 123-144.

Finstad, A.G., Forseth, T., Næsje, T.F., and Ugedal, O. 2004. The importance of ice cover for energy turnover in juvenile Atlantic salmon. J. Anim. Ecol. 73: 959–966

Fitzsimons, J. D., Clark, M., and Keir, M. 2009. Addition of round gobies to the prey community of Lake Ontario and potential implications to thiamine status and reproductive success of lake trout. Aquat. Ecosyst. Health Manag. 12(3): 296–312.

Fracz, A., and Chow-Fraser, P., 2013. Impacts of declining water levels on the quantity of fish habitat in coastal wetlands of eastern Georgian Bay, Lake Huron. Hydrobiologia 702: 151–169.

French, J.R.P., and Jude, D. J. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. J. Great Lakes Res. 27(3): 300–311.

Gliwicz, Z., J. Slon and Szynkarczyk, I. 2006. Trading safety for food: evidence from gut contents in roach and bleak captured at different distances offshore from their daytime littoral refuge. Freshw. Biol. 51: 823–839

GLRC (Great Lakes Regional Collaboration). 2005. Great Lakes Regional Collaboration Strategy. Great Lakes Regional Collaboration, Chicago Illinois. 70 pp. Available from https://www.gsgp.org/media/1847/glrc_strategy.pdf. [accessed 10 June 2020].

Guillard, J., and Vergès, C. 2007. The repeatability of fish biomass and size distribution estimates obtained by hydroacoustic surveys using various sampling strategies and statistical analyses. Int. Rev. Hydrobiol. 92(6): 605-617.

Hayden, T.A., Holbrook, C.M., Fielder, D.G., Vandergoot, C.S., Bergstedt, R.A., Dettmers, J.M., Krueger, C.C., and Cooke, S.J. 2014. Acoustic telemetry reveals large-scale migration patterns of walleye in Lake Huron. PLoS One 9(12): p.e114833

Hlevca, B., Cooke, S. J., Midwood, J. D., Doka, S. E., Portiss, R., and Wells, M. G. 2015. Characterisation of water temperature variability within a harbour connected to a large lake. J. Great Lakes Res. 41(4): 1010–1023.

Holden, J.P., Connerton, M.J., and Weidel, B.C. 2018. Hydroacoustic and Midwater Trawl Assessment of Pelagic Planktivores, 2018. Section 15, in 2018 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Hoyle, J.A., and Yuille, M.J. 2016. Nearshore fish community assessment on Lake Ontario and the St . Lawrence River : A trap net-based index of biotic integrity. J. Great Lakes Res. 42: 687–694.

Hoyle, J.A., Bowlby, J.N., Brousseau, C.M., Johnson, T.B., Morrison, B.J., and Randall, R.G. 2012. Fish community structure in the Bay of Quinte, Lake Ontario: The influence of nutrient levels and invasive species. Aquat. Ecosyst. Health Manag. 15(4): 370-384.

Hoyle, J.A., Boston, C.M., Chu, C., Yuille, M.J., Portiss, R., and Randall, R.G., 2018. Fish community indices of ecosystem health : How does Toronto Harbour compare to other Lake Ontario nearshore areas ? Aquat. Ecosyst. Health Manag. 21: 306–317.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.

Kidd, J. 1998. A Living Place: Opportunities for Habitat Regeneration in Toronto Bay. Toronto Bay Initiative.

Kidd, J., 2016. Within reach: 2015 Toronto and region remedial action plan progress report. www.torontorap.ca (accessed 10.30.17).

Krueger, C.C., Holbrook, C.M., Binder, T.R., Vandergoot, C.S., Hayden, T.A., Hondorp, D.W., Nate, N., Paige, K., Riley, S.C., Fisk, A.T., and Cooke, S.J. 2017. Acoustic telemetry observation systems: challenges encountered and overcome in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 75(10): 1755–1763

Larson, J.H., Trebitz, A.S., Steinman, A.D., Wiley, M.J., Mazur, M.C., Pebbles, V., Braun, H.A., and Seelbach, P.W. 2013. Great Lakes river mouth ecosystems: Scientific synthesis and management implications. J. Great Lakes Res. 39(3): 513-524.

Leisti, K.E. Gardner Costa, J. Jardine, J. unpublished. Fish Assessment Using Hydroacoustics with Concurrent Fish Sampling: A Comparison Among Hamilton Harbour, Toronto Harbour and Bronte Harbour, Lake Ontario. Can. Tech. Rep. Fish. Aquat. Sci. xxxx: viii + 23 p. DRAFT

Lester, N.P., Dunlop, W.I., and Willox, C.C., 1996. Detecting changes in the nearshore fish community. Can. J. Fish Aquat. Sci. 53: 391-402.

Lindgren, F., Rue, H., and Lindström, J. (2011). An explicit link between Gaussian fields and Gaussian Markov random fields: The stochastic partial differential equation approach. J. R. Stat. Soc. B 73(4): 423–498.

Lougheed, V.L., Theÿsmeÿer, T., Smith, T. and Chow-Fraser, P. 2004. Carp exclusion, food-web interactions, and the restoration of Cootes Paradise Marsh. J. Great Lakes Res. 30(1): 44-57.

Lynch, M.P., and Mensinger, A.F. 2012. Seasonal abundance and movement of the invasive round goby (*Neogobius melanostomus*) on rocky substrate in the Duluth-Superior Harbor of Lake Superior. Ecol. Freshw. Fish 21(1): 64–74.

Magnuson, J.J., Robertson, D.M., Benson, B.J., Wynne, R.H., Livingstone, D.M., Arai, T., Assel, R.A., Barry, R.G., Card, V., Kuusisto, E., Granin, N.G., Prowse, T.D., Stewart, K.M., and Vuglinski, V.S., 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289(5485): 1743–1746.

Mason, L.A., Riseng, C.M., Gronewold, A.D., Rutherford, E.S., Wang, J., Clites, A., Smith, S.D.P., and McIntyre, P.B., 2016. Fine-scale spatial variation in ice cover and surface temperature trends across the surface of the Laurentian Great Lakes. Clim. Change 138: 71–83.

McKenna, J.E. Jr. 2008. Diel variation in near-shore great lakes fish assemblages and implications for assessment sampling and coastal management. J. Freshw. Ecol. 23(1): 131–141

McQueen, D.J., Johannes, M.R.S., Post, J.R., Stewart, T.J., and Lean, D.R.S. 1989. Bottom-up and top-down impacts on freshwater pelagic community structure. Ecol. Monogr. 59(3): 289–309.

Midwood, J.D., and Chow-Fraser, P. 2012 Changes in aquatic vegetation and fish communities following five years of sustained low water levels in coastal marshes of eastern Georgian Bay, Lake Huron. Glob. Chang. Biol. 18: 93-105.

Midwood, J.D., Chapman, J.M., Cvetkovic, M., King, G.D., Ward, T.D., Cooke, S.J., and Suski, C.D. 2016. Diel variability in fish assemblage in coastal wetlands and tributaries of the St. Lawrence River Area of Concern: A cautionary tale for fisheries monitoring. Aquat. Sci.. 78(2): 267-277

Midwood, J.D., Gutowsky, L.F.G., Hlveca, B., Portiss, R., Doka, S., Wells, M.G., and Cooke, S.J. 2018a. Bowfin (*Amia calva*) acoustic telemetry: insight into the ecology of a living fossil. Ecol. Freshw. Fish 27: 225-236

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

Midwood, J.D., Rous, A.M., Doka, S.E., and Cooke, S.J. 2019a. Acoustic telemetry in Toronto Harbour: assessing residency, habitat selection, and within-harbour movements of fishes over a five-year period. Can. Tech. Rep. Fish. Aquat. Sci. 3331: xx + 174 p

Midwood, J.D., Leisti, K.E., Milne, S.W., and Doka, S.E. 2019b. Assessing seasonal changes in pelagic fish density and biomass using hydroacoustics in Hamilton Harbour, Lake Ontario in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3299: x + 63 pp.

Midwood, J.D., Tang, R.W., Doka, S.E, and Gardner-Costa, J.M. 2021. Comparison of approaches for modelling submerged aquatic vegetation in the Toronto and Region Area of Concern. J. Great Lakes Res. 47(2): 395-404.

Minns, C.K., Cairns, V.W., Randall, R.G., and Moore, J.E. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great lakes' areas of concern. Can. J. Fish. Aquat. Sci. 51(8): 1804-1822.

Minns, C.K., Kelso, J.R. and Randall, R.G. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. Can. J. Fish. Aquat. Sci. 53(S1): 403-414.

Murphy, S.C., Collins, N.C., and Doka, S.E. 2011. Thermal habitat characteristics for warmwater fishes in coastal embayments of Lake Ontario. J. Great Lakes Res. 37: 111–123.

Murphy, S.C., Collins, N.C., and Doka, S.E. 2012. The effects of cool and variable temperatures on the hatch date , growth and overwinter mortality of a warmwater fish in small coastal embayments of Lake Ontario. J. Great Lakes Res. 38: 404–412.

Muška, M., Tušer, M., Frouzová, J., Draštík, V., Čech, M., Jůza, T., Kratochvíl, M., Mrkvička, T., Peterka, J., Prchalová, M. and Říha, M., 2013. To migrate, or not to migrate: partial diel horizontal migration of fish in a temperate freshwater reservoir. Hydrobiologia, 707(1): 17-28.

Nelson, E.J.H., Holden, J., Eves, R., and Tufts, B. 2017. Comparison of diets for largemouth and smallmouth bass in eastern Lake Ontario using DNA barcoding and stable isotope analysis. PLoS ONE 12(8): 1–21.

Nilsson, C., Sarneel, J.M., Palm, D., Gardeström, J., Pilotto, F., Polvi, L.E., Lind, L., Holmqvist, D. and Lundqvist, H. 2017. How do biota respond to additional physical restoration of restored streams? Ecosystems 20(1): 144-162.

Olson, D. E., and Scidmore, W. J. 1962. Homing behavior of spawning walleyes. Trans. Am. Fish. Soc. 91: 355–361.

OMNRF (Ontario Ministry of Natural Resources and Forestry). 2017. Lake Ontario Fish Communities and Fisheries: 2016 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario, Canada. Retrieved from http://www.glfc.org/loc_mgmt_unit/LOA%2017.01.pdf

OMNRF (Ontario Ministry of Natural Resources and Forestry). 2020. Lake Ontario fish communities and fisheries. 2019 Annual Report of the Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario, Canada. Retrieved from http://www.glfc.org/loc_mgmt_unit/LOA%2020.01.pdf

Pace, M.L., Cole, J.J., Carpenter, S.R., and Kitchell, J.F. 1999. Trophic cascades revealed in diverse ecosystems. Trends Ecol. Evol. 14(12): 483–488.

Paul, M. J., and Meyer, J. L. 2001. Streams in the urban landscape. Annu. Rev. Ecol. Systemat. 32: 333–365.

Peat, T., Gutowsky, L., Doka, S., Midwood, J.D., Lapointe, N.W.R., Hlevca, B., Wells, M., Portiss, R., and Cooke, S.J. 2016. Comparative thermal biology and depth distribution of largemouth bass and northern pike in an urban harbour of the Laurentian Great Lakes. Can. J. Zool. 94(11): 767-776.

Penne, C.R., and Pierce, C.L. 2008. Seasonal distribution, aggregation, and habitat selection of Common Carp in Clear Lake, Iowa. T. Am. Fish. Soc. 137(4): 1050–1062.

Pennuto, C.M., Krakowiak, P.J., and Janik, C.E. 2010. Seasonal abundance, diet, and energy consumption of round gobies (*Neogobius melanostomus*) in Lake Erie tributary streams. Ecol. Freshw. Fish 19(2): 206–215.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 131–144.

Pierce, R.B., 2012. Northern Pike: ecology, conservation, and management history. University of Minnesota Press.

Poos, M., Dextrase, A.J., Schwalb, A.N., and Ackerman, J.D. 2010. Secondary invasion of the round goby into high diversity Great Lakes tributaries and species at risk hotspots: Potential new concerns for endangered freshwater species. Biol. Invasions 12(5): 1269–1284.

Randall, R.G., and Minns, C.K. 2002. Comparison of a Habitat Productivity Index (HPI) and an Index of Biotic Integrity (IBI) for measuring the productive capacity of fish habitat in nearshore areas of the Great Lakes. J. Great Lakes Res. 28(2): 240-255.

Rao, Y.R., and Murthy, C.R., 2001. Nearshore currents and turbulent exchange processes during upwelling and downwelling events in Lake Ontario. J. Geophys. Res. 106: 2667–2678.

Reyjol, Y., Brodeur, P., Mailhot, Y., Mingelbier, M., and Dumont, P. 2010. Do native predators feed on non-native prey? The case of round goby in a fluvial piscivorous fish assemblage. J. Great Lakes Res. 36(4): 618–624.

Roseman, E.F., Schaeffer, J.S., Bright, E., and Fielder, D.G. 2014. Angler-caught piscivore diets reflect fish community changes in Lake Huron. Trans. Am. Fish. Soc. 143(6): 1419–1433.

Rous, A.M., Midwood, J.D., Gutowsky, L.F.G., Lapointe, N.W.R., Portiss, R., Sciscione, T., Wells, M.G., Doka, S.E., and Cooke, S.J. 2017. Telemetry-determined habitat use informs multi-species habitat management in an urban harbour. Environ. Manage. 59: 118-128.

Rue, H., Riebler, A., Sørbye, S. H., Illian, J. B., Simpson, D. P., and Lindgren, F. K. 2017. Bayesian computing with INLA: A review. Annu. Rev. Stat. Appl. 4(1): 395–421.

Rush, S. A., Paterson, G., Johnson, T.B., Drouillard, K.G., Haffner, G.D., Hebert, C.E., Art, M.T., McGoldrick, D.J., Backus, S.M. Lantry, B.F., and Lantry, J.R. 2012. Long-term impacts of invasive species on a native top predator in a large lake system. Freshw. Biol. 57(11): 2342–2355.

Scarnecchia, D. L. 1992. A reappraisal of gars and bowfins in fishery management. Fisheries 17(5): 6–12.

Simmonds, E.J. and MacLennan, D. 2005. Fisheries Acoustics: Theory and Practice 2nd Edition. Blackwell Publishing, Oxford, UK.

Somero, G.N. 2005. Linking biogeography to physiology: evolutionary and acclamatory adjustments of thermal limits. Front. Zool. 2: 1–9.

Spiegelhalter, D.J., Best, N.G., Carlin, B.P., and Van Der Linde, A. 2002. Bayesian measures of model complexity and fit. J. R. Stat. Soc. B. 64(2): 583–639.

Steinhart, G.B., Marschall, E.A., and Stein, R.A. 2004a. Round goby predation on smallmouth bass offspring in nests during simulated catch-and-release angling. Trans. Am. Fish. Soc. 133(1): 121–131.

Steinhart, G.B., Stein, R.A., and Marschall, E.A. 2004b. High growth rate of young-of-the-year smallmouth bass in Lake Erie: A result of the round goby invasion? J. Great Lakes. Res 30(3): 381–389.

Stirling, M.R., 1999. Manual of Instructions: Nearshore community index netting (NSCIN). Ontario Ministry of Natural Resources, Lake Simcoe Fisheries Assessment Unit.

Stuart, I.G., and Jones, M. 2006. Large, regulated forest floodplain is an ideal recruitment zone for non-native Common Carp (*Cyprinus carpio* L.). Mar. Freshwater Res. 57(3): 333–347.

Toronto Remedial Action Plan (RAP). 1989. Metro Toronto Remedial Action Plan Environmental Conditions and Problems Definition. Toronto and Region Conservation Authority, Downsview, Ontario. 271 p. https://torontorap.ca/app/uploads/2019/12/RAP-Stage-1-Environmental-Conditions-and-Problem-Definition.pdf

Toronto Remedial Action Plan (RAP). 1994. Clean Waters, Clear Choices. Report prepared for the public. Toronto and Region Conservation Authority, Downsview, Ontario 116   p. https://torontorap.ca/app/uploads/2019/12/Clean_Waters_Clear_Choices-rsz-compressed.pdf

Toronto Remedial Action Plan (RAP). 2016. Within reach: remedial action plan progress report. Toronto and Region Conservation Authority, Downsview, Ontario. 90 pp. Available from https://torontorap.ca/app/uploads/2016/10/2015-RAP-Progress-Report.pdf.

TRCA (Toronto and Region Conservation Authority). 2003. Toronto Waterfront Aquatic Habitat Restoration Strategy (TWAHRS) [online]. Aquatic Habitat Toronto.

Available from https://trca.ca/conservation/aquatic-habitat-toronto/conservation-aquatic-habitat-toronto-strategy/ [accessed 19 January 2021].

Tufts, B., McCarthy, D., Wong, S., Elliott, C., Bridgeman, S., Nelson, E., Taylor, E., Lindenblatt, R. and Ridgway, M. 2019. Ecology and timing of black bass spawning in Lake Ontario and the St. Lawrence River: Potential interactions with the angling season. J. Great Lakes. Res. 45(5): 949–957.

Veilleux, M.A.N., Midwood, J.D., Boston, C.M., Lapointe, N.W.R., Portiss, R., Wells, M., Doka, S.E., and Cooke, S.J. 2018. Assessing occupancy of freshwater fishes in urban boat slips of Toronto Harbour. Aquat. Ecosyst. Health Manag. 21(3): 331–341.

Wallace, A.M., Croft-White, M.V. and Moryk, J., 2013. Are Toronto’s streams sick? A look at the fish and benthic invertebrate communities in the Toronto region in relation to the urban stream syndrome. Environ. Monit. Assess., 185(9): 7857-7875.

Walsh, C. J. 2004. Protection of in-stream biota from urban impacts: minimize catchment imperviousness or improve drainage design? Mar. Freshwater Res. 55: 317–326.

Watz, J., Bergman, E., Piccolo, J.J., and Greenberg, L., 2013. Effects of ice cover on the diel behaviour and ventilation rate of juvenile brown trout. Freshw. Biol. 58: 2325–2332.

Weber, M.J. and Brown, M.L., 2009. Effects of common carp on aquatic ecosystems 80 years after “carp as a dominant”: ecological insights for fisheries management. Rev. Fish. Sci. 17(4): 524-537.

Whillans, T.H. 1979. Historic transformations of fish communities in three Great Lakes bays. J. Great Lakes Res. 5(2): 195–215.

Whillans, T.H. 1982. Changes in Marsh Area Along the Canadian Shore of Lake Ontario. J. Great Lakes Res. 8(3): 570–577.

Yoshida, T., Urabe, J., and Elser, J.J. 2003. Assessment of “top-down” and “bottom-up” forces as determinants of rotifer distribution among lakes in Ontario, Canada. Ecol. Res. 18(6): 639–650.

Zuur, A.F., and Ieno, E.N., and Saveliev, A.A. 2017. Spatial, Temporal, and Spatial-Temporal Ecological Data Analysis with R-INLA. Highland Statistics Ltd., Newburgh, United Kingdom.

Zuur, A.F., and Ieno, E.N. 2018. Spatial, Temporal, and Spatial-Temporal Ecological Data Analysis with R-INLA. Volume II Highland Statistics Ltd., Newburgh, United Kingdom.

APPENDIX A: MODEL OUTPUT FROM TEMPORAL TRENDS IN METRIC VALUES FOR CRITERION FP-1A: TRCA ELECTROFISHING DATA – ASSESSMENT OF TRENDS (1989 – 2018) AND REGIONAL DIFFERENCES IN LITTORAL FISH ASSEMBLAGES IN THE TORONTO AND REGION AOC

Appendix A and D Model Scenarios Table of Contents

Each of the model output sections follows the same format. The fish community metric, the scale of model (ecotype of region), and the month the data were collected are shown at the top. The content of the sub-headings is briefly explained below.

Data Details: Information on any data that were excluded and the size of the final dataset that was used.

Model: The R code associated with model formula (f4), and the code to implement the model.

Validate Model: notes on the various tests to validate the model; also an assessment of whether the model with the spatial component had better fit [based on Deviance Information Criterion (DIC)].

Interpret and Present Numerical Model Output: Number of effective parameters for the model and associated DIC. The two tables show the posterior mean values, standard deviations, and 95% credible intervals for the parameters and hyper-parameters.

Equation 1. IBI – Ecotype - July.

Data Details:
Final sample size for the dataset was 981. Values where IBI=0 were excluded.

Model:
Model equation:
```
f4 <- formula(IBI.Beta ~ -1 + Intercept + Estuary.River + OpenCoast + Slip +
             f(Year, model = "rw1") +
             f(w, model = spde) +
             f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype))
```

Model call:
```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is -2420.4).

Test	**Notes/Comments**
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.4-0.75) vs (0.3-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -2561.5
Effective # Parameters = 90.3

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	0.372	0.032	0.309	0.435
Estuary.River	-0.07	0.06	-0.188	0.046
OpenCoast	-0.23	0.043	-0.319	-0.150
Slip	-0.29	0.081	-0.442	-0.123

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for beta observations	60.2	3.02	54.5	66.4
Precision for Year	14619	16700	393.8	59100
Theta1 for w	-0.934	0.481	-1.878	0.009
Theta2 for w	1.523	0.371	0.792	2.25
Precision for Year-Ecotype	325.6	157.0	119.4	721.0

Equation 2. IBI – Ecotype - October

Data Details:

Final sample size for the dataset was 322. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + Estuary.River + OpenCoast + Slip +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is -780).

Test	Notes/Comments
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.5-0.75) vs (0.3-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -798

Effective # Parameters = 27.8

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	0.52	0.16	0.14	0.91
Estuary.River	-0.15	0.07	-0.29	-0.02
OpenCoast	-0.20	0.05	-0.30	-0.10
Slip	-0.21	0.10	-0.40	0.01

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for beta observations	50.6	4.57	42.1	60.0
Precision for Year	16748	17600	814	63900
Theta1 for w	2.42	0.91	0.60	4.17
Theta2 for w	-1.56	0.83	-3.16	0.09
Precision for Year-Ecotype	697	897	104	2910

Equation 3. IBI – Region - Embayment - July

Data Details:
Final sample size for the dataset was 562. Values where IBI=0 were excluded.

Model:
Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is –1459.6).

Test	**Notes/Comments**
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.5-0.75) vs (0.4-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -1556
Effective # Parameters = 58.1

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	0.23	0.09	0.04	0.41
OtherEast	0.12	0.14	-0.15	0.40
OtherWest	0.15	0.11	-0.07	0.38
TorontoIslands	0.26	0.12	0.02	0.50
TTP	0.09	0.11	-0.13	0.32

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for beta observations	70.1	4.69	61.3	80
Precision for Year	243.9	159	74.6	664
Theta1 for w	-1.32	0.60	-2.56	-0.20
Theta2 for w	1.75	0.48	0.85	2.74
Precision for Year-Ecotype	12776	40700	701.3	76230

Equation 4. IBI – Region - Embayment - October

Data Details:
Final sample size for the dataset was 173. Values where IBI=0 were excluded.

Model:
Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
          family = "beta",
          data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **NO** (dic without spde is –459).

Test	**Notes/Comments**
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.5-0.65) vs (0.4-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests – not great fit though…

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -459
Effective # Parameters = 10.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	0.38	0.91	-0.39	1.29
OtherEast	0.03	0.12	-0.22	0.25
OtherWest	0.23	0.14	-0.04	0.52
TorontoIslands	0.27	0.12	0.05	0.51
TTP	0.11	0.10	-0.07	0.33

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for beta observations	56	6.33	44.7	69.6
Precision for Year	20504	19287	1565	71008
Theta1 for w	1.77	2.03	-2.04	5.94
Theta2 for w	-0.16	2.41	-4.93	4.54
Precision for Year-Ecotype	19450	18589	1570	68223

Equation 5. IBI – Region – Open Coast - July

Data Details:
Final sample size for the dataset was 212. Values where IBI=0 were excluded.

Model:
Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + EastBluffers + WestBluffers + Western +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is –559.5).

Test	Notes/Comments
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.4-0.6) vs (0.4-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Lower at some western sites

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -563
Effective # Parameters = 13.1

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-0.01	0.12	-0.24	0.24
EastBluffers	0.17	0.13	-0.09	0.42
WestBluffers	0.10	0.12	-0.14	0.33
Western	0.30	0.13	0.04	0.55

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for beta observations	61	6.1	49.8	73.7
Precision for Year	14448.9	22300	447	70441
Theta1 for w	1.71	0.98	-0.25	3.62
Theta2 for w	-0.32	1.08	-2.40	1.86
Precision for Year-Ecotype	20025	19200	1594	70516

Equation 6. $\mathrm{IBI}_{\mathrm{Adj}}$– Ecotype - July

Data Details:

Final sample size for the dataset was 948. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + Estuary.River + OpenCoast + Slip +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is --1011).

l**Test**	**Notes/Comments**
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.4-0.75) vs (0.3-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -1124

Effective # Parameters = 83.9

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-0.29	0.06	-0.41	-0.18
Estuary.River	-0.09	0.13	-0.35	0.16
OpenCoast	-0.61	0.09	-0.79	-0.43
Slip	-0.89	0.15	-1.20	-0.59

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for beta observations	12.04	0.58	10.9	13.2
Precision for Year	22.6	8.87	9.90	44.2
Theta1 for w	-2.69	1.17	-4.64	-0.11
Theta2 for w	2.34	0.67	0.90	3.48
Precision for Year-Ecotype	15776	16900	735	61157

Equation 7. IBI$_{Adj}$ – Ecotype - October

Data Details:

Final sample size for the dataset was 316. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + Estuary.River + OpenCoast + Slip +
          f(Year, model = "rw1") +
          f(w, model = spde) +
          f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
       control.predictor = list(A = inla.stack.A(StackFitA),
                       compute = TRUE),
       family = "beta",
       data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is --241).

Test	Notes/Comments
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.2-0.6) vs (0.0-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -308

Effective # Parameters = 26.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-0.14	0.56	-1.37	1.10
Estuary.River	-0.67	0.17	-1.00	-0.33
OpenCoast	-0.42	0.13	-0.66	-0.17
Slip	-0.22	0.22	-0.64	0.22

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for beta observations	9.62	0.82	8.12	11.3
Precision for Year	94.9	75.7	19.5	295.1
Theta1 for w	0.97	0.57	-0.13	2.09
Theta2 for w	-1.60	0.65	-2.89	-0.35
Precision for Year-Ecotype	14993	16600	511	59477

Equation 8. IBI$_{Adj}$ – Region - Embayment - July

Data Details:

Final sample size for the dataset was 561. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is –694).

Test	**Notes/Comments**
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.3-0.75) vs (0.1-0.8)
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -749.7

Effective # Parameters = 54.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-0.41	0.17	-0.73	-0.08
OtherEast	0.14	024	-0.34	0.62
OtherWest	0.15	0.20	-0.24	0.54
TorontoIslands	0.20	0.21	-0.22	0.61
TTP	0.07	0.20	-0.34	0.46

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for beta observations	15.9	1.02	13.9	17.9
Precision for Year	22.6	10.4	9.60	49.1
Theta1 for w	-2.48	0.83	-4.25	-1.00
Theta2 for w	2.19	0.57	1.16	3.39
Precision for Year-Ecotype	9920	13100	86.7	45464

Equation 9. IBI$_{Adj}$ – Region - Embayment - October

Data Details:

Final sample size for the dataset was 173. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                   compute = TRUE),
          family = "beta",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO** (dic without spde is –222).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests – not great fit though…

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -222
Effective # Parameters = 18.6

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	0.01	0.16	-0.31	0.32
OtherEast	-.80	0.21	-1.21	-0.40
OtherWest	0.19	0.19	-0.19	0.57
TorontoIslands	0.31	0.20	-0.09	0.70
TTP	-0.02	0.18	-0.37	0.34

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for beta observations	15.3	2.08	11.7	19.9
Precision for Year	125.3	199	11.8	593.8
Theta1 for w	-1.20	1.81	-4.83	2.29
Theta2 for w	2.09	1.04	0.25	4.32
Precision for Year-Ecotype	16401	17335	840.1	62912

Equation 10. $\mathrm{IBI}_{\mathrm{Adj}}$ – Region – Open Coast - July

Data Details:

Final sample size for the dataset was 210. Values where IBI=0 were excluded.

Model:

Model equation:

```
f4 <- formula(IBI.Beta ~ -1 + Intercept + EastBluffers + WestBluffers + Western +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO!** (dic without spde is –217.4).

Test	Notes/Comments
Overdispersion	unclear how to run for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (0.2-0.4) vs (0.0-0.8)
Residual normality	No concerns
Residuals vs Treatment	Less variance at centralwf
Variogram	No clear pattern
Spatial Residuals	Lower at some western sites

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -215

Effective # Parameters = 19.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-0.65	0.34	-1.27	-0.02
EastBluffers	-0.35	0.30	-0.94	0.24
WestBluffers	-0.27	0.30	-0.84	0.32
Western	-0.09	0.31	-0.69	0.53

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for beta observations	8.32	0.92	6.64	10.27
Precision for Year	111	267	8.00	613
Theta1 for w	0.57	1.71	-2.73	3.97
Theta2 for w	0.04	1.68	-3.27	3.34
Precision for Year-Ecotype	17900	18100	1044	66221

Equation 11. Total Catch – Ecotype – July

Data Details:
Final sample size for the dataset was 983. Dropped five sites with catch >400.

Model:
RowCatch = total catch
Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 10651).

Test	Notes/Comments
Overdispersion	Poisson model overdispersed; NBinomial - all good
Residuals vs Fitted	Ok, one high residuals
Fitted vs Observed	No concerns
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 10556.4.3
Effective # Parameters = 58.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-2.17	0.12	-2.40	-1.93
Estuary.River	-0.23	0.13	-0.50	0.03
OpenCoast	-0.37	0.11	-0.59	-0.15
Slip	-0.86	0.21	-1.25	-0.44

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Size of Nbinomial obs	1.74	0.08	1.58	1.91
Precision for Year	13.12	5.93	5.29	28.1
Theta1 for w	-0.13	0.36	-0.84	0.58
Theta2 for w	-0.05	0.37	-0.77	0.68
Precision for Year-Ecotype	2273.2	9945.5	31.1	14900

Equation 12. Total Catch – Ecotype – October

Data Details:

Final sample size for the dataset was 327. Dropped site with catch >400

Model:

RowCatch = total catch

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 3219).

Test	**Notes/Comments**
Overdispersion	Poisson model overdispersed; 0.58 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Lower variance for estuaries
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 3211

Effective # Parameters = 30.8

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-2.57	0.11	-2.79	-2.36
Estuary.River	-0.03	0.21	-0.44	0.40
OpenCoast	-1.21	0.15	-1.51	-0.90
Slip	-0.82	0.24	-1.29	-0.32

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size of Nbinomial obs	1.31	0.11	1.08	1.52
Precision for Year	11802	931000	21.57	51500
Theta1 for w	-1.54	0.88	-3.16	0.31
Theta2 for w	1.46	0.66	0.10	2.69
Precision for Year-Ecotype	21981	24800	1499	87500

Equation 13. Total Catch – Region – Embayment - July

Data Details:

Final sample size for the dataset was 562. Five sites dropped with catch >400.

Model:

RowCatch = total catch

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 6239).

Test	**Notes/Comments**
Overdispersion	Poisson model overdispersed; NBinomial is underdispersed, but likely better choice
Residuals vs Fitted	Ok, one high residuals
Fitted vs Observed	Spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 6222

Effective # Parameters = 28.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-3.04	0.93	-3.74	-2.09
OtherEast	0.98	0.35	0.25	1.63
OtherWest	0.90	0.38	0.10	1.64
TorontoIslands	1.27	0.33	0.66	1.96
TTP	0.76	0.21	0.35	1.18

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size of Nbinomial obs	2.32	0.14	2.05	2.61
Precision for Year	78.26	55.6	19.88	224.23
Theta1 for w	0.40	0.57	-0.67	1.56
Theta2 for w	-0.52	0.86	-2.27	1.08
Precision for Year-Ecotype	24061	26700	1887.6	95100

Equation 14. Total Catch – Region – Embayment – October

Data Details:

Final sample size for the dataset was 171. Five sites dropped with catch >375.

Model:

RowCatch = total catch

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1810).

Test	Notes/Comments
Overdispersion	Poisson model overdispersed; NBinomial is 0.004
Residuals vs Fitted	Ok, one high residuals
Fitted vs Observed	Ok, some spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1780

Effective # Parameters = 29.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-2.93	068	-4.38	-1.63
OtherEast	0.49	0.77	-1.02	2.05
OtherWest	-0.02	0.78	-1.51	1.67
TorontoIslands	0.36	0.80	-1.10	2.08
TTP	0.37	0.57	-0.70	1.57

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Size of Nbinomial obs	2.14	0.30	1.60	2.78
Precision for Year	20939	22000	1582	79264
Theta1 for w	-1.14	0.59	-2.30	0.02
Theta2 for w	0.33	0.83	-1.28	1.97
Precision for Year-Ecotype	201.7	384.0	12.47	1048.8

Equation 15. Total Catch – Region – Open Coast - July

Data Details:
Final sample size for the dataset was 214.

Model:
RowCatch = total catch
Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + EastBluffers + WestBluffers + Western +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 2255).

Test	**Notes/Comments**
Overdispersion	Poisson model overdispersed; NBinomial is underdispersed, but likely better choice
Residuals vs Fitted	Ok, one high residuals
Fitted vs Observed	Ok, but a fair amount of spread
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, fewer and generally lower values in centralWF

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 2256
Effective # Parameters = 25.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-3.91	0.52	-4.92	-2.88
EastBluffers	1.50	0.43	0.61	2.31
WestBluffers	1.25	0.41	0.42	2.01
Western	1.91	0.46	1.06	2.88

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size of Nbinomial obs	1.92	0.20	1.55	2.35
Precision for Year	8.83	4.66	3.12	20.78
Theta1 for w	0.67	1.31	-1.90	3.25
Theta2 for w	-0.51	1.41	-3.29	2.25
Precision for Year-Ecotype	19047	18700	1316	68194

Equation 16. Total Catch – Region – Open Coast - October

Data Details:
Final sample size for the dataset was 84. One site dropped with catch >700.

Model:
RowCatch = total catch

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + EastBluffers + WestBluffers + Western +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 708).

Test	**Notes/Comments**
Overdispersion	Poisson model overdispersed; NBinomial is 0.001, so better
Residuals vs Fitted	Ok, one high residuals
Fitted vs Observed	Not great, pretty vertical
Residual normality	Not great, but not too important
Residuals vs Treatment	CentralWF has lower variance
Variogram	No clear pattern
Spatial Residuals	Not ideal, lower residuals at the Western sites….

Model is ok, but likely too few samples

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 701
Effective # Parameters = 12.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-3.73	0.76	-5.13	-2.03
EastBluffers	-0.13	0.79	-2.03	1.20
WestBluffers	-0.82	0.81	-2.69	0.57
Western	0.51	0.76	-0.94	2.16

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size of Nbinomial obs	1.25	0.22	0.88	1.72
Precision for Year	19713	22100	1097	78920
Theta1 for w	-0.21	1.00	-2.06	1.84
Theta2 for w	-0.46	1.17	-2.85	1.74
Precision for Year-Ecotype	21533	22400	1579	80538

Equation 17. Total Catch of Native Fish – Ecotype - July

Data Details:

Final sample size for the dataset was 994. Subset for only species that were determined to be "Native". Includes individuals identified only to genus.

Model:

RowCatch = total catch of native fish

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 9393).

Test	Notes/Comments
Overdispersion	Overdisperssion with poisson; 0.989 with NBinomial, so all good
Residuals vs Fitted	One v. high residual at low fitted value
Fitted vs Observed	Ok, more spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	One clear outlier in slips (residual >15)
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 9205

Effective # Parameters = 77.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-2.88	0.12	-3.13	-2.65
Estuary.River	-0.29	0.21	-0.70	0.12
OpenCoast	-0.99	0.15	-1.29	-0.70
Slip	-1.52	0.30	-2.10	-0.91

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Psize for nbinomial obs	1.43	0.071	1.29	1.57
Precision for Year	19.58	12.0	6.40	51.24
Theta1 for w	-2.20	0.45	-3.11	-1.34
Theta2 for w	1.43	0.34	0.76	2.08
Precision for Year-Ecotype	16906	17700	1039.8	63829

Equation 18. Total Catch of Native Fish – Ecotype – October

Data Details:

Final sample size for the dataset was 332. Subset for only species that were determined to be "Native". Includes individuals identified only to genus. Dropped seven sites with values >200.

Model:

RowCatch = total catch of native fish

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                      compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 3572).

Test	Notes/Comments
Overdispersion	Overdispersed for Poisson; still overdisperesed with NBinomial, not clear that there are other options to resolve this problem.. so proceed?
Residuals vs Fitted	OK
Fitted vs Observed	Ok, some spread along low observed values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model fails basic tests, but there aren't many options to resolve overdispersion in NBinomial models. Can add more covariates and that may solve the problem, but we don't really have that…

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2950
Effective # Parameters = 45.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-2.93	0.13	-3.19	-2.68
Estuary.River	-0.07	0.24	-0.54	0.42
OpenCoast	-112	0.16	-1.45	-0.80
Slip	-0.68	0.45	-1.58	0.22

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Size of nbinomial observations	1.42	0.15	1.14	1.73
Precision for Year	20137	20511	1433	74577
Theta1 for w	-0.23	1.69	-3.26	3.34
Theta2 for w	0.43	1.42	-2.57	3.00
Precision for Year-Ecotype	6.58	3.74	2.27	16.35

Equation 19. Total Catch of Native Fish – Region - Embayment – July

Data Details:
Final sample size for the dataset was 565. Subset for only species that were determined to be "Native". Includes individuals identified only to genus. Dropped two sites with catch >450.

Model:
RowCatch = total catch of native fishes
Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
          offset(log(Effort) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 5742).

Test	**Notes/Comments**
Overdispersion	Overdisperssion with poisson; NBinomial unis 0.879
Residuals vs Fitted	Ok, some higher residuals
Fitted vs Observed	Ok, more spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concrns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 5697
Effective # Parameters = 42.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-3.87	0.39	-4.70	-3.15
OtherEast	1.14	0.46	0.23	2.06
OtherWest	1.08	0.46	0.21	2.07
TorontoIslands	1.45	0.49	0.57	2.50
TTP	0.82	0.31	0.21	1.43

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Psize for nbinomial obs	1.77	0.11	1.56	2.00
Precision for Year	29.97	21.5	7.69	86.9
Theta1 for w	-0.69	0.48	-1.61	0.28
Theta2 for w	0.27	0.60	-0.94	1.41
Precision for Year-Ecotype	19040	18800	1330	68800

Equation 20. Total Catch of Native Fish – Region - Embayment - October

Data Details:

Final sample size for the dataset was 171. Subset for only species that were determined to be “Native”. Includes individuals identified only to genus. Dropped two sites with catch >450.

Model:

RowCatch = total catch of native fishes

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
         offset(log(Effort)) +
           f(Year, model = "rw1") +
           f(w, model = spde) +
           f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 3590).

Test	Notes/Comments
Overdispersion	Ok, but close! 0.999
Residuals vs Fitted	Ok, some higher residuals
Fitted vs Observed	Ok, more spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	Less variance at CentralWF
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2427

Effective # Parameters = 101.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.00	1.13	-7.24	-2.79
OtherEast	2.08	1.32	-0.52	4.68
OtherWest	1.54	1.21	-0.85	3.93
TorontoIslands	1.78	1.24	-0.67	4.22
TTP	2.08	1.18	-0.23	4.42

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19714	19000	1221	69857
Theta1 for w	-3.23	0.32	-3.91	-2.66
Theta2 for w	1.76	0.28	1.25	2.36
Precision for Year-Ecotype	1.38	0.29	0.89	2.02

Equation 21. Total Catch of Native Fish – Region – Open Coast – July

Data Details:

Final sample size for the dataset was 213. Subset for only species that were determined to be "Native". Includes individuals identified only to genus. Dropped one site with catch >200. Full model not predicting well. First remove central WF b/c low sample sizes – still not predicting well, but model fit is better. Try subsetting for similar efforts (900-1100) – drops 14 points – This seems to work better.

Model:

RowCatch = total catch of native fishes

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept +  WestBluffers + Western +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                   compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2843).

Test	Notes/Comments
Overdispersion	Poisson = 0.997
Residuals vs Fitted	Ok, some spread at higher values
Fitted vs Observed	Ok, decent fit
Residual normality	Not great, but not too important
Residuals vs Treatment	Lowest variance at Western
Variogram	No clear pattern
Spatial Residuals	Ok, less variance at Western sties.

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1869
Effective # Parameters = 84.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-3.95	0.24	-4.42	-3.48
Region WestBluffers	-0.39	0.38	-1.15	0.36
Region Western	-0.59	0.90	-2.37	1.18

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19606	18900	1229	69517
Theta1 for w	-3.07	0.46	-4.01	-2.18
Theta2 for w	1.97	0.37	1.27	2.71
Precision for Year-Ecotype	1.27	0.25	0.84	1.82

Equation 22. Total Catch of Non-Native Fish – Ecotype - July

Data Details:

Final sample size for the dataset was 991. Subset for only species that were determined to be "Nonindigenous". Includes individuals identified only to genus (if appropriate). Dropped sites with value >450.

Model:

RowCatch = total catch of non-native fish

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 9319).

Test	Notes/Comments
Overdispersion	Overdisperssion with poisson; 0.334 with NBinomial, so all good
Residuals vs Fitted	Ok, bigger spread at low fitted values (but more samples there)
Fitted vs Observed	Ok, more spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	One clear outlier in slips (residual >15)
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 9201
Effective # Parameters = 86.1

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-3.01	0.24	-3.49	-2.52
Estuary.River	-0.14	0.19	-0.51	0.23
OpenCoast	-0.00	0.16	-0.32	0.32
Slip	-0.30	0.33	-0.94	0.34

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
size for nbinomial obs	1.07	0.06	0.96	1.18
Precision for Year	3.93	1.52	1.81	7.68
Theta1 for w	-0.35	0.33	-0.98	0.31
Theta2 for w	-0.40	0.42	-1.24	0.41
Precision for Year-Ecotype	75.40	258.75	5.12	450.30

Equation 23. Total Catch of Non-Native Fish – Ecotype - October

Data Details:

Final sample size for the dataset was 328. Subset for only species that were determined to be "NonIndigenous". Includes individuals identified only to genus. Dropped four sites with values >200.

Model:

RowCatch = total catch of native fish

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                 compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 4919).

Test	Notes/Comments
Overdispersion	0.996 so very close, but ok!
Residuals vs Fitted	OK
Fitted vs Observed	Ok, some spread along low observed values
Residual normality	Not great, but not too important
Residuals vs Treatment	Larger variance at embayments
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 3502

Effective # Parameters = 140

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-4.67	0.25	-5.15	-4.18
Estuary.River	-0.60	0.60	-1.78	0.58
OpenCoast	-1.47	0.34	-2.15	-0.81
Slip	-3.44	1.14	-5.74	-1.24

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17982	18200	1268	65791
Theta1 for w	-4.92	0.52	-6.06	-4.00
Theta2 for w	2.72	0.32	2.16	3.41
Precision for Year-Ecotype	0.57	0.13	0.35	0.87

Equation 24. Total Catch Non-Native Fish – Region - Embayment – July

Data Details:

Final sample size for the dataset was 480. Dropped three sites with catch >425. Remove effort from the model (>900 and <1100). ** doesn't' seem to fit well OtherEast

Model:

RowCatch = total catch non-native species

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
          family = "nbinomial",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 4617).

Test	Notes/Comments
Overdispersion	Poisson model overdisperssed nbinomaial; 0.024
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, fair amount of spread
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 4609

Effective # Parameters = 32.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	3.01	1.61	0.51	5.48
OtherEast	1.15	0.37	0.39	1.84
OtherWest	0.71	0.52	-0.51	1.56
TorontoIslands	1.02	0.38	0.23	1.73
TTP	0.60	0.27	0.05	1.13

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Size nbinomial obs	1.16	0.08	1.02	1.32
Precision for Year	6.84	3.02	2.82	14.41
Theta1 for w	0.43	0.84	-1.19	2.13
Theta2 for w	-0.71	1.30	-3.31	1.81
Precision for Year-Ecotype	16840	18100	760	65365

Equation 25. Total Catch Non-Native Fish – Region - Embayment – October

Data Details:

Final sample size for the dataset was 127. Dropped three sites with catch >200. Dropped centralwF b/c of limited time range. Remove effort from the model (>900 and <1100). ** doesn't' seem to fit well OtherEast. ** model fit overall is not ideal since there is overdispersion and evidence for some spatial dependence

Model:

RowCatch = total catch non-native species

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
          f(Year, model = "rw1") +
          f(w, model = spde) +
          f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
       control.predictor = list(A = inla.stack.A(StackFitA),
                    compute = TRUE),
       family = "nbinomial",
       data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1000).

Test	**Notes/Comments**
Overdispersion	Poisson model overdispersse; still overdispersed with nbinomail
Residuals vs Fitted	No concerns
Fitted vs Observed	Very vertical…
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Some low only areas, not ideal

Model fit is poor…. Likely low sample sizes?

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 991

Effective # Parameters = 9.1

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	3.37	1.81	-0.98	7.90
OtherWest	-0.18	0.76	-1.39	1.59
TorontoIslands	-0.23	0.67	-1.48	1.11
TTP	-0.02	0.01	-0.04	0.00

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size nbinomial obs	0.88	0.11	0.68	1.12
Precision for Year	24444	25846	2285	93200
Theta1 for w	0.60	1.10	-1.45	2.89
Theta2 for w	-1.66	1.05	-3.82	0.28
Precision for Year-Ecotype	22359	23490	1841	84300

Equation 26. Total Catch Non-Native Fish – Region – Open Coast – July

Data Details:

Final sample size for the dataset was 190. Subset for only species that were determined to be "NonIndigenous". Includes individuals identified only to genus. Drop CentralWF b/c limited samples Remove effort from the model (>900 and <1100). ** UNABLE to accurately estimate for the Western region, likely due to limited timeframe and poor model fit for this region.

Model:

RowCatch = total catch of non-native fish

Model equation:

```
f4.A <- formula(RowCatch ~  -1 + Intercept + WestBluffers + Western +
            f(Year, model = "rw1") +
             f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                 compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO!** (dic without spde is 1870 vs 1870).

Test	**Notes/Comments**
Overdispersion	Poisson overdispersed; Nbinomial underdispersed?
Residuals vs Fitted	OK
Fitted vs Observed	Pretty vertical, but decent fitted spread
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower at Western sites
Variogram	No clear pattern
Spatial Residuals	Generally lower values in central and Western sites

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1870

Effective # Parameters 19.6

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	3.89	0.12	3.67	4.13
WestBluffers	0.20	0.14	-0.08	0.48
Western	0.00	31.62	-62.09	62.03

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Size of NBinom obs	1.32	0.14	1.06	1.62
Precision for Year	2.82	1.36	1.02	6.24
Precision for Year-Ecotype	18687	18700	1326	68404

Equation 27. Total Catch of Native Cyprinids– Ecotype - July

Data Details:

Final sample size for the dataset was 994. Subset for only species that were determined to be “Native” and only where identified as Cyprinids. Includes individuals identified only to genus.

Model:

RowCatch = total catch of native cyprinids

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "nbinomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 6233).

Test	**Notes/Comments**
Overdispersion	Overdisperssion with poisson; 0.35 with NBinomial, so all good
Residuals vs Fitted	Extended residuals ~ in –ve range
Fitted vs Observed	Ok, some spread along low fitted values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 6120

Effective # Parameters = 75.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-4.62	0.19	-5.00	-4.24
Estuary.River	0.64	0.31	0.03	1.25
OpenCoast	-0.48	0.25	-0.96	0.00
Slip	-0.78	0.45	-1.64	0.12

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Psize for nbinomial obs	0.50	0.03	0.45	0.56
Precision for Year	1.88	0.71	0.87	3.61
Theta1 for w	-1.73	0.52	-2.74	-0.71
Theta2 for w	0.79	0.48	-0.15	1.72
Precision for Year-Ecotype	96.74	219.9	4.74	536.9

Equation 28. Total Catch of Native Cyprinids – Ecotype - October

Data Details:

Final sample size for the dataset was 994. Subset for only species that were determined to be "Native" and only where identified as Cyprinids. Includes individuals identified only to genus.

Model:

RowCatch = total catch of native cyprinids

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 6472).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.992 so all good
Residuals vs Fitted	Extended residuals ~ in –ve range
Fitted vs Observed	Ok, some spread along low fitted values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 3595

Effective # Parameters = 140.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.24	0.31	-5.87	-4.63
Estuary.River	0.83	0.73	-0.61	2.28
OpenCoast	-2.00	0.41	-2.81	-1.21
Slip	-0.22	1.32	-2.82	2.37

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17968	18100	1235.9	65785
Theta1 for w	-4.29	0.28	-4.90	-3.78
Theta2 for w	2.21	0.20	1.85	2.66
Precision for Year-Ecotype	0.32	0.006	0.21	0.45

Equation 29. Total Catch Native Cyprinids – Region – Embayment – July

Data Details:
Final sample size for the dataset was 557. Subset for only species that were determined to be “Native” and only where identified as Cyprinids. Includes individuals identified only to genus. Remove seven sites with catch >150.

Model:
RowCatch = total catch of native cyprinids
Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 9251).

Test	Notes/Comments
Overdispersion	Poisson = 0.999, so ok
Residuals vs Fitted	Extended fitted
Fitted vs Observed	Ok, some spread along low fitted values
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower variance at centralWF
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 6371
Effective # Parameters = 169.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-7.46	0.95	-9.39	-5.65
OtherEast	2.28	1.48	-0.61	5.26
OtherWest	1.86	1.11	-0.30	4.09
TorontoIslands	1.46	1.21	-0.93	3.85
TTP	2.32	1.18	0.04	4.70

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17364	17900	1191	64528
Theta1 for w	-4.60	0.43	-5.53	-3.81
Theta2 for w	2.29	0.31	1.73	2.95
Precision for Year-Ecotype	0.28	0.07	0.15	0.41

Equation 30. Total Catch Native Cyprinids – Region – Embayment – October

Data Details:

Final sample size for the dataset was 172. Subset for only species that were determined to be "Native" and only where identified as Cyprinids. Includes individuals identified only to genus. Remove four sites with catch >150. ** lots of gap in the data so high variance in years with no data.

Model:

RowCatch = total catch of native cyprinids

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                       compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 9251).

Test	**Notes/Comments**
Overdispersion	Poisson = 0.976, so ok
Residuals vs Fitted	Extended fitted
Fitted vs Observed	Ok, good range
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower variance at centralWF and Toronto Islands
Variogram	No clear pattern
Spatial Residuals	Smaller residuals at Islands and Western sites

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1530
Effective # Parameters = 88.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-8.74	1.96	-12.83	-5.09
OtherEast	5.05	2.28	0.71	9.70
OtherWest	2.98	2.11	-1.01	7.30
TorontoIslands	1.32	2.12	-2.71	5.66
TTP	3.51	2.08	-0.40	7.79

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	0.33	0.15	0.13	0.71
Theta1 for w	-4.56	0.53	-5.65	-3.57
Theta2 for w	2.31	0.38	1.61	3.09
Precision for Year-Ecotype	0.76	0.24	0.39	1.31

Equation 31. Total Catch Native Cyprinids – Region – Open Coast - July

Data Details:

Final sample size for the dataset was 204. Subset for only species that were determined to be "Native" and only where identified as Cyprinids. Includes individuals identified only to genus. Dropped central waterfront b/c of limited time spread.

Model:

RowCatch = total catch of native cyprinids

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2408).

Test	**Notes/Comments**
Overdispersion	Poisson = 0.94, so ok
Residuals vs Fitted	Extended fitted
Fitted vs Observed	Ok, pretty good fit
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower variance at Western sites
Variogram	No clear pattern
Spatial Residuals	Ok , but some lower residuals in Western sites

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1422.7

Effective # Parameters = 86.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-5.54	0.37	-6.28	-4.80
OtherEast	-0.52	0..61	-1.74	0.65
OtherWest	-0.18	0.91	-2.01	1.59

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	0.70	0.44	0.22	1.86
Theta1 for w	-3.79	0.50	-4.81	-2.84
Theta2 for w	2.14	0.40	1.39	2.94
Precision for Year-Ecotype	0.77	0.26	0.38	1.37

Equation 32. Total Catch Native Cyprinids – Region – Open Coast - October

Data Details:

Final sample size for the dataset was 76. Subset for only species that were determined to be “Native” and only where identified as Cyprinids. Includes individuals identified only to genus.
Dropped central waterfront b/c of limited time spread. Dropped one site with very high catch (>700 – in Western region). Lots of data gaps therefore output is challenging to interpret.

Model:

RowCatch = total catch of native cyprinids

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                 compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 497).

Test	Notes/Comments
Overdispersion	Poisson = 0.874, so ok
Residuals vs Fitted	Extended fitted and extended along 0-fitted, not ideal
Fitted vs Observed	Ok, pretty good fit
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower variance at Western and wester bluffers relative to east bluffers
Variogram	No clear pattern
Spatial Residuals	Not great, clearly higher values in east bluffers

Model is suspect given biased residuals driven by values at east bluffers.

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 323
Effective # Parameters = 40.3

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.47	1.59	-10.05	-3.09
OtherEast	-0.64	1.63	-3.81	2.79
OtherWest	-1.40	2.46	-6.88	3.76

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	0.24	0.10	0.09	0.49
Theta1 for w	-1.30	0.50	-2.26	-0.30
Theta2 for w	-0.57	0.75	-2.09	0.86
Precision for Year-Ecotype	4.46	3.52	0.80	13.73

Equation 33. Total Species Richness- Ecotype - July

Data Details:

Final sample size for the dataset was 983. Filtered out species that were not identified to genus, filtered out unk, filtered out hybrids.

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 4844.6).

Test	Notes/Comments
Overdispersion	0.43 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 4690.6

Effective # Parameters = 76.6

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-4.74	0.06	-4.87	-4.62
Estuary.River	-0.23	0.09	-0.40	-0.06
OpenCoast	-0.52	0.07	-0.66	-0.39
Slip	-0.79	0.15	-1.09	-0.50

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	191	150	45.5	590
Theta1 for w	-0.72	0.49	-1.75	0.18
Theta2 for w	0.82	0.46	-0.02	1.77
Precision for Year-Ecotype	298000	2260000	385	114000

Equation 34. Total Species Richness – Ecotype - October

Data Details:

Final sample size for the dataset was 322. Filtered out species that were not identified to genus, filtered out unk, filtered out hybrids.

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1638).

Test	Notes/Comments
Overdispersion	0.61 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Lower variance for estuaries
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1597

Effective # Parameters = 39.34

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-4.75	0.08	-4.93	-4.59
Estuary.River	-0.21	0.11	-0.43	0.01
OpenCoast	-0.65	0.08	-0.81	-0.48
Slip	-0.70	0.18	-1.04	-0.35

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	105.4	82.1	24.02	322.4
Theta1 for w	0.01	0.65	-1.29	1.24
Theta2 for w	0.25	0.64	-1.00	1.52
Precision for Year-Ecotype	8362	9777.8	172.1	34408.9

Equation 35. Total Species Richness – Region - Embayment – July

Data Details:

Final sample size for the dataset was 565. Set species that were not identified to genus/unk/hybrids to zero (not counted).

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
          offset(log(Effort) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2897).

Test	Notes/Comments
Overdispersion	Poisson model is ok 0.521
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, a bit vertical
Residual normality	Not great, but not too important
Residuals vs Treatment	One clear outlier in slips (residual >15)
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2854

Effective # Parameters = 31.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-4.93	0.14	-5.22	-4.67
OtherEast	0.22	0.17	-0.13	0.56
OtherWest	0.19	0.17	-0.13	0.54
TorontoIslands	0.29	0.18	-0.04	0.68
TTP	0.22	0.13	-0.04	0.47

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	15827	17400	825	62819
Theta1 for w	-0.10	0.67	-1.43	1.21
Theta2 for w	0.64	0.77	-0.86	2.16
Precision for Year-Ecotype	5229	8740	428.6	25522

Equation 36. Total Species Richness – Region - Embayment – October

Data Details:

Final sample size for the dataset was 565. Set species that were not identified to genus/unk/hybrids to zero (not counted).

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
         offset(log(Effort) +
           f(Year, model = "rw1") +
           f(w, model = spde) +
           f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 918).

Test	Notes/Comments
Overdispersion	Poisson model is ok 0.525
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, a bit vertical
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 904

Effective # Parameters = 32.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.21	0.29	-5.83	-4.71
OtherEast	0.51	0.31	-0.04	1.16
OtherWest	0.45	0.30	-0.10	1.09
TorontoIslands	0.52	0.30	-0.02	1.16
TTP	0.60	0.29	0.09	1.23

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17735	17987	1054	65678
Theta1 for w	-0.13	1.53	-2.82	3.14
Theta2 for w	0.80	1.33	-2.03	3.15
Precision for Year-Ecotype	206.6	291.9	28.5	908.2

Equation 37. Total Species Richness – Region – Open Coast - July

Data Details:
Final sample size for the dataset was 213. Set species that were not identified to genus/unk/hybrids to zero (not counted).

Model:
RowCatch = total species richness
Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + EastBluffers + WestBluffers  + Western  +
            offset(log(Effort) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                   compute = TRUE),
          family = "poisson",
          data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **NO!** (dic without spde is 942).

Test	**Notes/Comments**
Overdispersion	Poisson model is ok 0.391
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, a bit vertical
Residual normality	Not great, but not too important
Residuals vs Treatment	Less variance at centralWF
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, lower values in far west

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 929.7
Effective # Parameters = 14.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-5.89	0.24	-6.37	-5.43
EastBluffers	0.75	0.56	0.24	1.26
WestBluffers	0.41	0.26	-0.09	0.93
Western	0.93	0.27	0.40	1.46

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	15600	16934	672.1	10300
Theta1 for w	0.37	1.36	-2.14	3.19
Theta2 for w	0.15	1.29	-2.52	2.53
Precision for Year-Ecotype	18700	18408	1239	67356

Equation 38. Total Species Richness – Region – Open Coast - October

Data Details:

Final sample size for the dataset was 80. Set species that were not identified to genus/unk/hybrids to zero (not counted).

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + EastBluffers + WestBluffers  + Western  +
            offset(log(Effort) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                   compute = TRUE),
          family = "poisson",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO!** (dic without spde is 349).

Test	Notes/Comments
Overdispersion	Poisson model is ok 0.683
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, a bit vertical
Residual normality	Not great, but not too important
Residuals vs Treatment	Less variance at centralWF and westbluffers
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, lower values in far west

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 352.8

Effective # Parameters = 32.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.49	0.69	-6.72	-3.98
EastBluffers	0.01	0.42	-1.09	0.64
WestBluffers	-0.21	0.37	-1.08	0.42
Western	0.56	0.33	-0.04	1.28

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	18154	22822	937	78747
Theta1 for w	1.25	1.19	-1.03	3.65
Theta2 for w	-0.59	1.63	-3.69	2.71
Precision for Year-Ecotype	11636	16565	121.3	56855

Equation 39. Total Native Species Richness – Ecotype - July

Data Details:

Final sample size for the dataset was 994. Set species that were not identified to genus/unk/hybrids to zero (not counted) and set species defined as non-native to zero as well. Subset for only species that were determined to be "Native".

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 4577.2).

Test	Notes/Comments
Overdispersion	0.49 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 4409.3

Effective # Parameters = 74.0

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.06	0.08	-5.22	-4.90
Estuary.River	-0.23	0.10	-0.44	-0.03
OpenCoast	-0.72	0.08	-0.88	-0.56
Slip	-0.88	0.20	-1.27	-0.50

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	223.8	215.7	43.1	787
Theta1 for w	-0.72	0.48	-1.75	0.15
Theta2 for w	0.62	0.46	-0.19	1.59
Precision for Year-Ecotype	2655.3	5932.9	204.4	14500

Equation 40. Total Native Species Richness – Ecotype - October

Data Details:

Final sample size for the dataset was 322. Filtered out species that were not identified to genus, filtered out unk, filtered out hybrids. Subset for only species that were determined to be “Native”.

Model:

RowCatch = total species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1543).

Test	Notes/Comments
Overdispersion	0.58 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Lower variance for estuaries
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1516

Effective # Parameters = 42.7

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.10	0.13	-5.38	-4.83
Estuary.River	-0.26	0.13	-0.52	0.00
OpenCoast	-0.73	0.11	-0.94	-0.52
Slip	-0.50	0.24	-0.95	-0.01

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	87.1	90.1	13.1	323.0
Theta1 for w	0.41	0.47	-0.52	1.33
Theta2 for w	-0.37	0.56	-1.48	0.73
Precision for Year-Ecotype	1657.3	7673.0	9.08	11196.1

Equation 41. Total Native Species Richness – Region - Embayment - July

Data Details:

Final sample size for the dataset was 567. Subset for only species that were determined to be "Native". Includes individuals identified only to genus.

Model:

RowCatch = total richness of native fishes

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
          offset(log(Effort) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2801).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	All good =0.568
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, more spread at higher values
Residual normality	Not great, but not too important
Residuals vs Treatment	No concrns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2753

Effective # Parameters = 33.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.26	0.19	-5.67	-4.88
OtherEast	0.20	0.23	-0.27	0.65
OtherWest	0.17	0.24	-0.28	0.68
TorontoIslands	0.44	0.24	0.00	0.96
TTP	0.22	0.15	-0.08	0.51

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	10700	13800	134	48402
Theta1 for w	0.04	0.55	-1.05	1.12
Theta2 for w	0.25	0.69	-1.11	1.60
Precision for Year-Ecotype	1570	1900	228.7	6501.5

Equation 42. Total Native Species Richness – Region – Embayment – October

Data Details:

Final sample size for the dataset was 176. Subset for only species that were determined to be “Native”. Includes individuals identified only to genus. Dropped centralWF b/c low numbers. SPDE model is not “better”, can try dropping this model.
Model not predicting well.

Model:

RowCatch = total richness of native fishes

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
         offset(log(Effort) +
           f(Year, model = "rw1") +
           f(w, model = spde) +
           f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 794).

Test	Notes/Comments
Overdispersion	All good =0.607
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok,
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 793
Effective # Parameters = 19.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.14	0.59	-6.36	-3.98
OtherWest	0.21	0.09	0.03	0.37
TorontoIslands	0.15	0.08	-0.01	0.31
TTP	0.00	0.04	-0.07	0.08

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	33.9	24.5	8.40	98.5
Precision for Year-Ecotype	12066	15117	184.6	53119

Equation 43. Total Native Species Richness – Region – Open Coast - July

Data Details:

Final sample size for the dataset was 204. Subset for only species that were determined to be “Native”. Includes individuals identified only to genus. Count number of species. Exclude central WF b/c low reps.

Model:

RowCatch = total richness of native fishes

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + WestBluffers + Western +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                 compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 796).

Test	Notes/Comments
Overdispersion	Poisson = 0.513
Residuals vs Fitted	Ok, limited spread in fitted values (max 6)
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	No concerns

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 775

Effective # Parameters = 9.91

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.67	0.59	-6.99	-4.40
Region WestBluffers	-0.34	0.56	-0.84	0.18
Region Western	0.25	0.47	-0.72	1.26

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	14759	16300	547.5	57900
Theta1 for w	1.44	0.68	0.17	2.85
Theta2 for w	-1.48	0.96	-3.49	0.26
Precision for Year-Ecotype	18282	18200	1162	66700

Equation 44. Non-native Species Richness – Ecotype - July

Data Details:

Final sample size for the dataset was 994. Set species that were not identified to genus/unk/hybrids to zero (not counted) and set species defined as non-native to zero as well.

Model:

RowCatch = total non-native species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
          offset(log(Effort)) +
          f(Year, model = "rw1") +
          f(w, model = spde) +
          f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
       control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
       family = "poisson",
       data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2975).

Test	Notes/Comments
Overdispersion	0.244 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	Limited range
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2958

Effective # Parameters = 24.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.11	0.11	-6.32	-5.86
Estuary.River	-0.15	0.09	-0.33	0.02
OpenCoast	-0.06	0.08	-0.22	0.10
Slip	-0.48	0.13	-0.73	-0.23

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	149.5	110	36.8	439
Theta1 for w	1.79	0.63	0.52	3.01
Theta2 for w	-1.03	0.73	-2.42	0.43
Precision for Year-Ecotype	88764.7	11500	84.42	40700

Equation 45. Non-Native Species Richness - Ecotype- October

Data Details:

Final sample size for the dataset was 322. Set species that were not identified to genus/unk/hybrids to zero (not counted) and set species defined as non-native to zero as well.

Model:

RowCatch = total non-native species richness

Model equation:

```
f4 <- formula(RowCatch ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 998.1).

Test	**Notes/Comments**
Overdispersion	0.56 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	Small range
Residual normality	No concerns
Residuals vs Treatment	Lower variance for estuaries
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, lower in west

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1000.6
Effective # Parameters = 12.1

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.21	0.14	-6.48	-5.91
Estuary.River	-0.13	0.15	-0.43	0.17
OpenCoast	-0.33	0.13	-0.59	-0.09
Slip	-0.69	0.24	-1.16	-0.23

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	18688	18448	1267	67435
Theta1 for w	0.900	1.05	-1.23	2.92
Theta2 for w	-0.43	1.06	-2.45	1.71
Precision for Year-Ecotype	17336	17723.7	988.4	64738.3

Equation 46. Non-Native Species Richness – Region - Embayment – July

Data Details:

Final sample size for the dataset was 567. Model without SPDE is has very similar DIC and actually will yield some predictions, can try this one and see if works better…it does (actually predicts real data). So, using this approach.

Model:

RowCatch = total richness non-native species

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
          offset(log(Effort) +
            f(Year, model = "rw1") +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO** (dic without spde is 1712).

Test	Notes/Comments
Overdispersion	Poisson = 0.304
Residuals vs Fitted	No concerns
Fitted vs Observed	Smaller range for predictions (max 4 vs 5)
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1712

Effective # Parameters = 10.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.35	0.12	-6.60	-6.12
OtherEast	0.23	0.15	-0.06	0.52
OtherWest	0.34	0.13	0.09	0.61
TorontoIslands	-0.01	0.14	-0.27	0.27
TTP	0.236	0.14	-0.02	0.51

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	941.9	1477	94.5	4408
Precision for Year-Ecotype	20807	19412	1862.7	72354

Equation 47. Non-Native Species Richness – Region - Embayment – October

Data Details:
Final sample size for the dataset was 176.
Model without SPDE is has very similar DIC and actually will yield some predictions, can try this one and see if works better…it does (actually predicts real data). So, using this approach. Pretty patchy data…

Model:
RowCatch = total richness non-native species

Model equation:

```
f4 <- formula(RowCatch ~ -1 + Intercept + OtherEast + OtherWest+ TorontoIslands+ TTP+
         offset(log(Effort) +
           f(Year, model = "rw1") +
           f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **NO** (dic without spde is 524 (vs 525 for SPDE).

Test	**Notes/Comments**
Overdispersion	Poisson = 0.719
Residuals vs Fitted	No concerns
Fitted vs Observed	Smaller range for predictions (max 4 vs 5)
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Some Western sites with negative residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 524
Effective # Parameters = 5.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.23	0.18	-6.61	-5.89
OtherEast	0.30	0.22	-0.12	0.73
OtherWest	0.00	0.21	-0.41	0.43
TorontoIslands	-0.27	0.23	-0.71	0.19
TTP	0.10	0.21	-0.29	0.52

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	17752	17927	1075	65558
Precision for Year-Ecotype	19118	1857	1402	67980

Equation 48. Non-Native Species Richness – Region – Open Coast – July

Data Details:

Final sample size for the dataset was 204. Subset for only species that were determined to be "NonIndigenous". Includes individuals identified only to genus. Drop CentralWF b/c limited samples
Using model without SPDE

Model:

RowCatch = total richness of non-native fish

Model equation:

```
f4.A <- formula(RowCatch ~  -1 + Intercept + WestBluffers + Western +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO!** (dic without spde is 659 vs 660).

Test	**Notes/Comments**
Overdispersion	0.634 – all good
Residuals vs Fitted	OK
Fitted vs Observed	Pretty vertical, with fitted limited to ~3 (v 6 for observed)
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Generally lower values in Western sites

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 659
Effective # Parameters = 3.9

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.05	0.06	-6.17	-5.93
WestBluffers	-0.19	0.12	-0.43	0.04
Western	0.04	0.13	-0.23	0.29

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	18726	18431	1287	67385
Precision for Year-Ecotype	17787	17976	1070	65694

Equation 49. Non-Native Species Richness – Region – Open Coast – October

Data Details:

Final sample size for the dataset was 85. Subset for only species that were determined to be "NonIndigenous". Includes individuals identified only to genus. Using model without SPDE. V low sample size.

Model:

RowCatch = total richness of non-native fish

Model equation:

```
f4.A <- formula(RowCatch ~  -1 + Intercept + EastBluffers  + WestBluffers + Western +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **NO!** (dic without spde is 262 vs 262).

Test	**Notes/Comments**
Overdispersion	0.883– all good
Residuals vs Fitted	OK
Fitted vs Observed	Pretty vertical, with fitted limited to ~3 (v 6 for observed)
Residual normality	Not great, but not too important
Residuals vs Treatment	Lower spread at CentralWF and Western
Variogram	No clear pattern
Spatial Residuals	Generally lower values in Western sites

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 3502

Effective # Parameters = 3.9

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.76	0.33	-7.47	-6.16
EastBluffers	0.26	0.35	-0.39	1.00
WestBluffers	0.07	0.42	-0.73	0.91
Western	0.54	0.39	-0.18	1.33

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	18355	18250	1196	66755
Precision for Year-Ecotype	17936	18063	1095	66020

Equation 50. PPB – Ecotype – July

Data Details:
Final sample size for the dataset was 981. Zero inflated, which poses a challenge (350-981 with zeros). Try first with including zeros following data transformation recommend in Zuur and Ieno (2018). df2$PPB.Beta<-((df2$PPB/100)*(nrow(df2)-1)+0.5)/nrow(df2). Generally model fit is poor, but not any better if zeros are dropped. Suggests that treatment and year are poor predictors of PPB. For this parameter, majority of observations are less than target of 0.2. GLM fit with Gaussian would suggest increasing trend at all habitat types, but only Slips would come close to this.

Model:
PPB.Beta = transformed ppb

Model equation:

```
f4 <- formula(PPB.Beta ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is -10729).

Test	**Notes/Comments**
Overdispersion	Unclear how to calc.
Residuals vs Fitted	Odd, likely b/c of zero inflation
Fitted vs Observed	Very poor fit, vertical around 0.002
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok, fewer negatives on margins

Original model with offset(log(Effort)) had terrible fit, trying now with that component removed.

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -10771
Effective # Parameters = 32.5

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.29	0.19	-6.63	-5.92
Estuary.River	-0.18	0.11	-0.40	0.04
OpenCoast	-0.21	0.10	-0.40	-0.03
Slip	0.02	0.16	-0.30	0.34

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precison for beta obs.	844.0	30.6	779.4	899
Precision for Year	23993	31900	2086.1	104000
Theta1 for w	0.82	0.35	0.14	1.51
Theta2 for w	-0.60	0.86	-2.07	1.27
Precision for Year-Ecotype	16577.9	20100	507	70400

Equation 51. PPB – Ecotype – October

Data Details:

Final sample size for the dataset was 328. Zero inflated, which poses a challenge (83/322 with zeros). Transformed like July data.

Model:

PPB.Beta = transformed PPB

Model equation:

```
f4 <- formula(PPB.Beta ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is -3018).

Test	Notes/Comments
Overdispersion	Not sure how to calc
Residuals vs Fitted	Ok, zeros show up as line
Fitted vs Observed	Observed range compressed as is fitted…
Residual normality	Not great, but not that important
Residuals vs Treatment	No concerns
Variogram	No clear patterns
Spatial Residuals	Ok, no clear patterns

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -3045

Effective # Parameters = 13.9

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-5.37	0.34	-6.15	-4.60
Estuary.River	0.06	0.14	-0.22	0.32
OpenCoast	-0.17	0.12	-0.40	0.06
Slip	-0.18	0.17	-0.52	0.16

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precison for beta obs	477.8	40.5	402	561.1
Precision for Year	17840	20100	979.7	71345
Theta1 for w	1.59	0.55	0.50	2.68
Theta2 for w	-1.59	0.67	-2.91	-0.26
Precision for Year-Ecotype	18607.2	18400	1174.9	67525.3

Equation 52. PPB – Region - Embayment – July - without zeroes

Data Details:

Final sample size for the dataset was 423. Data are zero-inflated…350/631 with zeros
Remove where PPB = 0.

Model:

PPB.Beta = raw PPB

Model equation:

```
f4 <- formula(PPB.Beta ~ -1 + Intercept +  OtherEast  +  OtherWest+ TorontoIslands+ TTP+
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "beta",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is -899).

Test	Notes/Comments
Overdispersion	Not sure how to calc
Residuals vs Fitted	Ok
Fitted vs Observed	Near linear
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = -905
Effective # Parameters = 15.2

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-2.17	0.35	-2.88	-1.48
OtherEast	0.20	0.40	-0.58	1.02
OtherWest	0.13	0.41	-0.67	0.95
TorontoIslands	0.59	0.40	-0.18	1.40
TTP	0.22	0.33	-0.46	0.86

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision beta obs	4.72	0.35	4.06	5.45
Precision for Year	27011	33000	2130	113000
Theta1 for w	-0.36	0.80	-1.94	1.2
Theta2 for w	0.30	0.86	-1.36	2.02
Precision for Year-Ecotype	27724	33800	2343	11600

Equation 53. PPB – Region - Embayment – October - without zeroes

Data Details:
Final sample size for the dataset was 423. Data are zero-inflated…350/631 with zeros
Remove where PPB = 0. Exclude centralWF b/c of limited dataset.

Model:
PPB.Beta = raw PPB
Model equation:

```
f4 <- formula(PPB.Beta ~ -1 + Intercept +  OtherWest+ TorontoIslands+ TTP+
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year-Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
           control.predictor = list(A = inla.stack.A(StackFitA),
                                    compute = TRUE),
           family = "beta",
           data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is -160).

Test	**Notes/Comments**
Overdispersion	Not sure how to calc
Residuals vs Fitted	Gaps in fitted values, possible not complete range of values?
Fitted vs Observed	Some spread, but gap is still evident in fitted values
Residual normality	OK, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, some higher positives around central waterfront

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -168
Effective # Parameters = 13.9

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	0.07	0.35	-0.63	0.78
OtherWest	-1.70	0.48	-2.68	-0.77
TorontoIslands	-1.43	0.48	-2.39	-0.47
TTP	-1.39	0.48	-2.36	-0.41

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision beta obs	3.77	0.63	2.83	5.27
Precision for Year	19552	19200	1486	70400
Theta1 for w	-1.89	1.02	-3.95	0.04
Theta2 for w	1.43	0.88	-0.26	3.20
Precision for Year-Ecotype	20326	19900	1634	73300

Equation 54. PPB – Region – Open Coast – July - without zeroes

Data Details:
Final sample size for the dataset was 125. Data are zero-inflated…350/631 with zeros. Remove where PPB = 0.

Model:
PPB.Beta = raw PPB

Model equation:

```
f4 <- formula(PPB.Beta ~  -1 + Intercept + WestBluffers + Western +
              f(Year, model = "rw1") +
               f(w, model = spde) +
               f(Year-Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
           control.predictor = list(A = inla.stack.A(StackFitA),
                                    compute = TRUE),
           family = "beta",
           data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is -190.5).

Test	Notes/Comments
Overdispersion	Not sure how to calc
Residuals vs Fitted	Pretty vertical fit.
Fitted vs Observed	Near linear
Residual normality	OK, but not too important
Residuals vs Treatment	Less variance at Western sites
Variogram	No clear pattern
Spatial Residuals	Generally negative residuals at Western sites, likely will overpredict here

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = -190.2
Effective # Parameters = 5.4

Table: Posterior mean values, standard deviations, and 95% credible intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-1.52	2.82	-5.24	2.14
OtherEast	-0.42	0.47	-1.23	0.69
TTP	0.01	0.01	-0.01	0.03

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision beta obs	2.61	0.33	2.0	3.31
Precision for Year	19376	19400	1360	71059
Theta1 for w	1.13	1.81	-2.65	4.51
Theta2 for w	-0.43	2.36	-4.76	4.48
Precision for Year-Ecotype	18433	18300	1232	66836

APPENDIX B: TRENDS IN ENVIRONMENTAL CONDITIONS

During the exploration of available datasets related to environmental conditions, alternate figures were developed and these are presented here if of interest.

Ice Cover:

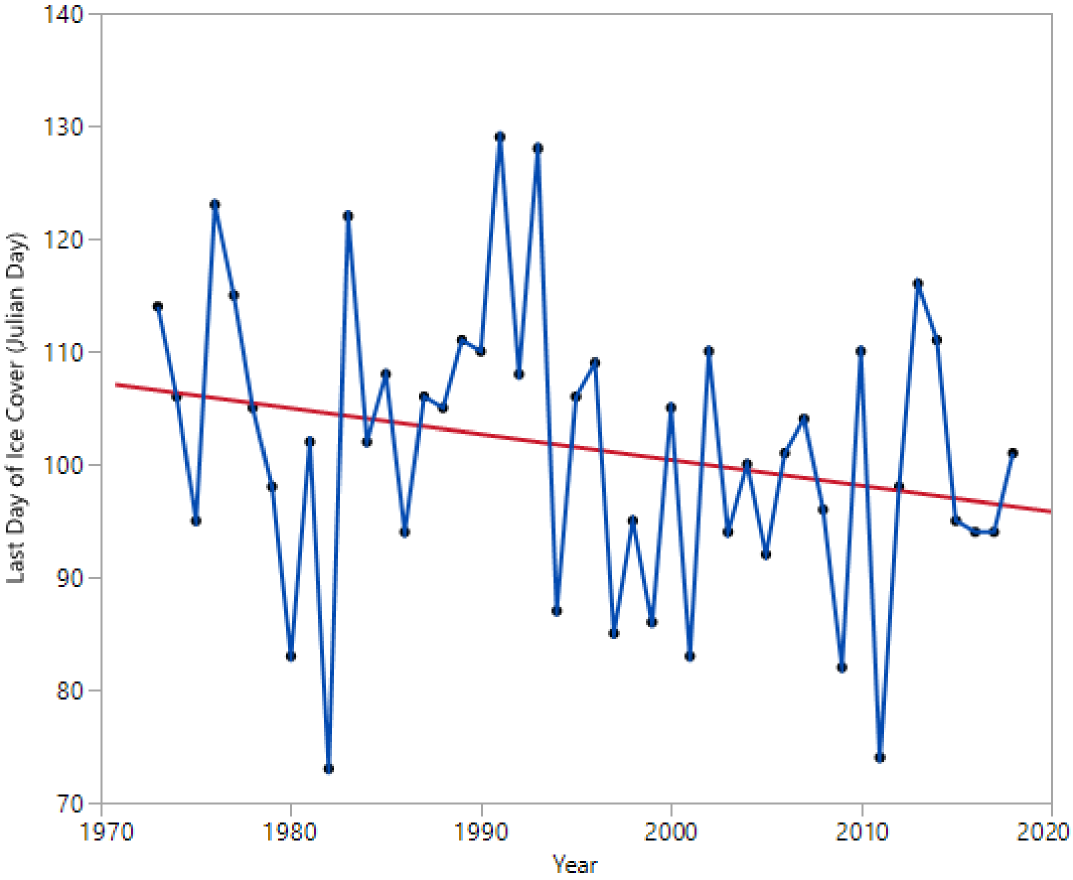

Figure B1. Last day of ice coverage (Julian Day). There is a linear relationship, but not statistically significant P = 0.052. If only data from RAP years is used (1988 **–** present) then there is a significant linear relationship (P = 0.047). Very mild winter in 1982/1983 made the relationship no longer significant, according to the P value. Very strong El Nino year in 1982/83 (https://ggweather.com/enso/oni.htm). Note that this is based on Pacific ocean temps, a number of other factors influence how El Nino or La Nina is manifested in the Great Lakes.

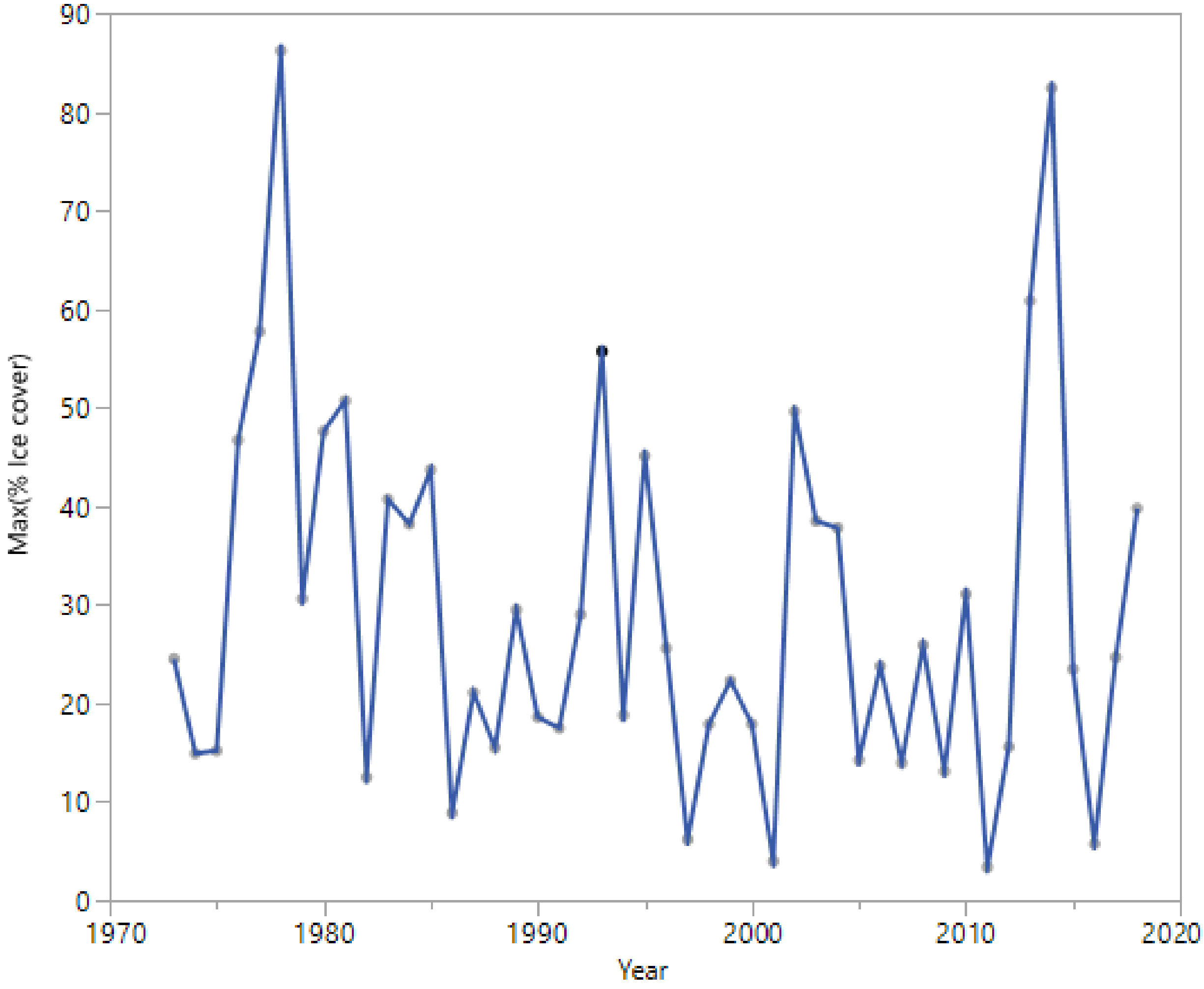

Figure B2. Maximum percent ice cover for the year. No significant linear trend.

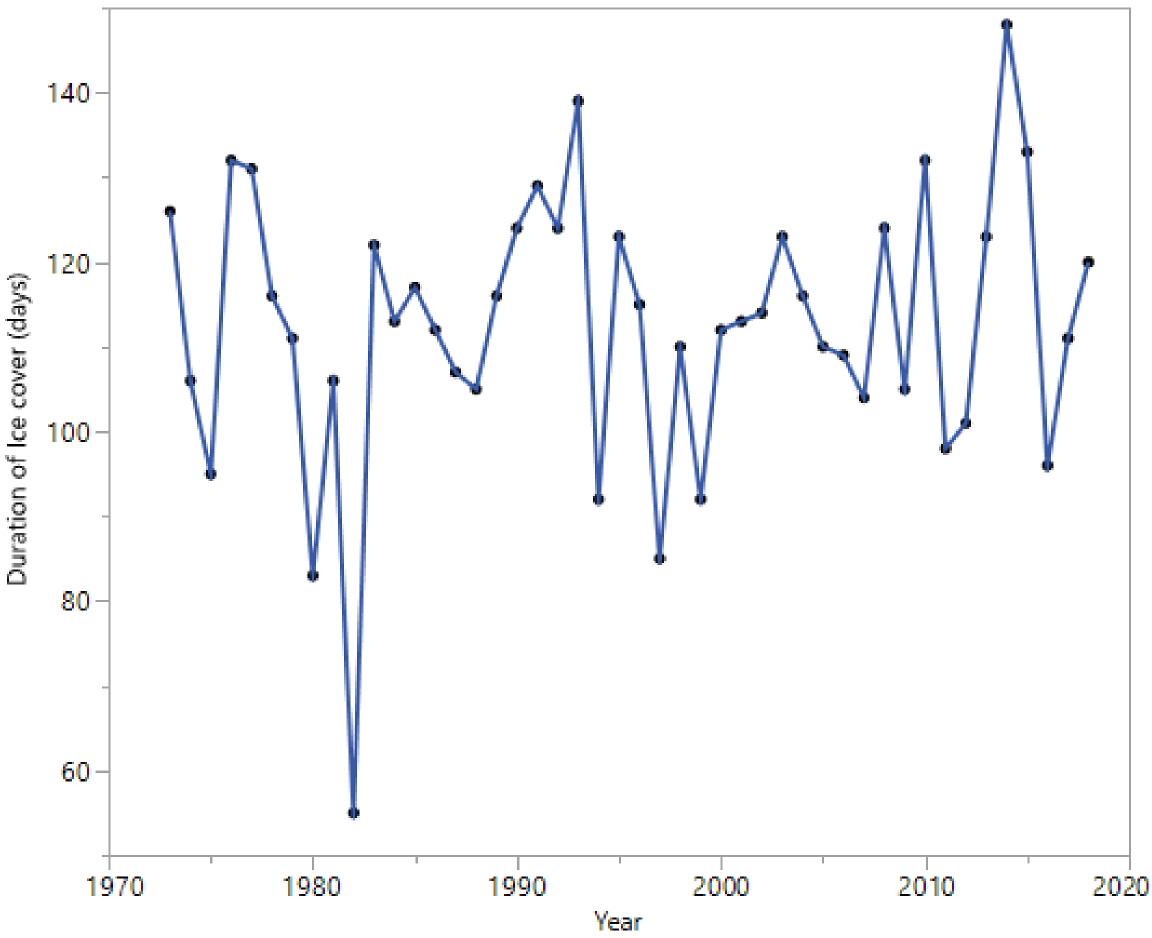

Figure B3. Last Duration of ice coverage. No significant linear trend. The winter of 1982/83 was an El Nino year.

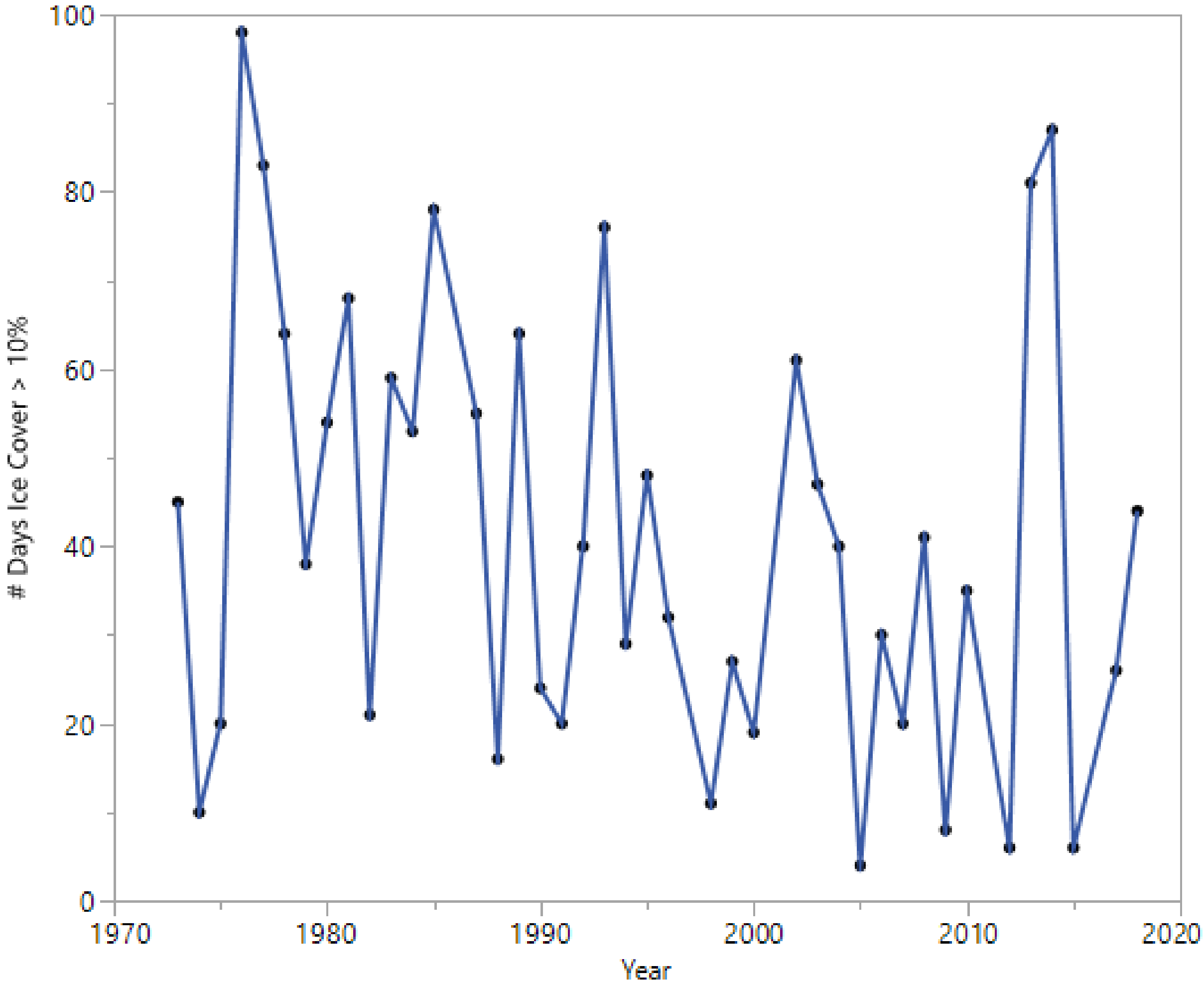

Figure B4. The number of days where Ice cover was greater than 10%. No significant linear trend.

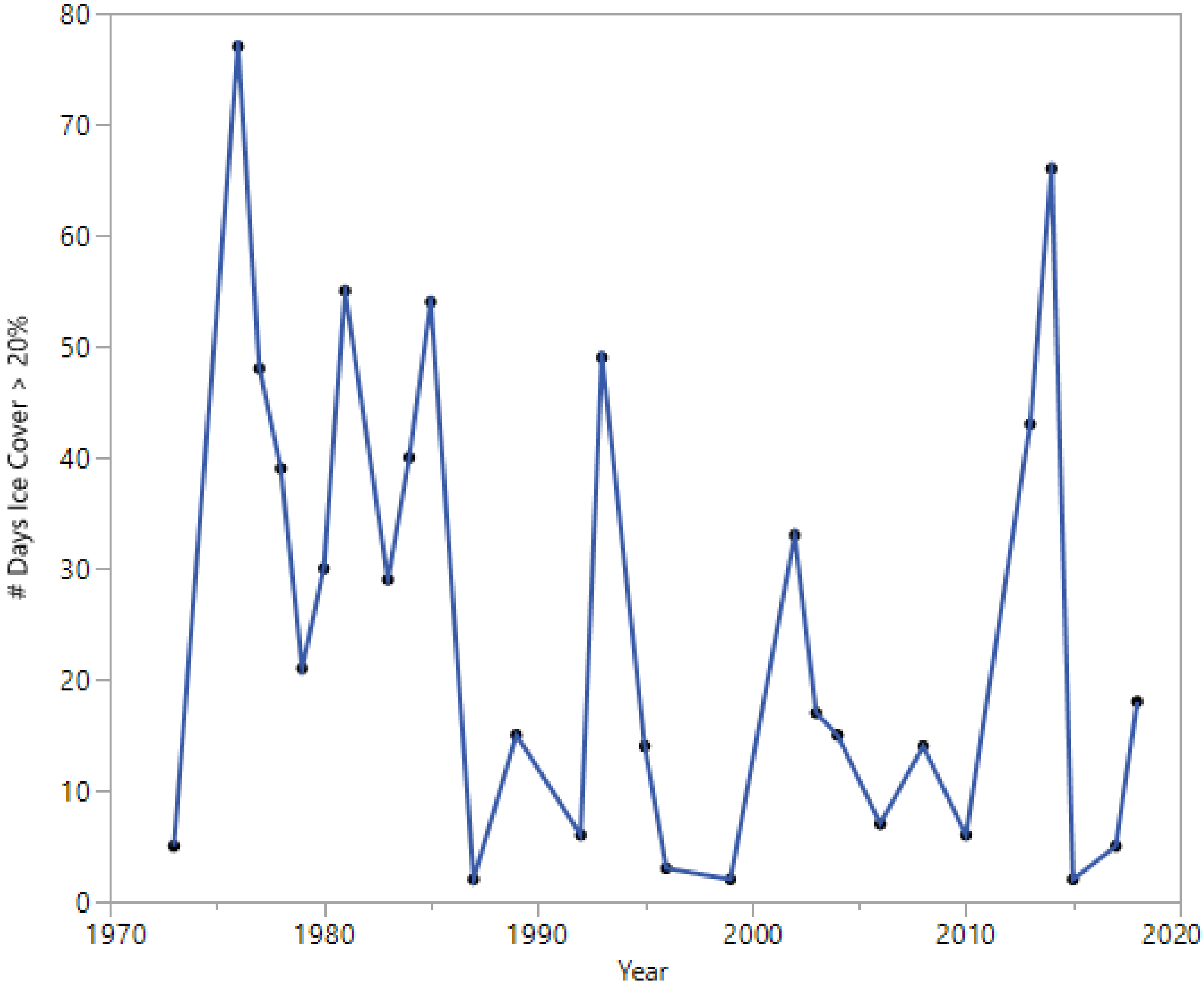

Figure B5. Number of days that the ice cover was > 20%. No significant linear trend.

__Water Levels:__

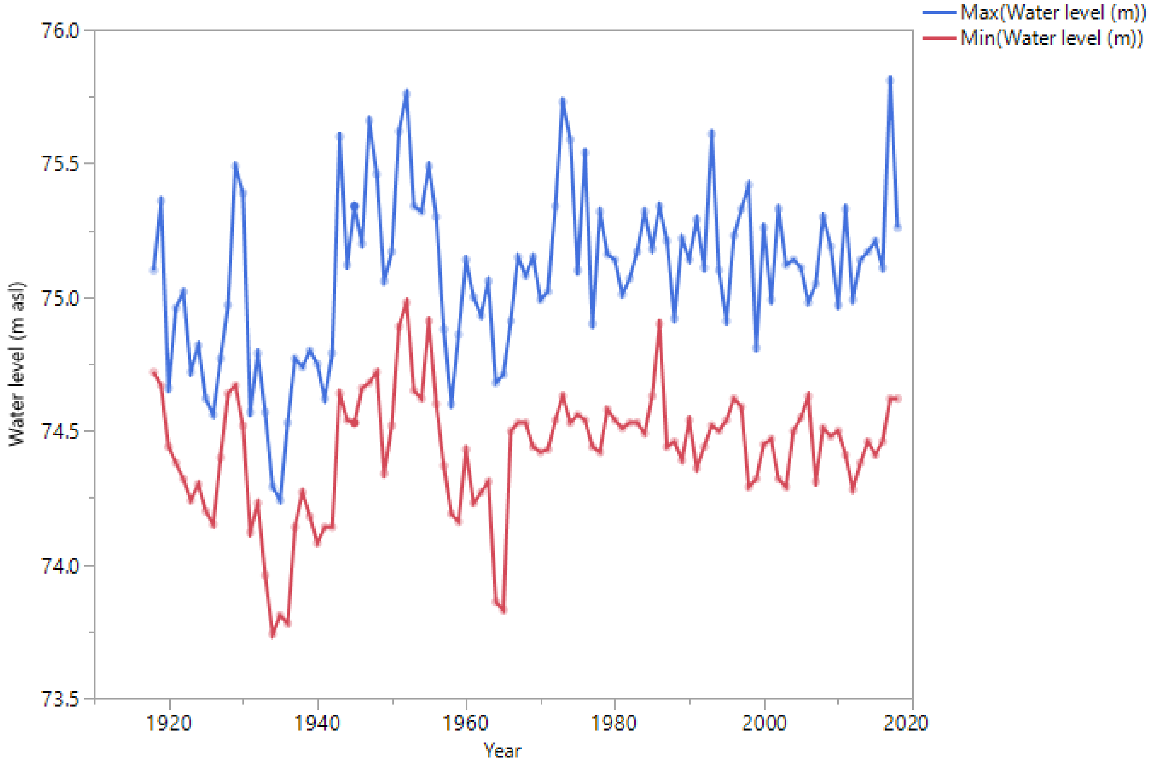

Figure B6. Max and Min water levels in Lake Ontario.

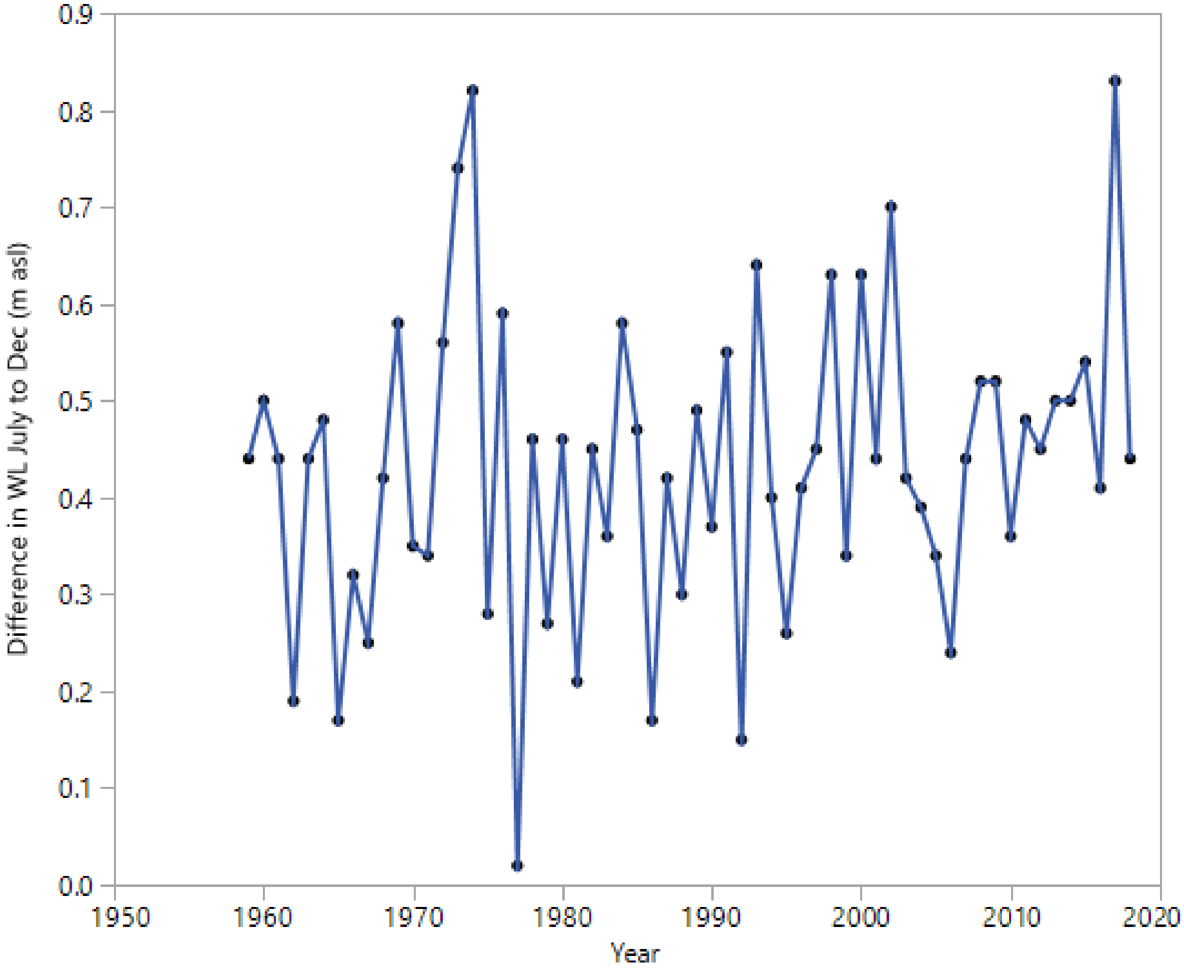

Figure B7. Difference in water level between July and October.

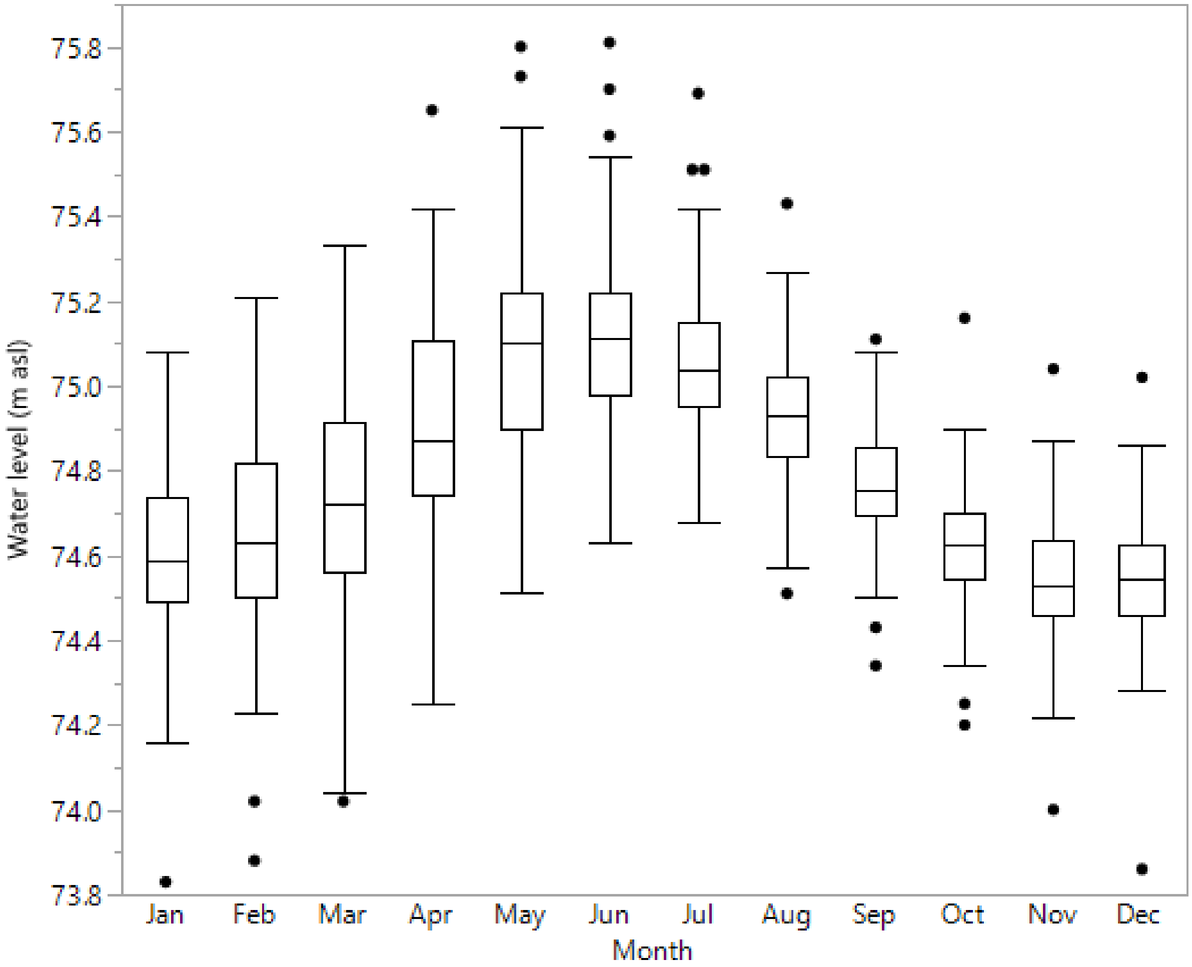

Figure B8. Box plots of water levels per month 1959 – 2018.

APPENDIX C: FISH SPECIES CHARACTERISTICS

Table C1. Fish species assignments as native, non-native, Centrarchidae, Cyprinids, Piscivores and whether they are considered an offshore species (if so, they are excluded during calculation of the adjusted index of biotic integrity). Common names are derived from the species or groups that were identified in the Toronto and Region Conservation Authority electrofishing dataset.

Common Name	Species	Native	Non-Native	Centrarchidae	Cyprinid	Piscivore	Offshore
Alewife	*Alosa pseudoharengus*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE
Ameiurus sp.	*Ameiurus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
American Brook Lamprey	*Lethenteron appendix*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
American Eel	*Anguilla rostrata*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Atlantic Salmon	*Salmo salar*	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE
Banded Killifish	*Fundulus diaphanus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Bigmouth Buffalo	*Ictiobus cyprinellus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Black Crappie	*Pomoxis nigromaculatus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Blacknose Dace	*Rhinichthys atratulus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Bluegill	*Lepomis macrochirus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Bluntnose Minnow	*Pimephales notatus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Bowfin	*Amia calva*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Brook Silverside	*Labidesthes sicculus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Brook Stickleback	*Culaea inconstans*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Brown Bullhead	*Ameiurus nebulosus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Brown Trout	*Salmo trutta*	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE
Burbot	*Lota lota*	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE
Catostomidae	*Catostomus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Central Mudminnow	*Umbra limi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Central Stoneroller	*Campostoma stoneroller*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE

Chinook Salmon	*Oncorhynchus tshawytscha*	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE
Coho Salmon	*Oncorhynchus kisutch*	FALSE	TRUE	FALSE	FALSE	TRUE	TRUE
Common Carp	*Cyprinus carpio*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Common Shiner	*Luxilus cornutus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Creek Chub	*Semotilus atromaculatus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Cyprinidae		TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Emerald Shiner	*Notropis atherinoides*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Etheostoma sp.	*Etheostoma*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Fathead Minnow	*Pimephales promelas*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Freshwater Drum	*Aplodinotus grunniens*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Gasterosteidae	*Culaea*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Gizzard Shad	*Dorosoma cepedianum*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Golden Shiner	*Notemigonus crysoleucas*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Goldfish	*Carassius auratus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Goldfish x Common Carp hybrid		FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Grass Carp	*Ctenopharyngodon idella*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Greater Redhorse	*Moxostoma valenciennesi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Green Sunfish	*Lepomis cyanellus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Green Sunfish x Pumpkinseed	*Lepomis*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Hornyhead Chub	*Nocomis biguttatus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Iowa Darter	*Etheostoma exile*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Johnny Darter	*Etheostoma nigrum*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Johnny/Tesselated Darter	*Etheostoma*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Lake Chub	*Couesius plumbeus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Lake Sturgeon	*Acipenser fulvescens*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Lake Trout	*Salvelinus namaycush*	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE
Lake Whitefish	*Coregonus clupeaformis*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Largemouth Bass	*Micropterus salmoides*	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
Lepomis sp.	*Lepomis*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Logperch	*Percina caprodes*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Longnose Dace	*Rhinichthys cataractae*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE

Longnose Gar	*Lepisosteus osseus*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Longnose Sucker	*Catostomus catostomus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Mottled Sculpin	*Cottus bairdi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Northern Pearl Dace	*Margariscus margarita*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Northern Pike	*Esox lucius*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Notropis sp.	*Notropis*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Pearl Dace	*Margariscus margarita*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Percidae		TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Pumpkinseed	*Lepomis gibbosus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Pumpkinseed x Bluegill	*Lepomis*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Quillback	*Carpiodes cyprinus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Rainbow Darter	*Etheostoma caeruleum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Rainbow Smelt	*Osmerus mordax*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
Rainbow Trout	*Oncorhynchus mykiss*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE
River Chub	*Nocomis micropogon*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Rock Bass	*Ambloplites rupestris*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
Rosyface Shiner	*Notropis rubellus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Round Goby	*Neogobius melanostomus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Rudd	*Scardinus erythrophthalmus*	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE
Salmo sp.		TRUE	FALSE	FALSE	FALSE	TRUE	TRUE
Sand Shiner	*Notropis stramineus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Sea Lamprey	*Petromyzon marinus*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE
Shorthead Redhorse	*Moxostoma macrolepidotum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Silver Redhorse	*Moxostoma anisurum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Smallmouth Bass	*Micropterus dolomieu*	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
Spotfin Shiner	*Cyprinella spiloptera*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Spottail Shiner	*Notropis hudsonius*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Threespine Stickleback	*Gasterosteus aculeatus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Trout-perch	*Percopsis omiscomaycus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Walleye	*Stizostedion vitreum vitreum*	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE
White Bass	*Morone chrysops*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE

White Perch	*Morone americana*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE
White Sucker	*Catostomus commersoni*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Wiper	*Morone*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Yellow Bullhead	*Ameiurus natalis*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Yellow Perch	*Perca flavescens*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE

APPENDIX D: MODEL OUTPUT FROM TEMPORAL TRENDS IN METRIC VALUES FOR CRITERION FP-2: TRENDS IN POPULATIONS OF TOP PREDATORS AND NON-NATIVE FISHES IN THE TORONTO AOC

Each of the model output sections follows the same format. The fish community metric, the scale of model (ecotype of region), and the month the data were collected are shown at the top. The content of the sub-headings is briefly explained below.

Data Details: Information on any data that were excluded and the size of the final dataset that was used.

Model: The R code associated with model formula (f4), and the code to implement the model.

Validate Model: notes on the various tests to validate the model; also an assessment of whether the model with the spatial component had better fit (based on Deviance Information Criterion [DIC}).

Interpret and Present Numerical Model Output: Number of effective parameters for the model and associated DIC. The two tables show the posterior mean values, standard deviations, and 95% credible intervals for the parameters and hyper-parameters.

Equation 55. Bowfin - JULY – Region – Embayment – Presence/Absence

Overview:

Given limited detections of Bowfin in many ecotypes/regions, analysis had to be paired down. Did explore dropping TTP as well (so only running for Toronto Islands) b/c of credible intervals that spanned from 0 to 1, but this did not change the outcome. Wide credible intervals also prevented any true trend from being detected. Could be function of low sample size and/or the lack of inclusion of other co-variates that may explain this trend.

Insufficient detections of Bowfin in October to proceed (11/332). Six of these were in the Toronto Islands and three at TTP.

Unlikely that evaluation of abundance would yield useful results as majority of encounters were of 1 individual (16/67 where N>1).

Data Details:

Only embayment and only Toronto Islands and TTP were included in the analysis for Bowfin.
Final sample size for the dataset was 290.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 259.7).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is truncated (max ~ 0.6)
Residual normality	Not great, but not too important
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 250.6
Effective # Parameters = 9.8

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-5.06	12.8	-30.39	29.90
TTP	-2.60	1.7	-6.62	-0.105

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	36.5	50.5	3.4	1.6e+02
Theta1 for w	-0.5	0.7	-1.8	8.6e-01
Theta2 for w	-1.3	1.6	-4.0	2.2e+00
Precision for Year.Ecotype	18608.9	18379.4	1259.1	6.7e+04

Equation 56. Common Carp - JULY – Ecotype – Presence/Absence

Data Details:

Final sample size for the dataset was 995.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1253).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1224

Effective # Parameters = 33.1

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.71	0.18	-7.08	-6.36
OpenCoast	0.76	0.36	0.08	1.48
Estuary.River	-1.19	0.26	-1.69	-0.69
Slip	-1.89	0.46	-2.81	-1.02

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	15789	17100	647	61822
Theta1 for w	-2.08	0.54	-3.13	-1.00
Theta2 for w	1.21	0.43	0.36	2.05
Precision for Year.Ecotype	17597	17900	1028	65433

Equation 57. Common Carp - October – Ecotype - Presence/Absence

Data Details:
Final sample size for the dataset was 332.

Model:
MetricPA = assigned as presence/absence of target species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **NO** (dic without spde is 417 vs 2168).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Western sites have lower residuals

Model passes basic tests, surprising that spatial is so poor.

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 417
Effective # Parameters = 4.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.68	0.15	-6.97	-6.37
OpenCoast	-0.63	0.37	-1.36	0.09
Estuary.River	-1.74	0.32	-2.40	-1.12
Slip	-1.44	0.46	-2.38	-0.59

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17908	18052	1088	65972
Precision for Year.Ecotype	18445	18288	1218	66899

Equation 58. Common Carp JULY – Region – Embayment - Presence/Absence

Data Details:

Final sample size for the dataset was 567.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 752).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 747

Effective # Parameters = 16.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.92	0.45	-7.81	-6.04
OtherEast	0.80	0.61	-0.39	2.02
OtherWest	-0.14	0.53	-1.21	0.91
TorontoIslands	1.25	0.56	0.22	2.42
TTP	-0.25	0.55	-1.35	0.85

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	24949	29000	1793	101000
Theta1 for w	-2.22	0.83	-3.88	-0.62
Theta2 for w	1.54	0.64	0.31	2.84
Precision for Year.Region	18259	18300	1160	66800

Equation 59. Common Carp - October – Region – Embayment - Presence/Absence

Data Details:

Final sample size for the dataset was 176.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                             compute = TRUE),
          family = "binomial",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **Yes** (dic without spde is 225). - marginal

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	OK, similar spread, but lower at TTP and TI
Variogram	No clear pattern
Spatial Residuals	Lower in western sites.

Model passes basic tests, but only ok great fit

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 224
Effective # Parameters = 9.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-8.15	5.78	-20.8	7.41
OtherEast	0.86	1.13	-1.33	3.17
OtherWest	0.24	2.16	-5.74	3.12
TorontoIslands	2.55	0.88	0.88	4.39
TTP	2.36	1.23	-0.23	4.81

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	25799	27600	2502	98658.7
Theta1 for w	-0.15	0.96	-1.89	1.87
Theta2 for w	-1.29	1.65	-4.67	1.82
Precision for Year.Region	24734	26200	2273.5	94462

Equation 60. Common Carp - JULY – Ecotype – CATCH

Data Details:

Final sample size for the dataset was 995.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                  compute = TRUE),
          family = "poisson",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 3132).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.76 so all good!
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2832
Effective # Parameters = 96.8

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.96	0.16	-7.29	-6.67
Estuary.River	0.96	0.27	0.44	1.51
OpenCoast	-0.87	0.22	-1.30	-0.42
Slip	-1.46	0.44	-2.35	-0.62

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	70.0	147	6.77	366
Theta1 for w	-2.61	0.37	-3.35	-1.88
Theta2 for w	1.59	0.30	1.00	2.19
Precision for Year.Ecotype	24.2	17.4	5.82	70.0

Equation 61. Common Carp - OCTOBER – Ecotype – CATCH

Data Details:

Final sample size for the dataset was 332.

Model:

MetricPA = assigned as catch of species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast + Slip +
             offset(log(Effort)) +
             f(Year, model = "rw1") +
             f(w, model = spde) +
             f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 976).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.865 so all good!
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, fair amount of spread for low valuse
Residual normality	No concerns
Residuals vs Treatment	Lower variance at Slips
Variogram	No clear pattern
Spatial Residuals	OK spread of residuals, more lower residuals in west and open coast

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 839

Effective # Parameters = 70.0

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-7.40	0.41	-8.30	-6.72
Estuary.River	0.19	0.61	-0.97	1.46
OpenCoast	-1.81	0.47	-2.75	-0.90
Slip	-1.34	0.87	-3..11	0.36

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	1.34	0.68	0.49	3.08
Theta1 for w	-3.08	0.50	-4.14	-2.17
Theta2 for w	1.44	0.48	0.57	2.45
Precision for Year.Ecotype	3.01e+06	5.06e+07	2.44	4.92e+06

Equation 62. Common Carp - JULY – Region – Embayment – CATCH

Data Details:
Final sample size for the dataset was 567.

Model:
MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 1931).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.734 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, limited range
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 1848
Effective # Parameters = 48.3

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-7.25	0.33	-7.92	-6.64
OtherEast	1.13	0.44	0.28	2.01
OtherWest	0.10	0.38	-0.66	0.86
TorontoIslands	1.15	0.37	0.43	1.91
TTP	0.01	0.40	-0.76	0.82

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19034	18200	1529	67514
Theta1 for w	-2.57	0.62	-3.83	-1.41
Theta2 for w	1.88	0.47	0.99	2.85
Precision for Year. Region	69.7	63.3	12.2	237.47

Equation 63. Common Carp - OCTOBER – Region – Embayment – CATCH

Data Details:

Final sample size for the dataset was 176.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 551).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.863 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Reduced variance at CentralWF (mostly -ve
Variogram	No clear pattern
Spatial Residuals	OK spread of residuals, some more negatives in west

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 533

Effective # Parameters = 48.0

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-9.01	1.40	-12.04	-6.53
OtherEast	1.28	1.49	-1.41	4.45
OtherWest	1.39	1.45	-1.22	4.51
TorontoIslands	2.53	1.43	-0.03	5.61
TTP	1.96	1.45	-0.64	5.06

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17054	15800	1115.8	58197
Theta1 for w	-3.21	0.89	-4.98	-1.48
Theta2 for w	2.16	0.68	0.84	3.50
Precision for Year.Region	2.39	0.90	1.10	4.58

Equation 64. Largemouth Bass - JULY – Ecotype – Presence/Absence

Data Details:

Drop OpenCoast from analysis b/c of low encounters, possibly also Estuary.River?
Potential differences among ecotypes (Based on GLM), with embayment increasing and estuary/river and slips decreasing.
Final sample size for the dataset was 780.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                           compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 862.0).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No big concerns, fair spread in both groups
Residual normality	Not great, but not too important
Residuals vs Treatment	Reduced range in Estuary.River and Slips
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 739.8
Effective # Parameters = 43.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-8.03	0.42	-8.92	-7.25
Estuary.River	-1.813	0.71	-3.30	-0.50
Slip	-1.66	0.89	-3.46	0.07

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	4.53	3.06	1.18	12.57
Theta1 for w	-2.33	0.46	-3.26	-1.47
Theta2 for w	0.75	0.42	-0.06	1.60
Precision for Year.Ecotype	17917	18200	1141.7	65955.60

Equation 65. Largemouth Bass - OCTOBER – Ecotype – Presence/Absence

Data Details:

Really only Embayment worth exploring.
Potential differences among ecotypes (Based on GLM), with embayment increasing and estuary/river and slips decreasing.
Final sample size for the dataset was 176.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                           compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 241.8).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok, fair spread in both groups
Residual normality	Not great, but not too important
Residuals vs Treatment	N/A
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 198.6
Effective # Parameters = 43.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-8.03	0.42	-8.92	-7.25
Estuary.River	-1.813	0.71	-3.30	-0.50
Slip	-1.66	0.89	-3.46	0.07

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	4.53	3.06	1.18	12.57
Theta1 for w	-2.33	0.46	-3.26	-1.47
Theta2 for w	0.75	0.42	-0.06	1.60
Precision for Year.Ecotype	17917	18200	1141.70	65955.60

Equation 66. Largemouth Bass - JULY – Region – Embayment – Presence/Absence

Data Details:

Final sample size for the dataset was 567.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                   compute = TRUE),
          family = "binomial",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 620.6).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 593.6

Effective # Parameters = 40.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-8.02	9.67	-27.16	17.63
OtherEast	-3.04	2.39	-7.93	1.15
OtherWest	3.21	3.25	-1.48	10.66
TorontoIslands	4.25	2.00	0.77	8.43
TTP	2.22	0.95	0.50	4.19

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	17193.1	17871	1171.2	64200
Theta1 for w	-0.659	0.43	-1.53	0.16
Theta2 for w	-1.381	1.28	-3.42	1.48
Precision for Year. Region	4.391	2.52	1.56	11.0

Equation 67. Largemouth Bass - OCTOBER – Region – Embayment – Presence/Absence

Data Details:
Drop CentralWF due to reduced timelines of sampling (only since ~2003?).
Final sample size for the dataset was 159.

Model:
MetricPA = assigned as presence/absence of target species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 182.2).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	Not great, but not too important
Residuals vs Treatment	OK, lower values at TTP and TI
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 171.6
Effective # Parameters = 12.39

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-8.03	1.57	-11.37	-4.73
OtherWest	-0.39	2.14	-5.49	3.48
TorontoIslands	3.82	2.24	-0.01	9.18
TTP	3.47	2.17	-0.32	8.57

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	18340.9	18400	1203.6	67000
Theta1 for w	-1.91	0.69	-3.27	-0.57
Theta2 for w	0.22	0.48	-1.41	1.88
Precision for Year.Region	26475.4	32500	1774.4	112000

Equation 68. Largemouth Bass - JULY – Ecotype - CATCH

Data Details:

Focus solely on embayment since limited presence for the rest.
Likely not appropriate to mash all regions into the analysis of embayments… should stick with the assessment at the Region level.
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) )
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1761.9).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	Yes, Poisson model no good… NBinomial is better (0.994)
Residuals vs Fitted	Not ideal, but ok
Fitted vs Observed	Ok, lots of spread along either axis
Residual normality	Not great, but not too important
Residuals vs Treatment	N/A
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1600.1
Effective # Parameters = 43.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-7.695	0.515	-8.795	-6.748

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Size of nbinomial observations	0.429	0.05	0.337	0.537
Precision for Year	2.639	1.70	0.774	7.098
Theta1 for w	-2.735	0.45	-3.638	-1.861
Theta2 for w	0.932	0.45	0.074	1.821

Equation 69. Largemouth Bass - JULY – Region – Embayment - CATCH

Data Details:

Despite some lower presence numbers for some regions, model still seems to fit fairly well…
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                           compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 3441.7).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.9, therefore all good.
Residuals vs Fitted	Not ideal, largely b/c of a few high values
Fitted vs Observed	OK
Residual normality	No concerns
Residuals vs Treatment	Greater variance for Toronto Islands
Variogram	No clear pattern
Spatial Residuals	Largest residuals in central waterfront, but plus/minus everywhere.

Model passes basic tests, but not really a great fit b/c of majority of catch in Toronto Islands. Unclear how to make model fit better

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 2238.3
Effective # Parameters = 111.3

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-10.0	1.12	-12.38	-7.98
OtherEast	-1.4	1.80	-5.04	2.09
OtherWest	1.15	1.30	-1.37	3.77
TorontoIslands	3.04	1.29	0.62	5.73
TTP	2.22	1.28	-0.18	4.89

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	1.57	0.905	0.547	3.93
Theta1 for w	-5.65	0.937	-7.43	-3.76
Theta2 for w	2.92	0.472	1.97	3.82
Precision for Year. Region	1.03	0.281	0.578	1.68

Equation 70. Largemouth Bass - OCTOBER – Region – Embayment - CATCH

Data Details:

Dropped CentralWF due to limited sampling time window (starts in 2003).

Data gaps for some years (e.g., 2000/2001 and 2006-2008) and treatments make for some odd credible intervals for these time periods. I don't think the model knows what to do during these year-treatment combos so it makes very expansive and likely inaccurate predictions. Would trust the years when data were available more so than the years when there was no data since the observed vs fitted plot looks quite good.

Final sample size for the dataset was 159.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1184.0).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.91, therefore all good.
Residuals vs Fitted	Not ideal, largely b/c of a few high values
Fitted vs Observed	OK, better than July
Residual normality	No concerns
Residuals vs Treatment	Greater variance for TTP, but not too bad
Variogram	No clear pattern
Spatial Residuals	Largest residuals in central waterfront, but plus/minus everywhere.

Model passes basic tests.

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 789.33
Effective # Parameters = 70.4

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-8.42	2.01	-12.49	-4.52
OtherWest	2.96	1.56	-0.00	6.20
TorontoIslands	3.73	1.72	0.58	7.43
TTP	-0.00	0.11	-0.23	0.22

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	17311	18000	1188	64846
Theta1 for w	-4.39	0.692	-5.88	-3.18
Theta2 for w	1.94	0.498	1.04	2.98
Precision for Year. Region	0.72	0.30	0.22	1.34

Equation 71. Northern Pike - JULY – Ecotype – Presence/Absence

Data Details:

Dropping open.coast given low encounter rates.
Final sample size for the dataset was 780.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 981.0).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 862.2
Effective # Parameters = 52.4

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-7.34	0.30	-7.96	-6.78
Estuary.River	-2.03	0.66	-3.39	-0.80
Slip	-0.92	0.69	-2.28	0.45

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	11.33	11.5	2.04	41.3
Theta1 for w	-3.20	0.70	-4.41	-1.70
Theta2 for w	1.63	0.45	0.66	2.43
Precision for Year.Ecotype	19018.40	18600	1282.30	68063.60

Equation 72. Northern Pike - OCTOBER – Ecotype – Presence/Absence

Data Details:

Dropping open.coast given low encounter rates.
Final sample size for the dataset was 247.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + Slip +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 333.9).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Smaller range for Estuary.River
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals, possibly lower in the far west?

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 280.7
Effective # Parameters = 19.3

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-6.34	3.39	-12.41	2.34
Estuary.River	-0.17	0.81	-1.80	1.39
Slip	0.49	1.34	-2.05	3.24

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	18624.9	18400	1257.0	67304
Theta1 for w	-1.16	0.42	-1.92	-0.289
Theta2 for w	-1.22	0.75	-2.80	0.12
Precision for Year.Ecotype	18459.9	18400	1271.6	66841

Equation 73. Northern Pike - JULY – Region – Embayment – Presence/Absence

Data Details:

Suggestion that there are different responses through time for each group (declining in the central waterfront, but increasing elsewhere). Confirmed, although main trend of interest is a decline in the Toronto Islands. Elsehwere is generally stable, although some suggestion that increasing in the west? Final sample size for the dataset was 567.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 703).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 638.6

Effective # Parameters = 10.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-8.38	0.72	-9.86	-7.00
OtherEast	1.43	1.01	-0.53	3.49
OtherWest	0.61	0.85	-1.04	2.34
TorontoIslands	2.29	0.89	0.59	4.11
TTP	0.93	0.86	-0.75	2.66

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19079	18600	1260.7	68283.5
Theta1 for w	-4.12	0.86	-5.71	-2.35
Theta2 for w	2.35	0.47	1.39	3.22
Precision for Year. Region	4.59	3.18	1.28	13.00

Equation 74. Northern Pike - October – Region – Embayment – Presence/Absence

Data Details:

Dropping Central Waterfront b/c low samples and skewed towards more recent data.
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                         compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 179.5). - marginal

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	OK, similar spread, but lower at TTP and TI
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 176.7
Effective # Parameters = 10.2

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-6.81	4.46	-16.03	4.95
OtherWest	-1.34	2.71	-9.22	1.29
TorontoIslands	2.16	1.57	-0.78	5.17
TTP	2.13	1.39	0.10	5.18

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19039.3	18738	1353.1	68477.9
Theta1 for w	-0.103	1.22	-2.44	2.35
Theta2 for w	0.637	2.34	-3.03	5.94
Precision for Year. Region	1448.1	46454.5	3.26	7948.4

Equation 75. Northern Pike - JULY – Ecotype - CATCH

Data Details:

Dropping open.coast given low encounter rates.
Final sample size for the dataset was 780.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + Slip +
              offset(log(Effort)) +
              f(Year, model = "rwl") +
              f(w, model = spde) +
              f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                                   compute = TRUE),
          family = "poisson",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 1919.99).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.71 so all good!
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Slightly lower variance at Estuary.River
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1648.4
Effective # Parameters = 81.6

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-7.60	0.31	-8.22	-7.02
Estuary.River	-1.82	0.60	-3.04	-0.70
Slip	-0.59	0.73	-2.03	0.84

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	18275	19200	1244	69490
Theta1 for w	-3.14	0.53	-4.26	-2.17
Theta2 for w	1.53	0.50	0.63	2.57
Precision for Year.Ecotype	3.85	1.57	1.58	7.64

Equation 76. Northern Pike - OCTOBER – Ecotype - CATCH

Data Details:
Dropping open.coast given low encounter rates.
Final sample size for the dataset was 247.

Model:
MetricPA = assigned as catch of species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + Slip +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 1059.2).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.83 so all good!
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Lower variance at Estuary.River and Slips
Variogram	No clear pattern
Spatial Residuals	OK spread of residuals, lower to west and in slips

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 808.9
Effective # Parameters = 65.6

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-7.08	0.43	-8.03	-6.31
Estuary.River	-1.11	0.80	-2.74	0.44
Slip	-0.61	1.13	-2.85	1.61

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	19201.8	18800	1277	68503
Theta1 for w	-2.81	0.46	-3.80	-1.99
Theta2 for w	1.20	0.48	0.34	2.23
Precision for Year.Ecotype	1.14	0.50	0.39	2.32

Equation 77. Northern Pike - JULY – Region – Embayment - CATCH

Data Details:
Final sample size for the dataset was 159.

Model:
MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                            compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? **YES** (dic without spde is 1426.99).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.71 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = 1308.8
Effective # Parameters = 67.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-8.48	0.56	-9.62	-7.43
OtherWest	0.58	0.65	-0.68	1.88
TorontoIslands	1.65	0.65	0.40	2.97
TTP	1.06	0.65	-0.20	2.36

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	6.67	3.86	2.07	16.66
Theta1 for w	-4.03	0.89	-5.79	-2.31
Theta2 for w	2.44	0.56	1.35	3.56
Precision for Year. Region	27.69	18.75	6.98	76.53

Equation 78. Northern Pike - OCTOBER – Region – Embayment - CATCH

Data Details:

Drop centralWF b/c of low numbers
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherWest + TorontoIslands + TTP+
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                 compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 644.4).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.81 – all good
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	OK spread of residuals, some more negatives in west

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 593.4
Effective # Parameters = 45.6

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-7.22	1.01	-9.31	-5.07
OtherWest	-1.22	1.54	-5.21	1.06
TorontoIslands	1.43	1.38	-1.35	4.51
TTP	0.72	1.42	-2.57	3.47

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	8.16	7.74	1.39	28.67
Theta1 for w	-2.17	0.49	-3.13	-1.18
Theta2 for w	0.68	0.76	-0.85	2.14
Precision for Year. Region	22.20	21.06	3.01	78.21

Equation 79. Round Goby - JULY – Ecotype – Presence/Absence

Data Details:

Insufficient detections at the slips suggest this habitat type should be dropped from the analysis (suggest we use a 5% detection threshold for treatment inclusion?).
Clear increase in presence of round goby with first detection in 2003. Decline in presence ~2015ish, but still evident in the system.
Suggest re-running with pre-2003 data dropped. Not critical for the assessment.
Data could likely support a hurdle model with catch.
Final sample size for the dataset was 877.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                           compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? Can't evaluate b/c DIC is INF – likely because this species absent at the start of the time period. Could re-run with a shortened timeframe since we know it was not in the system pre-2003?

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	Slightly less variance at estuaries
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = Can't estimate
Effective # Parameters = Can't estimate

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-10.30	0.88	-12.39	-8.94
Estuary.River	-2.36	0.48	-3.34	-1.45
OpenCoast	-0.93	0.30	-1.54	-0.34

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	0.64	0.31	0.23	1.42
Theta1 for w	-0.70	1.01	-2.74	1.24
Theta2 for w	-0.06	0.91	-1.78	1.77
Precision for Year.Ecotype	18732.50	18500	1242.60	67725.60

Equation 80. Round Goby – Ecotype – OCTOBER – Presence/Absence

Data Details:

Insufficient detections at the estuary.river and slips suggest these habitat types should be dropped from the analysis (suggest we use a 5% detection threshold for treatment inclusion and/or min presence samples of 15?).
Clear increase in presence of round goby with first detection in 2003. Wide credible intervals, likely due to reduced sample size for presence at OpenCoast (and overall low sample size compared to July).
Suggest re-running with pre-2003 data dropped. Not critical for the assessment.
Data likely insufficient for abundance models.
Final sample size for the dataset was 261.

Model:

MetricPA = assigned as presence/absence of target species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OpenCoast +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                           compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? Can’t evaluate b/c DIC is INF – likely because this species absent at the start of the time period. Could re-run with a shortened timeframe since we know it was not in the system pre-2003?

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = Can’t estimate
Effective # Parameters = Can’t estimate

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-10.70	3.39	-18.21	-2.99
OpenCoast	-0.42	0.64	-1.65	0.84

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	1.30	1.14	0.233	4.31
Theta1 for w	-0.43	0.57	-1.52	0.72
Theta2 for w	-1.54	0.78	-3.11	-0.06
Precision for Year.Ecotype	18657.90	18400	1247.40	67320.60

Equation 81. Round Goby - JULY – Region – Embayment – Presence/Absence

Data Details:
Final sample size for the dataset was 877.

Model:
MetricPA = assigned as presence/absence of target species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                          compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:
Is spatial model better? Can't evaluate b/c DIC is INF – likely because this species absent at the start of the time period. Could re-run with a shortened timeframe since we know it was not in the system pre-2003?

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:
Deviance Information Criterion (DIC) = Can't estimate
Effective # Parameters = Can't estimate

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-9.96	4.95	-19.13	1.85
OtherEast	-0.92	0.81	-2.60	0.57
OtherWest	0.30	0.92	-1.64	2.07
TorontoIslands	-0.69	0.75	-2.24	0.73
TTP	0.41	0.93	-0.78	1.70

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	0.63	0.35	0.20	1.52
Theta1 for w	0.28	1.72	-2.97	3.75
Theta2 for w	-0.99	2.11	-5.22	3.08
Precision for Year. Region	18381.80	18300	1222.40	66753.20

Equation 82. Round Goby - JULY – Region – OpenCoast – Presence/Absence

Data Details:

Should drop CentralWF b/c of no detections there…
Final sample size for the dataset was 215.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + WestBluffers + Western +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
         control.predictor = list(A = inla.stack.A(StackFitA),
                                  compute = TRUE),
         family = "binomial",
         data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? Can't evaluate b/c DIC is INF – likely because this species absent at the start of the time period. Could re-run with a shortened timeframe since we know it was not in the system pre-2003?

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	No concerns
Residual normality	No concerns
Residuals vs Treatment	No concerns
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = Can't estimate
Effective # Parameters = Can't estimate

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-9.89	1.39	-12.93	-7.91
WestBluffers	0.10	1.39	-2.89	2.69
Western	1.99	1.68	-1.32	5.43

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	18502.4	18400	1266	66952
Theta1 for w	-0.56	2.04	-4.03	3.87
Theta2 for w	0.08	1.68	-3.47	3.11
Precision for Year. Region	085	0.59	0.22	2.39

Equation 83. Round Goby - JULY – Ecotype - CATCH

Data Details:

Insufficient detections at the slips suggest this habitat type should be dropped from the analysis
Final sample size for the dataset was 877.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                                compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 4506).

Test	Notes/Comments
Overdispersion	0.977 so all good.
Residuals vs Fitted	No concerns
Fitted vs Observed	Fair amount of spread
Residual normality	No concerns
Residuals vs Treatment	Much less variance as estuary…
Variogram	No clear pattern
Spatial Residuals	OK spread of residuals, but few high areas in general

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 3239
Effective # Parameters = 99.7

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-11.27	0.94	-13.45	-9.77
Estuary.River	-2.04	1.22	-4.46	0.36
OpenCoast	-0.54	1.02	-2.56	1.48

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	0.57	0.24	0.24	1.15
Theta1 for w	-5.54	0.57	-6.76	-4.55
Theta2 for w	2.91	0.35	2.30	3.65
Precision for Year.Ecotype	3.96	1.89	1.49	8.75

Equation 84. Round Goby - JULY – Region – Embayment - CATCH

Data Details:

Final sample size for the dataset was 567.

Model:

MetricPA = assigned as catch of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + OtherEast + OtherWest + TorontoIslands + TTP+
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "poisson",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 2729).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	0.977 so all good.
Residuals vs Fitted	No concerns
Fitted vs Observed	OK, some excessive spread near 0
Residual normality	No concerns
Residuals vs Treatment	Greater range for OtherWest
Variogram	No clear pattern
Spatial Residuals	Good spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 1974.8

Effective # Parameters = 92.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-11.24	1.73	-15.06	-8.26
OtherEast	-1.42	2.28	-5.92	3.07
OtherWest	-0.82	1.84	-4.40	2.85
TorontoIslands	-1.35	1.93	-5.15	2.45
TTP	0.12	1.85	-3.48	3.80

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	0.45	0.19	0.18	0.93
Theta1 for w	-6.70	0.80	-8.43	-5.29
Theta2 for w	3.41	0.44	2.63	4.35
Precision for Year. Region	1.48	0.44	0.79	2.53

Equation 85. Round Goby - JULY – Region – OpenCoast - CATCH

Data Details:

Drop centralWF
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as catch of target species
Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + WestBluffers + Western +
              offset(log(Effort)) +
              f(Year, model = "rw1") +
              f(w, model = spde) +
              f(Year. Region, model = "rw1", replicate = as.numeric(Region)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
          control.predictor = list(A = inla.stack.A(StackFitA),
                               compute = TRUE),
          family = "poisson",
          data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 554).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	Notes/Comments
Overdispersion	0.98 so all good.
Residuals vs Fitted	No concerns
Fitted vs Observed	OK
Residual normality	No concerns
Residuals vs Treatment	Greater range for EastBluffers
Variogram	No clear pattern
Spatial Residuals	Ok spread, some lower values east of central waterfront..

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 500.6
Effective # Parameters = 46.9

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Intercept	-10.17	1.03	-12.55	-8.54
WestBluffers	-0.52	1.64	-4.10	2.39
Western	1.50	1.83	-2.19	5.06

Hyperparameters:	Mean	Standard Dev.	2.5% Quantile	97.5% Quantile
Precision for Year	18714	18400	1268	67397
Theta1 for w	-2.16	0.64	-3.43	-0.91
Theta2 for w	1.11	0.66	-0.18	2.42
Precision for Year. Region	0.47	0.16	0.23	0.84

Equation 86. Smallmouth Bass - JULY – Ecotype – Presence/Absence

Overview:

Insufficient samples at the slips, so drop this habitat type.
Likely insufficient samples sizes to take a deeper dive into the Region…. Possbily just at east bluffers?
October analysis likely not possible as only 19 records SMB, 11 in embayments, 3 in estuaries, and 5 in opencoast.

Credible intervals span whole range (0-1) and model fit looks fairly poor. Could try isolating just Open.Coast (possibly even just east bluffers) and see if that performs better.
OpenCoast only model has issues with spatial dependence since almost all detections are at eastbluffers.
Even just with EastBLuffers data lone there is poor fit and no suggestion of a trend. A simple GLM does predict an increase at EastBLuffers and OpenCoast in general.

Data Details:

Final sample size for the dataset was 877.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept + Estuary.River + OpenCoast  +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde) +
            f(Year.Ecotype, model = "rw1", replicate = as.numeric(Ecotype)))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                              compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 582.8).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Ok Range, “presence” with low fit values, which suggests poor fit
Residual normality	Not great, but not too important
Residuals vs Treatment	Smaller range of residuals for estuary/river
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 250.6
Effective # Parameters = 15.6

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-8.62	3.16	-15.33	-0.86
Estuary.River	0.47	0.48	-0.44	1.47
OpenCoast	-0.17	0.46	-1.11	0.71

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	25283	26700	2324.9	96275
Theta1 for w	-0.14	0.718	-1.47	1.34
Theta2 for w	-1.84	0.816	-3.52	-0.32
Precision for Year.Ecotype	23139	23800	1990.6	86014

Equation 87. Walleye - JULY – Region – Embayment – Presence/Absence

Overview:

Very low encounter/catch rates for Walleye. Likely can only support a global embayment assessment.

Data Details:

Only using embayment data.
Final sample size for the dataset was 567.

Model:

MetricPA = assigned as presence/absence of target species

Model equation:

```
f4 <- formula(MetricPA ~  -1 + Intercept +
            offset(log(Effort)) +
            f(Year, model = "rw1") +
            f(w, model = spde))
```

Model call:

```
I4 <- inla(f4, control.compute = list(dic = TRUE, config=TRUE),
        control.predictor = list(A = inla.stack.A(StackFitA),
                        compute = TRUE),
        family = "binomial",
        data = inla.stack.data(StackFitA))
```

Validate Model:

Is spatial model better? **YES** (dic without spde is 237.1).

Insert standardized/Pearson residuals versus fitted values plots for each covariate in the model

Test	**Notes/Comments**
Overdispersion	N/A for this type of model
Residuals vs Fitted	No concerns
Fitted vs Observed	Fitted range is very truncated (max ~ 0.25)
Residual normality	Not great, but not too important
Residuals vs Treatment	N/A
Variogram	No clear pattern
Spatial Residuals	Ok spread of residuals

Model passes basic tests

Interpret and Present Numerical Model Output:

Deviance Information Criterion (DIC) = 221.3
Effective # Parameters = 11.3

Table: Posterior mean values, standard deviations, and 95% confidence intervals for the parameters.

Fixed effects:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Intercept	-10.9	2.14	-15.1	-4.55

Hyperparameters:	**Mean**	**Standard Dev.**	**2.5% Quantile**	**97.5% Quantile**
Precision for Year	8.32	8.66	1.26	30.85
Theta1 for w	0.50	1.61	-2.90	3.39
Theta2 for w	-0.91	1.90	-4.20	3.19