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APPLICATION OF THE TARGET FISH COMMUNITY MODEL TO AN URBAN RIVER SYSTEM

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Abstract

Several models have been developed to assess the biological integrity of aquatic systems using fish community data. One of these, the target fish community (TFC) model, has been used primarily to assess the biological integrity of larger, mainstem rivers in southern New England with basins characterized by dispersed human activities. We tested the efficacy of the TFC approach to specify the fish community in the highly urbanized Charles River watershed in eastern Massachusetts. To create a TFC for the Charles River we assembled a list of fish species that historically inhabited the Charles River watershed, identified geomorphically and zoogeographically similar reference rivers regarded as being in high quality condition, amassed fish survey data for the reference rivers, and extracted from the collections the information needed to define a TFC. We used a similarity measurement method to assess the extent to which the study river community complies with the TFC and an inference approach to summarize the manner in which the existing fish community differed from target conditions. The five most abundant species in the TFC were common shiners (34%), fallfish (17%) redbreast sunfish (11%), white suckers (8%), and American eel (7%). Three of the five species predicted to be most abundant in the TFC were scarce or absent in the existing river community. Further, the river was dominated by macrohabitat generalists (99%) while the TFC was predicted to contain 19% fluvial specialist species, 43% fluvial dependent species, and 38% macrohabitat generalist species. In addition, while the target community was dominated by fish intolerant (37%) and moderately tolerant (39%) of water quality degradation, the existing community was dominated by tolerant individuals (59%) and lacked intolerant species expected in the TFC. Similarity scores for species, habitat use specialization, and water quality degradation tolerance categories were 28%, 35% and 66%, respectively. The clear pattern of deviations from target conditions when observing fish habitat requirements strongly suggests that physical habitat change should be a priority for river enhancement in the Charles River. Comparison of our target and existing fish communities to those from a comprehensive study of Northeastern fish assemblage responses to urban intensity gradients revealed very similar results. Likewise, comparison of our TFC community and affinity scores to those of other TFCs from similar regions also yielded similar results and encouraging findings. Based on the positive results of these comparisons, the utility of the findings from the inference approach, and the widespread adoption of the TFC in the Northeast US, it appears that the TFC approach can be used effectively to identify the composition of a healthy fish community and guide river enhancements in both highly urbanized and non-urbanized streams and rivers in the Northeast US.

Keywords: target fish community; river enhancement; Charles River; habitat; water quality; urbanization; biological integrity

1 Introduction

The US Clean Water Act calls for efforts to restore and maintain the physical, chemical, and biological integrity of the Nation's waters. Biological integrity has been defined as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr, 1991). Models have been developed to use fish communities to empirically assess the biological integrity of aquatic systems (Fausch et al., 1990; Halliwell et al., 1999; Hughes, 1995; Karr, 1981, Kanno et al., 2009). A more recent target fish community (TFC) approach has been developed to define the community of fish appropriate for a mainstem river in New England with a watershed dominated by a variety of human activities (Bain and Meixler, 2008). The adoption of the TFC by the Commonwealth of Massachusetts and the State of New Hampshire as a component of their water resources policy development process highlights the importance of the TFC as a valuable approach to biological integrity assessment of large rivers (Legros and Parasiewicz, 2007).

The TFC uses fish data from multiple ecologically healthy reference river sites with geomorphically and zoogeographically similar characteristics as the study river to define a target fish community. The TFC approach has been used to assess the status of fish communities on the Ipswich, Assabet, Housatonic, and most remaining mainstem rivers in Massachusetts (Armstrong et al., 2001; Kashiwagi and Richards, 2009; Kearns et al., 2005; Lang et al., 2001; Parker et al., 2004), the Pomperaug, Saugatuck and Eightmile Rivers in Connecticut (Parasiewicz et al., 2007a; Parasiewicz et al., 2007b), the Quinebaug River in Massachusetts and Connecticut (Bain and Meixler, 2008), and the

Souhegan River in New Hampshire (Ballesterro et al., 2007). Southeastern New Hampshire watersheds generally have between 5-10% impervious cover, with central areas of New Hampshire decreasing to only 1-5% and northern parts of the state experiencing even less (Theobald et al., 2009). Connecticut watersheds generally have from 1-5% impervious cover though the south-central portion of the state and portions near New York City increase in impervious cover up to 25%. Most of the rivers in western and central Massachusetts have watersheds with approximately 1-5% impervious cover. From central Massachusetts east, impervious cover increases and areas around Boston are expected to exceed 25% impervious cover and reach values in the range of 50-55%. Of the locations in which the TFC has been applied, the Charles River is thus far the only location in which the impervious cover is likely to exceed 25%. Nearby Ipswich and Neponset Rivers have watersheds with impervious cover of 6% and 9%, respectively. Thus, to date, the TFC has not been applied to a highly urbanized river system.

Recent research has shown that fish assemblages of urban streams are functionally less diverse than nonurban streams (May et al., 1997; Weaver and Garman, 1994) and increased impervious cover reduces fish species richness and alters fish assemblage structure and function (Meador et al., 2005). Further, striving for natural habitats and communities may not be practical in such a highly altered ecosystem, and a focus on solely natural environmental characteristics may not yield feasible habitat enhancement actions (Stoddard et al., 2006). By testing the application of the TFC model in the highly urbanized Charles River watershed in eastern Massachusetts, we could: 1) assess the integrity of this highly urbanized river system; 2) characterize the deviations of the fish community from natural conditions, and 3) facilitate river habitat enhancement decisions. The calculation processes are described, the resulting fish community is given, and a comparative analysis identifying deviations between the expected (TFC) and existing fish communities is illustrated. Potential reasons for such deviations, related to the biological integrity of the study area, are then suggested using an inference-based approach and river enhancement actions are identified.

2 Methods

The Charles River watershed in eastern Massachusetts is one of the most densely populated watersheds in New England region of the United States. Profound changes in the watershed over the last 400 years, from forested to agrarian to forested/suburban land use, have resulted in diminished ecological integrity and extensive water quality degradation in the river and its tributaries, reduced flows in the river, water extraction, diminished groundwater supplies, degraded fisheries and wildlife habitat, introduced non-native floral and faunal species, and eliminated, reduced or substantially altered fish and wildlife communities (CRWA, 2003; McIntyre et al., 2003). As the longest river entirely within the state of Massachusetts, the Charles River flows 129 km northeast to the coast from the town of Milford to Boston Harbor encompassing a watershed of 798 km^2 (Figure 1; Weiskel et al., 2005). All tidal influence has been removed from the Charles River by a dam at the river’s mouth. The primary areas of commercial and industrial land uses and medium to high density residential development in the watershed are along the I-495 corridor, in the upper reaches, and in the eastern portion of the watershed near the city of Boston (CRWA, 2003). Low to medium density residential uses, open space, and forested areas are more prevalent in the western portion of the watershed (CRWA, 2003).

Our TFC approach, modeled after Bain and Meixler (2008), involved the following steps. We assembled a zoogeographic list of fish species that were likely to have historically inhabited the Charles River watershed, identified comparable reference rivers regarded as being in quality condition, assembled fish survey data for the reference rivers, extracted from the collections the information needed to define a target community, and demonstrated the use of the target community to assess and interpret the existing fish community status in the Charles River. Overall, our approach sought to extract the minimum necessary information from natural resource managers and past fishery surveys to construct a future target fish community to be attained through river enhancement practices. Throughout the process we sought input from regional fisheries experts to ensure that the species compositions of the proposed fish community model were conducive to management objectives for the Charles River and consistent with the resident fish fauna expected to occur in the area.

We used historical data from Charles River fishery surveys completed in 1969, 1975 and 1981 to develop a grand list of potential fish species in the Charles River watershed (Bergin, 1969; MA DFW, 1975; MA DFW, 1981). This yielded 34 species. We supplemented these results with a review of "Inland Fishes of Massachusetts" by Hartel et al. (2002), which raised the total to 53 species. Species found commonly in reference rivers were added to this list to bring the total to 61 species. From this list, 24 species were deleted for a variety of reasons based on consultations with regional fisheries experts: ten marine and estuarine species only enter coastal freshwater habitats (e.g., Atlantic silverside, *Menidia menidia*, and winter flounder, *Pseudopleuronectes americanus*), two species have a restricted distribution to estuarine and coastal areas in the New England region but are more prevalent in other United States regions (e.g., ninespine stickleback, *Pungitius pungitius*, and hogchocker, *Trinectes maculatus*; Hartel et al., 2002), nine species were judged out of range (e.g. eastern blacknose dace, *Rhinichthys atratulus*, and Atlantic salmon, *Salmo salar*; Hartel et al., 2002), and three were historically introduced species that failed to become established (e.g., rainbow trout, *Oncorhynchus mykiss*, tiger muskellunge, *Esox masquinongy x Esox lucius*, and bowfin, *Amia calva*; Hartel et al., 2002). Anadromous fish were included in the list of potential species based on the fact that the Charles River dam, located at the mouth of the Charles River between the Charlestown and North End sections of Boston, has a fish ladder and a locking procedure allowing passage of migrating fish. These fish were included as a component of the target community in the broader context of contemporary river restoration planning and management.

Fifty coastal rivers from Maine to New York and 31 smaller rivers in New Hampshire, Massachusetts and Connecticut were investigated for use as reference rivers. We sought reference rivers with physical, geomorphic and hydrological characteristics similar to those of the Charles River (in parentheses): ecoregion (59), gradient (0.001), drainage area (798 km^2), stream order (4), and annual flow (8.58 cms). Reference rivers were considered candidates if their values for these parameters were within the following criteria thresholds for at least three parameters: at least a portion of the reference river watershed must be within the same ecoregion as the target river; a difference in gradient of no more than 0.002 m from the target river; no less than half or more than double the drainage area of the target river; no more than one deviation from the stream order of the target river; and no less than half or more than double the annual flow of the target river.

We also required that the reference rivers be relatively unimpaired (yellow or green in the National Coastal Conditions Report USEPA, 2001 or class A or B in USEPA, 1990 EPA's waterbody classifications for TMDLs), be undammed or have fewer dams than the target river, and be undeveloped with fewer water withdrawals than the target river. Finally, the reference rivers must have fish community data collected in the last twenty years from at least two free-flowing reaches and with at least ten individuals of the most abundant species present. We selected a set of potential rivers that best fit these criteria.

The reference rivers were not considered to be in a fully natural or pristine state but instead were recognized as high quality rivers with the best source of data for characterizing a feasible and currently relevant fish fauna that could inhabit the Charles River. The rivers chosen and their fish survey years were the Exeter (1999, 2000), Lamprey (2003), Souhegan (2005), and Piscataquog (1996) Rivers in New Hampshire, the Salmon (1989) and Yantic (1993) Rivers in Connecticut, and the Pawcatuck (2002, 2003) River in Rhode Island (Table 1; Figure 1). The fish survey records were comprehensive in species identifications and considered by natural resource agency staff to be indicative of local fish faunas.

The reference river data were analyzed using simple spreadsheet calculations. First, the numbers of fish by species were tallied for all collections available from each of the reference rivers. Then, the species tallies were divided by the total number of individuals captured to obtain the proportion of total individuals by species in each river. Proportions of each species were summed across the reference rivers. The summed proportions were then ranked (1 being the most common). Next, all introduced and out-of-range fishes were excluded to focus river restoration efforts on target native species. Stocked species (rainbow trout, brown trout, *Salmo trutta trutta*, brook trout, *Salvelinus fontinalis,* and Atlantic salmon) were also removed from the analysis since these only inhabit the rivers at the stocked sizes and thus provide no useful information on the wild fish community. The outcome of these data manipulations was a ranked list of native fish species reflecting the order of abundance of species in the pooled reference river data. Rankings were not recalculated after the deletion of introduced, stocked and out-of-range species to avoid over representing the expected proportions of native fish species.

Fish species ranks were converted to expected TFC proportions. Expected proportions were computed by converting species ranks to reciprocals (1/rank), summing these in decimal form, and dividing the reciprocal rank (decimal) by the sum of all reciprocal ranks. Uncommon species (each comprising less than 3% of the total fish community) were combined into a group called other, and the expected proportion of this group was the remainder of the expected proportions that together equal one. The calculation follows a rank-weighting technique that has been found through experience (Bakus et al., 1982; Edwards, 1977; Hwang and Yoon, 1981; Johnson and Huber, 1977) to closely approximate category count distributions seen in social research results. This method has recently been extended to fish communities (Bain and Meixler, 2008).

The target and existing fish communities were compared using the percent model affinity procedure of Novak and Bode (1992). The percent model affinity method yields values on a scale from 0 to 100 that describe the extent that a fish collection from the Charles River matched our TFC. High affinity values correspond to higher levels of correspondence with the TFC. The percent model affinity method uses a percent similarity measure computed as:

$$\text{Percent similarity} = 100 - 0.5\,(\text{sum}\ |\text{target } P - \text{observed } P|)$$

where P is the proportion of each species in the community or collection. The observed proportions of the top target fishes were used to identify whether Charles River fish species were present in expected abundances, under represented, or overly abundant. Fish species expected in the river that were not recorded were also identified. The significance of the deviations from a target community was interpreted by reviewing the habitat requirements and pollution tolerances for species in the observed abundance groups.

Species habitat requirements and pollution tolerances were classified using regional and state ichthyology books (Becker, 1983; Burr and Warren, 1986; Jenkins and Burkhead, 1994; Lee et al., 1980; Pflieger, 1975; Robison and Buchanan, 1988; Scott and Crossman, 1973; Trautman, 1981). As a group, these reference books describe the North American life history of fish. Habitat requirements were summarized into three macrohabitat (water body type) classes: macrohabitat generalists (MG), fluvial dependents (FD), and fluvial specialists (FS). These groupings have been found effective in relating fish community change to river habitat alteration (Bain et al., 1988; Kinsolving and Bain, 1993; Quinn and Kwak, 2003). Some adjustment was made to the classifications to accommodate regional differences in habitat requirements. Two of the habitat classifications (fallfish, *Semotilus corporalis*, and brook trout) were changed from generalists to fluvial specialists. Striped bass (*Morone saxatilis*) was reclassified as a fluvial dependent. American eel (*Anguilla rostrata*) is a catadromous fish (migrates to sea for spawning) that requires access to stream habitats to complete its life cycle. However, this fish was classified as a macrohabitat generalist since it occupies a wide range of habitats throughout its life. For pollution tolerance classifications, we used the classifications of Barbour et al. (1999) and Halliwell et al. (1999) for Northeast US fishes: intolerant (I), moderately tolerant (M), or tolerant (T). Finally, species were designated as native or exotic (introduced) from Hartel et al. (2002).

3 Results

After the deletions, our review of the potential and known fishes of the Charles River resulted in a list of 37 species (Table 2). The species list contains native and introduced fishes, and a full range of sensitivities to habitat and water quality degradation. Some of these species have not been recorded in recent sampling, but are still considered candidates for collection in any survey.

The fish composition data for the seven reference rivers provided the minimum information needed for specifying the rank order of species in the target community. Common shiners (*Luxilus cornutus*) were dominant in three of the seven rivers, and highly abundant in the other four. Fallfish were the dominant species in one river and highly abundant in two other rivers. These two fishes were ranked first and second respectively, with other highly ranked fishes common in most of the reference rivers. Species with expected proportions of less than 3% had increasingly sporadic presence in the reference river collections. We pooled all species with less than 3% expected proportions into a group called other. The rank order and expected proportion of species in our target community for the Charles River is: common shiner (34%), fallfish (17%), redbreast sunfish (*Lepomis auritus*, 11%), white sucker (*Catostomus commersonii*, 8%), American eel (7%), brown bullhead (*Ameiurus nebulosus*, 4%), pumpkinseed (*Lepomis gibbosus*, 3%) and other (16%, Table 3; Figure 2). We project from these results a target community for river restoration that would have seven common species comprising 84% of all fish. The rank order and actual proportion of species in our existing Charles River community is: bluegill (*Lepomis macrochirus*, 31%), American eel (17%), redbreast sunfish (11%), yellow perch (*Perca flavescens*, 8%), largemouth bass (*Micropterus salmoides*, 8%), pumpkinseed (5%), golden shiner (*Notemigonus crysoleucas*, 5%), white perch (Morone Americana, 3%), common carp (Cyprinus carpio, 3%), black crappie (*Pomoxis nigromaculatus*, 3%), and others (6%, Table 4, Figure 2). Percentages for target and existing fish community composition and absolute differences are given in Table 5.

From the eleven mainstem study sites of the Charles River, 1,775 fish were collected comprising 37 species. The average number of fish collected at each site was 161, but ranged from 20 to 481 (Table 4). The average number of species identified per site was nine, but ranged from three to fourteen.

Across all sites, contributions of redbreast sunfish and pumpkinseed were appropriate but American eel was present far above the target level, and other common target species were rare or absent. The overrepresentation of American eel would not have been surprising if abundances at these sites were low, but sites with higher than expected American eel densities had absolute abundances of 46 to 249 individuals (Table 4). The contribution of minor members to the target community was high: 65% versus 16%. Additionally, species not expected to be common (bluegill, largemouth bass, yellow perch) were recorded in high abundance (31%, 8% and 8%, respectively).

Using the survey data from eleven mainstem reaches of the Charles River, a comparison was made between the TFC and the existing fish communities. Similarity among target and observed communities was summarized with the percent affinity measure (no similarity [0] to a perfect match [100]). When interpreting affinity values it is important to note that though TFC proportions are valid for the entire length of the river, we do not expect to find the same distribution at every site.

Affinity index values in the Charles River varied from 19% to 42% with an average affinity of 28% across all sites and a standard deviation of 7% (Table 4). Sites with the lowest affinity values had fish communities that deviated strongly from target community specifications. In general, the key components (species with expected proportions over 3%) of the target community were recorded in very low numbers (5% to 20% versus expected 84%). All common target species except pumpkinseed, American eel and redbreast sunfish were well below expectations or absent including the expected dominant species common shiner and fallfish. Also, several fishes expected in low abundances (members of the other class) were sometimes found in high abundances (94%) largely due to presence in some sites of bluegill, largemouth bass, yellow bullhead (*Ameiurus natalis*) and/or yellow perch. Some sites in the upstream and midstream portion of the watershed conformed more closely to the target community and the target community's common species were better represented. Species not expected in high numbers, such as bluegill and largemouth bass, remained common but less so than in the sites with the lowest affinity values. Overall, these sites have most of the expected species present but in abundances deviating from specifications.

Information on fish species' habitat use specialization and water quality degradation tolerance provides possible reasons for deviations from the target community (Table 6). Overall, similarity scores for habitat use specialization and water quality degradation tolerance categories were 35% and 66%, respectively. The Charles River is currently dominated by macrohabitat generalists (99%). However, the TFC predicted that the river should contain 19% fluvial specialist species, 43% fluvial dependent species, and 38% macrohabitat generalist species. The abundances of species that specialize or depend on stream habitats were consistently beneath their target community expectations. All species found in abundances greater than expected were habitat generalists. Species not recorded included mostly habitat generalists and several fluvial specialists/dependents. In general, fluvial oriented species were concentrated in the underrepresented group and absent in the overabundant group.

Analysis of sensitivity to water quality degradation revealed that all three of the native pollution intolerant species (common shiner, bridle shiner, *notropis bifrenatus*, and creek chubsucker, *Erimyzon oblongus*) in the Charles River were missing in the collections (Table 6). In addition, while the target community is dominated by intolerant (37%) and moderately tolerant fish (39%), the existing community is dominated by tolerant individuals (59%).

4 Discussion

This paper provides a practical and scientific method for characterizing the fish community and guiding river enhancement efforts in a highly urbanized ecosystem. The fish community we developed for the Charles River is precise in its definition, feasible to attain, and functional as a standard for measuring environmental improvement.

Our analysis documents the strong deviation of the existing Charles River fish community from the TFC. This deviation is not unexpected as the Charles River is one of the most developed rivers in Massachusetts and impairments in the river have been extensively studied (Weiskel et al., 2005). More than 80 percent of the river kilometers in the watershed are listed as impaired for aquatic life use (Kashiwagi and Richards, 2009). The causes of impairment include barriers to fish passage, nutrient enrichment, and elevated temperature attributed to municipal discharges, habitat alteration caused by impoundments, and non-point source pollution. These impairments are also illustrated by the widespread consumption advisories for elevated levels of PCBs, mercury, and DDT (DEP, 2007).

Several factors had a strong influence on the target community we developed even though the computations and target community projections appear fixed. First, reference river selection was guided by a suite of parameters developed in consultation with regional fisheries experts. In this case the rivers were selected as regionally comparable rivers considered in good to excellent status. In practical terms, we proceeded with the implied perspective that the Charles River would be regarded as enhanced and in ecological balance if it contained a fish community much like that seen in the reference rivers. Therefore, the choice of reference rivers frames the expectations of river improvement with the TFC acting as a tool to illustrate the goal in tangible and measurable units. The decision to orient the enhancement of the Charles River toward native fishes, despite the importance of some introduced sportfish species, also influenced the target community. This decision resulted in the removal of several common fishery species (e.g. bluegill, largemouth bass) from the key specifications (species with expected proportions greater than 3%) of the TFC. Had introduced species been included in the target community, a solid component of it would have been habitat generalists commonly associated with lentic and impounded waters. This could have steered river enhancement toward maintaining impounded habitats along the Charles River. Further, several fluvial species present in sizable proportions in the reference rivers (e.g. blacknose dace, *Rhinichthys atratulus*, tessellated darter, *Etheostoma olmstedi*) were considered out of zoogeographic range for the Charles River. Had these been included in the TFC, the composition of fluvial species would have been higher.

There was some variation in community composition among the seven reference rivers considered quality rivers for the region. Common species varied in their relative abundance by river and generally uncommon species were occasionally abundant. The variability among similarly sized rivers in the region suggests it would likely be impossible to specify precisely what the fish community should be for the Charles River or other urbanized rivers. Anticipating this, our approach aimed to specify a realistic and generalized target community stated in precise terms for use as a standard in management and river enhancement. Under this approach, we lessened the influence of reference rivers by using rank abundances to define target community composition instead of directly computing community proportions from reference river data. Also, the use of a set of reference rivers helped to moderate the influence of any one river in defining a target community. Overall, our approach extracts the minimum needed information from the reference rivers (species ranks) and then combines this empirical information with a theoretical community composition property.

Comparing the composition of the Charles River TFC against TFCs from eighteen other rivers in Massachusetts, we found that three (common shiner, fallfish, and white sucker) of the top four species in the Charles River TFC were among the top six species in the TFCs for seventeen of the eighteen rivers (Kashiwagi and Richards, 2009). In seven of the rivers, common shiner, fallfish, and white sucker were the top listed species.

Similarity testing of the TFC and existing fish communities was conducted for eleven rivers, including the Charles River, from which sufficient data were available (Kashiwagi and Richards, 2009). Affinity index values ranged from a low of 22% to a high of 76%; the Charles River was on the low end at 28%. The other rivers with low affinity values, the Blackstone, Ipswich, Shawsheen and Concord Rivers, were also in eastern Massachusetts. Likewise, similarity values based on habitat-use categories and tolerance categories across the eleven rivers placed the Charles River nearly at the bottom for both groups (Kashiwagi and Richards, 2009). Again, these values were consistent with scores from other rivers in the region.

We illustrated application of the TFC for Charles River enhancement using mainstem collections. The recent Charles River survey data indicate an existing fish fauna that differs from the target community. Many abundant fishes were predicted by the TFC to be found in relatively low numbers, and these overly abundant fishes tended to be habitat generalists and tolerant of impaired water quality. Thus the mix of species appears changed by prevailing river conditions and species introductions, and evidence for both habitat and water quality degradation was seen in the summary of species by abundance group. Our results compare favorably with those found by Meador et al. (2005) in their 2000 fish sampling of urbanized waterbodies in the Northeastern Coastal Zone ecoregion. Like us, Meador et al. (2005) found that yellow perch, bluegill, and largemouth bass were among the most commonly sampled species in highly urbanized areas, with yellow bullhead and pumpkinseed also abundant.

The results of our application of the TFC to fish survey data from eleven sites in the Charles River show how restoration guidance can be derived. The fishes known to be most sensitive to habitat degradation (fluvial specialists and fluvial dependents) were mostly found underrepresented in the Charles River. These results are corroborated by fish data from the nearby Ipswich River which also had elevated proportions of macrohabitat generalists (95%; Armstrong et al., 2001). Similarly, Meador et al. (2005) found that highly urbanized areas are negatively correlated with fluvial specialist species richness.

Seven native fish species were missing from the Charles River system (common shiner, sea lamprey, *Petromyzon marinus*, brook trout, fallfish, creek chubsucker, American shad, *Alosa sapidissima*, and striped bass) and two were found in numbers well below expectations (white sucker and blueback herring, *Alosa aestivalis*). This again corresponds with the results of Meador et al. (2005) which found that urbanization is negatively correlated with the presence of common shiner, sea lamprey, brook trout, white sucker, fallfish, and creek chubsucker. All seven fishes found in higher than expected abundances were habitat generalists, four were introduced species, and the most abundant species were normally associated with impounded and lentic waters. The pattern of deviations from target conditions seen using habitat requirements strongly suggests that physical habitat change should be a priority for river enhancement in this case.

Target fish application results were also reviewed relative to water quality sensitivity. Pollution tolerant and moderately tolerant fishes were found in all categories of deviation from target community composition. However, the lack of a clear pattern of pollution tolerance classifications for under and over-represented species suggests that habitat conditions are more strongly influencing community composition than water quality conditions. One clear result was seen for those species most sensitive to water quality degradation (pollution intolerant). All three of these pollution intolerant fish species (common shiner, bridle shiner and creek chubsucker) were missing from the study reach collections suggesting present or past water quality conditions might be stressful for very sensitive species. This result is not entirely surprising as urbanization is associated with increases in tolerant species and the decline of sensitive species (Onorato et al., 2000; Scott and Helfman, 2001; Wang et al., 2000). Hence, the pattern of deviations from target fish composition suggests that habitat alterations are more influential to the fish community than water quality degradation thus providing some general guidance on enhancement strategies.

5 Conclusions

The clear pattern of deviations from target conditions when observing fish habitat requirements strongly suggests that physical habitat change should be a priority for river enhancement in the Charles River. Very similar results were found during comparison of our target and existing fish communities to those from the comprehensive study of

Northeast fish assemblage responses to urban intensity gradients (Meador et al., 2005). Likewise, comparison of our TFC composition and affinity values with those of other rivers in Massachusetts (Kashiwagi and Richards, 2009) underscored that the Charles River deviates more strongly from target conditions than most other rivers in the region, however the community composition of the Charles River TFC is very similar to the TFCs used in other rivers.

The utility of the TFC as a valuable approach to biological integrity assessment is further highlighted through its adoption by the Commonwealth of Massachusetts and the State of New Hampshire as a component of their water resources policy development process (Legros and Parasiewicz, 2007). Successful application of the TFC throughout much of the Northeast US underscores its applicability in large, non-urbanized streams. Based on these positive results, the utility of the findings from the inference approach, and the widespread adoption of the TFC in the Northeast US, it appears that the TFC can be used effectively to identify the composition of a healthy fish community and guide river enhancements in both highly urbanized and non-urbanized rivers in the Northeast US. To date, the TFC has only been applied within New England. However, it is likely that the approach outlined here would be useful in regions outside of the New England area (e.g. Southeast US) if reference rivers with similar conditions could be found from which to build a TFC. Future efforts will explore the application of the TFC in other regions of the US.

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Figure captions

Figure 1. Reference rivers (labeled) used to develop the Charles River target fish community (source: Kashiwagi and Richards, 2009).

Figure 2. Existing and target fish communities in the Charles River.

Figure 1

Figure 1.

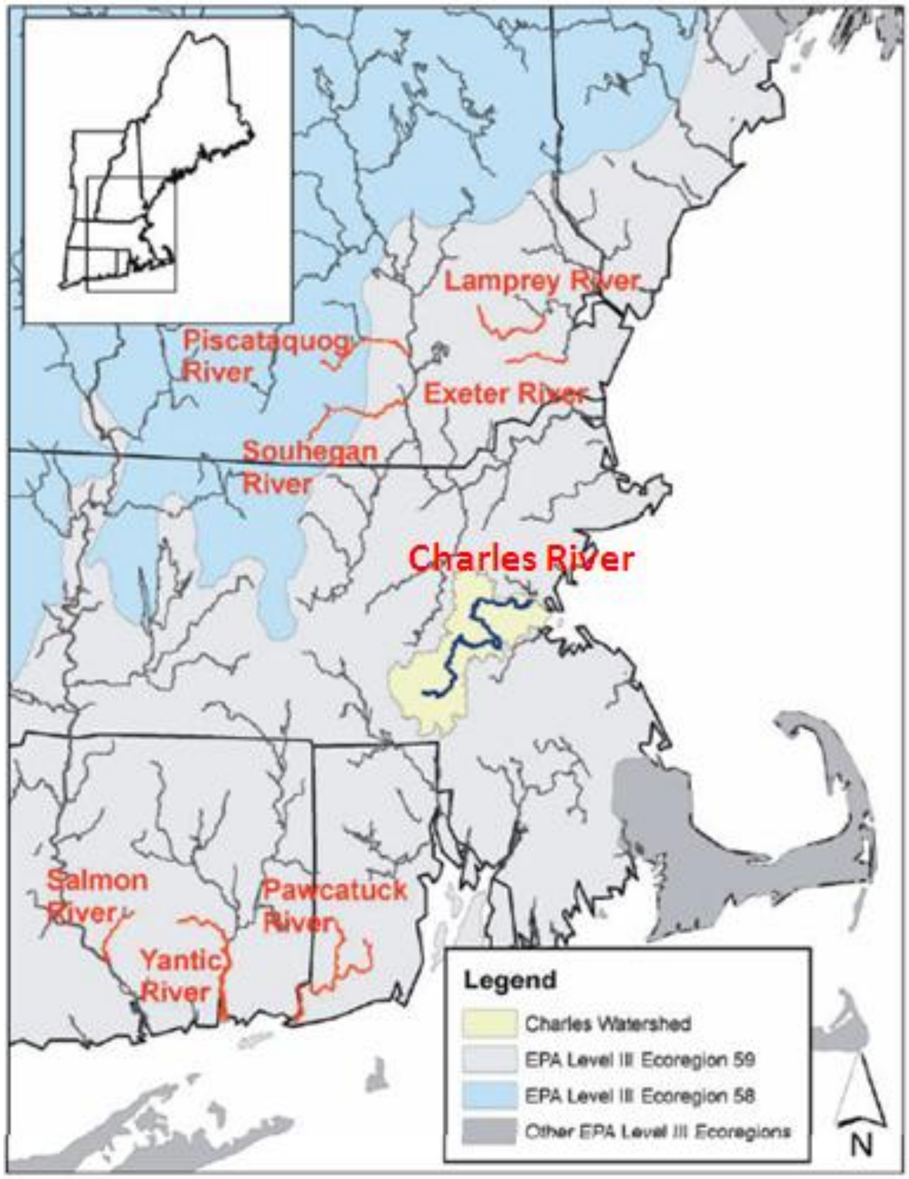
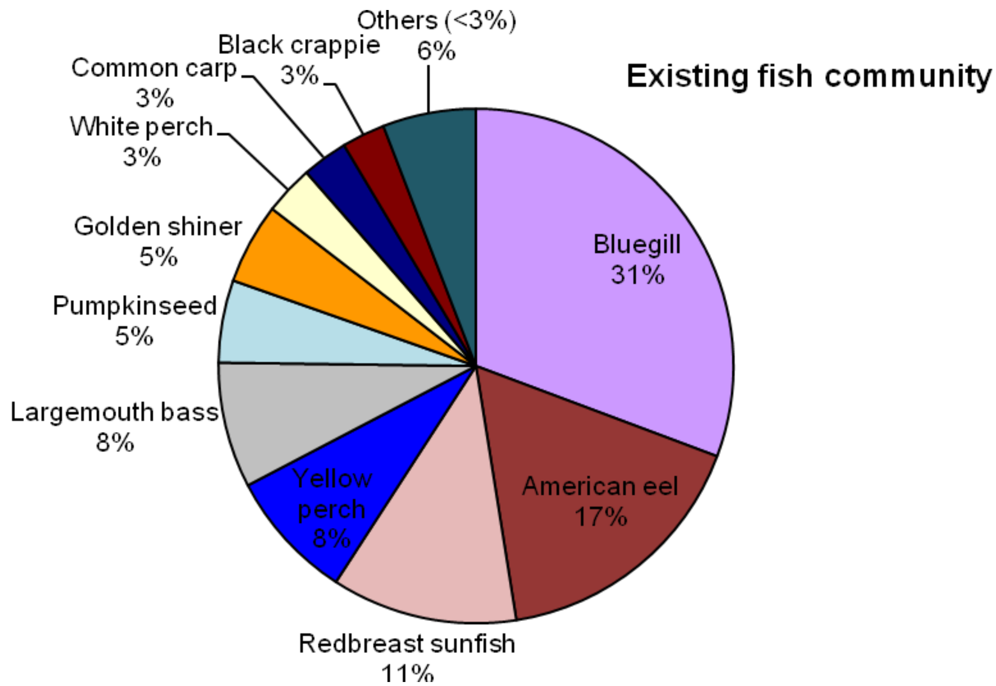
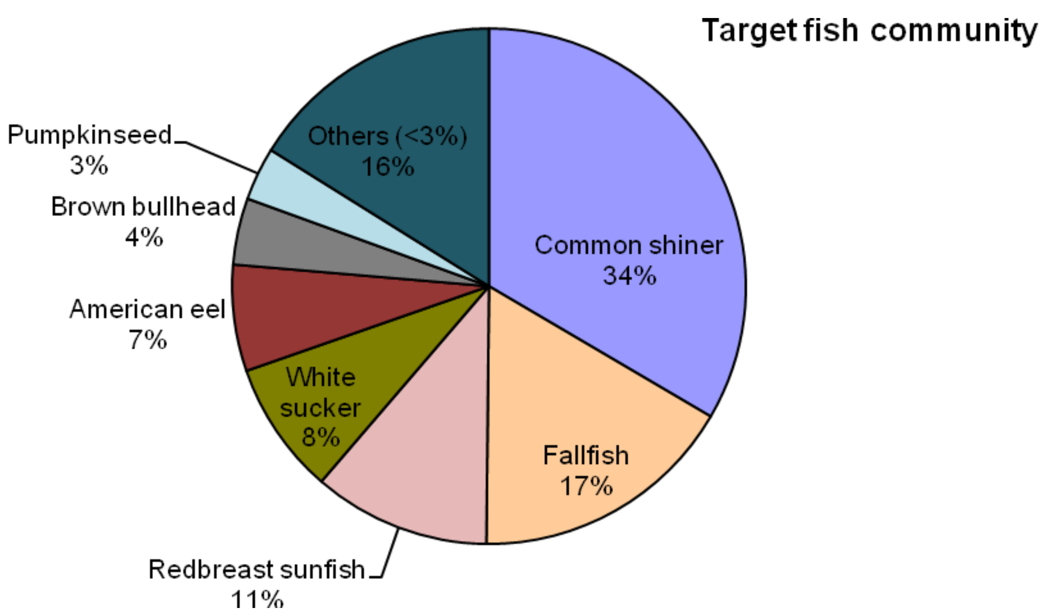


Figure2

Figure 2.





Tables

Table 1. Physical characteristics of the Charler River and reference rivers used to develop the Charles River target fish community.

River	State	Drainage area (km^2)	Gradient over study reach	Level III ecoregion	Stream order	Annual flow (cms)
Charles River	***MA***	***798***	***0.001***	***59***	***4***	***8.58***
Pawcatuck River	RI	259	0.001	59	5	7.93
Exeter River	NH	164	0.003	59	3	2.49
Lamprey River	NH	474	0.001	59	4	5.49
Piscataquog River	NH	523	0.003	58	5	8.72
Salmon River	CT	259	0.004	59	4	5.24
Souhegan River	NH	443	0.003	58/59	4	7.59
Yantic River	CT	233	0.001	59	3	4.70

Table 2. Expected fishes of the Charles River basin. Codes are given for introduced (I) and native (N) species and habitat classification classes fluvial specialists (FS), fluvial dependent (FD), and macrohabitat generalists (MG). Pollution tolerance is classified as tolerant (T), moderate tolerant (M), and intolerant (I) of poor water quality.

Common name	Scientific name	Introduced or native	Habitat use class	Pollution tolerance
Anguillidae				
American eel	*Anguilla rostrata*	N	MG	T
Catostomidae				
Creek chubsucker	*Erimyzon oblongus*	N	FS	I
White sucker	*Catostomus commersoni*	N	FD	T
Centrarchidae				
Banded sunfish	*Enneacanthus obesus*	N	MG	M
Black crappie	*Pomoxis nigromaculatus*	I	MG	M
Bluegill	*Lepomis macrochirus*	I	MG	T
Largemouth bass	*Micropterus salmoides*	I	MG	M
Pumpkinseed	*Lepomis gibbosus*	N	MG	M
Redbreast sunfish	*Lepomis auritus*	N	MG	M
Smallmouth bass	*Micropterus dolomieu*	I	MG	M
Clupeidae				
Alewife	*Alosa pseudoharengus*	N	MG	M
American shad	*Alosa sapidissima*	N	FD	M
Blueback herring	*Alosa aestivalis*	N	FD	M
Cyprinidae				
Bridle shiner	*Notropis bifrenatus*	N	MG	I
Common carp	*Cyprinus carpio*	I	MG	T
Common shiner	*Luxilus cornutus*	N	FD	I
Fallfish	*Semotilus corporalis*	N	FS	M
Golden shiner	*Notemigonus crysoleucas*	N	MG	T
Goldfish	*Carassius auratus*	I	MG	T
Rudd	*Scardinius erythrophthalmus*	I	MG	T
Spottail shiner	*Notropis hudsonius*	N	MG	M
Cyprinodontidae				
Banded killifish	*Fundulus diaphanus*	N	MG	T
Esocidae				
Chain pickerel	*Esox niger*	N	MG	M
Northern pike	*Esox lucius*	I	MG	I
Redfin pickerel	*Esox americanus*	N	MG	M
Ictaluridae				
Brown bullhead	*Ameiurus nebulosus*	N	MG	T
Channel catfish	*Ictalurus punctatus*	I	MG	M
White catfish	*Ameiurus catus*	I	MG	M
Yellow bullhead	*Ameiurus natalis*	I	MG	T
Moronidae				
Striped bass	*Morone saxatilis*	N	FD	M
White perch	*Morone americana*	N	MG	M
Osmeridae				
Rainbow smelt	*Osmerus mordax*	N	MG	M
Percidae				
Swamp darter	*Etheostoma fusiforme*	N	MG	M
Yellow perch	*Perca flavescens*	N	MG	M
Petromyzontidae				
Sea lamprey	*Petromyzon marinus*	N	FD	M
Salmonidae				
Brook trout	*Salvelinus fontinalis*	N	FS	I
Brown trout	*Salmo trutta*	I	FD	I

Table 3. Fish species counts in reference river collections with their mean rank and expected contribution to the target fish community. Introduced, stocked and out-of-range species were removed (dashed entries) from the target fish community.

Species	Pawcatuck River	Exeter River	Lamprey River	Piscataquog River	Souhegan River	Salmon River	Yantic River	Mean rank	Expected proportion
Alewife			21					31	0.01
American eel	5	18	288	8		266	22	5	0.07
Atlantic salmon			13			630		-	-
Banded killifish						1		34	0.01
Banded sunfish	1							28	0.01
Black crappie			18					-	-
Blacknose dace		1	19	5	349	179	185	-	-
Blueback herring			2					35	0.01
Bluegill	8	1	358		3	27	108	-	-
Bridle shiner			54					29	0.01
Brook trout	12					31		-	-
Brown bullhead	22		11	1		1	11	8	0.04
Brown trout			3		6	103	30	-	-
Chain pickerel	2	4	38			5	4	19	0.02
Common shiner		24	2140	47	633	403	367	1	0.33
Creek chubsucker			22		5			30	0.01
Fallfish		7	767	6	419	3	1037	2	0.17
Golden shiner	6		239		13		1	17	0.02
Lake chub		13						-	-
Largemouth bass	1		95	4	36	18	21	-	-
Longnose dace			287	9	80	383		-	-
Longnose sucker				3				-	-
Margined madtom				31				-	-
Pumpkinseed	10	1	377	5	1	2	167	10	0.03
Rainbow trout			1	5	3	9	1	-	-
Redbreast sunfish		15	948	15	267		451	3	0.11
Redfin pickerel	4	3	6	1				18	0.02
Rock bass			18					-	-
Sea lamprey						72		23	0.01
Smallmouth bass			128	48		135	130	-	-
Spottail shiner				3			2	26	0.01
Tessellatted darter	6					51	150	-	-
White sucker	2	3	324	11	275	109	871	4	0.08
Yellow bullhead			51	7	7			-	-
Yellow perch			77		4		6	25	0.01
Total	79	90	6305	209	2101	2428	3564		

Table 4. Target fish community specifications for the Charles River as compared to eleven sites in the mainstem of the Charles River sampled from 2000-2003.

Species	Target community %	Percent composition by site (river kilometer) 9 No	9 %	21 No	21 %	30 No	30 %	30 No	30 %	33 No	33 %	71 No	71 %	100 No	100 %	103 No	103 %	112 No	112 %	113 No	113 %	115 No	115 %	All sites combined No	All sites combined %
Common shiner	33																								
Fallfish	17																								
Redbreast sunfish	11					63	66	64	61	1	1	9	2	46	18	3	2	10	22	11	6			207	12
White sucker	8	3	3			2	2	4	4	4	2	3	1	1	0					4	2	1	1	22	1
American eel	7					22	23	9	9					85	34	10	6	27	59	138	73	7	5	298	17
Brown bullhead	4	1	1					1	1			2	0											4	0
Pumpkinseed	3	1	1	4	20			4	4	8	4	41	9	6	2	9	5			17	9	2	1	92	5
Others (<3%)	16	82	94	16	80	8	8	23	22	170	93	426	89	111	45	155	88	9	20	20	11	132	93	1152	65
Alewife																									
Banded killifish																									
Banded sunfish																									
Black crappie		1	1							9	5	31	6	3	1	4	2							48	3
Blacknose dace																									
Blueback herring																2	1					3	2	5	0
Bluegill		55	63					12	11	79	43	222	46	100	40	61	34			12	6	4	3	545	31
Bridle shiner																									
Brook trout																									
Brown trout								1	1															1	0
Carp										4	2	3	1			30	17					14	10	51	3
Chain pickerel		3	3					1	1	3	2	9	2	1	0	2	1							19	1
Creek chubsucker																									
Golden shiner		1	1									84	17			1	1			1	1	3	2	90	5
Lake chub																									
Largemouth bass		10	11	2	10	7	7	5	5	27	15	62	13	2	1	20	11					5	4	140	8
Longnose dace																									
Longnose sucker																									
Margined madtom																									
Rainbow trout										2	1													2	0
Redfin pickerel		3	3	2	10							1	0											6	0
Rock bass																									
Sea lamprey																									
Smallmouth bass																		9	20	4	2	1	1	14	1
Spottail shiner																									
Tessellatted darter																									
White catfish														4	2	2	1							6	0
White perch								2	2	26	14	2	0			4	2					21	15	55	3
Yellow bullhead		9	10	12	60	1	1	1	1					1	0	1	1							25	1
Yellow perch								1	1	20	11	12	2			28	16			3	2	81	57	145	8
Affinity index value		22		19		28		42		22		22		37		27		34		28		23		39	

Table 5. Percentages for target and existing Charles River fish community composition. Highlighted rows indicate dominant species in the TFC that are scarce in the existing community.

Fish species	TFC percentage	Existing community percentage	Absolute difference
Common shiner	34	-	34
Fallfish	17	-	17
Redbreast sunfish	11	12	1
White sucker	8	1	7
American eel	7	17	10
Brown bullhead	4	-	4
Pumpkinseed	3	5	2
Chain pickerel	2	1	1
Golden shiner	2	5	3
Redfin pickerel	2	-	2
Banded killifish	1	-	1
Banded sunfish	1	-	1
Bridle shiner	1	-	1
Creek chubsucker	1	-	1
Spottail shiner	1	-	1
Yellow perch	1	8	7
Bluegill[a]	-	31	31
Black crappie[a]	-	3	3
Common carp[a]	-	3	3
Largemouth bass[a]	-	8	8
Smallmouth bass[a]	-	1	1
White perch	-	3	3
Yellow bullhead[a]	-	1	1

[a]Non-native species

Table 6. Review of Charles River species relative to target community abundances, source, habitat requirements and pollution tolerances. Codes are given for introduced (I) and native (N) species and habitat classification classes fluvial specialists (FS), fluvial dependent (FD), and macrohabitat generalists (MG). Pollution tolerance is classified as tolerant (T), moderate tolerant (M), and intolerant (I) of poor water quality.

Species	Rank in target fish community	Introduced or native	Habitat requirements	Pollution tolerance	Comments
Consistently underrepresented target fish species					
Brown bullhead	8	N	MG	T	Below expectations
Common shiner	1	N	FD	I	Always absent
Fallfish	2	N	FS	M	Always absent
White sucker	4	N	FD	T	Well below expectations
Variously abundant target fish species					
American eel	5	N	MG	T	Variously absent, in expected proportions, or abundant
Pumpkinseed	10	N	MG	M	Variously absent, in expected proportions, or abundant
Redbreast sunfish	3	N	MG	M	Variously absent, in expected proportions, or abundant
Missing native target fish species					
Alewife	31	N	MG	M	Always absent
Banded killifish	34	N	MG	T	Always absent
Banded sunfish	28	N	MG	M	Always absent
Bridle shiner	29	N	MG	I	Always absent
Creek chubsucker	30	N	FS	I	Always absent
Sea lamprey	23	N	FD	M	Always absent
Spottail shiner	26	N	MG	M	Always absent
Overly abundant species					
Bluegill	-	I	MG	T	Often abundant
Carp	-	I	MG	T	Sometimes abundant
Golden shiner	17	N	MG	T	Sometimes abundant
Largemouth bass	-	I	MG	M	Often abundant
White perch	-	N	MG	M	Sometimes abundant
Yellow bullhead	-	I	MG	T	Sometimes abundant
Yellow perch	25	N	MG	M	Often abundant