Modeling Response of IBI Scores to Artificial Changes in the Catches of Managed Fish Species in the Hamilton Harbour Area of Concern

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Indices of Biological Integrity (IBIs) are integral to the assessment of fish populations in the Hamilton Harbour Area of Concern. We ran simple, seasonal models to manipulate 2012 and 2018 electrofishing catch data for five fish species that either have been managed, or have the potential to be managed. Our objective was to determine what changes in catch were needed to meet Hamilton Harbour's IBI delisting target score of 55 – 60. Manipulating only a single species was insufficient to raise IBI scores to reach this target and adding native fish species to the catch dataset had a greater effect than removing non-native species. Target IBI scores could be reached by combining additions and removals of four species; however, in cases where initial IBI scores were low (<40), the number of fish required to reach targets was greater than any catches documented in Lake Ontario. Season was an important factor, with fall initial IBI scores greater than either spring or summer; fall samples were therefore more likely to reach IBI targets with fewer added or removed fish. Despite indirect benefits to removing non-native fishes and restoring top predators, focusing solely on a single species is unlikely to alter the IBI significantly. Future efforts should seek to also increase species richness and catch for multiple native fishes.

RÉSUMÉ

Gardner Costa J., Marshall, E.E.M., Boston, C.M., and Midwood J.D. 2022. Modeling response of IBI scores to artificial changes in the catches of managed fish species in the Hamilton Harbour Area Of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3511: ix + 52 p.

Les indices d'intégrité biologique (IIB) font partie intégrante de l'évaluation des populations de poissons dans le secteur préoccupant du port de Hamilton. Nous avons exécuté des modèles saisonniers simples afin de manipuler les données sur les prises par pêche électrique de 2012 et 2018 pour cinq espèces de poissons qui ont été visées par des mesures de gestion, ou qui pourraient l'être. Notre objectif était de déterminer quels changements dans les prises étaient nécessaires pour atteindre les scores cibles de l'IIB du port de Hamilton qui permettraient son retrait de la liste, soit 55 à 60. La manipulation d'une seule espèce n'a pas été suffisante pour augmenter les scores de l'IIB jusqu'à cet objectif, et l'ajout d'espèces de poissons indigènes à l'ensemble des données sur les prises a eu un effet plus important que le retrait d'espèces non indigènes. Les valeurs cibles de l'IIB ont pu être atteintes en combinant les ajouts et les retraits de quatre espèces. Toutefois, dans les cas où les scores initiaux de l'IIB étaient faibles (<40), le nombre de poissons nécessaire pour atteindre les cibles était supérieur à toutes les captures documentées dans le lac Ontario. La saison était un facteur important, les scores initiaux de l'IIB de l'automne étant supérieurs à ceux du printemps ou de l'été; ils étaient donc susceptibles d'atteindre les cibles avec le retrait ou l'ajout d'un moins grand nombre de poissons. Malgré les avantages indirects de l'élimination des poissons non indigènes et du rétablissement des prédateurs de niveau trophique supérieur, il est peu probable que l'IIB puisse être modifié de façon significative si l'on se concentre sur une seule espèce. Les efforts futurs devraient viser également à accroître la richesse des espèces et les prises pour plusieurs poissons indigènes.

INTRODUCTION

Indices of Biological Integrity (IBI) are composite metrics that use biological information to derive a relative score (usually 0 – 100) that provides a quick and easy-to-interpret measure of ecosystem condition (Karr 1981, Simon 2020). IBIs have been developed to assess the condition of freshwater ecosystems such as streams, rivers, wetlands, and embayments using information for a variety of taxa including macrophytes, birds, invertebrates, and fish (Simon 2020). The results from IBI are frequently used by scientists and managers to explore trends through time, assess the response of a population or community to management actions (e.g., habitat rehabilitation), and to compare the health and diversity of a community to other similar areas (Simon 2020).

Ecosystem health is of specific concern within Great Lakes Areas of Concern (AOC). In 1985 the International Joint Commission (IJC) identified 42 environmentally degraded areas within the Great Lakes as AOC (a 43rd was designated in 1991), where water quality, environmental processes, and biota were impaired due to development, pollution, invasion of non-native species, and reduced/degraded habitat [International Joint Commission (IJC) 1987, Hartig and Thomas 1988, Hartig et al. 2020]. Two years later, the United States and Canadian governments amended the *Great Lakes Water Quality Agreement* and both countries agreed to detail and implement Remedial Action Plans (RAPs) to rehabilitate impairments within the AOCs. Since the creation of the AOCs, federal, provincial and state, and municipal governments have worked with stakeholders to implement RAPs and address the 14 Beneficial Use Impairments (BUIs) created to address remediation efforts [Canada-Ontario Agreement (COA) 1992, Hartig et al. 2020]. The BUIs describe human or ecological uses of an area that have been lost or impaired because of environmental degradation and AOCs may be delisted once all impaired BUIs have been remediated and assessed as unimpaired or, in rare cases, when no further rehabilitation can be undertaken. For each of the BUIs, delisting targets must be developed, monitored, and compared to ecologically similar reference areas to track progress and provide direction to managers regarding actions that can be implemented to rehabilitate impaired BUIs (Hartig et al. 2020).

To assess BUI #3, degradation of fish and wildlife populations, Minns et al. (1994) developed an IBI (herein the sole IBI that is discussed) using fish abundance and biomass data to quantify fish community health in littoral areas of the Great Lakes and to help set delisting targets for AOCs. In Minns et al. (1994), the IBI and BUI targets were derived from data collected in degraded and reference locations in and around three Great Lakes AOCs (Hamilton Harbour, Bay of Quinte, and Severn Sound) to create an IBI that is sensitive to the full range of ecosystem conditions (Boston et al. 2016; Minns et al. 1994). This IBI has been applied to fish populations in seven AOCs across a 30+ year dataset and is the *de facto* fish population metric used by Canadian government agencies on the Great Lakes and connecting channels (Boston et al. 2016; Smokorowski et al. 1998; Hoyle et al., 2018; Randall and Minns 2002, Pratt and O’Connor 2011; Midwood et al. 2021). The IBI is a composite fish community index made up of 12 metrics (Table 1). It uses raw fish catch data and groups species based on native/non-native status, trophic structure (related to adult diet), water quality (intolerant species richness, % generalist biomass), and habitat preferences (e.g., centrarchid or cyprinid species richness relates to the quality of nearshore habitat; see Appendix Table A1). There are eight metrics that act to increase the IBI score and four metrics that decrease the final score; the sum of all metrics in a pristine fish community scenario would equal 100 and would not have any non-native species as part of the assemblage or an imbalance in trophic structure related to generalist species (i.e., not greater than 33.3% of biomass). In addition to the IBI, an adjusted IBI score (IBI_{adj}) can also be calculated to remove the influence of offshore pelagic species on nearshore catch. A high percentage of offshore species in the catch is an indication of impairment in nearshore habitat, particularly in more sheltered areas; sites that have healthy nearshore fish assemblages (IBI score >60) tend to have <10% of offshore species contributing to total numbers and biomass (Minns et al. 1994; Boston et al. 2016; Brousseau et al. 2011).

Although some AOCs have either been delisted or are soon to be delisted (Hartig et al. 2020), several, such as Hamilton Harbour, have seen little to no improvement in IBI scores since its designation as an AOC (Boston et al. 2016); this is despite long-term remedial efforts by the RAP (e.g., habitat creation, reductions in phosphorus loadings, and invasive species control). For Hamilton Harbour, there are two main delisting criteria and several secondary criteria that can be used to track the recovery process for the fish populations component of BUI#3 (wildlife populations are assessed separately for this BUI). Criterion a and b are described below, and criterion b relates specifically to IBI scores:

a. "*Shift from a fish community indicative of eutrophic environments (e.g. White Perch, Alewife, bullheads, and carp) to a self-sustaining community more representative of a mesotrophic environment with a balanced trophic composition that includes top predators (e.g. Northern Pike, Largemouth Bass and Walleye) and other native species (e.g. Suckers, Yellow Perch and Sunfishes).*"

b. "*Attain an Index of Biotic Integrity (IBI) of 55 – 60 for Hamilton Harbour and maintain the target score for two sequences of monitoring carried out a minimum of every three years. The IBI incorporates components of native species richness, numbers and biomass; piscivore biomass; non-native species; and reflects water quality and the quality of fish habitat."* [p. 1, Bay Area Restoration Council (BARC) 2012].

Previous iterations of delisting criteria included specific targets for IBI_{adj} (see Table 4 in Smokorowski et al. 1998); however, these targets were dropped to simplify criteria and because improvements to IBI generally lead to increases in IBI_{adj}. In these works, we chose five species and explore how changes in their populations could affect IBI scores. These species are recognized by the RAP as important in achieving a balanced trophic composition (based on their inclusion in the delisting criteria) and have the potential to be or are actively managed within Hamilton Harbour, they include: Common Carp [*Cyprinus carpio*], Goldfish [*Carassius auratus*], Northern Pike [*Esox lucius*], Walleye [*Sander vitreus*], and Smallmouth Bass [*Micropterus dolomieu*]. Common Carp and Goldfish were selected as species of interest since they are non-native fishes that are frequently captured in the harbour. Both these species have been targets for passive (e.g., exclusion barriers) and active (e.g., capture and culling) management both within Hamilton Harbour and other areas where they are considered invasive (Lougheed et al. 2004, Mataya et al. 2020). In contrast, Northern Pike and Walleye are both important top predators that were historically abundant in Hamilton Harbour (Holmes and Whillans 1984). Walleye are currently stocked into the system, with evidence for successful establishment of year classes from 2012 and 2016 stocking events [Ontario Ministry of Natural Resources and Forestry (OMNRF) 2019]. While Northern Pike are not currently stocked, they have been targets of past habitat remediation efforts within the harbour and are listed explicitly within RAP documents as a focal species (BARC 2012). Smallmouth Bass are also included in RAP documents as targets for remediation, but are not currently managed.

A lack of a clear response in IBI scores to rehabilitation efforts is the impetus for the present work since there is a need to determine potential management actions that may result in tractable improvements. Since the Minns et al. (1994) IBI is the main delisting criteria for the fish populations BUI, our objective was to model and determine what changes in the five focal species are necessary to meet the IBI target of 55 – 60 in Hamilton Harbour. Addition or removal of these species was modeled both individually and in various combinations to determine the maximum response in IBI [and IBI adjusted (IBI_{adj})] score that could be achieved through their targeted management. By using electrofishing datasets from recent years (2012 and 2018), we model the response of IBI scores to the removal of undesirable species (Common Carp and Goldfish), the addition of desirable top-predators (Northern Pike, Walleye, and Smallmouth Bass), and combinations of both removals and additions, with the goal of determining how many of these fish would need to be removed or caught before Hamilton Harbour IBI targets would be met. Given the well documented seasonal and diel variability in fish habitat use and resulting capture (Helfman 1986; Pope and Willis 1996; Jordan et al. 1998; Muška et al. 2013; Midwood et al. 2016), the models are further broken down by season and day versus night. Understanding the impact of adding or removing these fish from the catch on the resulting IBI score can provide an indication of the likely response from direct management intervention on these species and the potential IBI score that could be achieved. Therefore, these works can be used to guide the selection and implementation of management actions.

METHODS

STUDY SITE

Hamilton Harbour has been described several times in multiple papers (Holmes and Whillans 1984, Smokorowski et al. 1998, BARC 2012, Boston et al. 2016, Leisti et al. 2016) but briefly, Hamilton Harbour (43°14’N, 79°51’W) is a protected embayment located at the western end of Lake Ontario. The Harbour has a surface area of 22 km^2, a mean depth of 13 m, and a maximum depth of 26 m. Over the last 100 years, dense urban development and anthropogenic stress have impaired Hamilton Harbour’s ability to support aquatic life (COA 1992). Historically, the harbour was an extensively marshy area, with large wetland areas found along the majority of the southern shore in addition to Cootes Paradise marsh (Holmes and Whillans 1984). Intensive industrialization and infilling on all shores but primarily the south shore throughout the latter half of the 20^{th} century and the removal of shoals and other coarse substrates from most of the harbour resulted in a >70 % loss of aquatic habitat (Holmes and Whillans 1984). Consequently, the harbour’s fish community is impaired with a limited amount of appropriate nursery, spawning, and juvenile nearshore habitat for both lithophyllic and phytophyllic species. Invasive fish species have also threatened the integrity of the fish community (Boston et al. 2016). Additionally, eutrophication has been a significant factor contributing to poor water quality, due in part to three wastewater treatment plant outputs flowing directly into the Harbour from the watershed (Hiriart-Baer et al. 2009).

ELECTROFISHING DATASET

Base data used for modeling were taken from Fisheries and Oceans Canada’s long-term electrofishing database wherein surveys have been completed roughly every other year from 1988-present (Boston et al. 2016). Over the years, electrofishing was conducted in the day (late afternoon to 30 minutes before sunset) and night (30 minutes after sunset until 30 minutes before sunrise), and in three seasons; spring (May and June), summer (July and August), and fall (September and October; Table 2). A standard protocol was used to electrofish and data were collected using a transect approach along the same set of 30 100-m transects in approximately 1.5 m depth (Brousseau et al. 2005, Boston et al. 2016). Electrofishing was carried out using a Smith-Root SR20E electrofishing boat (length = 6.1 m, beam = 1.9 m) equipped with a 7.5-kW generator to produce the electric current (output standardized to 8.0 A where possible, range between 6.0 and 8.0 A; Brousseau et al. 2005). All captured species were identified and their fork length (± 1 mm) and wet mass (± 1 g) were measured before they were released. Species caught in large numbers were counted and batch-weighed after recording length and mass for the first 20 individuals. In addition to data for Hamilton Harbour, datasets from several areas were also compiled to provide a comparison for total catch and maximum number of fish caught per transect for any available years of electrofishing (Table 3). Data from outside of Hamilton Harbour were not used for modeling but to provide context for realistic expectations of changes in catch of species of interest if fish populations improve.

ELECTROFISHING INDEX OF BIOTIC INTEGRITY (IBI)

For each electrofishing transect a fish-based IBI was calculated following methods outlined in Minns et al. (1994); its components are described in the introduction. This IBI uses metrics that can generally be grouped based on species richness, trophic structure, or abundance and biomass (Table 1). These metrics are converted to scaled metrics (Ms) to provide values that range between 0 and 10 (lower and upper limits). This scaling is done relative to the impact that specific metric may have on the environment, such that it is not always a 1:1 change, positive correlation, or it may cap at a value in which greater/lesser values will not elicit any change in the scaled metric. These scaled metrics are then compiled to derive an overall IBI value. Metrics, IBI, and adjusted IBI (IBI_{adj}; excludes offshore species) were calculated for each transect. Scores were calculated in R (version 3.6.1), and the code necessary to run the IBI is included in the Appendix.

For the present work, changes in the catch of individual species will (in most instances) lead to a change in the final IBI score, however this is not necessarily so because each of the metrics within the IBI score will be affected differently. This is because contributions to metrics are linked to species traits or characteristics, thus the addition or removal of an individual species will only be reflected in the metrics it is associated with. This is further complicated by the upper standardized metric (Ms = 10) and lower (Ms = 0) limits for a metric (Table 1) since, for a change to manifest, the addition or removal of an individual must be within the range of values by which that metric will vary (i.e., if a Ms is at its maximum, adding more fish will not change IBI scores). For example, for the SNIN (Non-Indigenous Species Richness) metric, the presence of 3 or more non-native fish species yields the minimum Ms value of 0 (Ms = 0 if 3 or more species present), whereas the absence of non-native fish species yields the maximum Ms value of 10 (Ms = 10 if 0 species present). So, if there were four non-native fish species captured in a transect, the complete removal of one species from the transect will not change the final Ms value for SNIN (i.e., still 0). The only way for removal to result in a change in the Ms value in this scenario would be for two non-native species to be completely removed from the transect (moving it within the range of the Ms=10 and Ms = 0 thresholds and resulting in SNIN Ms value of 3.33). As such, the addition or removal of an individual may or may not result in a shift in the final IBI score.

MODELING FISH CATCH

Raw fish catch data were used instead of randomly generated data to better apply our modeling results to real-world management actions. We used 2012 and 2018 as our test years because they were collected recently, had both day and night data for all three seasons (although 2018 was missing daytime fall data). Data from 2018 were generally considered to have some of the lowest IBI scores from more recent years and should therefore respond strongly to the addition of desirable species or the removal of non-native species. Data from 2012 were used to compare to 2018 because IBI scores in 2012 are representative of the long-term average IBI score for Hamilton Harbour and allowed for an illustration of differences in the response of the IBI between day and night over each season.

Season and time of day are important factors that impact the distribution (vertical and horizontal) of fishes, in Hamilton Harbour (Midwood et al. 2019) and other freshwater ecosystems (e.g., Jordan et al. 1998; Muška et al. 2013). Changes in water temperature among seasons trigger spawning events or can alter habitat, such as creating anoxic zones in Hamilton Harbour in the summer (Bowlby et al 2016) and compressing habitat for fishes in certain zones of the harbour (Midwood et al. 2019; Flood et al. 2021). Time of day affects fish behaviour; fish have been observed to school more during the day than at night in Hamilton and Toronto harbours (Midwood et al. 2019, Midwood et al. 2018, respectively), and acoustic telemetry tracking of four of our focal fish species in Hamilton Harbour has suggested variable encounter rates based on time of day and season (Larocque et al. 2020). Ultimately, however, IBI scores should reflect healthy fish communities regardless of season or time of sampling. For this reason, final IBI scores for the Hamilton Harbour AOC are calculated by pooling seasonal and day/night data (Boston et al. 2016). As noted previously, in the present work models were applied to each sampling event (three seasons by day and night). By separating the data in this manner, we were modeling at the same temporal scale in which we sampled to more directly address the question of "how many more fish would need to be caught per sampling trip in order to see changes in IBI scores?”.

Models were built in R and were composed of two main sections: 1) iteratively adding or removing species, and 2) calculating the IBI and IBI_{adj} scores for the modified catch data. For each species of interest (either for adding Northern Pike, Walleye, Smallmouth Bass, or removing Common Carp, and Goldfish), fish were added or removed incrementally from 1 to a total of 100 fish across randomly selected transects for that sampling period (combination of season and day or night). The fish were randomly added across all transects for a total of 100 individuals. For each addition or removal increment across random transects, the model was iterated 100 times to provide a measure of variance. Species of interest that were added to the 2018 transect catch data included a mean weight (calculated from all individuals of that species over all Hamilton Harbour electrofishing years; Northern Pike = 1.887 kg; Walleye = 1.048 kg, Smallmouth Bass = 0.478 kg). For removals, randomly selected unique records of species of interest (Common Carp or Goldfish) were incrementally removed from the 2018 base dataset until all individuals of that species were gone from the dataset; so if there were only 50 Goldfish in the dataset, resulting IBI scores would not change past 50 removals. Mean weights were not required for removals since unique records (catch, weight, length, etc.) of caught fish were being removed. Values were calculated up to 100 removals for each species to remain consistent and allow for the results of combinations of additions/removals to be modeled.

One hundred fish was arbitrarily chosen as the maximum number of fish to be added or removed. This value was found to be large enough to observe changes in IBI and was greater than the actual range of the fish catch observed at other electrofishing sites in the Great Lakes

(Table 3). One hundred iterations were chosen to provide an estimate of variance given that the random assignment of fish additions could drastically change a transect-level IBI score if that species was not originally captured there.

IBI and IBI_{adj} were then calculated for each combination of additions or removals for each iteration according to Minns et al. (1994). Mean IBI or IBI_{adj} values (± standard deviation) were calculated for each season (spring, summer, fall) and separately for night and day data. IBI_{adj} values for Walleye were not calculated since this species is considered a pelagic fish and would thus be removed from its calculation. Modeled data were plotted (mean IBI ± standard deviation for season, day or night, and year) by the number of fish being added and removed, with separate trends for each season. Plots were interpreted based on the number of fish (or combination of fish) that would need to be added or removed in order for the resulting IBI scores to meet current delisting targets of 55 – 60 for the IBI. Models were run for each individual species, as well as combinations of multiple species additions and/or removals; however, additions and removals were implemented independently for each species such that at a fish catch change of five (for example) in a scenario with both Northern Pike, Walleye, and Common Carp there would be five new Northern Pike added, five new Walleye, added, and five Common Carp removed (Table 4).

RESULTS

Initial IBI scores for 2018 spring, summer, and fall were 41, 31, and 40, respectively, and 8, 20, and 27 for IBI_{adj} (Figure 1 – 7; 2012 graphs for species are included in the Appendix for reference; Figure A1 – A8). No addition or removal of a single species was able to improve IBI scores to the upper IBI target of 60, but combination models of additions and removals did pass the low end of the target of 55 (Table 4). Scenarios for Smallmouth Bass yielded similar results as Northern Pike since metric groupings for these species are nearly identifcal. Due to these similarities, Smallmouth Bass were left out of the multi-species combinations since their contribution would be comparable to Northern Pike. Smallmouth Bass are discussed briefly in the Appendix. Combinations of additions/removals of the other four species did improve IBI scores and reached the target score between 55 and 60; however, the number of fish added or removed to reach those targets greatly exceeded previous fish catch from any of the similar areas sampled on the Great Lakes (Table 3). IBI_{adj} scores showed slightly weaker responses for Northern Pike and Smallmouth Bass, and little to no impact on IBI_{adj} for non-native removals. IBI_{adj} values are only shown for Northern Pike models as the values are no different for Walleye and there was little to no response for removals.

Single Species Models

Northern Pike: In 2018, only six Northern Pike were caught and three was the greatest number of Northern Pike caught in a single transect. For reference, our electrofishing database shows that the highest number of Northern Pike caught was 34 fish in 1999 from 97 transects in the

Bay of Quinte (Table 3). Adding 100 Northern Pike to the total catch resulted in an approximately 10 point increase in IBI score for spring and summer (closer to 15 for fall; Figure 1, Table 4). Fall values reached the lower IBI target of 55 at the addition of 70 fish; however, no season hit the 60 point target and there were limited gains in IBI score after 80 fish additions. For IBI_{adj}, no season reached anywhere near IBI targets (there is currently no IBI_{adj} target, but previoulsy targets ranged between 50 – 60) but values for all seasons increased approximately 20 points after adding 100 Northern Pike.

Walleye: Twenty-one Walleye were caught in 2018 with a maximum of three individuals in a single transect . For reference, our electrofishing database shows that the highest number of Walleye caught was 29 fish across 93 transects in the Bay of Quinte in 2015 (Table 3). Adding 100 Walleye to the total catch resulted in an approximately 15 point increase in IBI scores for all seasons (closer to 17 for fall; Figure 2, Table 4). For the fall season only, the addition of the 90 fish raised the score past the 55 point threshold. No season hit the 60 point target and, similar to Northern Pike, the values showed small gains after 80 fish additions.

Common Carp: Fifty-five Common Carp were captured in 2018; 4 was the maximum number of Common Carp caught in a single transect. For reference, our database shows that the highest number of Common Carp caught (from sites outside of Hamilton and Toronto) was 19 fish across 59 transects in 1990 from Bay of Quinte (Table 3). Since there were only 55 Common Carp caught in 2018 across all seasons, there were only approximately 18 fish available to remove within any season (fewest number were caught in the fall; Figure 3, Table 4). As such, the trendlines for all seasons flatline after 20 removals since there were no more individuals to remove. Given the limited number of fish for removal, the IBI showed poor improvement, with a less than 5 point increase in IBI score; however, in this single species scenario, Goldfish remain in the dataset and contribute to lower IBI scores.

Goldfish: In 2018, 109 Goldfish were caught with a maximum of 16 caught in a single transect. For reference, our electrofishing database shows that the highest number of Goldfish caught was 3 fish across 38 transects in 1990 from Matchedash Bay in Lake Huron (Table 3). Of the 109 Goldfish caught across all seasons in Hamilton Harbour, most were caught in the summer (nearly 60 fish) with similar catch in spring and fall (just less than 25 fish each; Figure 4). For spring and fall, there were neglible IBI increases regardless of the number of records that were removed. For the summer, there was an approximately 5 point gain in IBI score, though nearly 60 Goldfish had to be removed to achieve this gain. The IBI showed less improvement from Goldfish removals than for Common Carp removals with less than 5 point IBI increases despite removing 109 (total for all seasons) Goldfish from the data; however, in this single species scenario, Common Carp remain in the dataset and contribute to lower IBI scores.

Multi-Species Models

For all multi-species models, the x-axis shows the total number of fish added or removed for an individual species.

The combined addition of Northern Pike and Walleye resulted in IBI scores of 55 when 55 of each species was added and reached IBI scores of 60 after an increase in 100 of each species for the fall season only (Figure 5, Table 4). Spring values nearly hit the 55 target after the addition of 100 Northern Pike and Walleye. IBI scores rose approximately 20 points for fall and summer, and 15 points for spring. The fall dataset responded more strongly to the addition of fish compared to the spring, despite similar starting IBI scores. For the IBI_{adj}, all seasons showed a weak response (increases of less than 10 points) for additions of 100 of each species.

The addition of Northern Pike and removal of Common Carp reached the 55 target for fall only, at approximately 58 fish (58 additions, all Common Carp removed) and began to flatline around 80 additions/removals; no season reached the upper IBI target of 60 (Figure 6, Table 4). IBI scores rose quickest from 0 – 12 fish additions or removals (rising 4, 8, and 6 IBI points in the spring, summer, and fall, respectively); however, after all the Common Carp available in the dataset were removed, the curve flattened showing a similar pattern to the Northern Pike only model. Overall, summer and fall showed a nearly 20 IBI point increase and nearly 15 points for the spring. This scenario would yield similar results as the combined addition of any one top predator (e.g., Northern Pike, Smallmouth Bass, or Walleye) and removal of either Common Carp or Goldfish, as such, the full range of potential combinations of single additions and removals were not modeled.

The only scenario where both targets were surpassed was when all four species were altered (adding Northern Pike and Walleye, removing Common Carp and Goldfish), but only for the fall season at an individual species change of approximately 37 and 77 fish for the 55 and 60 IBI targets, respectively (Figure 7, Table 4), demonstrating the comparatively large increase in additions/removals that would be required for a modest 5-point gain in IBI score. IBI scores increased most rapidly while Common Carp were still in the dataset to be removed (IBI scores stop changing at 15, 14, and 9 fish removals for spring, summer, and fall, respectively), and gains diminished after individual species changes of 50 fish. IBI_{adj} showed a weaker response to additions and removals (Walleye are not included in IBI_{adj} calculations) and started to plateau at 25 fish, with a less than 10 point increase in IBI_{adj} for all seasons, none of which reached IBI targets.

For comparison, we ran the same scenario where all four species were altered but for 2012 data (Figure 8, Table 4), where intial IBI scores were 28, 38, and 52.5 and IBI_{adj} scores were 23, 31, and 38 for spring, summer, and fall, respectively (lower than those seen in 2018). For IBI scores all seasons hit the 55 target at individual species changes of 71, 79, and 4 for spring, summer, and fall (only fall hit the 60 target at individual species changes of 8 fish).

Summer and fall scores rose approximately 17 IBI points after the addition/removal of 100 fish; spring showed the greatest response rising approximately 20 points. As before, IBI scores increased most rapidly while Common Carp were still in the dataset, and gains diminished after 50 fish. None of the IBI_{adj} scores reached target scores, and showed less than 10 point gains after the addition and removal of 100 fish per species.

When we further divided the 2012 dataset into day and night (no day samples were taken in the fall in 2018) and ran a scenario for all four species we found that night samples surpassed an IBI score of 55 at individual species changes of 37, 23, and 4 for spring, summer, fall, respectively (Figure 9, Table 4). Only the fall data for day samples reached an IBI target of 55 at 3 additions/removals. For the daytime data, spring (starting score of 22) had a greater positive repsonse to the scenario than summer (starting score of 31; Figure 9).

DISCUSSION

The objective of this modelling exercise was to determine if target IBI scores can be achieved by artificially manipulating the catch of select species of interest that are or can be managed by fisheries agencies within the Hamilton Harbour AOC. Given the scenarios run, it is theoretically possible to reach IBI targets, but this comes with several caveats including the number of species managed, the number of fish that need to be removed or added, and the season and time of day used to assess target values. The response of IBI scores was greater for additions than removals, but to reach IBI targets with additions of only one or two species would require catching more fish than would realistically be possible based on maximum catch rates in less degraded areas. Generally, manipulation of at least four species was necessary to achieve BUI targets with quasi-realistic changes in catch. This reinforces the need for improvements to species richness, which was most highly correlated with IBI scores in an assessment of habitat productive capacity in Lake Ontario in Randal and Minns (2002).

IBI_{adj} scores never reached the target IBI, and responded more to the removal of non-native species than additions of top predators. Before IBI_{adj} was removed from official delisting criteria, targets were set at scores between 50 – 60 (Table 4 in Smokorowski et al. 1998). Given the small impact of the selected species, IBI_{adj} is unlikely to reach these former delisting criteria targets. Further, current species-specific management outlined in this report is unlikely to benefit IBI_{adj} scores for the harbour therefore most discussion henceforth will primarily apply to the IBI. Future works could focus on modeling solely nearshore species since the IBI_{adj} was intended to assess these communities (i.e., no offshore species such as Walleye in the calculations) and healthy nearshore areas should not be dominated by offshore species (as is currently the case in Hamilton Harbour; Minns et al. 1994; Boston et al. 2016).

Catch records from DFO's electrofishing database for similar ecotypes as Hamilton Harbour, including current and former AOCs from Lakes Ontario, Erie, and Huron provide context for the likelihood of catching additional Northern Pike and Walleye. All of these sites also have mean IBI scores well above the Hamilton Harbour target of 55, suggesting less impaired ecosystem conditions and thus healthier fish communities. Since 1989, 216 Northern Pike and 220 Walleye were caught at nine locations across 1134 samples, via electrofishing. Most of these fish were caught in the Bay of Quinte, an area well known for its comparatively healthy predator populations (OMNRF 2019; Boston et al. 2016). As noted, the greatest single year catch for Northern Pike and Walleye were 29 and 31, respectively. In Hamilton Harbour, where catches of these species are low (e.g., 6 Northern Pike, and 21 Walleye in 2018), it is unlikely that scenarios with more than 30 fish additions to the community are realistic. This is likely true even if the fish community in Hamilton Harbour was determined to be "unimpaired" as they are in Bay of Quinte and Severn Sound. Given these values from less impaired systems and noted likely maximum catch for top predators, only the scenarios with additions and removals of at least four fish species are likely to meet IBI targets, and only for the fall at night (and 2012 day) datasets. This suggests that management actions that yield changes only to the species of interest modeled here, barring likely but unquantified associated changes in the overall fish community, are unlikely to produce the desired improvements in fish community metrics.

Since 1988, there were 53 species recorded in the DFO electrofishing database. Though none of the five species of interest here were the most abundant species in the entire dataset, they were recognized as important species to the community; three top predators in low abundance and recognized in the BUI delisting criteria, and two invasive species where Common Carp have a history of management and Goldfish have potential analogous management options (BARC 2012). In addition to their recognized importance and impact for the fish community, these four species (excluding Smallmouth Bass) were the most likely to have ready-to-implement actions associated with them. Northern Pike were historically abundant (Holmes and Whillans 1984) and have been the focus of several remediation efforts in Lake Ontario, including in the Hamilton Harbour and Toronto and Region AOCs (Casselman and Lewis 1996). Their top-down effects from predation are likely beneficial to the native fish community, and their habitat requirements are well known and overlap with the Hamilton AOC's goals of increasing the distribution of aquatic vegetation and reducing water quality impairments like low dissolved oxygen and high turbidity (BARC 2012, Casselman and Lewis 1996). Juvenile and adult habitat of Northern Pike are considered limiting in Lake Ontario in general, based on year-class observations (Casselman and Lewis 1996) and modeling (Minns et al. 1996), and the focus of managing this species thus far has been through habitat remediation (e.g., Grindstone and Red Hill Creek marshes). Emerging evidence for lower catch per unit effort of Northern Pike in Hamilton Harbour (0.33) relative to Toronto Harbour (0.88) and to a lesser extent the Bay of Quinte (0.56; OMNRF 2019), would suggest that habitat limitations likely persist within the AOC.

Walleye life histories are well described (Bozek et al. 2011); however, less is known about Walleye recruitment and status of habitat in Hamilton Harbour. Walleye are currently stocked within Hamilton Harbour (stocking started in 2012); 1 million fry and 80 thousand summer fingerlings were stocked in 2018 and expected to continue every other year (OMNRF 2019). While Walleye populations have increased in Hamilton Harbour since stocking began, the goal of stocking was to re-establish natural recruitment of the species in the harbour (OMNRF 2019). Based on preliminary evidence from spring spawning electrofishing sampling and a Walleye egg collection pilot study, stocked Walleye do spawn in the harbour (OMNRF 2017; Midwood unpublished data); however, we do not know if those spawning events lead to successful recruitment. Larval surveys before stocking or in non-stocking years would provide evidence of recruitment of Walleye in the harbour, and incidental capture of young-of-year Walleye that do not match the stocking cycle are suggestive of some level of recruitment (Boston unpublished data). To our knowledge, we have not observed verified non-stocked juvenile Walleye in the harbour in recent years. Walleye are an economically important species (Bozek at al. 2011) so stocking efforts will continue but given the moderate influence of adding Walleye to the IBI (and no influence on IBI_{adj}), as well as the lack of evidence of natural recruitment, the RAP should discuss whether it is appropriate to include stocked Walleye in the calculation of an IBI since their presence and abundance is not necessarily indicative of the conditions within the ecosystem and their persistence is dependent on continued intervention.

The weak positive response of removals of the selected non-native species (as shown in the non-native-only scenario) suggests that management actions taken towards reducing solely Goldfish and Common Carp will not directly lead to large increases in IBI scores for the harbour. In our results the biggest gains in IBI score for invasive removal occurred in conjunction with additions of desirable species (multi-species models). This suggests that the reduction in populations of invasive species is most impactful to IBI scores when their removal allows the native fish community to respond (e.g., allows increase in native species richness – an overly simplified view of community dynamics), and therefore the biggest impacts are indirect.

Functionally, removal-only scenarios showed little change because there are a finite number of individuals to remove and other non-native species (e.g., Alewife [*Alosa pseudoharengus*], Round Goby [*Neogobius melanostomus*], and Rudd [*Scardinius erythrophthalmus*]) may provide redundancy that keeps non-native metrics (SNIN/PNNI/PBNI; Table 1) at their maxima. PBNI (percent non-indigenous biomass) and PGEN (percent generalist biomass) are likely the main metrics that will respond to removal of Goldfish and Common Carp given their large body size compared to many of the other non-native species. Also, Goldfish (mean weight from the electrofishing dataset of 0.46 kg) are smaller than Common Carp (mean weight from the electrofishing dataset of 3.54 kg), therefore Goldfish's impact on these biomass metrics is smaller. Given these factors, direct removal of these species provides only a minor benefit to the final IBI score; however, there are indirect benefits associated with managing these two species.

Common Carp impact fish habitat by decreasing vegetation, and increasing turbidity, thereby altering nutrient dynamics in a system (Matsuzaki et al. 2009, Weber and Brown 2009). Given their broad diets, in high densities (such as in Hamilton Harbour) Common Carp can negatively impact populations of invertebrates and small fishes (Matsuzaki et al. 2009); the same can be expected of Goldfish due to similarities in life histories (Lorenzoni et al., 2010; Smith and Walker 2004). Whether through habitat alteration or interspecific competition, these two species influence fish and fish habitat and thus their management may have added benefits such as improved water clarity, decreases in nutrients, increased aquatic vegetation, and decreased predation on small fishes and invertebrates (Weber and Brown 2009, Dalu et al. 2020). These indirect benefits for management of non-native species have not been assessed in the present work, but the noted lower catch of Common Carp and Goldfish from other areas in the Great Lakes with higher IBI scores may be suggestive of how their removal may not only affect the resulting IBI score but also the fish community in general. So, while altering their number directly for IBI calculations is unlikely to produce desired IBI scores, indirect benefits from reducing numbers of Common Carp and Goldfish make their management within the harbour an essential element of fish population recovery.

For invasive species, the five broad categories of control involve prevention, eradication, excluding, genetically modifying, and either biological controls or pheromone manipulation (Rytwinski et al. 2018). Prevention is the most effective strategy, however, both Common Carp and Goldfish are already present in Hamilton Harbour, and genetic modifications or biological controls can be time or cost-prohibitive with uncertain efficacy, therefore eradication is the most often used strategy once invasive species are present (Rytwinski et al. 2018). Realistically, the most feasible control techniques for Hamilton Harbour involve exclusion and eradication, and even then, complete eradication is unrealistic (Britton et al. 2011). Exclusion of these species has already been implemented at the Cootes Paradise fishway, where exclusion barriers have had success with reductions in catch of Common Carp and some improvements in water quality (Lougheed et al. 2004, Mataya et al. 2020), but cannot stop younger individuals that can fit through the bar spacing. Passage by young individuals and the availability of other potential spawning areas, albeit likely less desirable than Cootes Paradise, allow these species' to persist in the AOC. Eradication could be carried out by chemical means (McClay 2005, Dalu et al. 2020) but can harm native fishes (McClay 2005). The most appropriate eradication technique to be utilized in the harbour is physical removal. If undertaken, current telemetry studies could be leveraged to use tagged individuals of invasive species to track aggregations of non-tagged conspecifics for removal (Bajer et al. 2011). Removals of Common Carp have been shown to be beneficial (Dalu et al. 2020), but the efficacy of species removals is not often assessed, or the study design is inappropriate for evaluation (Rytwinski et al. 2018). Given the preponderance of fish catch information in the harbour, there is an opportunity to undertake a well-designed study on the efficacy of removal of Common Carp and Goldfish. It is important to note, however, that eradication can be difficult to implement depending on public optics, permitting, and the ongoing commitment and cost to remove non-native species (Britton et al. 2011). If future actions utilize any of these control measures, clear objectives, measurable criteria, and a well-planned assessment should be considered.

Fall data yielded higher IBI scores than other seasons in every scenario, with spring and summer yielding similar and lower scores. Night IBI scores were also higher and responded more strongly to additions and removals than day data in 2012; IBI scores from day sampling for the fall were slightly higher than night but both started in the 50s, nearly within the target IBI range already. Currently, IBI scores used for the BUI assessment are not broken down into diel or seasonal groups. In Hamilton Harbour, there are markedly lower IBI scores in the spring and summer, however, in less degraded systems, IBI scores do not exhibit this seasonal pattern, which is the impetus behind combining data from multiple seasons into a more global score for the actual assessment of the IBI targets. Factors such as time of day and season should be considered for the upcoming assessment of Hamilton Harbour, with consideration of regionally-derived targets for diel-season pairs and a determination of the factors limiting fish communities in Hamilton Harbour during the spring and summer.

Given the estimated catch needed to improve IBI scores and the actual catch from regionally similar areas, it seems unlikely that management of one or even all modeled species will achieve the IBI targets to allow delisting of the fish population BUI. From a review of IBI metrics in 2018 and previous studies (Randall and Minns 2002), it is evident that native species richness (which also includes the Centrarchid, Intolerant, and Cyprinid Richness metrics) and total catch of native fishes are major contributing factors to persistently low IBI scores (Appendix Figure A9 – A12). The species modeled in the present study will contribute to some (e.g., native species richness and catch), but not all these metrics, hence limited evidence for marked changes in IBI scores from additions or removals of our target species. This report used simple additions or subtractions of fish to simulate changes in catch and did not consider how target species would directly or indirectly interact with the rest of the fish community and resulting richness. We expect that managing these target species would provide a benefit to the native fish community, but the direction and magnitude of these benefits cannot easily be quantified.

The path forward for increasing native species richness is the restoration of wetland habitat in Cootes Paradise and Grindstone Creek Marshes and the restoration or enhancement of habitat (including water quality improvements) within the harbour, as many smaller-bodied species (e.g., Cyprinids or Centrarchids) are not easily managed but can be found within the watersheds that feed into the harbour (e.g., Red Hill Creek; McCallum et al. 2019). These areas may serve as local source populations to re-colonize the harbour,if required, or aid in the recovery of species currently present in low numbers to recover back to a more balanced trophic composition and native species richness. While determining the effect of habitat improvements on fish communities can be difficult (Taylor et al. 2019), there has previously been broad evidence of wetland fish species richness improving since implementation of the RAP program in Lake Ontario (Seilheimer et al. 2011). Many wetland species appear to be missing or are captured in low numbers in Hamilton Harbour including Pumpkinseeds

[*Lepomis gibbosus*], Bluegill [*Lepomis macrochirus*]; Yellow Perch (OMNRF 2019). As such, the RAP delisting criteria reflects the desire for a balanced self-sustaining native fish community and trophic composition. The pending assessment of fish habitat within Hamilton Harbour paired with recent modeling of dissolved oxygen fluctuations (Flood et al. 2021) will be an essential element in quantifying the amount of habitat in the AOC, assessing its quality and residual impairment, and identifying actions that can be completed to improve habitat conditions to promote recovery of more native fishes. Given the evidence in the literature for improvements in habitat from managing non-native fish species (Lougheed et al. 2004, Dalu et al. 2020), removal of the two modeled non-native species is a promising management option for improving habitat conditions and will provide a limited increase in IBI scores through their absence alone. From the present work it is evident that a holistic recovery of native fish populations will be required to reach the delisting criteria.

If future works should continue, our modeling could be rerun with other species but the connection between changing the populations of those suggested species and management actions to effect change are less clear than they are for the selected species in this report. New scenarios should focus on underperforming metrics, likely related to increasing native species richness across the harbour, rather than single species manipulations. These types of scenarios could provide support for habitat (physical and chemical) restoration; likely the only path to recovery for species that cannot or have not been directly managed to date.

CONCLUSION

We ran simple models to manipulate DFO’s 2012 and 2018 electrofishing catch data of five RAP-identified fish species that have previous evidence and methods for the management of their populations. Our objective was to determine what changes in catch of these five species were needed to meet the RAP IBI targets of 55 – 60, across three seasons. We found that manipulating only a single species was insufficient to raise IBI scores to their targets, and that adding native fish species to the catch dataset had a greater impact than removing non-native species from the catch. Combining additions and removals of at least four fish species, we found that we could reach the target IBI scores; however, in cases where initial IBIs were low (<40), the number of fish required to reach targets was greater than any catch that has been observed in similar areas in Lake Ontario, Huron, and Erie. Seasonal variability in fish catch is well documented in the literature and we found clear differences in seasonal responses to manipulation of catch data and the resulting IBI scores in Hamilton. Fall catch and its resulting initial IBIs were greater than either spring or summer and were therefore more likely to reach IBI targets with fewer added or removed fish. Ongoing works in both Toronto and Hamilton harbours are exploring seasonal fish community differences for future characterization of these AOCs. Although there may be indirect benefits of restoring top predators to establish top-down control on the fish community, focusing solely on specific species is unlikely to alter the IBI significantly, and therefore constitutes only one of many actions needed to delist fish populations criteria. Similarly, managing Common Carp and Goldfish will likely have indirect benefits to the IBI, evidenced by literature supporting habitat improvements upon their removal. Future scenarios should focus on increases to species richness and the response of the IBI, which will most likely be achieved through habitat (physical and chemical) restoration of Hamilton Harbour. Our present and future results should be used to support the prioritization of management actions within the AOC.

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Table 1. Index of Biological Integrity (IBI) metrics (Minns et al. 1994) and their effect on IBI scores. The slope and intercept and upper and lower standardized metric values are shown. Species are categorized according to these metrics and are assigned in Appendix Table 1.

Metric Code	Metric Name	Metric Group	Metric Variable	Slope	Intercept	Ms=0	Ms=10	Influence on IBI
BNAT	Biomass of Natives (kg)	Native	Biomass	0.83	0	0	12	Positive
SCEN	Centrarchid Species Richness	Centrarchid	Count Of Species	3.33	0	0	3	Positive
SINT	Intolerant Species Richness	Intolerant	Count Of Species	5.00	0	0	2	Positive
SCYP	Native Cyprinid Species Richness	Cyprinid	Count Of Species	5.00	0	0	2	Positive
SNAT	Native Species Richness	Native	Count Of Species	1.25	0	0	8	Positive
SNIN	Non-Indigenous Species Richness	Non-Indigenous	Count Of Species	-3.33	10	3	0	Negative
NNAT	Number of Native Individuals	Native	Number	0.083	0	0	120	Positive
PGEN	Percent Generalist Biomass	Generalist	Biomass	-0.15	15	100	33.3	Negative
PBNI	Percent Non-Indigenous by Biomass	Non-Indigenous	Biomass	-0.10	10	100	0	Negative
PNNI	Percent Non-Indigenous by Number	Non-Indigenous	Number	-0.10	10	100	0	Negative
PPIS	Percent Piscivore Biomass	Piscivore	Biomass	0.30	0	0	33.3	Positive
PSPE	Percent Specialist Biomass	Specialist	Biomass	0.30	0	0	33.3	Positive
POFB	*Percent Off-Shore by Biomass	Offshore	Biomass	1.00	0	0	100	Negative
POFN	*Percent Off-Shore by Number	Offshore	Number	1.00	0	0	100	Negative

* These metrics are only used for the calculation of the adjusted IBI.
Ms = standardized metric

Table 2. Number of electrofishing transects sampled in Hamilton Harbour (1988-2019) for three time periods (day, night, crepuscular) from May-October. Years of interest are highlighted in **bold**.

				Number of Transects					
Location	**Ecotype**	**Year**	**Time Period**	**May**	**June**	**July**	**August**	**September**	**October**
Hamilton	Embayment	1988	Day	6	83	87	43		
Hamilton	Embayment	1988	Night		9	27	24		
Hamilton	Embayment	1988	Crepuscular		20	12	12		
Hamilton	Embayment	1990	Day	17	16	20	11		
Hamilton	Embayment	1990	Night	3	2	1	5		
Hamilton	Embayment	1990	Crepuscular	3	2	1	2		
Hamilton	Embayment	1992	Day	23		14			
Hamilton	Embayment	1992	Night	16		13	7		
Hamilton	Embayment	1992	Crepuscular	5		10			
Hamilton	Embayment	1993	Day			4	1		
Hamilton	Embayment	1993	Night			21	2		
Hamilton	Embayment	1993	Crepuscular			6	1		
Hamilton	Embayment	1995	Day	3	14	6	5	10	
Hamilton	Embayment	1995	Night	3	6	6	11	13	
Hamilton	Embayment	1995	Crepuscular	2	2		3	1	
Hamilton	Embayment	1996	Day		18	16	19	15	2
Hamilton	Embayment	1996	Night		14	13	18	24	
Hamilton	Embayment	1996	Crepuscular		7	6	2	4	
Hamilton	Embayment	1997	Day	14		21	19	16	
Hamilton	Embayment	1997	Night	8		12	21	26	
Hamilton	Embayment	1997	Crepuscular	3		1	3		
Hamilton	Embayment	1998	Day		15	15	20	13	
Hamilton	Embayment	1998	Night		12	18	16	22	
Hamilton	Embayment	1998	Crepuscular		1	3		1	
Hamilton	Embayment	2002	Day		18	16	15	7	
Hamilton	Embayment	2002	Night		13	12	17	22	1
Hamilton	Embayment	2002	Crepuscular		3	5	4	6	1
Hamilton	Embayment	2006	Day		10	6		10	
Hamilton	Embayment	2006	Night		21	25		21	
Hamilton	Embayment	2008	Day		1	2			
Hamilton	Embayment	2008	Night		30	35	30	31	
Hamilton	Embayment	2010	Day		16	24	30	12	
Hamilton	Embayment	2010	Night		15	25	28	19	
Hamilton	**Embayment**	**2012**	**Day**		**26**	**25**	**35**	**13**	
Hamilton	**Embayment**	**2012**	**Night**		**25**	**12**	**43**	**19**	**27**
Hamilton	Embayment	2013	Day		32	29	30	30	
Hamilton	Embayment	2013	Night		32	30	30	30	
Hamilton	Embayment	2016	Day		29	25			
Hamilton	Embayment	2016	Night		25	40	30		27
Hamilton	**Embayment**	**2018**	**Day**		**30**	**7**			

Hamilton	**Embayment**	**2018**	**Night**	**31**	**30**	**4**	**31**	**28**
Hamilton	Embayment	2019	Day		28	31	28	
Hamilton	Embayment	2019	Night	30	31	29	31	30

Table 3. Total and maximum (per transect) catch of species of interest, and mean Index of Biological Integrity (IBI) and IBI adjusted (IBIadj) scores across sites in Lakes Ontario, Erie (1994), and Huron (1989-2016).

	Catch totals												
Area and years sampled	**Total Common Carp**	**Max Common Carp**	**Total Goldfish**	**Max Goldfish**	**Total Pike**	**Max Pike**	**Total Walleye**	**Max Walleye**	**Mean IBI**	**s.d.**	**Mean IBIadj**	**s.d. adj**	***n***
Bay of Quinte, Lake Ontario	77	7			143	6	187	31	70	16	62	19	545
1989	13	3			17	5	27	31	69	14	50	18	34
1990	19	7			25	4	27	12	58	23	49	25	59
1992					6	2	11	6	69	14	58	14	17
1999	7	1			34	3	11	2	72	15	68	17	97
2001	1	1			16	5	8	7	73	17	68	20	42
2004					5	3	4	4	72	9	68	13	12
2007	3	3			8	2	27	12	74	9	66	14	55
2009	9	3			18	6	21	7	77	14	70	18	60
2011	13	2			6	1	22	6	69	16	63	18	76
2015	12	3			8	3	29	7	66	15	60	17	93
Green Island, Lake Huron	7	2			9	4	3	1	65	15	63	16	54
1995	3	1			7	4	2	1	63	18	60	20	27
2016	4	2			2	1	1	1	67	10	66	10	27
Hog Bay, Lake Huron	17	8			8	2	4	3	65	17	65	17	85
1990	5	2			2	2	1	1	62	19	61	19	28
1992	1	1							48	2	48	2	6
1995	3	8			4	1			68	16	68	16	18
2002	5	2			1	1			67	16	66	16	13
2016	3	3			1	1	3	3	72	12	71	13	20
Longpoint, Lake Erie	3	2			12	4			74	13	74	13	27
1994	3	2			12	4			74	13	74	13	27
Matchedash Bay, Lake Huron	10	3	3	1	10	2	5	5	65	11	63	13	59
1990	8	2	3	1	5	1	5	5	66	11	62	14	38
2016	2	3			5	2			65	12	65	12	21
Prince Edward County, Lake Ontario	2	1			21	3	11	2	72	14	70	15	105
1998					3	1	1	1	74	11	73	11	11
1999					11	3	1	1	78	9	77	8	24
2007					6	2	1	2	81	9	79	10	10
2009	1	1			1	2	2	2	77	9	75	10	18
2011									62	16	62	16	18
2015	1	1					6	1	63	17	60	19	24

Penetang Bay, Lake Huron	14	3	1	1	4	1	7	3	63	20	60	22	166
1990	11	3	1	1	4	1	1	2	59	17	56	18	84
1992									30	28	21	24	12
2002	1	1							66	17	64	18	28
2016	2	3					6	3	79	8	76	10	42
Prescott, Lake Ontario	1	1			5	4	2	2	64	15	60	19	21
1994	1	1			5	4	2	2	64	15	60	19	21
Sturgeon Bay, Lake Huron	1	1			4	1	1	1	65	17	64	17	51
1992					2	1			57	20	57	20	23
2016	1	1			2	1	1	1	72	9	71	9	28
Grand Total	**132**		**4**		**216**		**220**						**1113**

Table 4. List of scenarios run for each species in 2012 and 2018 and the number of fish (up to 100 per species) that were added or removed to meet Index of Biological Integrity (IBI) target scores between 55-60. Seasons are denoted by abbreviation next to the number of fish. Values for additions and removals are per species; for multi-species suchs as Northern Pike + Carp models, a value of 58 indicates that to reach the target IBI, 58 Pike were added and up to 58 Carp were removed, if there were that many available in the catch data.

Year	Species	Model type	# fish to reach IBI of 55	# fish to reach IBI of 60
2012	*Northern Pike*	*add*	*8F*	*40F*
2012	*Walleye*	*add*	*12F*	*68F*
2012	*Smallmouth Bass*	*add*	*12F*	*70F*
2012	*Carp*	*removed*	*7F*	*DNR*
2012	*Goldfish*	*removed*	*DNR*	*DNR*
2012	Northern Pike + Walleye+ Carp + Goldfish	add & removed	71Sp, 79S, 4F	8F
2012	*Northern Pike + Walleye+ Smallmouth Bass + Carp + Goldfish*	*add & removed*	*44Sp, 55S, 3F*	*87Sp, 7F*
2018	Northern Pike	add	70F	DNR
2018	Walleye	add	90F	DNR
2018	*Smallmouth Bass*	*add*	*90F*	*DNR*
2018	Carp	removed	DNR	DNR
2018	Goldfish	removed	DNR	DNR
2018	Northern Pike + Carp	add & removed	58F	DNR
2018	Northern Pike + Walleye	add	55F	DNR
2018	Northern Pike + Walleye + Carp + Goldfish	add & removed	37F	77F
2018	*Northern Pike + Walleye+ Smallmouth Bass + Carp + Goldfish*	*add & removed*	*54Sp, 54S, 31F*	*92S, 55F*

Abbreviations next to values indicate season: F= fall, Sp= spring, S= summer
Italicized, red model entries' graphs are found in the appendix
DNR= did not reach the threshold after addition or removal of 100 fish

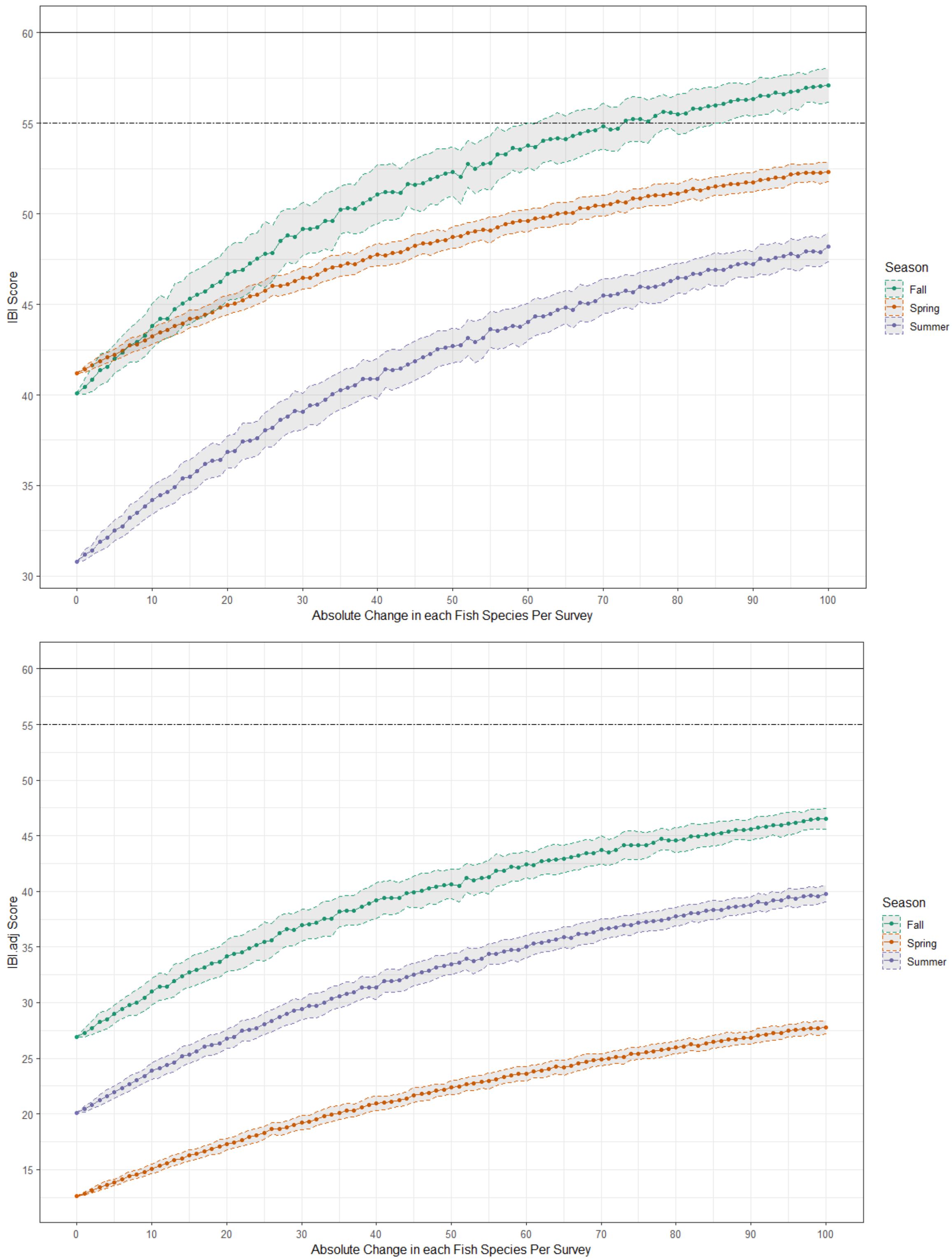


Figure 1. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted ($IBI_{.adj}$, bottom) scores through the addition of 100 Northern Pike (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

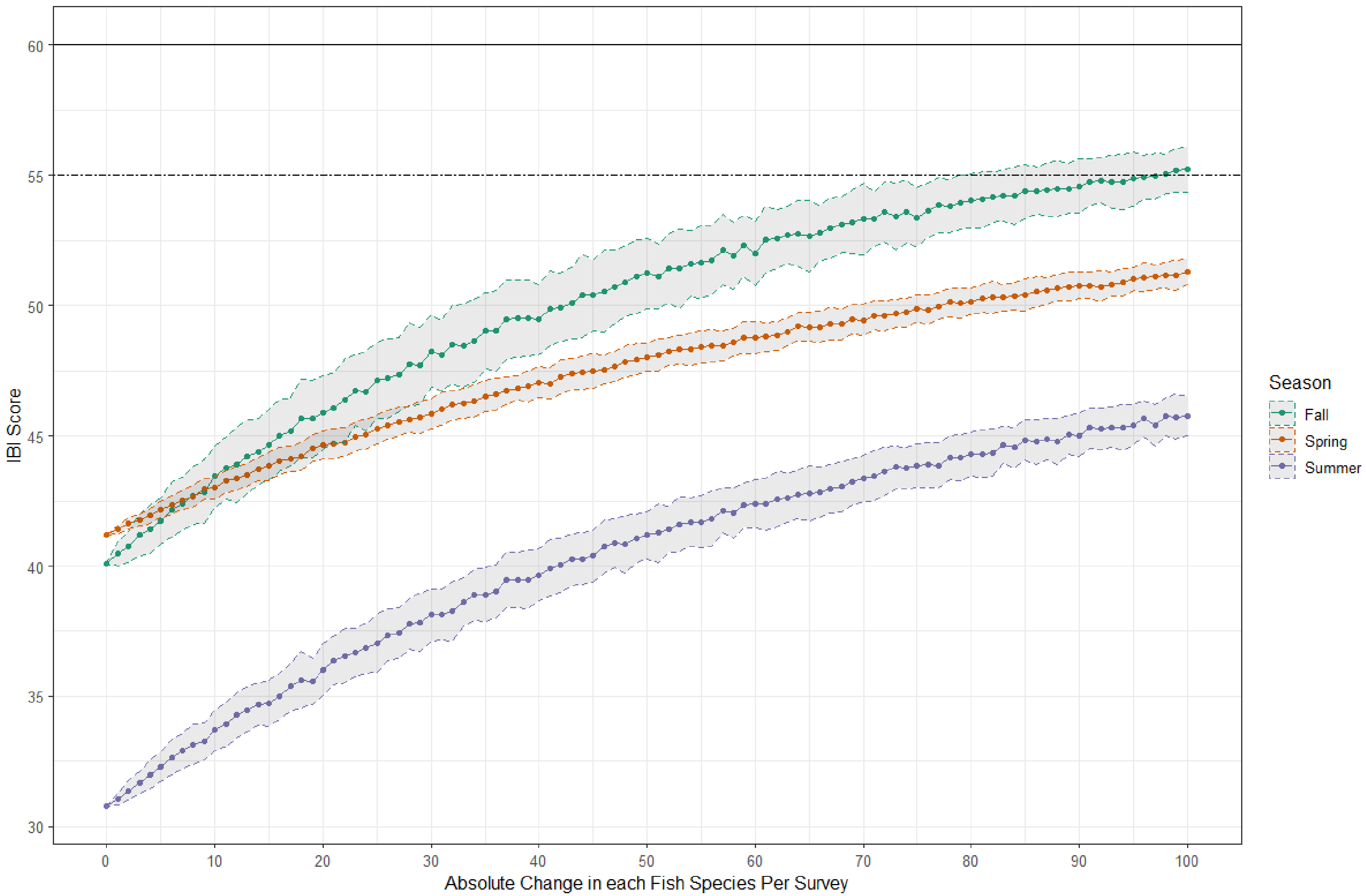


Figure 2. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of up to 100 Walleye (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as unimpaired. IBI_{adj} values for Walleye were not calculated since this species is considered a pelagic fish and would thus be removed from its calculation.

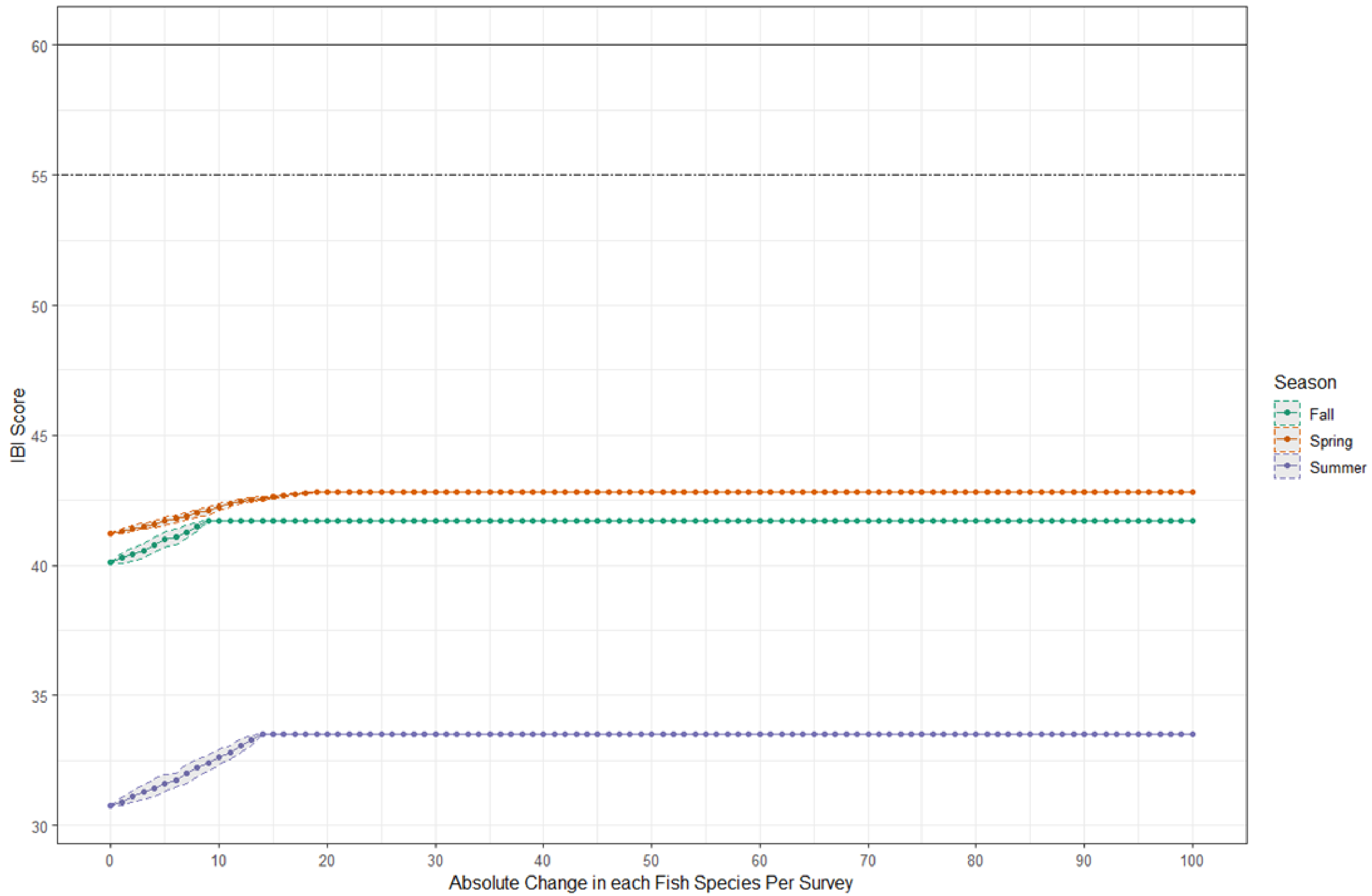


Figure 3. Modeled changes of Index of Biological Integrity (IBI) scores through the removal of up to 100 Common Carp (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired. Shift to a horizontal line in modeled output indicates that all Common Carp that were captured in that season have been removed.

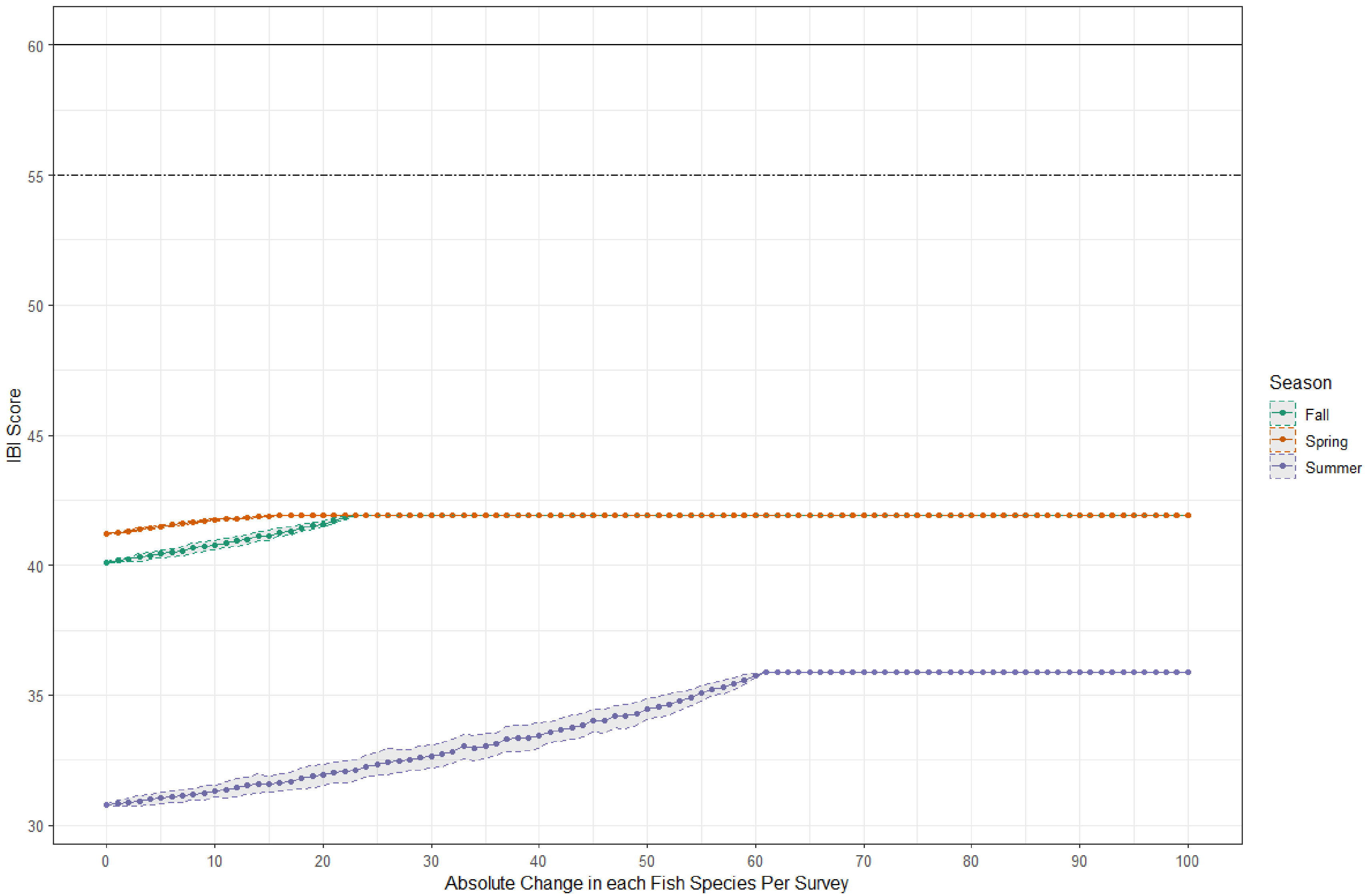


Figure 4. Modeled changes of Index of Biological Integrity (IBI) scores through the removal of up to 100 Goldfish (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired. Shift to a horizontal line in modeled output indicates that all Goldfish that were captured in that season have been removed.

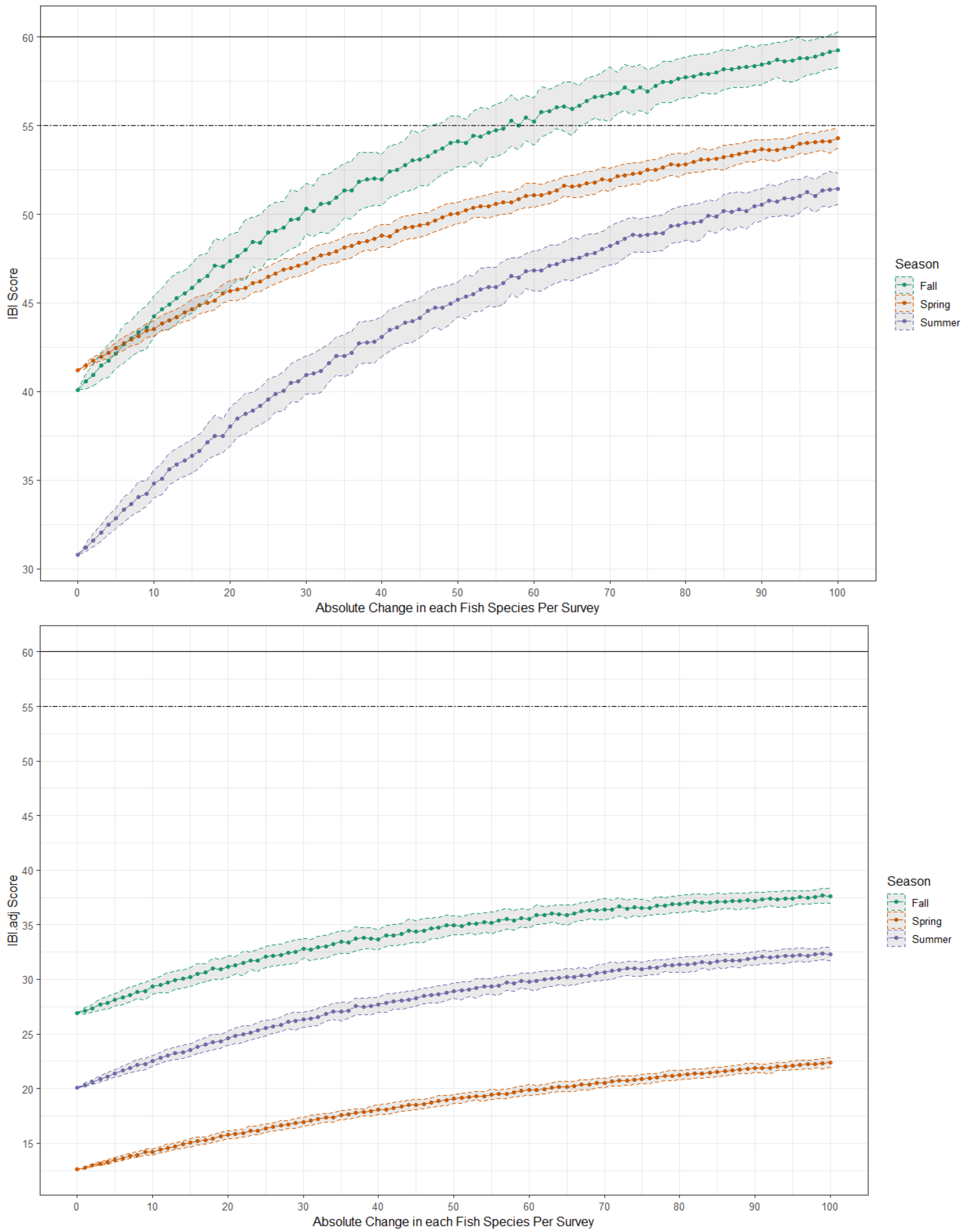


Figure 5. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted ($IBI._{adj}$, bottom) scores through the addition of 100 Northern Pike and Walleye each (100 replicates total) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

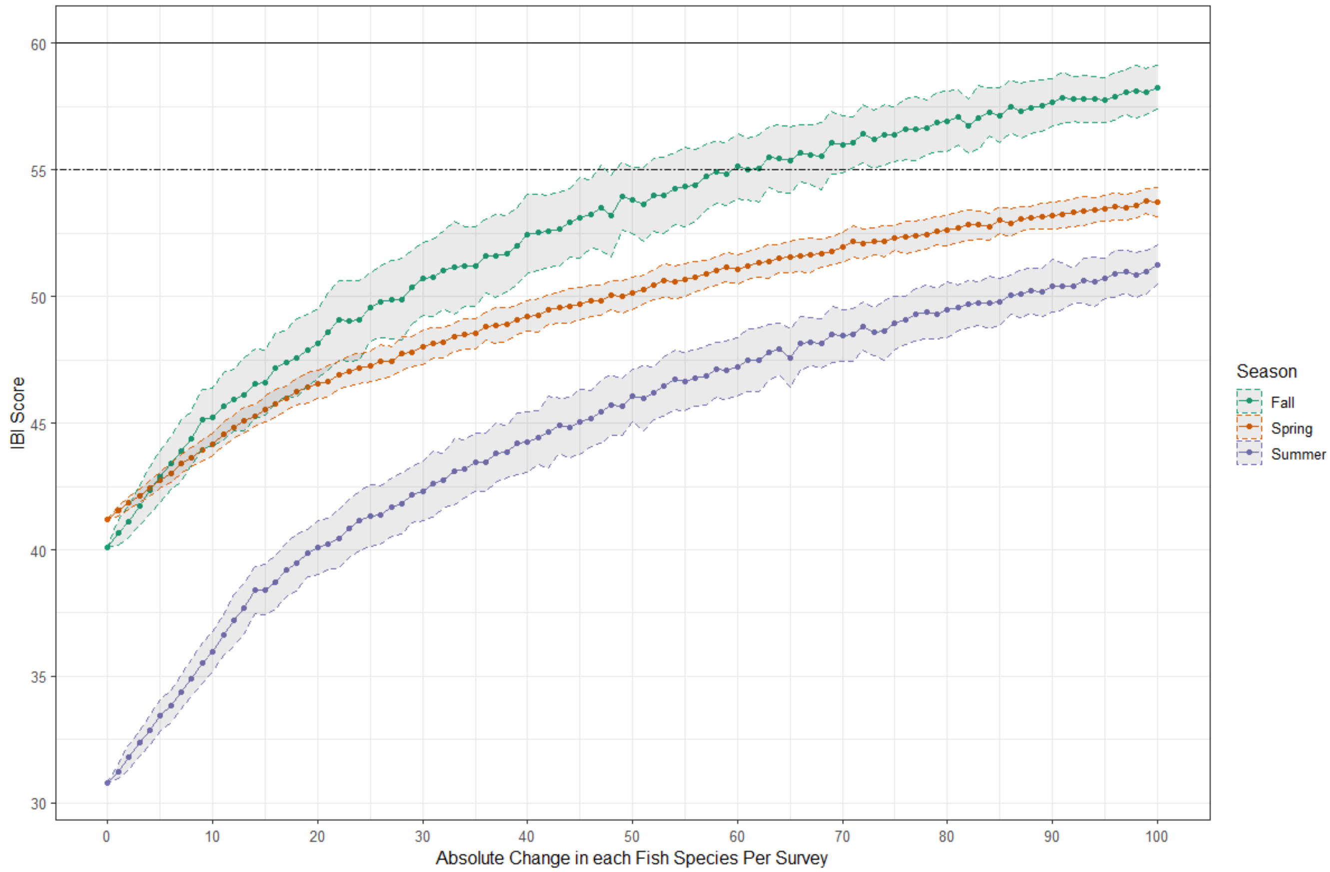


Figure 6. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of 100 Northern Pike and removal of up to 100 Common Carp (100 replicates total) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

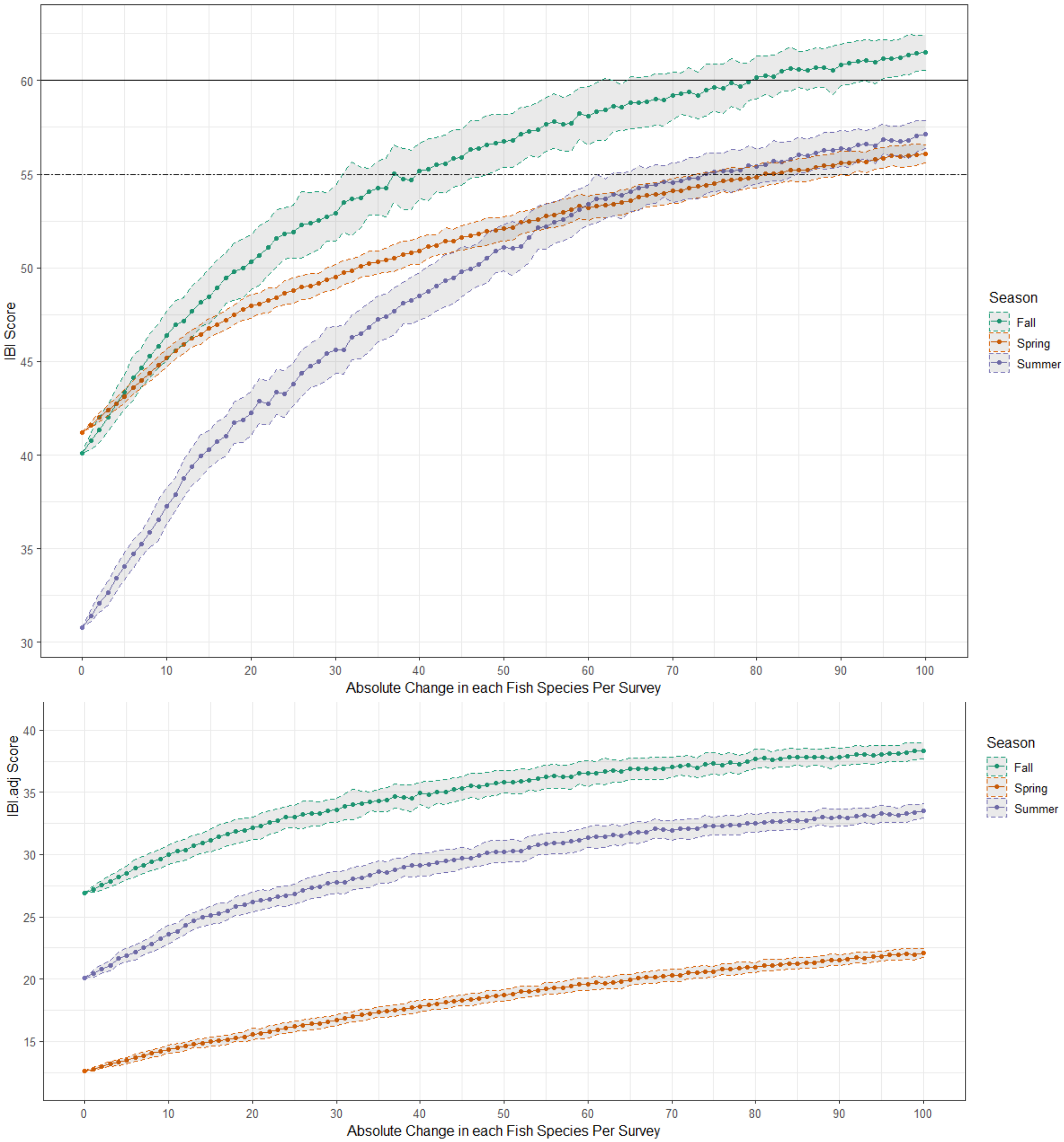


Figure 7. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted (IBI.$_{adj}$, bottom) scores through the addition of 100 Northern Pike and Walleye each, and removal of up to 100 Common Carp and Goldfish each (100 replicates total) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

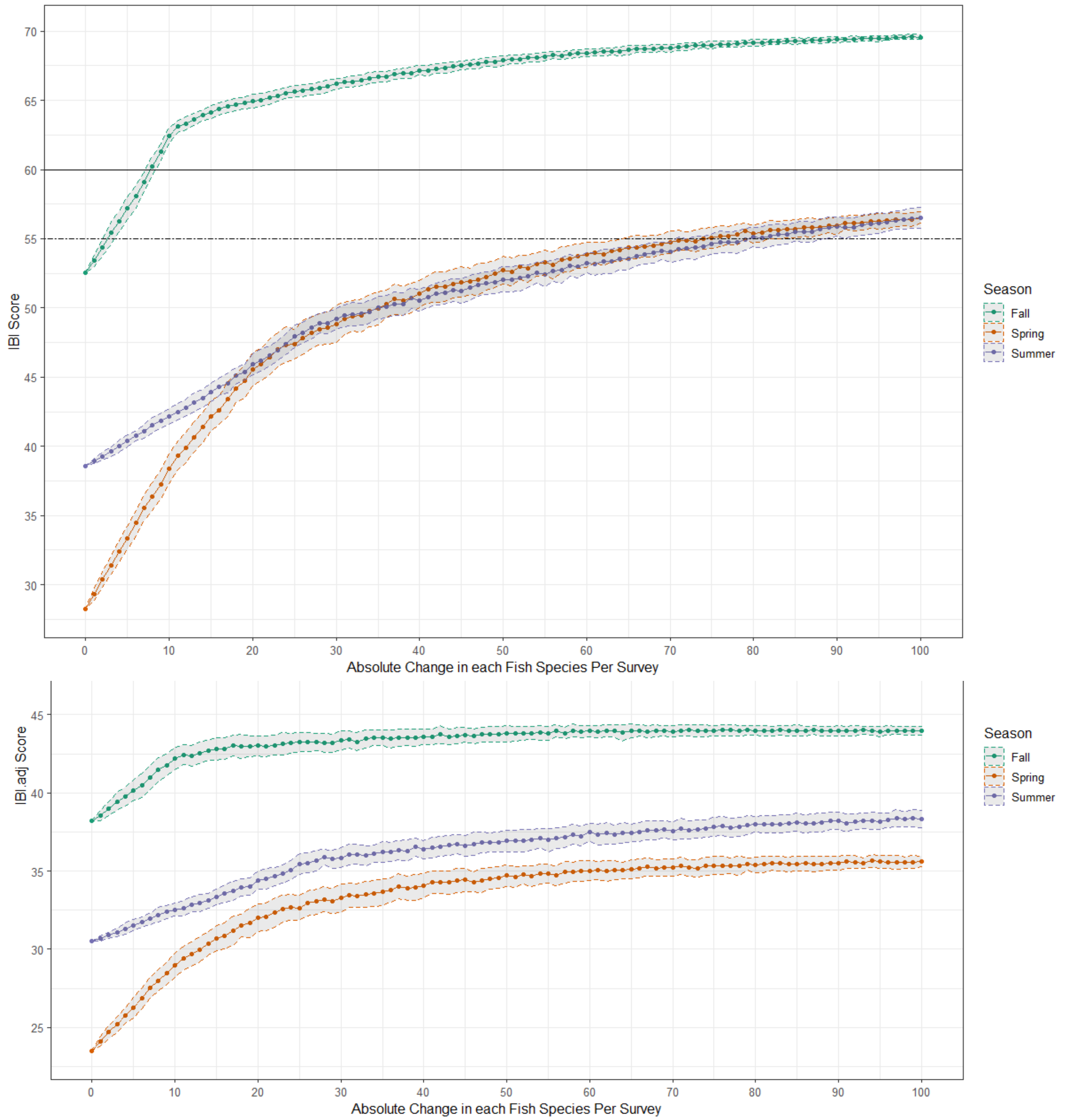


Figure 8. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted (IBI.$_{adj}$, bottom) scores through the addition of 100 Northern Pike and Walleye each, and removal of up to 100 Common Carp and Goldfish each (100 replicates total) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

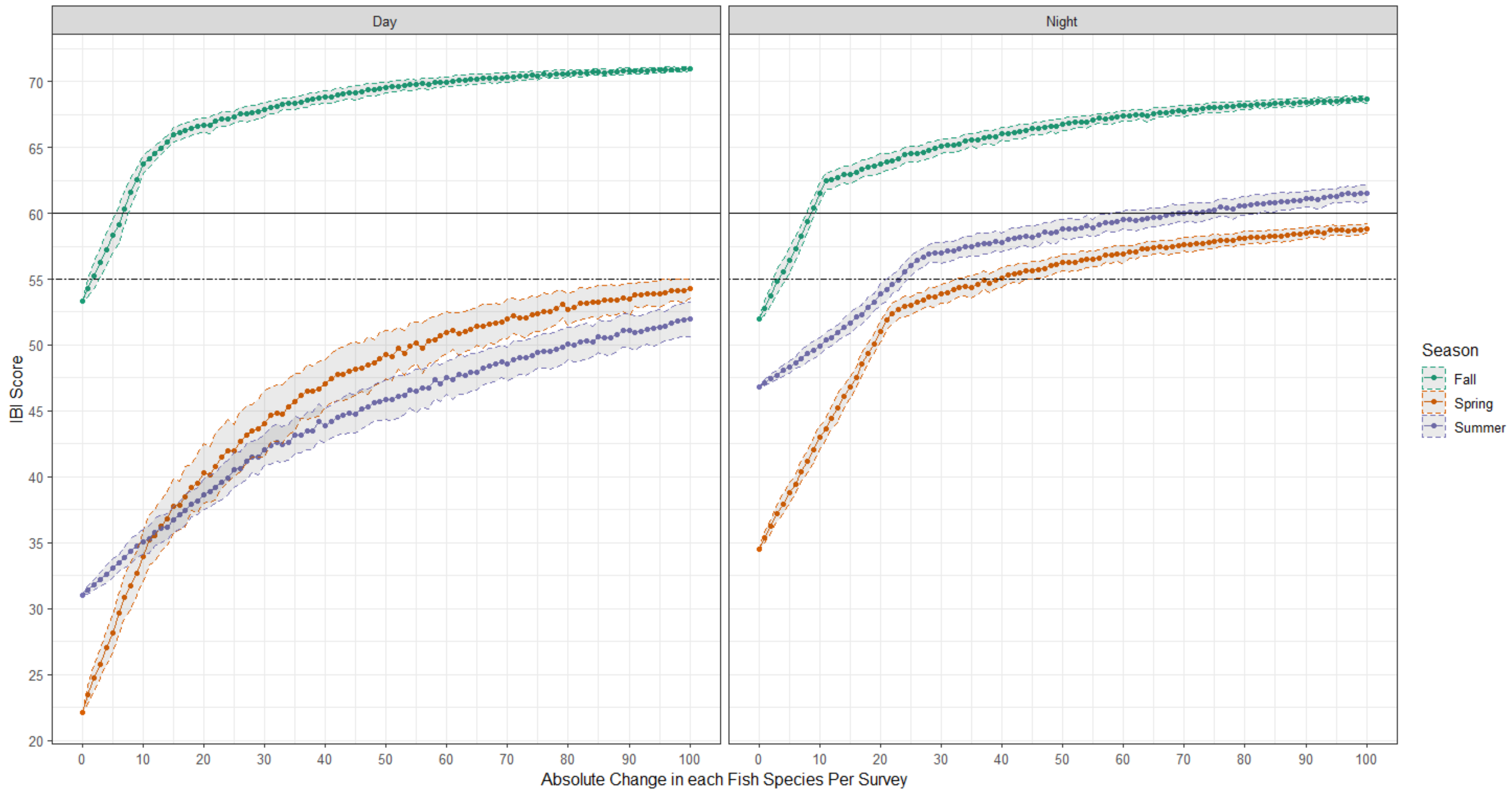


Figure 9. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of 100 Northern Pike and Walleye each, and removal of up to 100 Common Carp and Goldfish each (100 replicates total) for Hamilton Harbour in 2012, across three seasons separated by day and night. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

APPENDIX

Scenarios for 2012 IBI are included in appendix figures A1:A5. Smallmouth Bass are included in the appendix as they were intially proposed as a species of interest but provide similar information to Northern Pike and are unlikely to be targeted with management actions.

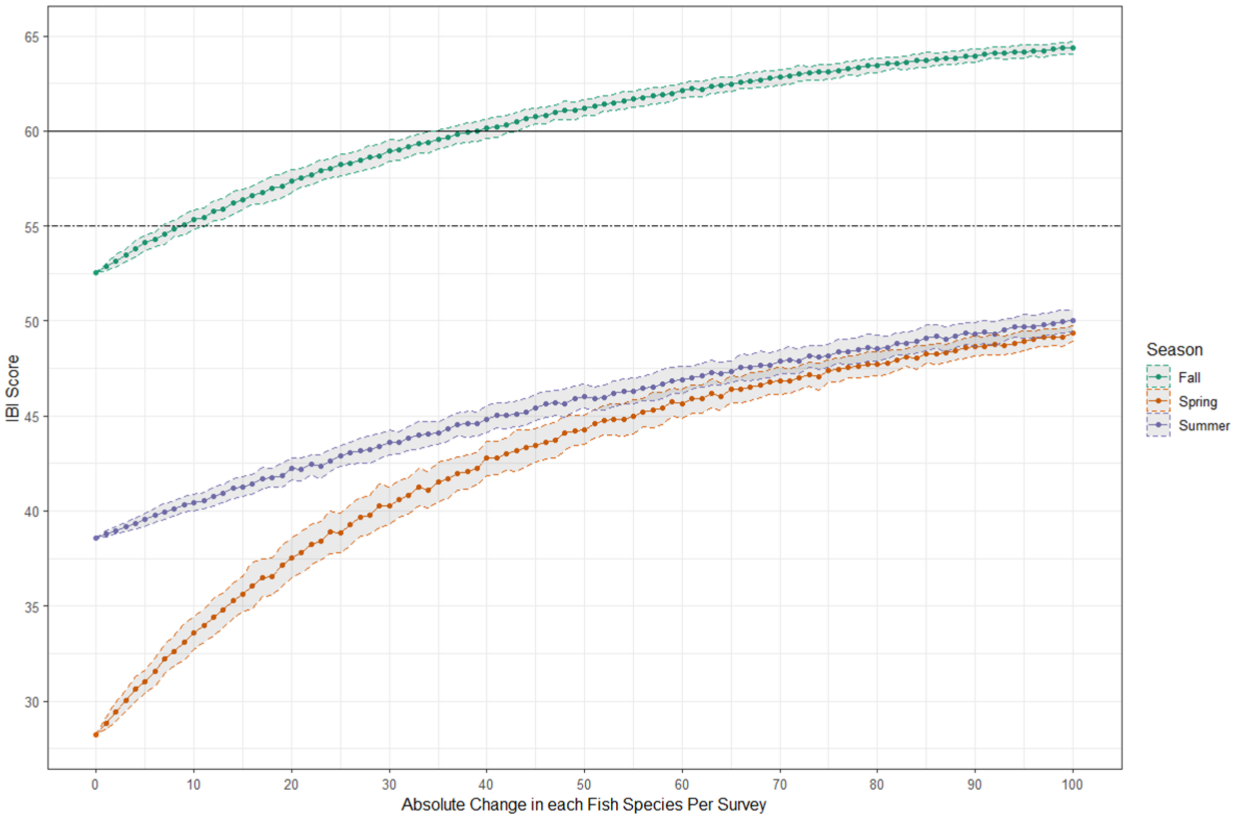
Smallmouth Bass: In 2018, only six Smallmouth Bass were caught (11 in 2012); two was the greatest number of Smallmouth Bass caught in a single transect (3 in 2012). Adding 100 Smallmouth Bass to the total catch resulted in approximately 10 IBI point increase for spring and 15 points for summer and fall; Figure A5 (for 2012) A6 (for 2018). Fall values reached the 55 IBI target at the addtion of 86 fish; however, no season hit the 60 point target and the values showed little gains after 80 fish additions. For IBI_{adj}, no season reached anywhere near targets but values for all seasons increased approximately 15 IBI points after adding 100 fish.

Table A1. Species codes and metric classifications for the Minns et al. (1994) Index of Biological Integrity for fish species caught in Hamilton Harbour. Species of interest are highlighted in **bold**.

Common Name	Species Code	Genus	Species	Native	Non-Indigenous	Centrarchid	Cyprinid	Intolerant	Piscivore	Generalist	Specialist	Offshore
Alewife	F0061	*Alosa*	*pseudoharengus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
American eel	F0251	*Anguilla*	*rostrata*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Atlantic salmon(l)	F0077	*Salmo*	*salar*	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
Banded killifish	F0261	*Fundulus*	*diaphanus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Bigmouth buffalo	F0166	*Ictiobus*	*cyprinellus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Black buffalo	F0174	*Ictiobus*	*niger*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Black bullhead	F0231	*Ameiurus*	*melas*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Black crappie	F0319	*Pomoxis*	*nigromaculatus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Blackchin shiner	F0199	*Notropis*	*heterodon*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Blacknose dace	F0210	*Rhinichthys*	*atratulus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Blacknose shiner	F0200	*Notropis*	*heterolepis*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE
Blackstripe topminnow	F0262	*Fundulus*	*notatus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Bluegill	F0314	*Lepomis*	*macrochirus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Bluntnose minnow	F0208	*Pimephales*	*notatus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Bowfin	F0051	*Amia*	*calva*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Bridle shiner	F0197	*Notropis*	*bifrenatus*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE
Brook silverside	F0361	*Labidesthes*	*sicculus*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Brook stickleback	F0281	*Culaea*	*inconstans*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Brown bullhead	F0233	*Ameiurus*	*nebulosus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Brown trout	F0078	*Salmo*	*trutta*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Burbot	F0271	*Lota*	*lota*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Common Carp	**F0186**	***Cyprinus***	***carpio***	**FALSE**	**TRUE**	**FALSE**	**FALSE**	**FALSE**	**FALSE**	**TRUE**	**FALSE**	**FALSE**
Carp x Goldfish hybrid	F0601	*Carassius x Cyprinus*		FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Central mudminnow	F0141	*Umbra*	*limi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Centrarchidae	F0310			TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Chain pickerel	F0135	*Esox*	*niger*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Channel catfish	F0234	*Ictalurus*	*punctatus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Chinook salmon	F0075	*Oncorhynchus*	*tshawytscha*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Coho salmon	F0073	*Oncorhynchus*	*kisutch*	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Common shiner	F0198	*Luxilus*	*cornutus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Creek chub	F0212	*Semotilus*	*atromaculatus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Emerald shiner	F0196	*Notropis*	*atherinoides*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Esox sp.	F0134	*Esox*		TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Etheostoma sp.	F0348	*Etheostoma*		TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Fallfish	F0213	*Semotilus*	*corporalis*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE

Fantail darter	F0339	*Etheostoma*	*flabellare*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Fathead minnow	F0209	*Pimephales*	*promelas*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Finescale dace	F0183	*Phoxinus*	*neogaeus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Fourspine stickleback	F0284	*Apeltes*	*quadracus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	TRUE
Freshwater drum	F0371	*Aplodinotus*	*grunniens*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Gizzard shad	F0063	*Dorosoma*	*cepedianum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Golden redhorse	F0170	*Moxostoma*	*erythrurum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Golden shiner	F0194	*Notemigonus*	*crysoleucas*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Goldfish	**F0181**	***Carassius***	***auratus***	**FALSE**	**TRUE**	**FALSE**	**FALSE**	**FALSE**	**FALSE**	**TRUE**	**FALSE**	**FALSE**
Grass pickerel	F0133	*Esox*	*americanus vermicul.*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Gravel chub	F0187	*Erimystax*	*x-punctatus*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
Greater redhorse	F0172	*Moxostoma*	*valenciennesi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Green sunfish	F0312	*Lepomis*	*cyanellus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Hornyhead chub	F0192	*Nocomis*	*biguttatus*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
Iowa darter	F0338	*Etheostoma*	*exile*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Johnny darter	F0341	*Etheostoma*	*nigrum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Lake chub	F0185	*Couesius*	*plumbeus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Lake chubsucker	F0164	*Erimyzon*	*sucetta*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Lake trout	F0081	*Salvelinus*	*namaycush*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE
Lake whitefish	F0091	*Coregonus*	*clupeaformis*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Largemouth bass	F0317	*Micropterus*	*salmoides*	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Logperch	F0342	*Percina*	*caprodes*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Longear sunfish	F0315	*Lepomis*	*megalotis*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Longnose dace	F0211	*Rhinichthys*	*cataractae*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE
Longnose gar	F0041	*Lepisosteus*	*osseus*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Mimic shiner	F0206	*Notropis*	*volucellus*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
Minnow Family	F0180			FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Mottled sculpin	F0381	*Cottus*	*bairdi*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Moxostoma sp.	F0177	*Moxostoma*		TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Muskellunge	F0132	*Esox*	*masquinongy*	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Northern hog sucker	F0165	*Hypentelium*	*nigricans*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Northern Pike	**F0131**	***Esox***	***lucius***	**TRUE**	**FALSE**	**FALSE**	**FALSE**	**FALSE**	**TRUE**	**FALSE**	**FALSE**	**FALSE**
Pugnose minnow	F0207	*Opsopoeodus*	*emiliae*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
Pugnose shiner	F0195	*Notropis*	*anogenus*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE
Pumpkinseed	F0313	*Lepomis*	*gibbosus*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Quillback	F0161	*Carpiodes*	*cyprinus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Rainbow darter	F0337	*Etheostoma*	*caeruleum*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Rainbow smelt	F0121	*Osmerus*	*mordax*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Rainbow trout	F0076	*Oncorhynchus*	*mykiss*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
River chub	F0193	*Nocomis*	*micropogon*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
River redhorse	F0173	*Moxostoma*	*carinatum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Rock bass	F0311	*Ambloplites*	*rupestris*	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Round Goby	F0366	*Neogobius*	*melanostomus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Rudd	F0220	*Scardinus*	*erythrophthalmus*	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE

Salmo sp.	F0085			TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
Sand shiner	F0204	*Notropis*	*stramineus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Sculpins	F0385	*Cottus*		TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Sea lamprey	F0014	*Petromyzon*	*marinus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Shorthead redhorse	F0171	*Moxostoma*	*macrolepidotum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Silver lamprey	F0013	*Ichthyomyzon*	*unicuspis*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Silver redhorse	F0168	*Moxostoma*	*anisurum*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Silvery minnow	F0190	*Hybognathus*	*regius*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Slimy sculpin	F0382	*Cottus*	*cognatus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Smallmouth bass	F0316	*Micropterus*	*dolomieu*	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Spotfin shiner	F0203	*Cyprinella*	*spiloptera*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Spottail shiner	F0201	*Notropis*	*hudsonius*	TRUE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE	FALSE
Spotted sucker	F0167	*Minytrema*	*melanops*	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
Stonecat	F0235	*Noturus*	*flavus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Striped shiner	F0217	*Notropis*	*chrysocephalus*	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Sunfish sp.	F0320	*Lepomis*		TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Tadpole madtom	F0236	*Noturus*	*gyrinus*	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE
Threespine stickleback	F0282	*Gasterosteus*	*aculeatus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Trout-perch	F0291	*Percopsis*	*omiscomaycus*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Tubenose Goby	F0367	*Proterorhinus*	*maroratus*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Walleye (yellow pickerel)	**F0334**	***Stizostedion***	***vitreum vitreum***	**TRUE**	**FALSE**	**FALSE**	**FALSE**	**FALSE**	**TRUE**	**FALSE**	**FALSE**	**TRUE**
White bass	F0302	*Morone*	*chrysops*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
White crappie	F0318	*Pomoxis*	*annularis*	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
White perch	F0301	*Morone*	*americana*	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
White sucker	F0163	*Catostomus*	*commersoni*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Yellow bullhead	F0232	*Ameiurus*	*natalis*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Yellow perch	F0331	*Perca*	*flavescens*	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE



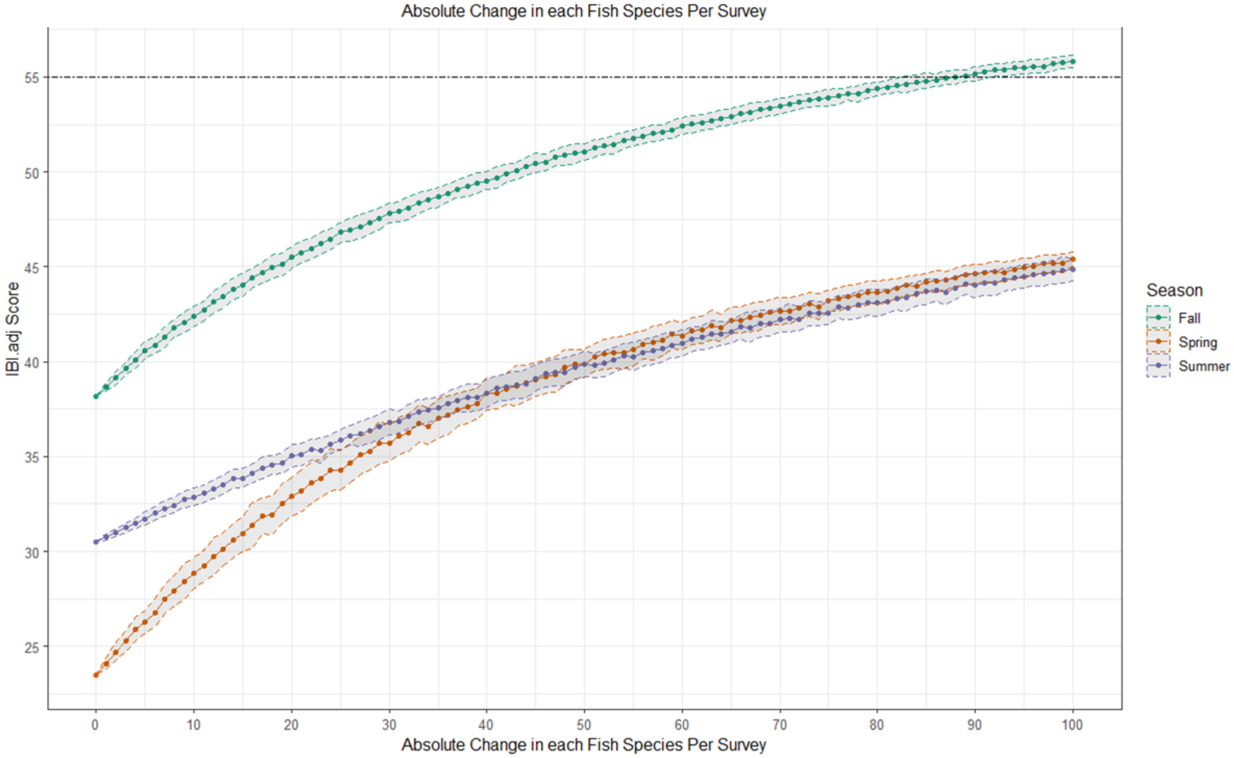


Figure A1. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted ($IBI._{adj}$, bottom) scores through the addition of 100 Northern Pike (100 replicates each) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

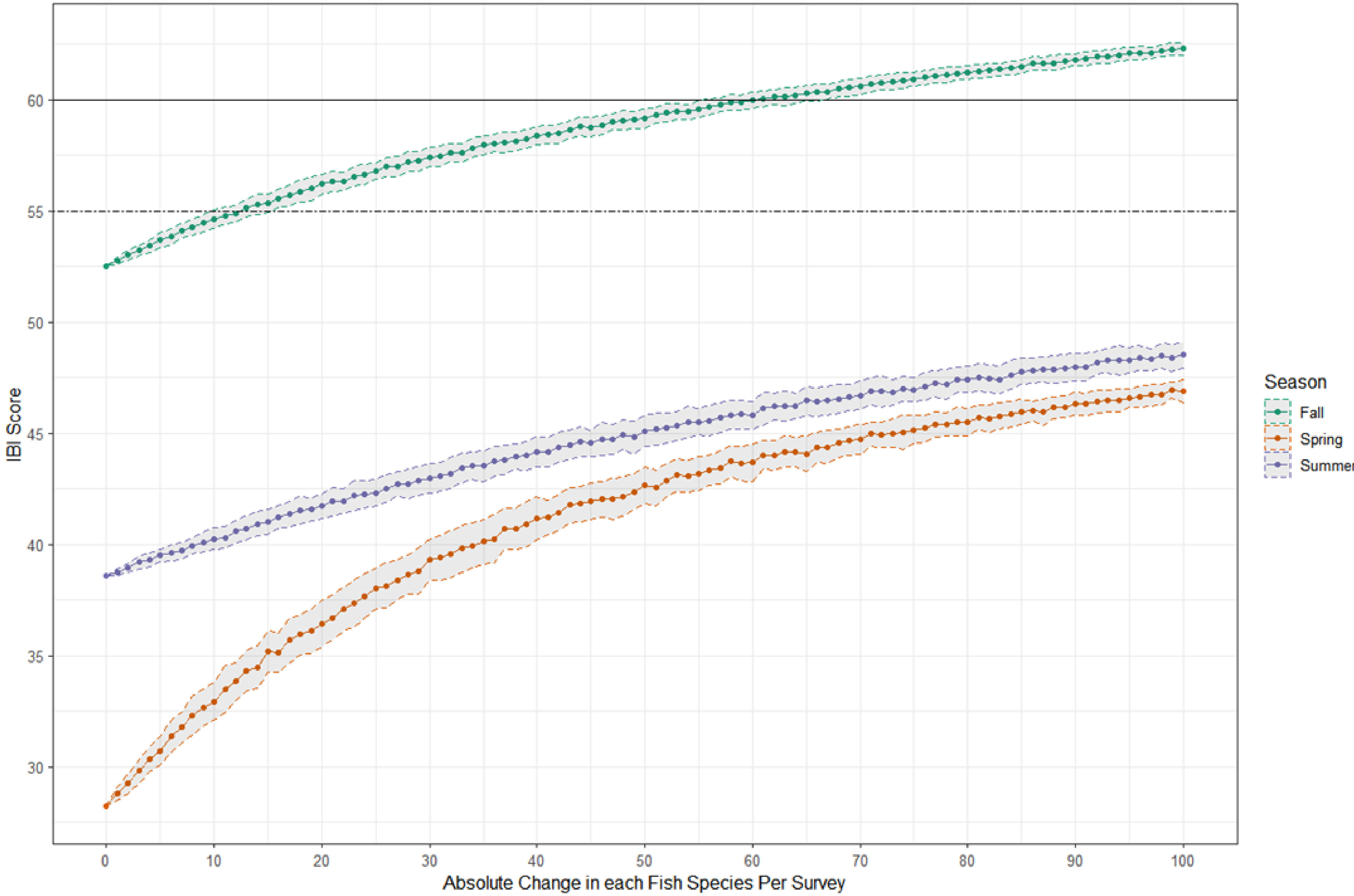


Figure A2. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of 100 Walleye (100 replicates each) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired. IBIadj values for Walleye were not calculated since this species is considered a pelagic fish and would thus be removed from its calculation.

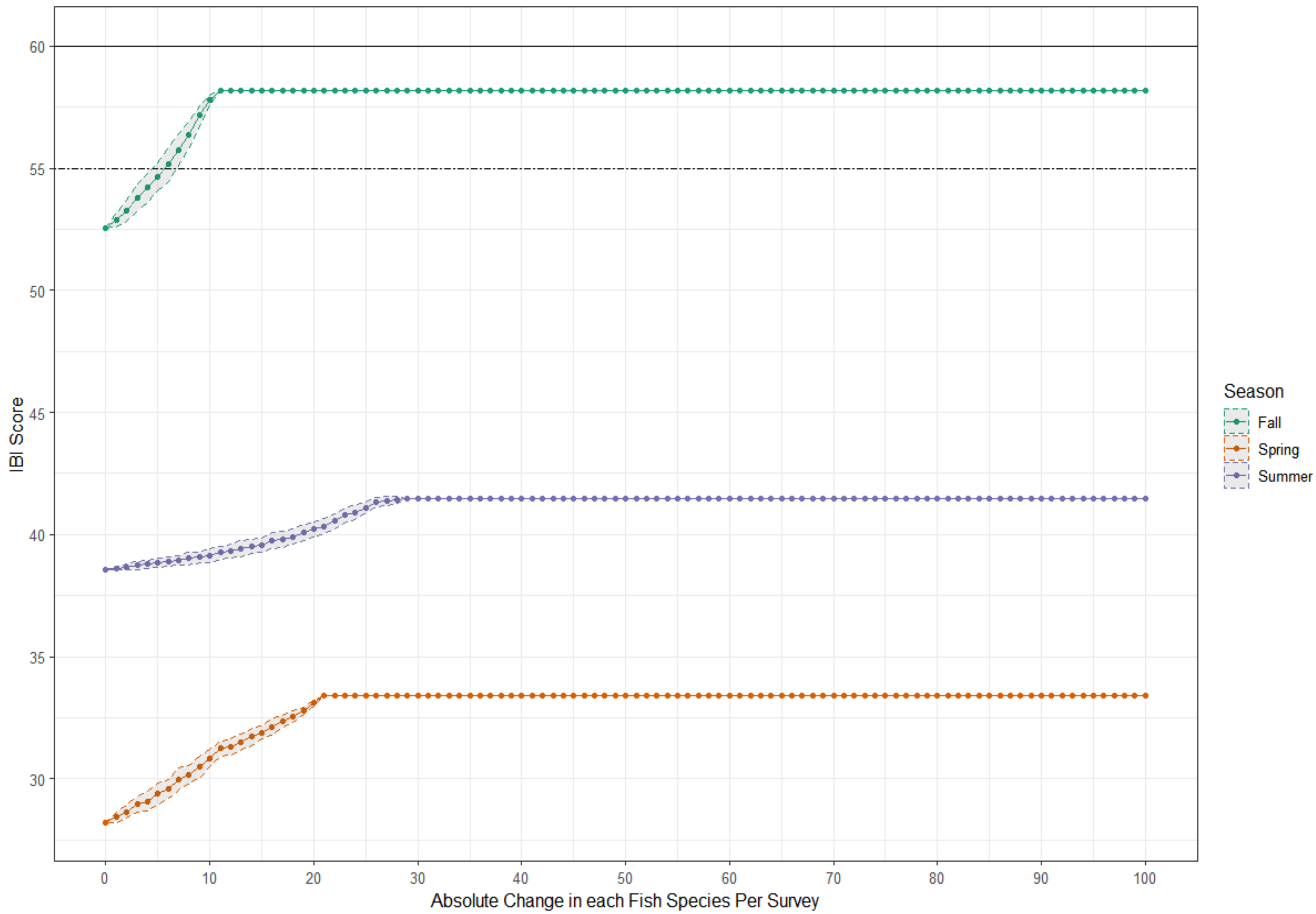


Figure A3. Modeled changes of Index of Biological Integrity (IBI) scores through the removal of up to 100 Common Carp (100 replicates each) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired. Shift to a horizontal line in modeled output indicates that all Common Carp that were captured in that season have been removed.

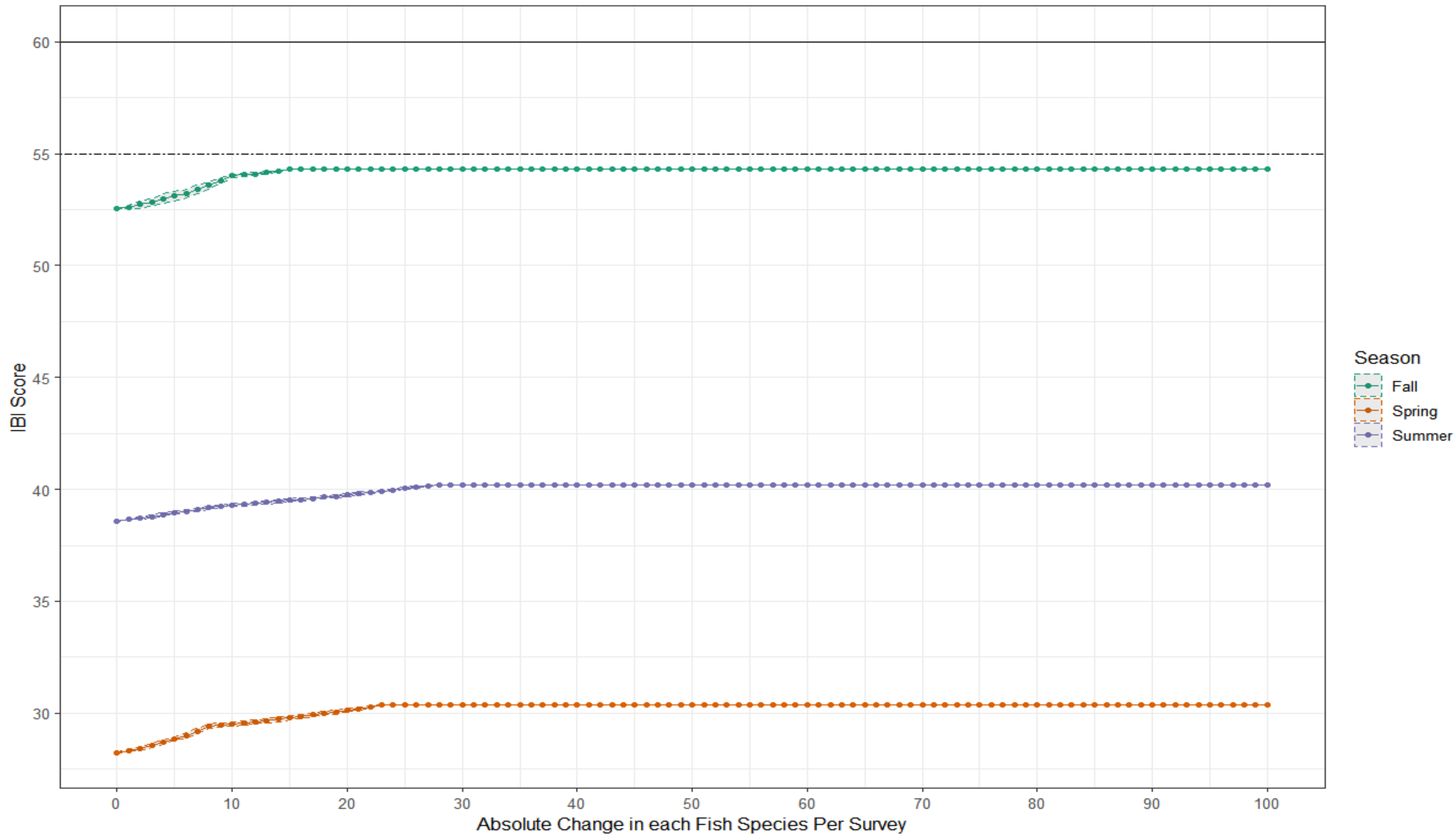


Figure A4. Modeled changes of Index of Biological Integrity (IBI) scores through the removal of up to 100 Goldfish (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired. Shift to a horizontal line in modeled output indicates that all Goldfish that were captured in that season have been removed.

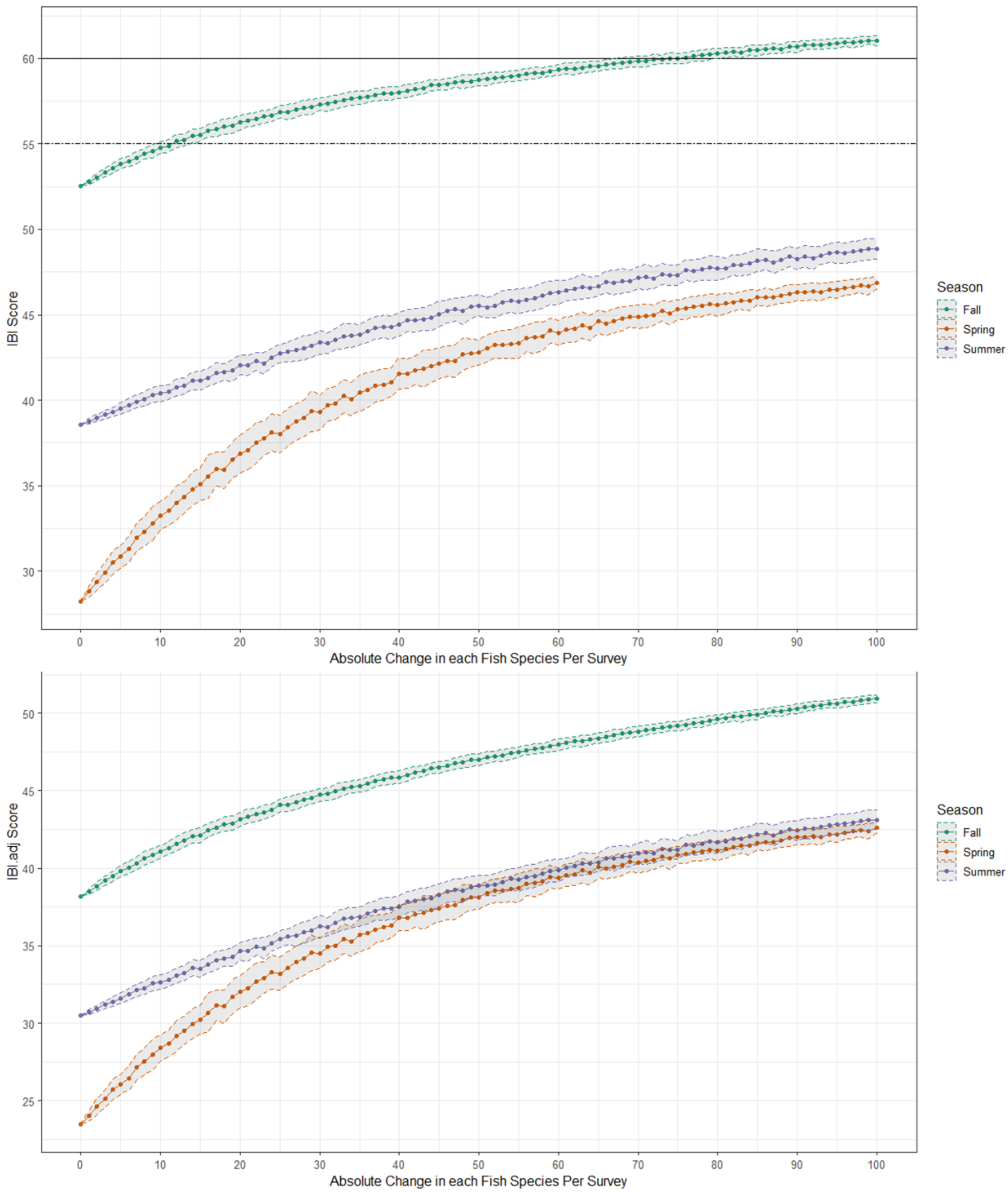


Figure A5. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted ($IBI._{adj}$, bottom) scores through the addition of 100 Smallmouth Bass (100 replicates each) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

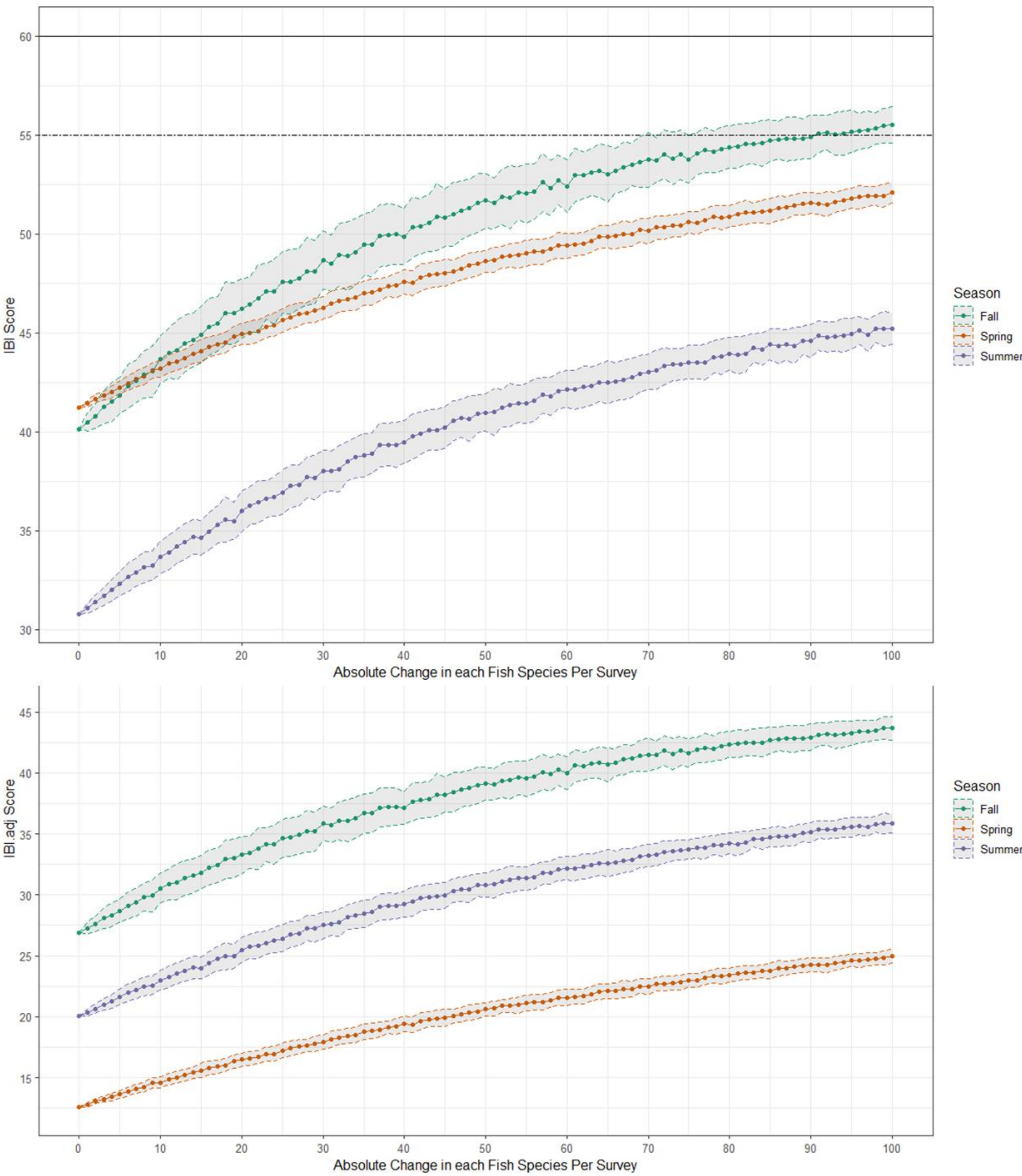


Figure A6. Modeled changes of Index of Biological Integrity (IBI, top) and IBI adjusted ($IBI._{adj}$, bottom) scores through the addition of 100 Smallmouth Bass (100 replicates each) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

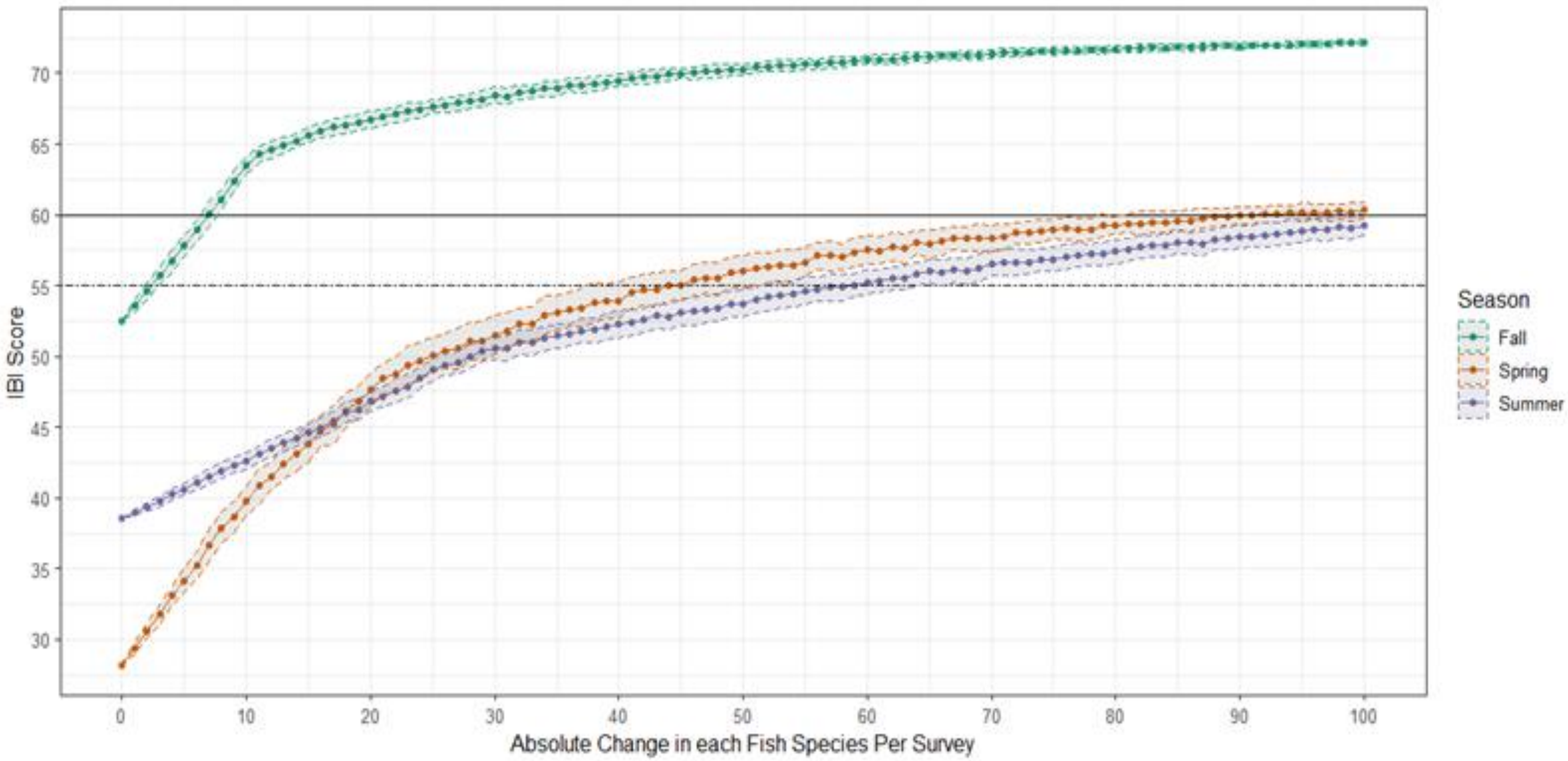


Figure A7. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of 100 Smallmouth Bass, Northern Pike, and Walleye each, and removal of up to 100 Common Carp and Goldfish each (100 replicates total) for Hamilton Harbour in 2012, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

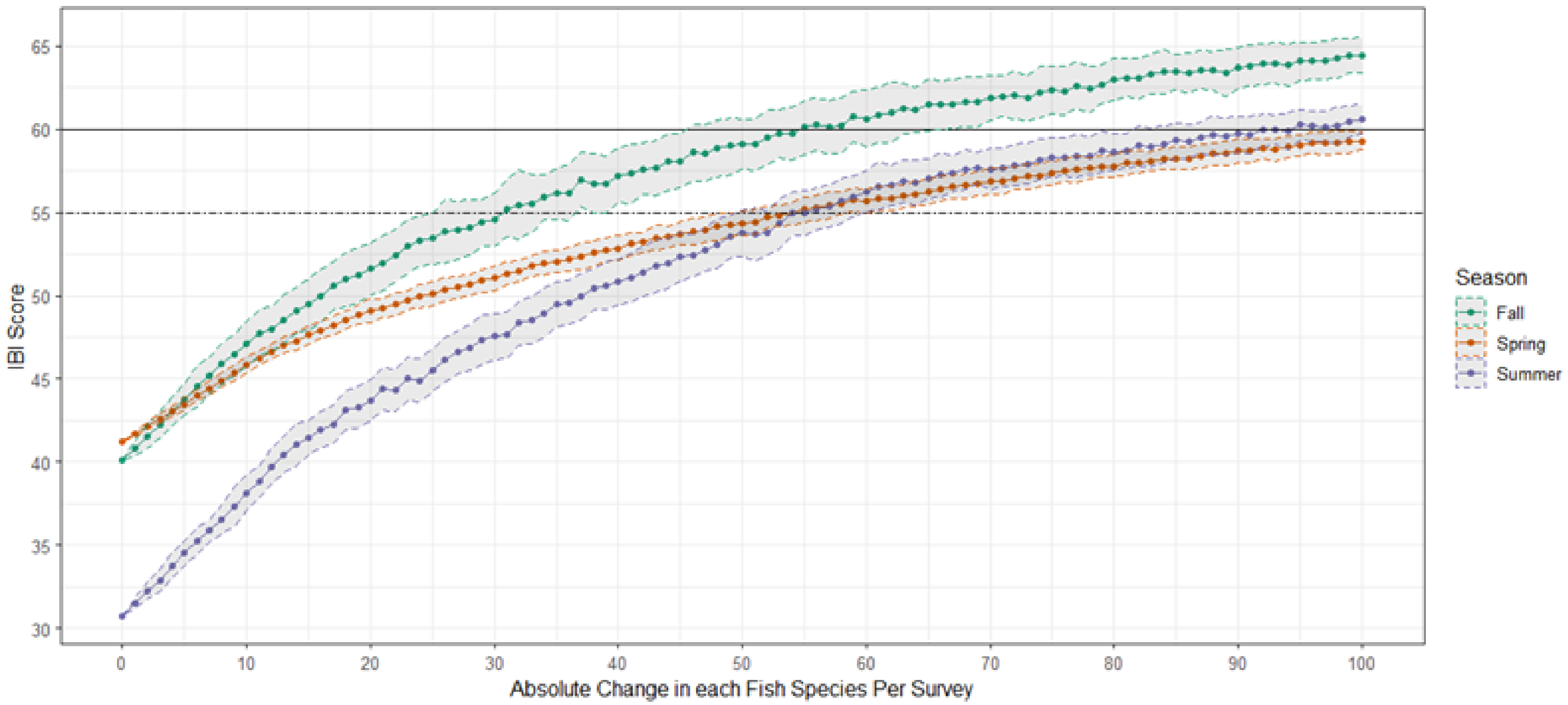


Figure A8. Modeled changes of Index of Biological Integrity (IBI) scores through the addition of 100 Smallmouth Bass, Northern Pike, and Walleye each, and removal of up to 100 Common Carp and Goldfish each (100 replicates total) for Hamilton Harbour in 2018, across three seasons. Lines at IBI scores of 55 and 60 indicate targets for delisting fish communities as impaired.

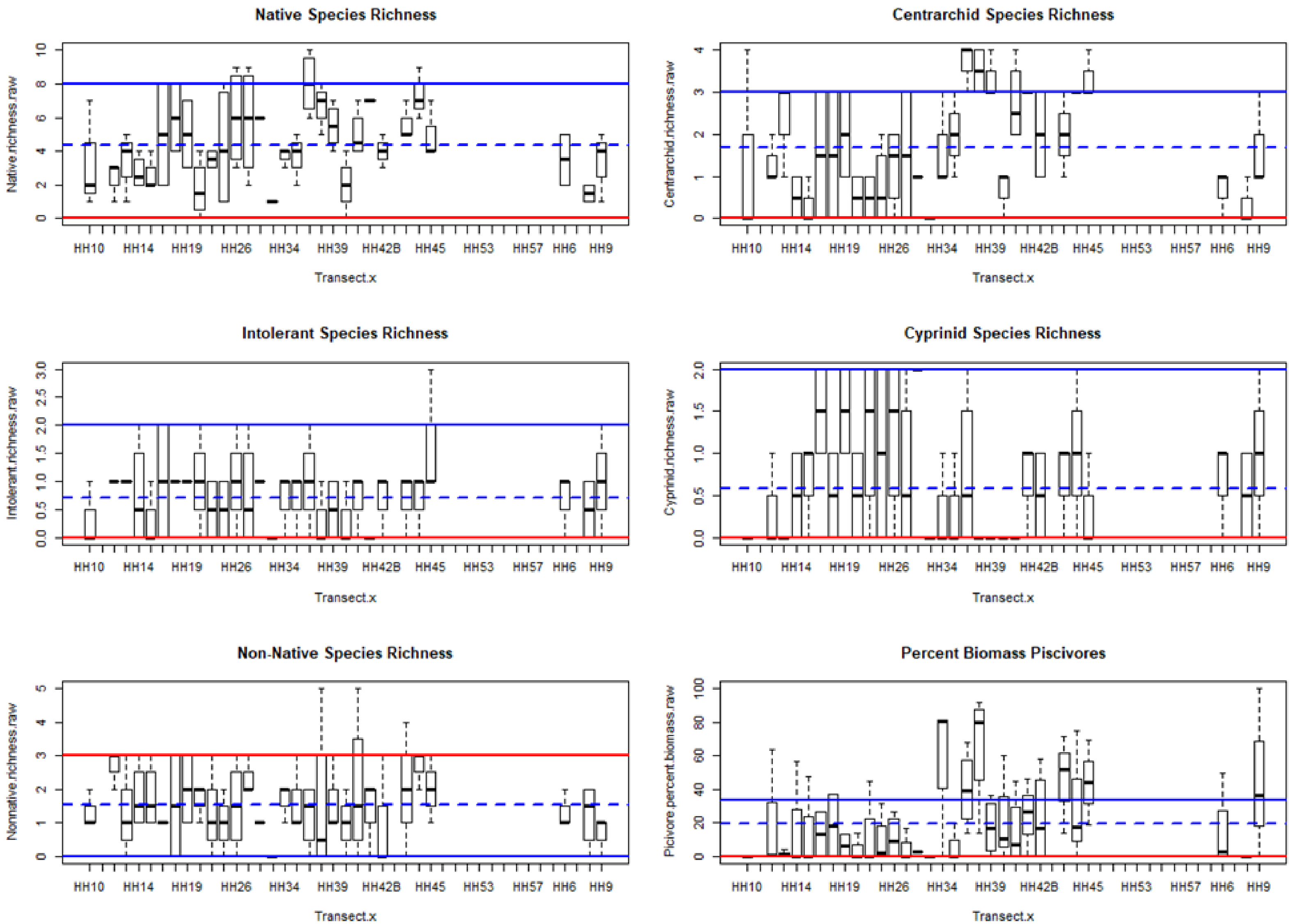


Figure A9. Metrics (metrics 1 – 6 of 12) of 2012 electrofishing data to calculate indices of biological integrity (IBI). The solid blue line is the upper threshold for the metric (maximum contribution to the IBI), the solid red line is the lower threshold for the metric (minimum contribution to the IBI), the dotted blue lines is the average the mean value of the metric. Transects with no bar at the 0 mark on the y axis were not sampled in this year.

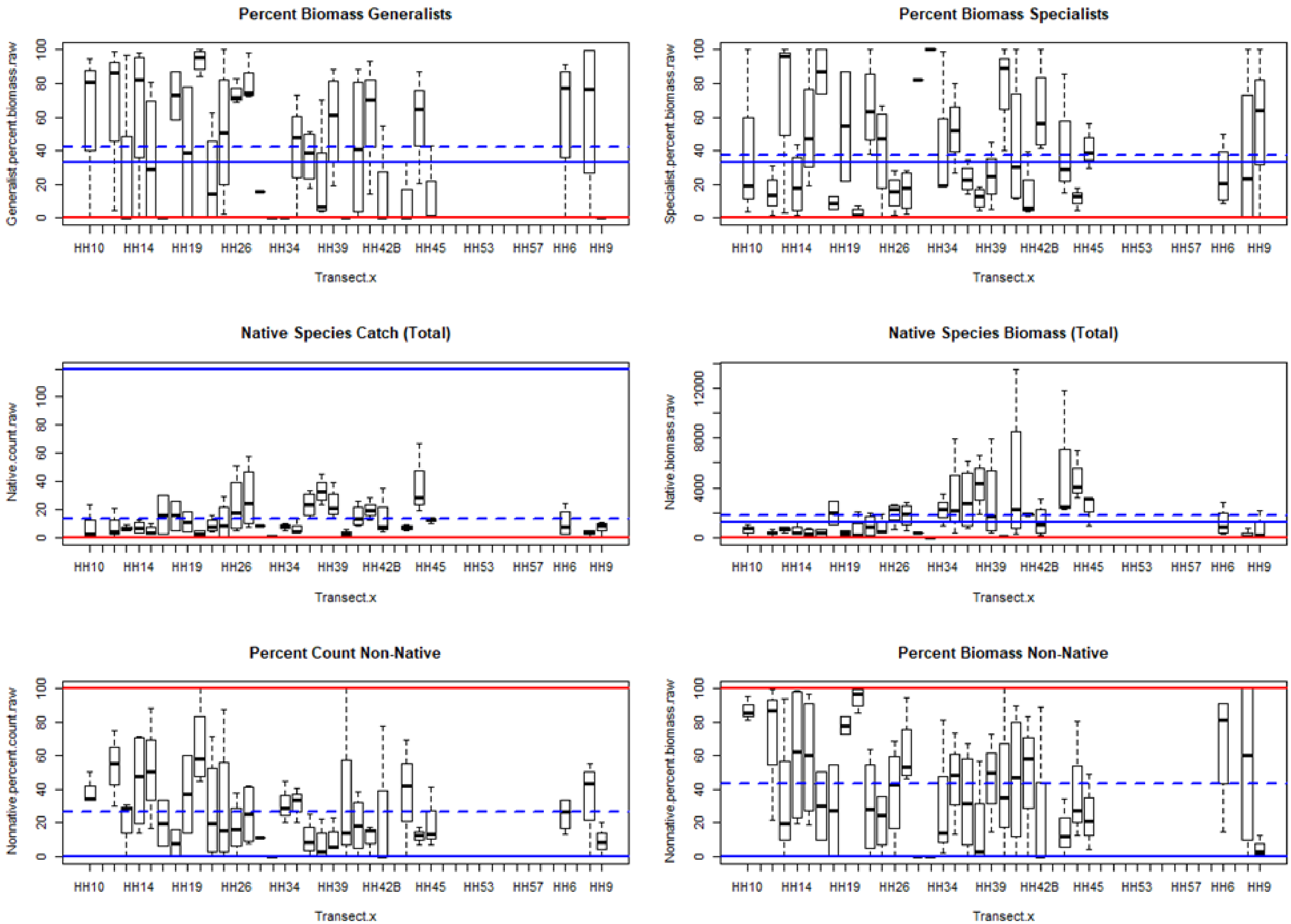


Figure A10. Metrics (metrics 7 – 12 of 12) of 2012 electrofishing data to calculate indices of biological integrity (IBI). The solid blue line is the upper threshold for the metric (maximum contribution to the IBI), the solid red line is the lower threshold for the metric (minimum contribution to the IBI), the dotted blue lines is the average the mean value of the metric. Transects with no bar at the 0 mark on the y axis were not sampled in this year.

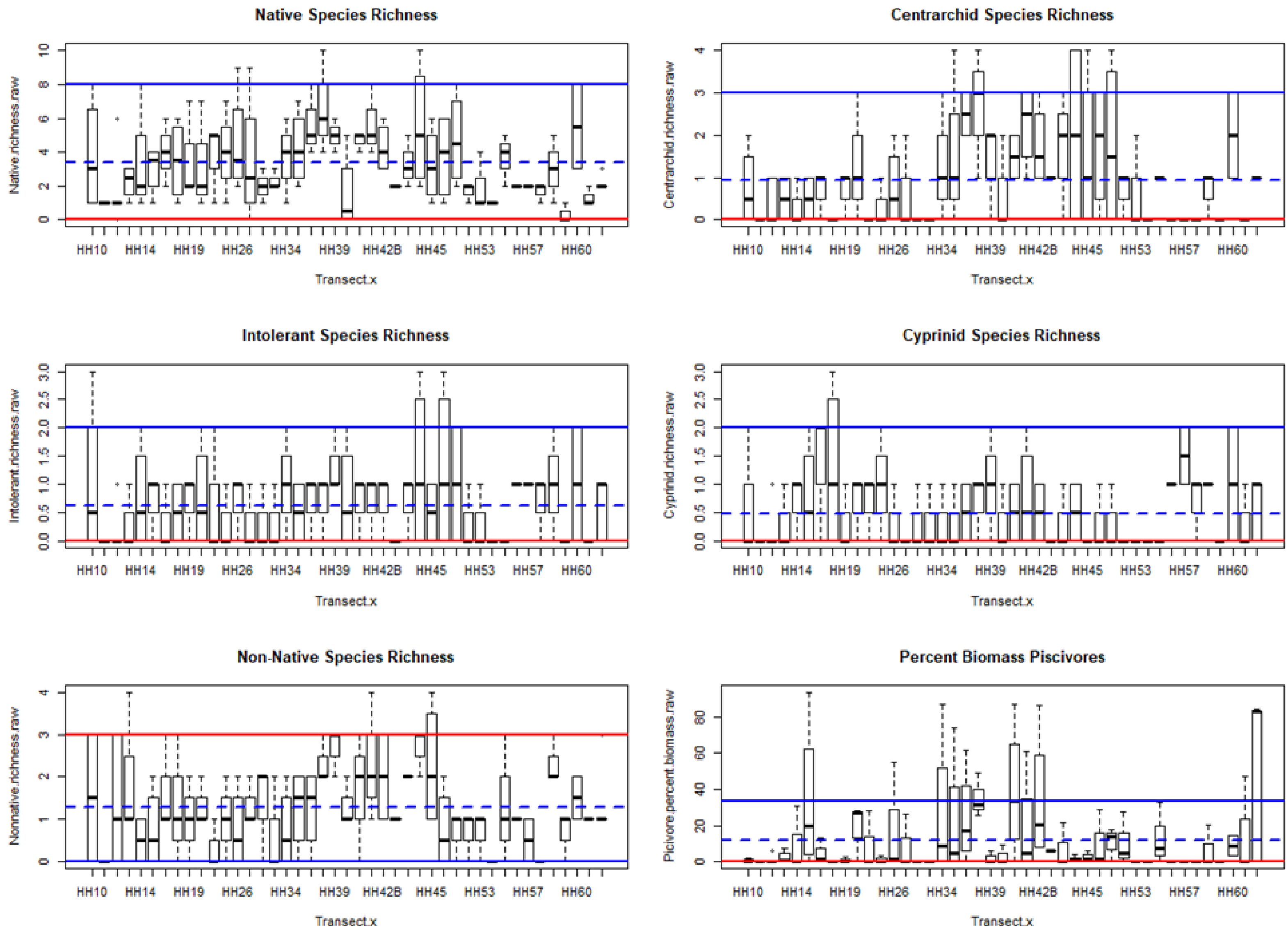


Figure A11. Metrics (metrics 1 – 6 of 12) of 2018 electrofishing data to calculate indices of biological integrity (IBI). The solid blue line is the upper threshold for the metric (maximum contribution to the IBI), the solid red line is the lower threshold for the metric (minimum contribution to the IBI), the dotted blue lines is the average the mean value of the metric. Transects with no bar at the 0 mark on the y axis were not sampled in this year.

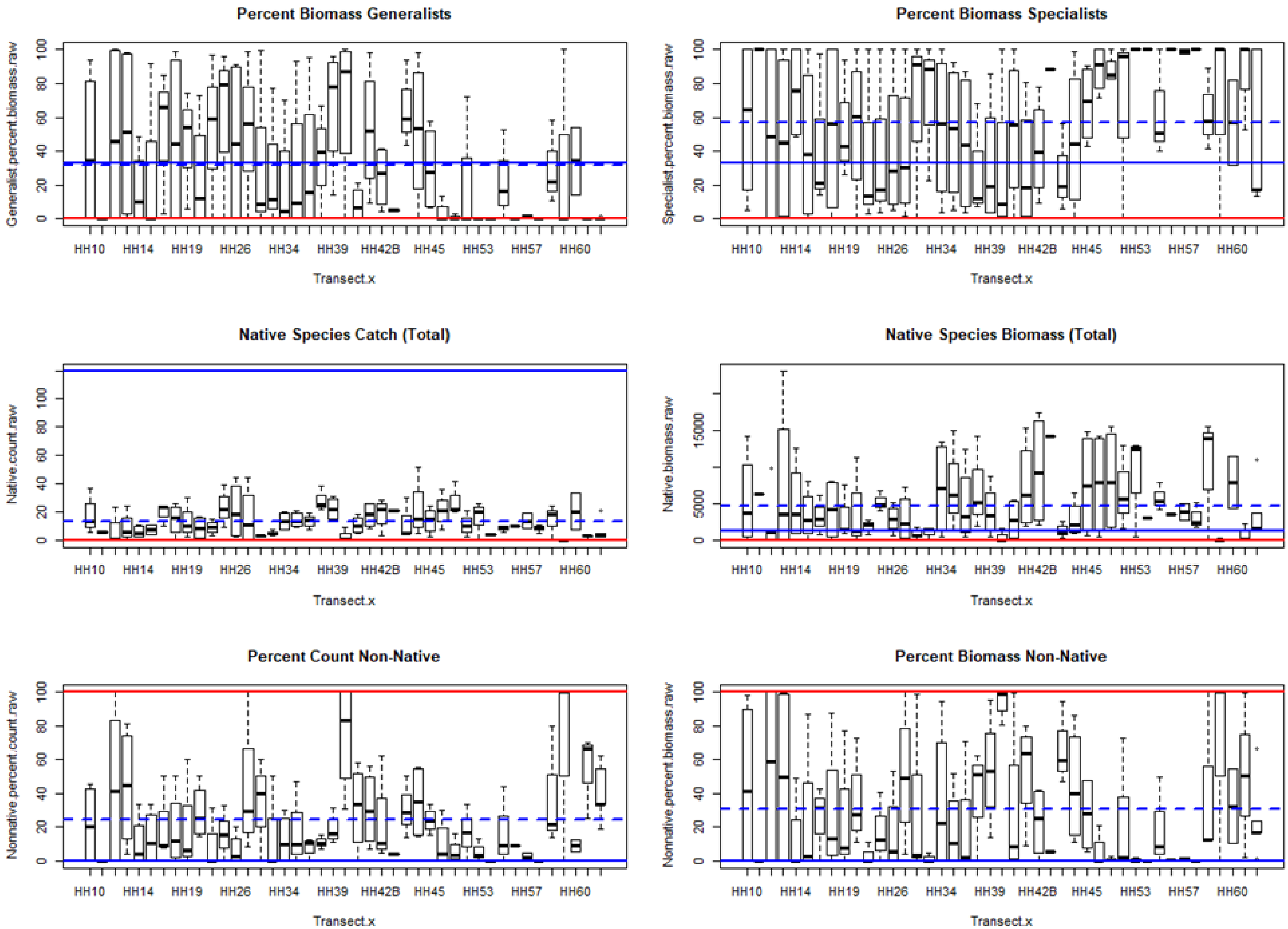


Figure A12. Metrics (metrics 7 – 12 of 12) of 2018 electrofishing data to calculate indices of biological integrity (IBI). The solid blue line is the upper threshold for the metric (maximum contribution to the IBI), the solid red line is the lower threshold for the metric (minimum contribution to the IBI), the dotted blue lines is the average the mean value of the raw metric. Transects with no bar at the 0 mark on the y axis were not sampled in this year.