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Evaluating the Effect of Common Carp Control on Restoration of a Coastal Wetland in the Laurentian Great Lakes

Daniel J. Moore [1,2] **and Nicholas E. Mandrak** [2,3,*]

[1] Central Lake Ontario Conservation Authority, 100 Whiting Avenue, Oshawa, ON L1H 3T3, Canada; dmoore@cloca.com or danjames.moore@mail.utoronto.ca
[2] Department of Physical and Environmental Science, University of Toronto Scarborough, 1265 Military Trail, Toronto, ON M1C 1A4, Canada
[3] Department of Biological Sciences, University of Toronto Scarborough, 1265 Military Trail, Toronto, ON M1C 1A4, Canada
* Correspondence: nicholas.mandrak@utoronto.ca; Tel.: +1-416-208-2248

Abstract: Great Lakes coastal wetlands are under considerable stress from numerous anthropogenic threats, including the introduction of invasive species. Common Carp, an invasive species in North America, has been well documented as an influential wetland stressor. This study documents the impact of Common Carp reintroduction on a restored wetland fish community and abiotic and vegetation variables. Oshawa Second Marsh was restored using an exclusion berm with a fish grate and manual water-level drawdown to re-establish vegetation. Five years into restoration monitoring, Common Carp regained access to the wetland after the fish grate was vandalized. Fish community health was monitored over time using multimetric and multivariate approaches based on abiotic and vegetation variables. Improvements in fish community health were observed during restoration monitoring, but after Common Carp reintroduction, fish community health decreased and the community homogenized. Seven of the ten abiotic and vegetation variables monitored changed significantly after Common Carp reintroduction. This study highlights the impact that Common Carp has on the functional integrity of coastal wetlands and the significance of its management for restoration.

Keywords: wetland; restoration; fish community; water quality; multimetric; multivariate

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1. Introduction

Coastal wetland fish communities have been subject to an increasing severity of anthropogenic impacts [1–3]. Climate change, land-use conversion, non-native species, water-level regulation, and a rapidly growing human population have put considerable pressure on existing fish communities [1,2,4]. Common Carp, *Cyprinus carpio*, a non-native, invasive species to North America, has been identified as a significant threat to wetland health due to its benthivorous feeding habit, size, abundance, and preference for wetlands for spawning and nursery habitat [5–8]. It aggregates in accessible coastal wetlands to spawn, resulting in unnaturally high levels of biomass feeding, waste excretion, suspended sediments, disruption of zooplankton dormant life-cycle stages, and aquatic vegetation growth reduction [5,6,9,10]. Common Carp is a proficient invader due to its high fecundity, growth rate, and tolerance of a wide variety of environmental conditions [11].

Common Carp has direct (e.g., sediment suspension through physical movement) and indirect (impacts on trophic structure) impacts on water quality that have been documented to influence fish community health [3,10,12]. Increased turbidity and higher than normal conductivity are correlated with low fish community health [9,13–15]. Various strategies have been implemented to improve water quality in coastal wetlands, ranging from carp management to large-scale watershed restoration and stewardship. Watershed-scale water-quality improvements can be difficult to achieve, especially in older urbanized areas, making indirect improvements through physical barriers and Common Carp management an appealing option.

Despite this, long-term Common Carp management is difficult due to the costs of current strategies and the complexities of coastal wetland processes. One of the more common management techniques for Common Carp is exclusion from spawning grounds using physical barriers. These barriers vary in design and are managed either by manually sorting fish, exclusive selective passage, or removing connectivity for all fish species [2,6,16]. The reduction in connectivity does provide benefits, such as the option to mitigate water-level fluctuations in Lake Ontario that are managed for anthropogenic purposes [2,5]. This lack of natural hydrology impacts wetland function and structure, which can be, in part, mitigated by designing physical barriers that incorporate hydrological manipulation. Temporarily removing all connectivity and simulating low water levels stimulates seed-bank regeneration, promoting increased emergent vegetation that, in turn, can theoretically improve water quality [5]. This process can incur additional challenges that need to be considered. For example, local natural wetland hydrology is altered, management is potentially indefinite, and barrier structures can be expensive to install and maintain. Physical barriers allow the mitigation of larger water-level regulation processes but alter local hydrology, impacting residence times, flow patterns, and nutrient and energy retention [17,18]. Balancing the challenges and benefits of this approach needs further evaluation.

Oshawa Second Marsh (OSM) is a 123-hectare provincially significant coastal wetland on Lake Ontario that underwent various restoration projects because it was identified as impaired [18]. Upstream watershed impacts were reduced by rerouting the creek around the wetland directly to Lake Ontario. To regulate water levels and exclude aquatic invasive species, a water-control structure with a fish grate was installed to allow continued hydrological connectivity, although reduced, of the wetland to Farewell Creek, approximately 500 m upstream of Lake Ontario. The species targeted for exclusion from the wetland was Common Carp, while allowing continued access by Northern Pike (*Esox lucius*) and other migratory native species. The restoration project had many phases, with the final component in 2004 being a drawdown of water levels. This simulated historical low water levels and allowed the reestablishment of aquatic vegetation through seed bank exposure and Common Carp removal. In 2009, the fish grate was vandalized, allowing Common Carp to re-access the marsh. This resulted in a monitoring dataset that contains five years of data during restoration and five years following Common Carp reintroduction. Vandalism of the Common Carp control structure allows, unfortunately, a unique opportunity to evaluate the restoration actions. The objective of this study is to evaluate how restoration and subsequent reintroduction of Common Carp impacted the fish community, water chemistry, and vegetation variables at OSM.

2. Materials and Methods

2.1. Study Area

OSM is currently monitored through the Durham Region Coastal Wetland Monitoring Program (DRCWMP) [19]. A total of 138 sampling events for the 16 DRCWMP wetlands and 15 Bay of Quinte (BoQ) Remedial Action Plan (RAP) wetlands were completed between 2005 and 2015 (Figure 1, Table A2). For the purpose of this study, a subset of the 138 sampling events was used. All sampling events at OSM, except in 2012 due to extremely low water levels, were included, and all sampling events in all wetlands classified by the DRCWMP fish Index of Biotic Integrity (IBI) as excellent health were included as the reference condition (Table A2). All wetlands were sampled in August or early September.

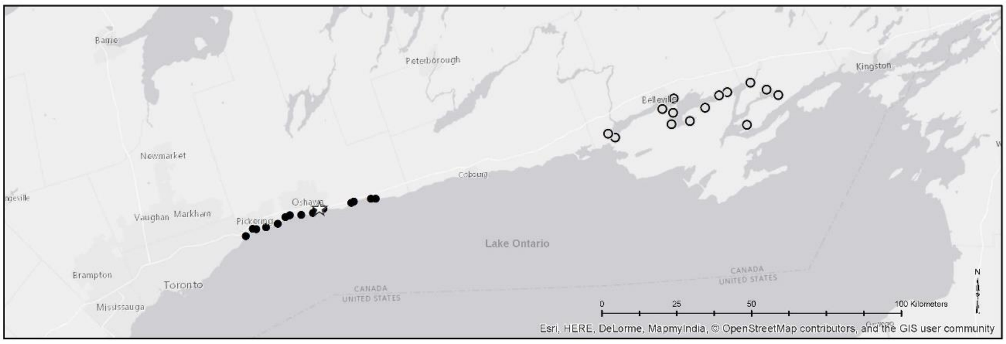

Figure 1. Coastal wetlands monitored by the Durham Region Coastal Wetland Monitoring Program and the Bay of Quinte Remedial Action Plan, Beneficial Use Impairment monitoring. The star represents Oshawa Second Marsh; the open circles represent sites included as Excellent fish IBI; the black circles are sites not included in the analysis. Table A2 provides a summary of the wetlands.

2.2. Fish Sampling

Fish sampling was completed by boat electrofishing. A 4.9 m Jon boat with a Smith-Root 2.5 kW G.P.P. electrofishing unit was used (Smith-Root, Vancouver, WA, USA). Point sampling along 7 to 12 transects was completed for each wetland and combined as a single sampling event [19]. The number of transects per wetland was dependent on habitat variability and wetland size. Each habitat type (shoreline, open water, inlet, outlet, or beach) within an identified wetland boundary is targeted by at least one transect. The voltage was adjusted based on an amperage meter to standardize to approximately 2000 watts of total power. Transects were 44 m in length with six equally spaced points that had 20 s of electricity used for a total of 120 s per transect. Fish were captured, identified, fork length and weight measured, and any anomalies (e.g., eroded fins, tumors, lesions) recorded for the first 10 individuals per species. The remaining individuals of each species were counted and batch-weighted. Fish were identified in the field, and physical and digital vouchers were taken for further verification when necessary.

2.3. Environmental Data

Abiotic and vegetation variables were recorded at the beginning of each transect. Abiotic variables included the following: turbidity (NTU); conductivity (μS cm); total dissolved solids (mg/L); salinity (g/kg); dissolved oxygen (mg L^{-1}); water depth (measured to nearest cm using meter stick or weighted string if over 1 m); water temperature (°C); dominant substrate (estimation based on grain size); air temperature (°C); wind strength (estimated using Beaufort wind strength scale (0–12); wind direction (azimuthal direction); and cloud cover (estimated based on tenths scale). Turbidity was measured using an HACH 2100Q portable turbidimeter (HACH Company, Loveland, CO, USA). Conductivity, total dissolved solids, salinity, dissolved oxygen, and water temperature were measured using an YSI ProQuatro multiparameter meter (Cole-Parmer, Rue Jean-Perrin, QC, Canada). Vegetation was estimated along the entire length of the transect, visually covering 2 m on either side, as the proportion of submerged, emergent, and floating vegetation cover. In addition, vegetation types were identified by species, and percent cover and vegetation height for each species were estimated. For each wetland, abiotic and vegetation data were averaged across all transects, separately for each year. Water-quality analysis was completed in July, which included total phosphorus (TP, mg/L) and turbidity, water temperature, conductivity, and pH that were used to calculate a Water Quality Index (WQI) value [3]. In July and August, additional aquatic vegetation sampling was undertaken. At 20 randomly selected 1 m^2 quadrats per wetland, all submerged aquatic vegetation (SAV) was identified, and percent cover and vegetation height were estimated. This information is used in a Submerged Aquatic Vegetation (SAV) IBI [20,21].

2.4. Data Analysis

To determine the impact of Common Carp, fish community composition and health were compared at OSM before and after Common Carp recolonization and between OSM and Excellent health sampling events in other DRCWMP wetlands. The Excellent group represents all sites that scored an Excellent fish IBI score using the DRCWMP fish IBI; OSM_Pre represents OSM sampling from 2005 to 2009 during Common Carp exclusion; and OSM_Post represents OSM sampling from 2010 to 2015, excluding 2012, after Common Carp had colonized. The DRCWMP coastal wetland fish IBI was used as a measure of fish community health [20]. Means of biomass, abundance, Shannon–Wiener diversity index, and richness were calculated for each sampling event and group. Due to varying numbers of transects per sampling event, total biomass and abundance were standardized by area (m^2). Differences in environmental variables between groups were evaluated by a one-way analysis of variance (ANOVA), and Tukey's post-hoc pairwise test [22] was used to identify significant pairwise differences. If data were non-parametric, as determined by the Shapiro–Wilk test, the Kruskal–Wallis one-way analysis of variance was used, and pairwise differences were determined using the Mann–Whitney U-test statistic [22]. For multivariate analysis, species data were square-root transformed to reduce the impacts of dominant species [23]. To determine the most appropriate ordination technique, a Detrended Correspondence Analysis (DCA) was completed on the species assemblage matrix [23]. A Canonical Correspondence Analysis (CCA) was subsequently used as the length of the longest DCA gradient was greater than 2.5 and CCA tolerates skewed species and environmental data [24–27]. Eight environmental variables significantly correlated with fish IBI were included in the CCA. Because of the multicollinearity between conductivity, salinity, and total dissolved solids, only conductivity was used in the analysis as it had fewer missing values. Further examination of CCA results was undertaken using ANOSIM and SIMPER [28]. ANOSIM is a non-parametric permutation MANOVA that measures the variation between groups to determine if the distance is significant. Using OSM_Pre, OSM_Post, and Excellent groups, ANOSIM was run using the Bray–Curtis similarity index based on 9999 permutations. ANOSIM pairwise-relationship significance was based on Bonferroni-corrected p values less than 0.05. SIMPER is based on total dissimilarity between groups and identifies which species most influence the difference between groups. All data analyses were completed using PAST [29].

To determine if the fish community composition was becoming more similar to the Excellent community, the distance of each OSM sampling event to the Excellent group centroid was measured. Distance and change in distance were used to determine if the site was moving toward the reference Excellent group, using the assumption that movement toward the reference Excellent group is an improvement in health.

To further interpret species composition between different groups and species locations on the CCA, species were classified based on anthropogenic stressors [30]. To determine the relative abundance of piscivores, feeding diets were determined using Coker et al. [31]. Species with a diet high in fish were classified as piscivores. Outliers were removed if their z score was greater than three to reduce the influence of these points on subsequent analysis [32,33].

3. Results

A total of 6955 fish, representing 41 species, were caught in 39 sampling events at 16 wetlands (Tables A1 and A3). Of the 39 sampling events, 5 were in the OSM_Pre monitoring group (2005–2009), 5 were in the OSM_Post monitoring group (2010–2015), and the remaining 29 sites from 15 wetlands were in the Excellent IBI group. Excellent sites were represented by the most species (38) followed by OSM_Pre (14) and OSM_Post (12, Table A3). Five sensitive species were in the Excellent group, and none were in the OSM_Pre or OSM_Post groups. OSM_Post had the highest overall fish abundance, and the other two groups, OSM_Pre and Excellent, had similar values, but none were found to be significantly different (H = 2.044, $p = 0.36$, Table 1). The largest contributors to abundance in the OSM_Post group were Fathead

Minnow (*Pimephales promelas*) (average of 182 individuals per sampling event) and Goldfish (*Carassius auratus*) (average of 107 individuals per sampling event), combining for almost 80% of the total catch. Brown Bullhead (*Ameiurus nebulosus*) and Common Carp combined for another 17% of the total catch, with the four species combining for 97% of the total abundance at OSM_Post sites. As a result, OSM_Post had the lowest Shannon–Wiener diversity index score, which was significantly different than the other groups (F = 5.994, $p = 0.006$). OSM_Post had the highest biomass values, but differences between groups were not significant (H = 2.6, $p = 0.27$). The Excellent group had significantly higher richness than both OSM_Pre and OSM_Post (F = 13.63, $p < 0.001$). Richness ranged from 8 to 19 at Excellent sites, 6 to 10 at OSM_Pre sites, and 4 to 8 at OSM_Post sites. Piscivore abundance did not differ significantly between OSM_Pre and OSM_Post but was significantly higher at Excellent sites (F = 26.7, $p < 0.001$, Table 1).

Table 1. Average species richness, biomass, abundance, and Shannon–Wiener diversity index scores for the Excellent reference sites, Oshawa Second Marsh pre-Common Carp monitoring (OSM_Pre), and Oshawa Second Marsh post-Common Carp (OSM_Post) monitoring.

	Excellent	**OSM_Pre**	**OSM_Post**
Abundance (fish/m^2)	0.334	0.354	0.531
Piscivore abundance (fish/m^2)	0.183	0.004	0.006
Common Carp abundance (fish/m^2)	0.001	0.001	0.036
Biomass (g/m^2)	2.32	1.07	2.69
Richness	12.1	7.4	6.4
Shannon–Wiener Diversity Index	1.54	1.43	0.99

Thirteen environmental variables were examined for significant differences between the Excellent, OSM_Pre, and OSM_Post groups. Of the 13 variables, 10 had significant differences between groups based on ANOVA (Figure 2). Dissolved oxygen, air, and water temperatures were not significantly different. Environmental variables were different between the Excellent and the OSM_Pre and OSM_Post groups for all ten environmental variables, and seven were significantly different between OSM_Pre and OSM_Post. The three variables not significantly different between OSM groups were WQI, conductivity, and water depth.

Relationships between the fish community and eight environmental variables were analyzed using CCA to determine their relative influence on fish communities. The first two axes of the CCA explained 78.26% of the variation (Figure 3). The Excellent group is located on the center-left side of the plot, the OSM_Pre group is located on the right side of the center, and OSM_Post is on the far right side, as shown by 95% ellipses (Figure 3). ANOSIM results indicated the three groups were significantly different (R = 0.9797, $p < 0.001$) and that the difference was driven by the dissimilarity between Excellent and both the OSM_Pre and OSM_Post ($p = 0.0003$ for both) groups and between the OSM_Pre and OSM_Post ($p = 0.0216$) groups, as indicated by the pairwise results. WQI, SAV IBI, submergent vegetation, and water depth had the strongest relationships with the Excellent group, and conductivity and turbidity had the strongest relationships with the OSM groups. The species with the strongest relationship to the Excellent group, based on the CCA plot, were Johnny Darter (*Etheostoma nigrum*), Bridle Shiner (*Notropis bifrenatus*), sunfish species (*Lepomis*), and Brook Silverside (*Labidestes sicculus*), and the species with the strongest relationship with OSM groups were Green Sunfish (*Lepomis cyanellus*), Gizzard Shad (*Dorosoma cepdianum*), Goldfish, and Fathead Minnow (Figure 3). When all three groups were pooled, SIMPER analysis identified that Yellow Perch (*Perca flavescens*), Fathead Minnow, Goldfish, Bluegill (*L. macrochirus*), and Brown Bullhead contributed the most to dissimilarities (Table 2). The largest overall difference was between the Excellent group and OSM_Post (88.99%), and the smallest difference was between OSM_Pre and OSM_Post

(58.9%, Table 2). The overall dissimilarity between the OSM_Pre and Excellent groups was 17% less than between the OSM_Post and Excellent groups. OSM_Post had the largest ellipse size, followed by OSM_Pre, and the Excellent group had the smallest, suggesting that the Excellent group had the least within-group variation (Figure 3).

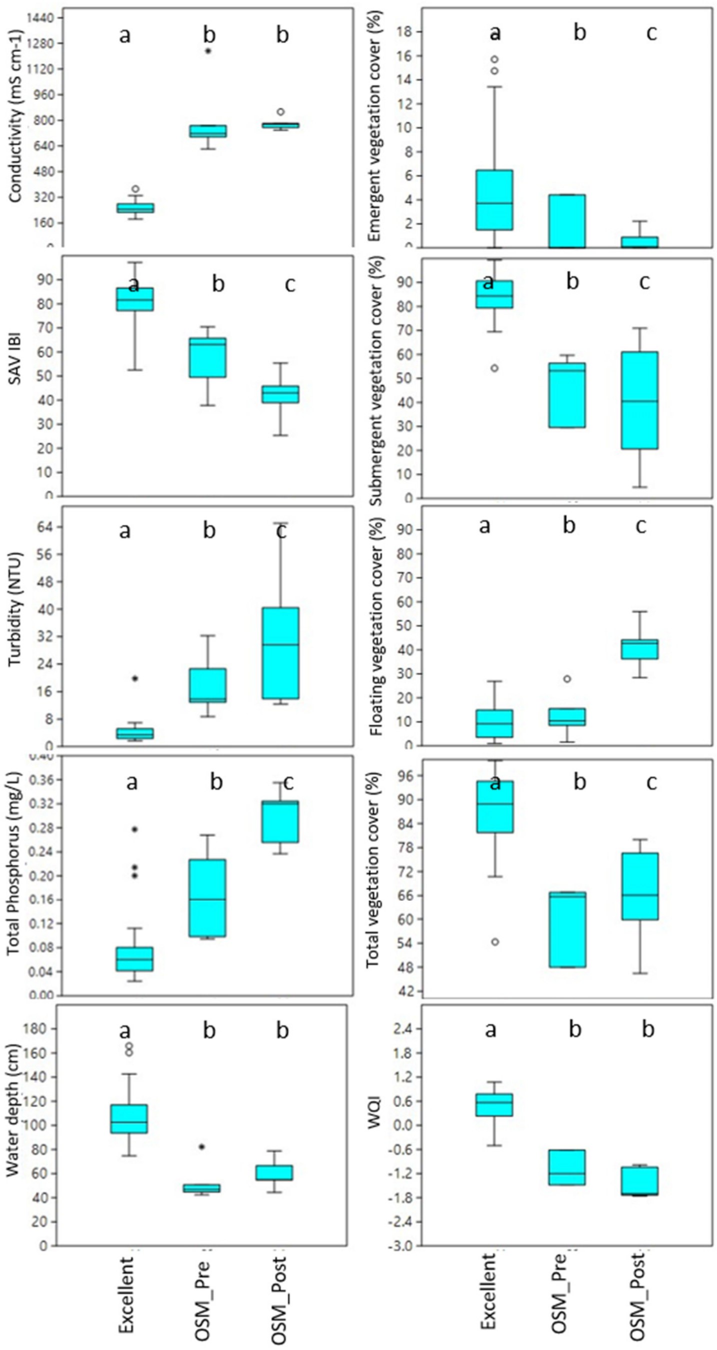

Figure 2. Box-and-whisker plots for the 10 environmental variables significantly differing between the Excellent, pre-Common Carp monitoring (OSM_Pre), and post-Common Carp (OSM_Post) monitoring. Lower-case letters represent significant pairwise differences based on Tukey's or Mann–Whitney pairwise tests (depending on normality).

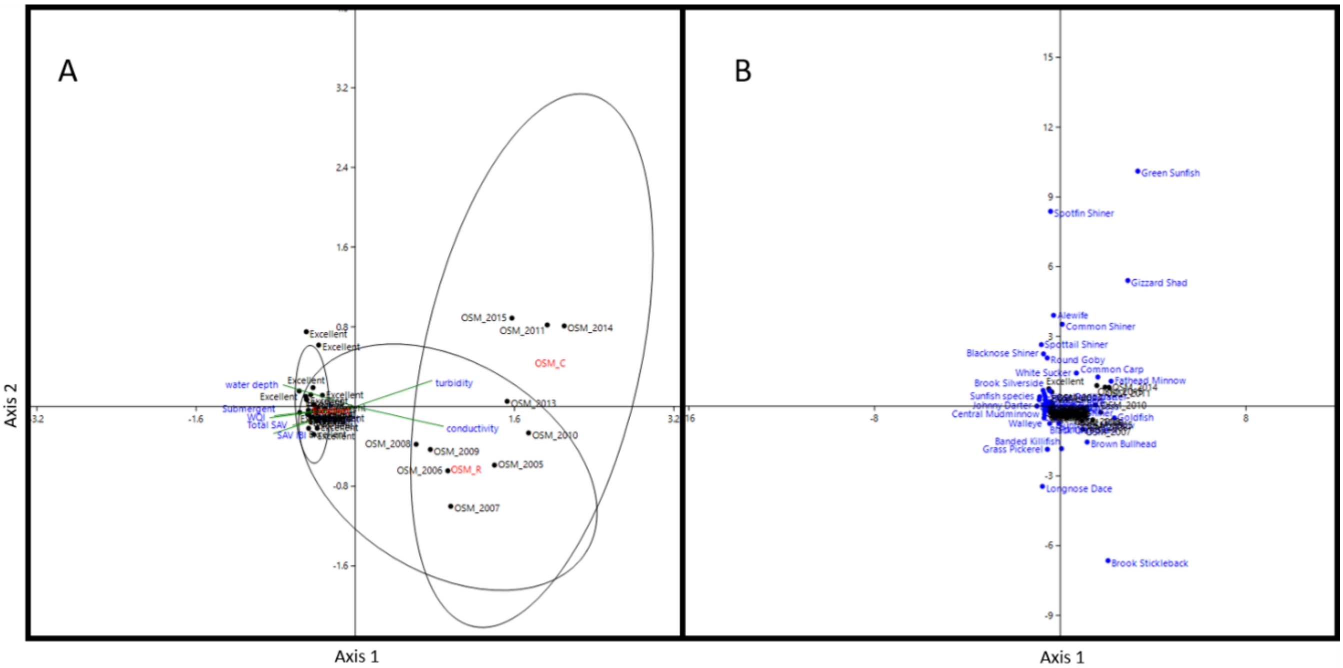

Figure 3. Ordination plot (CCA) for 39 coastal wetland fish sampling events representing three groups: Excellent condition, OSM_Pre, and OSM_Post. (**A**)—group centroids, 95% ellipses, and environmental variables. (**B**)—fish species.

Table 2. SIMPER results showing overall dissimilarity of fish community composition and species with the largest contribution to dissimilarity between groups.

Group 1	Excellent	Excellent	OSM_Pre	All pooled
Group 2	OSM_Pre	OSM_Post	OSM_Post	
Overall dissimilarity (%)	71	88.99	58.9	78.2
Species	Yellow Perch (18.12)	Fathead Minnow (16.61)	Fathead Minnow (22.39)	Yellow Perch (15.05)
	Goldfish (11.75)	Yellow Perch (14.08)	Pumpkinseed (16.89)	Fathead Minnow (13.47)
	Brown Bullhead (10.48)	Goldfish (12.61)	Goldfish (15.22)	Goldfish (12.42)
	Bluegill (8.489)	Bluegill (8.621)	Common Carp (12.58)	Bluegill (8.33)
	Fathead Minnow (8.154)	Common Carp (7.28)	Brown Bullhead (10.27)	Brown Bullhead (8.09)

To track the trajectory of the OSM fish community, the distance between each OSM sampling point and the centroid of the Excellent group ellipse was measured, and the distances were averaged by group (Figure 4). The average distance to the Excellent group was significantly different when comparing OSM_Pre to OSM_Post ($p < 0.001$). The largest change in distance was between 2009 and 2010, when OSM transitioned from OSM_PRE to OSM_POST (1.21), which was over double the average change in distance (0.52). The coefficient of variation for the distance to the Excellent centroid was 0.28. Sampling events OSM_2006 to OSM_2009 show a general movement toward the Excellent group, but, at OSM_2010, the dissimilarity between the Excellent group increased considerably. OSM_Post has high variability (distance between CCA plot points), but the majority is on axis 2, remaining far from the Excellent group on axis 1.

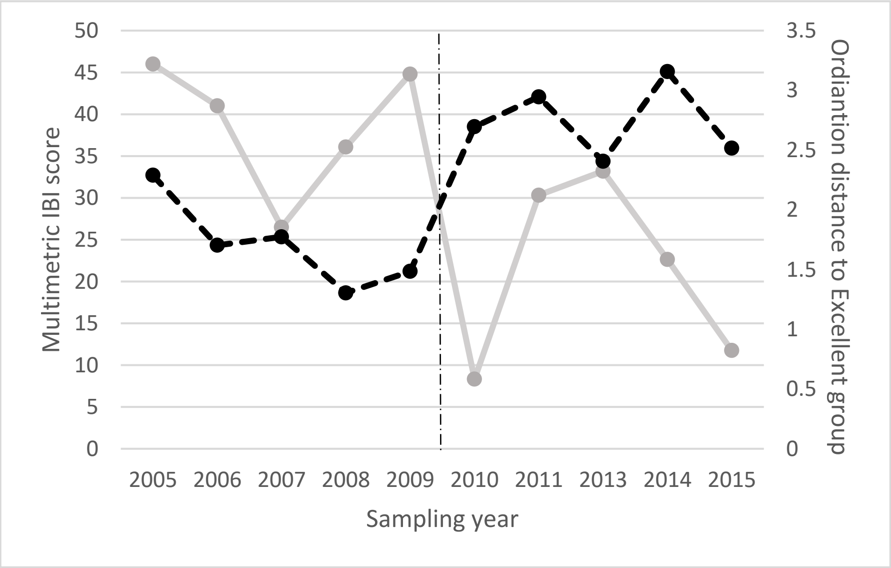

Figure 4. Comparing changes in fish community scores using multimetric and multivariate approaches. DRCWMP IBI is used for the multimetric score (grey solid line), and the Euclidean distance between OSM sampling events and the centroid of the Excellent group ellipse is used as a measure of fish community health for multivariate analysis (black dashed line). The vertical line represents the approximate time Common Carp regained access to Oshawa Second Marsh.

The DRCWMP fish IBI is used as a measure of fish community health. Changes in fish IBI over time at OSM were tracked (Figure 4). The highest fish IBI score was in 2005 with 2009 s (46.0 and 44.8, respectively). The lowest score was in 2010 (8.33), which is also the year that had the largest change in fish IBI scores (−36.5). The coefficient of variation for all OSM sites fish IBI scores was 0.43.

4. Discussion

The results of this study indicate that the reintroduction of Common Carp had a significant impact on coastal wetlands due to changes to water quality and vegetation. Ten environmental variables were significantly different between the Excellent fish IBI group, OSM_Pre, and OSM_Post. Fish abundance and biomass were highest in OSM_Post, largely driven by a few tolerant invasive species, including Common Carp, but had the lowest diversity and richness, with four species making up 97% of the populations. After Common Carp recolonization, fish community health decreased, as determined by the fish IBI and by multivariate restoration trajectories. The distance between the Excellent group and OSM_Post was significantly larger than OSM_Pre, indicating a more tolerant, degraded system. Restoration monitoring indicated increasing fish community health until Common Carp gained access and the fish community became increasingly dissimilar to the Excellent group. This dissimilarity occurred rapidly within the first year, followed by a consistent dissimilarity over the next four years, demonstrating the potential impact of Common Carp on a newly restored wetland. There were significant differences between fish IBI in OSM_Pre and OSM_Post group averages, but they did have range overlap and a higher coefficient of variation. The impacts of Common Carp have been well documented [8,10], but our research demonstrates the impacts they have on fish communities and wetland health immediately after restoration efforts if recolonization of Common Carp occurs.

Despite restoration occurring at OSM only a few years previously, most environmental variables had significant negative relationships with Common Carp reintroduction. Two abiotic variables increased with the re-colonization of Common Carp: turbidity and TP, which may have contributed to the decreases in the vegetation variables. Turbidity increases caused by Common Carp have been documented to impact aquatic vegetation, decreasing reproductive and foraging habitat for native fish species and impairing biotic interactions, such as visual foraging [6,12,13,34–36]. Only three variables were not significantly different following Common Carp re-colonization. Water depth was not expected to change as restored bathymetry was not part of the restoration strategy, and WQI and conductivity values may not have changed due to a lack of a specific restoration strategy to mitigate these stressors. Given that the degree of hydrological connection between Farewell Creek and Oshawa Second Marsh did not change after the addition of carp, it is reasonable to assume an improvement would not be seen given that upstream inputs are the source of poor water quality and remained consistent over that time period.

A higher richness is expected in healthier wetlands due to increased habitat quality, diversity, and cover, which is consistent with the results of our study [13,37,38]. Species richness at OSM was lower than the Excellent group but decreased further after the reintroduction of Common Carp (OSM_Post) and a decrease in habitat quality. Areas with high anthropogenic stressors have been documented to have homogenous fish communities, consistent with our findings [39]. Sensitive species were present in the Excellent group but not in either of the OSM groups. It is unknown if sensitive species have been extirpated from OSM and, if conditions improved after restoration, whether source populations would be geographically close enough to recolonize and reflect the higher richness, or if this is an indication of only partial success of the restoration project.

Increased biomass is typically viewed as positive but becomes more complex when large invasive species, such as Common Carp, are present. Biomass ranged between 1.07 g/m^2 at OSM_Pre, 2.32 g/m^2 at the Excellent group, and 2.69 g/m^2 at OSM_Post, but the at Excellent sites, biomass was largely driven by large native species rather than Common Carp. The low biomass in OSM_Pre represents a time when Common Carp were absent but larger native fish had not colonized the wetland. Biomass more than doubled after Common Carp were reintroduced to the wetland. Common Carp accounted for 38% of the biomass but only 2.4% of the abundance and had a negative relationship with fish IBI in Durham Region Coastal Wetlands (D. Moore, unpubl. data). Lougheed et al. [6] reported Common Carp biomass to be as high as 2600 kg/ha, and Minns et al. [37] found that native species account for less than half of the total biomass, in large part because of the influence of Common Carp, in littoral fish assemblages of three Areas of Concern, including the Bay of Quinte. The boat electrofishing protocol used in DRCWMP typically under-represents Common Carp due to its size, speed, and evasive abilities in shallow coastal wetlands with little vegetation cover, yet it still contributes significantly to biomass calculations in this monitoring. To better understand the impact and peak abundance of Common Carp, multiple sampling techniques to better estimate population size and sampling in multiple seasons would be beneficial [19,20].

Trophic structure has been documented to play an important role in wetland restoration. Certain species, such as Common Carp, or portions of the trophic structure, such as piscivores, have been found to indirectly influence water clarity and vegetation structure, which is largely consistent with our results [5,9,34,40–43]. The OCM_Post community had few piscivores when compared to the Excellent group, which may have contributed to the high abundance and low diversity of fish species. In the absence of piscivores, an increased abundance of tolerant species, in this situation largely Common Carp, translates to higher levels of benthivory-depleting filter-feeding zooplankton through consumption [5], excess re-suspension of sediment particles damaging the filter apparatus [44], disturbing dormant stages of zooplankton [5], and increasing concentrations of mineral matter in the water column [45]. Fewer zooplankton, especially larger zooplankton, result in a transition to, or maintenance of, a turbid phytoplankton system as fewer organisms are available to control phytoplankton abundance [6,9,41,46]. Following Common Carp removal at OSM (OSM_Pre), an increase in piscivores was expected but not observed. Given upstream water quality could not be improved through restoration, this may have prevented piscivore abundance increases, which led quickly to reverting back to its previous state when Common Carp regained access to the wetland. This underlies the importance of considering physical, chemical, and biological interactions holistically when completing restoration projects.

A reference-condition approach (RCA) was applied given the lack of pre-development baseline data for OSM. The restoration trajectory, as measured by the change in distance to the Excellent group centroid, indicates improving fish community health between 2005 and 2009. The change in distance from 2009 to 2010, when Common Carp regained access, is the largest increase in distance (0.98) from the Excellent group centroid, synonymous with poorer fish community health. Natural variation is unlikely to be the entire cause given that this is well over double the average change in distance for OSM (0.42) and the longest ellipse length for the Excellent group (0.39). This suggests that the reintroduction of Common Carp into OSM resulted in a decrease in fish community health to below 2005 levels. Watershed conditions and certain species may play a role in maintaining or influencing a turbid, phytoplankton-dominated system, but, given the combination of Common Carp biomass and its life history, it appears to have had a significant role in altering habitat conditions. Common Carp are known to be present at the Excellent sites, primarily the Bay of Quinte, and have similar abundance as OSM_Pre, but fish community health is consistently high in the Excellent group coastal wetlands [37,47]. The reasons for its impact in Durham Region may be due to the intensity of other anthropogenic stressors within the watersheds. Croft-White et al. [48] reported a significant difference in urban land use at a watershed scale between Durham Region (30–50%) and the Bay of Quinte (<5%). Common Carp may have a greater impact on coastal wetland ecosystems when they are already subjected to other stressors. Although not specific to coastal wetlands, stressed aquatic and terrestrial ecosystems are susceptible to being invaded [49–52]. Again, this emphasizes the importance of a holistic restoration strategy to avoid autocatalytic processes between Common Carp and watershed stressors.

The multivariate and multimetric approaches provided similar results, but greater variation was found in the multimetric approach, resulting in more overlap between the OSM_Pre and OSM_Post groups. Indicators with lower variation are more appropriate indicators as the impact of temporal variation is reduced [53].

5. Conclusions

Fish community health slowly increased after restoration, then decreased immediately to pre-restoration values after the reintroduction of Common Carp. The fish community composition after restoration increased in similarity to the Excellent group but may have been limited by time, as restoration had only occurred five years earlier, or other factors, such as the limited connectivity through the fish grate or unimproved water quality, may have prevented reaching the Excellent group ellipse regardless of time. Further restoration efforts, including Common Carp removal, a reinforced fish grate, and another drawdown to re-establish vegetation communities, are currently underway, which will allow continued monitoring of these impacts and relationships to environmental variables. Given that the current fish community is in poor health, understanding the role of those fish in maintaining a high-turbidity, phytoplankton-driven community would be valuable. If those fish maintain poor conditions, understanding how to break that positive feedback cycle (e.g., increased piscivore biomass) to return to a clear macrophyte community is needed in a system with numerous stressors. As summarized by Minns et al. [54], scientific evidence and principles are necessary to develop restoration into a science, and this study contributes to that process.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. List of all fish species included in this study. Sensitive or tolerant rating was based on [31] and piscivore was determined by whether fish consumption was high based on [32].

Common Name	Scientific Name	Tolerance	Piscivore
Alewife	*Alosa pseudoharengus*	Tolerant	
American Eel	*Anguilla rostrata*	Sensitive	Yes
Banded Killifish	*Fundulus diaphanus*	Tolerant	
Black Crappie	*Pomoxis nigromaculatus*	Tolerant	
Blackchin Shiner	*Notropis heterodon*	Sensitive	
Western Blacknose Dace	*Rhinichthys obtusus*	Tolerant	
Blacknose Shiner	*Notropis heterolepis*	Sensitive	
Bluegill	*Lepomis macrochirus*	Tolerant	
Bluntnose Minnow	*Pimephales notatus*	Tolerant	
Bridle Shiner	*Notropis bifrenatus*	Sensitive	
Brook Silverside	*Labidesthes sicculus*	Tolerant	
Brook Stickleback	*Culaea inconstans*	Tolerant	
Brown Bullhead	*Ameiurus nebulosus*	Tolerant	
Central Mudminnow	*Umbra limi*	Tolerant	Yes
Common Carp	*Cyprinus carpio*	Tolerant	
Common Shiner	*Luxilus cornutus*	Tolerant	
Emerald Bowfin	*Amia ocellicudta*	Tolerant	Yes
Fathead Minnow	*Pimephales promelas*	Tolerant	
Gizzard Shad	*Dorosoma cepedianum*	Tolerant	
Golden Shiner	*Notemigonus crysoleucas*	Tolerant	
Goldfish	*Carassius auratus*	Tolerant	
Grass Pickerel	*Esox americanus vermiculatus*	Sensitive	Yes
Green Sunfish	*Lepomis cyanellus*	Tolerant	
Johnny Darter	*Etheostoma nigrum*		
Northern Largemouth Bass	*Micropterus nigrans*	Tolerant	Yes
Logperch	*Percina caprodes*	Tolerant	
Longnose Dace	*Rhinichthys cataractae*	Tolerant	
Northern Pike	*Esox lucius*	Tolerant	Yes
Pumpkinseed	*Lepomis gibbosus*	Tolerant	
Rock Bass	*Ambloplites rupestris*	Tolerant	
Round Goby	*Neogobius melanostomus*	Tolerant	

Table A1. *Cont.*

Common Name	Scientific Name	Tolerance	Piscivore
Silver Redhorse	*Moxostoma anisurum*	Tolerant	
Spotfin Shiner	*Cyprinella spiloptera*	Tolerant	
Spottail Shiner	*Hudsonius hudsonius*	Tolerant	
Sunfish species	*Lepomis* spp.		
Tessellated Darter	*Etheostoma olmstedi*	Tolerant	
Walleye	*Sander vitreus*	Tolerant	Yes
White Bass	*Morone chrysops*	Tolerant	Yes
White Sucker	*Catostomus commersonii*	Tolerant	
Yellow Perch	*Perca flavescens*	Tolerant	Yes

Table A2. Summary of all wetlands included in this study. Years of sampling and coordinates for wetland centroid included in the study.

Wetland Name	Region	Sampling Years	Latitude	Longitude
Airport Creek Marsh	Quinte	2012	44.176117	−77.096944
Big Island East Marsh	Quinte	2008, 2013	44.132709	−77.191766
Big Island West Marsh	Quinte	2008, 2012	44.094032	−77.258117
Blessington Creek Marsh	Quinte	2009, 2013	44.164071	−77.321675
Carnachan Bay Marsh	Quinte	2011, 2014	44.074796	−77.021394
Carrying Place Marsh	Quinte	2009, 2014	44.054563	−77.572057
Dead Creek Marsh	Quinte	2010, 2015	44.067101	−77.600465
Frenchman's Bay Marsh	Durham	2015	43.815726	−79.090901
Hay Bay Marsh North	Quinte	2008	44.177803	−76.932037
Hay Bay Marsh South	Quinte	2008, 2011, 2014	44.160020	−76.885154
Lower Napanee Marsh	Quinte	2010, 2011, 2014	44.200906	−76.997626
Oshawa Second Marsh	Durham	2005–2011, 2013–2015	43.873219	−78.811350
Robinson Cove	Quinte	2012	44.114650	−77.281498
Sawguin Creek Central Marsh	Quinte	2012, 2015	44.121685	−77.326227
Sawguin Creek Ditched Marsh	Quinte	2009	44.086974	−77.335135
Sawguin Creek North Marsh	Quinte	2010, 2011, 2014	44.133841	−77.371001

Table A3. A summary of species caught within each group (Excellent—reference sites deemed to have Excellent fish communities by DRCWMP IBI, OSM_PRE—Oshawa Second Marsh post-restoration monitoring (2005–2009), OSM_POST—Oshawa Second Marsh post-Common Carp monitoring (2010–2015).

Species	Excellent	OSM_Pre	OSM_Post
Alewife	x		
American Eel	x		
Banded Killifish	x	x	x
Black Crappie	x	x	
Blackchin Shiner	x		

Table A3. *Cont.*

Species	Excellent	OSM_Pre	OSM_Post
Blacknose Dace	x		
Blacknose Shiner	x		
Bluegill	x	x	
Bluntnose Minnow	x	x	x
Bridle Shiner	x		
Brook Silverside	x		
Brook Stickleback	x	x	
Brown Bullhead	x	x	x
Central Mudminnow	x		
Common Carp	x	x	x
Common Shiner	x		
Emerald Bowfin	x		
Fathead Minnow	x	x	x
Gizzard Shad			x
Golden Shiner	x	x	
Goldfish		x	x
Grass Pickerel	x		
Green Sunfish			x
Johnny Darter	x		
Largemouth Bass	x		x
Logperch	x		
Longnose Dace	x		
Northern Pike	x	x	
Pumpkinseed	x	x	x
Rock Bass	x		
Round Goby	x		
Silver Redhorse	x		
Spotfin Shiner	x		
Spottail Shiner	x		
Sunfish species	x		
Tessellated Darter	x		
Walleye	x		
White Bass	x		
White Sucker	x	x	x
Yellow Perch	x	x	x
Total	37	14	12

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