Published in final edited form as:
Fish Res. 2021 January 1; 223: 105749. doi:10.1016/j.fishres.2020.105749.

Correspondence between a recreational fishery index and ecological condition for U.S.A. streams and rivers

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Abstract

Sport fishing is an important recreational and economic activity, especially in Australia, Europe and North America, and the condition of sport fish populations is a key ecological indicator of water body condition for millions of anglers and the public. Despite its importance as an ecological indicator representing the status of sport fish populations, an index for measuring this ecosystem service has not been quantified by analyzing actual fish taxa, size and abundance data across the U.S.A. Therefore, we used game fish data collected from 1,561 stream and river sites located throughout the conterminous U.S.A. combined with specific fish species and size dollar weights to calculate site-specific recreational fishery index (RFI) scores. We then regressed those scores against 38 potential site-specific environmental predictor variables, as well as site-specific fish assemblage condition (multimetric index; MMI) scores based on entire fish assemblages, to determine the factors most associated with the RFI scores. We found weak correlations between RFI and MMI scores and weak to moderate correlations with environmental variables, which varied in importance with each of 9 ecoregions. We conclude that the RFI is a useful indicator of a stream ecosystem service, which should be of greater interest to the USA public and traditional fishery management agencies than are MMIs, which tend to be more useful for ecologists, environmentalists and environmental quality agencies.

Keywords

sport fishing; MMI; IBI; ecosystem services

Introduction

One goal of the U.S.A. Clean Water Act (USA, 1972) is fishable waters and this statute reflects the importance of fish in U.S.A. society. Sport fishing is enjoyed by approximately 12 million anglers, supports over 400,000 jobs, and generates over $63 billion in sales in the

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U.S.A. (USFWS, 2012; NMFS, 2015). In some rural U.S.A. counties with high-quality fisheries, fishing is the major source of income and jobs (Hughes, 2015; Woody, 2018; Colvin et al., 2019). Gamefish was the top ecosystem service item listed by Willamette Basin, Oregon, survey participants (Weber and Ringold, 2019). Southwick and Loftus (2017) estimated fish replacement prices based on fish culture costs because of the need to assess damages from fish kills to pollutant dischargers. Their price estimates varied by species and individual sizes, which in turn are affected by hatchery location, productivity and consumer demand. Clearly, fish and fishing have great value to U.S.A. anglers, citizens and economies.

As part of USEPA's National Rivers and Streams Assessment (NRSA; USEPA, 2016b) fish assemblages and their environments are sampled across the U.S.A. at over 2000 sites every five years through use of standard methods (Hughes and Peck, 2008; USEPA, 2013a, b) as recommended by Bonar et al. (2009). Although the fish sampling method is standardized, it offers only a one-day snapshot and is not a quantitative measure of all fish species, sizes or absolute abundances at a site (Reynolds et al., 2003; Kanno et al., 2009). In addition, sampling was restricted from sites with listed species, especially when adult salmonids might have been present. Despite those limitations, the USEPA survey provides a means to make rigorous national and regional estimates of fish assemblage status and trends through the use of multimetric indicators (MMIs), as well as the natural and anthropogenic pressures and stressors limiting those assemblages (Esselman et al., 2013; USEPA, 2016b; Herlihy et al., 2019; 2020). The Esselman et al., USEPA and Herlihy et al. assessments were based on the condition of entire fish assemblages—both game and non-game species—as indicated by the MMI scores. The ecological indicators used in those assessments were designed for assessing ecological status and trends.

Recreational fishery indicators have been focused on game fishery assessments. Anglers are beneficiaries of ecosystem goods and services provided by streams (Ringold et al., 2013) and angling satisfaction is largely indicated by the size, abundance and accessibility of game fish, as well as the aesthetic appeal of the site and social factors. For example, Hunt (2006) generated a conceptual model for predicting fishing site choice based on costs, fishing quality, environmental quality, facility development, encounters with other anglers, and fishing regulations.

Hickman (2000) developed a sportfishing quality index for Tennessee Valley Authority reservoirs based largely on fish population data for specific sport species. Oliveira et al. (2009) produced a fishery quality index for all Portuguese streams and found that higher scores were correlated positively with stream size and IBI (index of biotic integrity) scores in coldwater streams, but not in warmwater streams. Melstrom et al. (2015) created a random utility maximization model for predicting the monetary benefits of recreational fishing based on game fish biomass and fishing trip information in Michigan hydrologic units. Other similar fishery quality models based on economic predictors have also been developed from angler reports (e.g., Morey et al., 1993; 2002; Jakus et al., 1998; Hunt et al., 2007), water body condition (e.g., Phaneuf, 2002; Von Haefen, 2003), or a combination of both (e.g. Jones and Lupi, 2000; Murdock, 2006) at the basin or state/province spatial extents. Ringold et al. (2013) used the combination of game fish abundance, site appeal and

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site access to predict the proportion of stream length having low, medium, or high levels of fishing quality for each of 12 western U.S.A. states. Esselman et al. (2015) estimated biomasses for five separate gamefish taxa across Michigan through use of 16 environmental predictor variables. Most of these models are based on environmental predictors of recreational fishery quality, the relative desirability of the fishing site, and the human benefits and costs of the angling experience. Furthermore, all but Oliveira et al. (2009) and Ringold et al. (2013) are based on data collected across relatively small spatial extents (i.e., a single state, province, basin, or lake).

Clearly, many factors, both ecological and social, affect angler satisfaction (Arlinghaus 2006). However, the Clean Water Act's fishable goal is focused on what aquatic ecosystems alone may provide for anglers, not the multiple environmental, social, economic, and aesthetic factors that affect the angling experience. In addition, angler goals differ markedly. For example, the objective of many youthful anglers may be to simply catch a lot of fish, that of many anglers fishing for food is to provide one or more meals, whereas that of trophy anglers is to catch very large fish. Some recreational anglers may simply seek solitude in a beautiful place.

Recreational fishery indices (RFIs) provide numerical estimates of sport fishing that could be used for determining quantitative relationships between recreational fisheries and natural and anthropogenic predictor variables. Nonetheless, to date there has been no rigorous national or ecoregional estimate of recreational fisheries for U.S.A. lotic waters based on site-specific fish assemblage surveys. In addition, there has been no estimate of site-specific recreational fishery values that link fish assemblage survey results with a consistent set of weights reflecting actual fish taxa, sizes, and abundances (i.e., the costs of culturing those fish). Although Herlihy et al. (2020) modeled MMI site scores against environmental predictors across the conterminous U.S.A., RFI scores have not been rigorously linked to landscape predictor variables nationally or regionally. Therefore, our objective in this paper is to develop an RFI for conterminous U.S.A. streams and rivers based on the NRSA data together with the monetary costs of culturing individual game fish species to various sizes provided by the American Fisheries Society in Appendix A of Southwick and Loftus (2017). We used the Southwick and Loftus (2017) numbers because they offer a nationally consistent data set that is widely used for evaluating the costs of culturing the fish lost in fish kills resulting from industrial waste spills and for assessing damages in legal proceedings. The fish culturing costs are based on six regional estimates of hatchery production costs (structures, water, water treatment, electricity, prophylactic chemicals, equipment, employees, overhead) obtained by surveying private, state, tribal and federal hatchery managers. For large fish of many species, the cost per pound was extrapolated from length-weight data. The Southwick and Loftus fish culturing costs are the only nationally consistent dataset that we are aware of for weighting virtually all game species. But they underestimate the true value of fish losses and are inappropriate for species that are listed as endangered or threatened or for trophy-sized fish. Also, the Southwick and Loftus (2017) numbers do not represent aesthetic or social (nonuse) values nor the values to anglers (users) of any particular fish species. Furthermore, local values may vary from regional or national estimates and the value of an individual mass-produced sport fish derived from these weights may be markedly less than that of a less popular species that is not mass-produced. Finally, hatchery fish lack the genetic and survivability characteristics of wild fish (Christie et al. 2016; Salvanes 2017; Winans et al. 2017). The USEPA (1990) determined that most U.S.A. states used Southwick and Loftus values for determining the monetary value of fish lost in fish kills. For example, the state of Virginia (DEQ 2002) used those specific fish species values for assessing losses and the costs of their replacement following fish kills. King (2015) also used fish replacement costs for assessing salmonid losses in an Irish river. Therefore, we relate the variations in RFI scores to variations in several regional predictor variables measured at catchment and local spatial extents as recommended in Hughes et al. (2019) and compare them with the MMI results of Herlihy et al. (2020). Herlihy et al. (2020) found that MMI scores were only weakly to moderately correlated with specific environmental variables and that the most important predictor variables varied with ecoregion. Therefore, we predicted that RFI scores would also show similar weak to moderate correlations with environmental variables, as well as varying by ecoregion. The MMI scores are based on entire fish assemblages and least-disturbed reference conditions, whereas the RFI scores are based on game fish and their hatchery production costs. Therefore, we predicted weak correlations between MMI and RFI scores. It is common to have very aesthetically attractive angling sites, including high quality riparian areas, that have water quality problems (particularly toxics). On the other hand, eutrophication linked with poorer ecological conditions can be expected to produce more and bigger tolerant fish (Oliveira et al., 2009; Esselman et al., 2015), and thus produce higher RFI scores. In addition, the NRSA site attractiveness is a subjective indicator. Field crews are asked to judge the site based on what they see, hear, smell and feel, as well as how likely they would be to return to the site to recreate. Because of such antagonistic relationships between sport fish and ecological quality, as well as the subjective nature of the site attractiveness assessment, we also predicted that RFI scores would be weakly correlated with site attractiveness.

Material and methods

Study design

The NRSA field crews sampled 2,288 sites with fish assemblages during summer 2013 and 2014 across the conterminous U.S.A. through use of a probability-based design (Stevens and Olsen, 2004; Olsen and Peck, 2008; USEPA, 2016a). The NRSA selected sites from the National Hydrography Dataset (USGS 2013) representing ~1,231,000 km of lotic waters ranging from great rivers to headwater streams. The study design was spatially balanced and stratified to distribute sites as evenly as possible geographically and by ecoregion and stream size. In addition, 497 hand-picked least-disturbed reference sites were sampled. The NRSA uses nine ecoregions for reporting results (Herlihy et al., 2008; 2020). Out of all those 2,785 sampled sites (Figure 1), 1,561 produced consistent environmental data and game fish species at an average of six species per site. Site numbers ranged from as few as 88 sites in the Xeric Ecoregion to as many as 250 sites in the Northern Appalachians Ecoregion (Table 1). During each one-day sampling visit, crews collected fish assemblage data and measured chemical and physical habitat variables.

Fish data

Fish were collected by backpack or boat electrofishing, except 2% of the sites were seined because of high conductivity water (USEPA, 2013a, b). Site lengths were determined around the randomly chosen sample points to ensure adequate characterization of the fish assemblage at the site (Reynolds et al., 2003; Hughes and Herlihy, 2007; 2012; Hughes and Peck, 2008). In wadeable sites <13 m wide, the site length was 40 channel widths, or a minimum of 150 m. In wadeable sites >13 m wide, and boatable sites, the site length was the longer of 500 m or 20 channel widths. In the large wadeable and boatable sites, sampling continued until 500 fish were collected or a site length of 40 channel widths was sampled. Fish were identified, measured (total length) and counted at the site, then released alive unless used for subsequent analyses. Fish names were taken from Page et al. (2013).

Environmental data

We examined 39 environmental variables for associations with RFI scores (Table 2). For water quality, one grab sample was collected at in the middle of wadeable stream sites, and at the site downriver boundary in boatable rivers (USEPA, 2013a, b). Samples were shipped to the U.S. Environmental Protection Agency laboratory in Corvallis, Oregon, and to a few state laboratories. In the laboratory, pH, conductivity and turbidity were measured by meters, sulfate and chloride were measured by ion chromatography, total phosphorus and total nitrogen were measured by persulfate digestion and colorimetry, and dissolved organic carbon was measured with a carbon analyzer.

Physical habitat conditions were determined as indicated in Hughes and Peck (2008), USEPA (2013a, b) and Kaufmann et al. (1999). Multiple measurements were taken at 11 evenly spaced transects along the site. Woody riparian vegetation, anthropogenic disturbances, fish concealment, substrate composition, and wetted and bankfull stream depth and width data were recorded at each transect on standardized field forms. Between transects, channel slope, depths and widths, habitat unit types and substrates were recorded at 11 systematic intervals. Field data were converted into metrics (Table 2) as described by Kaufmann et al. (1999, 2008).

Natural and anthropogenic landscape variables were based on site or catchment spatial extents. Latitude, longitude, elevation and site appeal data were based on the site. Catchment climate, soil, and anthropogenic pressure data are from StreamCat (Hill et al., 2016). Site appeal was scored subjectively by the field crew from 1 (low) to 5 (high) depending on the overall desirability or attractiveness of the site for recreation (USEPA, 2013a,b).

Data analyses

MMI development.—In NRSA, fish assemblage condition was assessed through use of separate multimetric indices (MMIs) for each of the nine ecoregions. MMI metrics and scoring were based on screening hundreds of potential metrics by assessing their ranges, evaluating their repeatability, adjusting for natural variation, determining their sensitivity to anthropogenic disturbance, and assessing their redundancy (Hughes et al., 1998; McCormick et al., 2001; USEPA, 2016a). Each fish MMI has 8 metrics representing each of eight classes: non-native, taxonomic composition, habitat guild, reproductive guild, migratory

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strategy, richness, tolerance to disturbance, and trophic guild. Metrics were adjusted for catchment area if the R^2 of the metric-area relationship at reference sites was > 0.10. Each final metric was scored from 0 to 10 linearly between bottom and top reference values (USEPA, 2016a). The eight fish metric 0–10 scores (ranging from 0 to 10) were summed and multiplied by 1.25 to produce an MMI ranging from 0 to 100. Because MMI metrics, raw values, reference conditions, and metric scoring differ among ecoregions, the MMI scores are not equivalent across all ecoregions.

RFI development.—For each of the 1,561 sites with sufficient samples of game fish, we calculated a site-specific recreational fishery index (RFI) score:

$$\mathrm{RFI_{site}} = \sum_{i=1}^{S} \sum_{j=1}^{L} \mathrm{W_{ij}N_{ij}}$$

where S = a particular game fish species; L = the number of length classes of that species; N = the number of individuals of that species for that length class and W = the dollar cost (or weight) of that length class for that species (from Southwick and Loftus, 2017). We used $\log_{10}$ for the RFI because initial results indicated raw RFI scores ranged from 0.12 to 3,211.8 (a few cents to thousands of dollars). The Southwick and Loftus numbers were calculated from the costs of culturing fish in hatcheries to various lengths, with increased costs accruing to larger individuals. Those values for a 25 cm individual ranged from $0.70 (drum) to $34 (sturgeon). Fish species were deemed as game fish as in FishBase (https://www.fishbase.se/search.php) and ancillary web descriptions if needed. Taxa missing from Southwick and Loftus (2017) were given dollar weights for taxa in the same fish family or as fish in a family occupying a similar trophic/habitat guild. For example, Tench *Tinca tinca* were weighted in the same manner as Common Carp *Cyprinius carpio* and Striped Mullet *Mugil cephalus* were weighted as if they were a sciaenid. Because the fish size classes in the NRSA database (2.5–15 cm, >15–30 cm, >30 cm) differed from those in Southwick and Loftus (2017), we used the average dollar weight of the Southwick and Loftus lengths matching the NRSA size classes. The NRSA size classes were chosen to reflect fish lengths deemed desirable to most anglers, common length requirements in state angling regulations, and what many consider a large fish. In the few cases where our fish lengths exceeded those in Southwick and Loftus (2017), we used the existing values and extrapolated linearly. Because ours is a national index, because our analytical ecoregions differ markedly from the regions in Southwick and Loftus, and because we wanted to evaluate ecosystem services in a consistent manner, we used the national average fish culturing costs of Southwick and Loftus rather than their regional costs. We note that their fish species culturing costs do not necessarily equate with angler preferences, and some mass-produced species may cost less to culture but be preferentially targeted by anglers.

Statistical analyses.—Following USEPA (2016b) and Herlihy et al. (2020), we assessed RFI scores in each of the nine ecoregions versus the MMIs and site appeal ratings through use of Pearson correlations and the 38 environmental predictor variables via multiple linear regressions. Prior to regression analyses, we checked correlations among variables to avoid multicollinearity then removed the least ecologically robust variable when correlations were ≥0.8. After performing initial regressions, we omitted one environmental variable (RBS, relative bed stability) that was not available for all sites, and then repeated the regressions. MMI scores, percentage variables, variables ranging from 0–10, pH, and logarithmic variables (substrate size, relative bed stability index) were not transformed. The other predictor variables were log transformed (Table 2). We then ran a full 37-variable stepwise linear regression for each of the nine ecoregions using SYSTAT v.13 (2009). For each ecoregion, the final model was selected based on the value for the F-test and variables were selected for each ecoregion based on variable entry and exit values of p=0.05. We checked model fit with scatter plots and the amount of variability accounted for by the models was assessed using adjusted R^2. For each of the nine ecoregions, we also ran full model linear regressions by each of the predictor classes of variables and assessed variability accounted for using adjusted R^2. Pearson correlations were performed using RFI, NRSA ecoregion-specific fish MMI scores, and NRSA site appeal scores for each of the nine ecoregions.

Results

The RFI scores ranged across three orders of magnitude in each of the nine ecoregions; however, median scores were lower in the Northern Plains, Western Mountains and Xeric Ecoregions (Figure 2). Median scores were highest in the Coastal Plains, Northern Appalachian Plateau, Southern Appalachians, and Upper Midwest Ecoregions; but the central tendencies of the RFI scores in all nine ecoregions indicated high proportions of sites with highly valued fisheries (RFI ~100). The 15 most commonly collected game fish occurred in 11.8% (Brook Trout *Salvelinus fontinalis*) of the stream length to 60% (Bluegill *Lepomis macrochirus*) of the river length and the weights (dollar costs) of the largest individuals collected varied from $0.72 (Common Carp *Cyprinus carpio*) to $33.46 (Smallmouth Bass *Micropterus dolomieu*) each (Appendix A). Low RFI scores in each ecoregion but the Coastal Plains were less than 1 (a few cents), whereas high RFI scores in each ecoregion were greater than 1000 ($1000) in all but the Xeric (606), Western Mountains (837), and Northern Plains (919) (Appendix B).

The regression model fits between the RFI scores and the environmental predictor variables varied widely among ecoregions (Table 3). Moderately high coefficients of determination (R^2; 0.569–0.695), explaining 57–70% of the variation, were obtained for the Upper Midwest, Coastal Plains, Southern Appalachian Plateau, Temperate Plains, and Northern Appalachian Plateau ecoregions. The R^2 values were low (0.214–0.454), explaining 21–45% of the variation for the Southern Plains, Northern Plains, Western Mountains, and Xeric ecoregions, as well as the whole conterminous USA, which also reflected their higher standard errors.

No single environmental variable or class of environmental variables were significant for predicting RFI scores across all nine ecoregions (Table 4; Table 5). Channel width was significant in six ecoregions, channel slope and percent and sand and fines in four, and fish cover, percent fast habitat types, longitude, catchment area, catchment integrity and erodibility in three ecoregions each (Table 4). The number of significant predictor variables varied from 3 to 12 in the Xeric and Temperate Plains ecoregions, respectively (Table 4). The class of geophysical variables explained >50% of the RFI variation in four ecoregions (Table 5). The RFI and MMI scores were only weakly to moderately correlated, with R^2

ranging from 0.01% for the Upper Midwest and Xeric ecoregions to 36% for the Northern Appalachian Plateau (Table 5). As predicted, all RFI-MMI correlations were weakly negative except for the Northern Plains. The RFI-site appeal correlations were weakly positive in all nine ecoregions as expected, but somewhat higher than most RFI-MMI correlations (Table 5), explaining from 2.5% (Western Mountains Ecoregion) to 19.1% (Northern Appalachians). Sites in higher order streams tended to have higher RFI scores; however, those scores varied by one to three orders of magnitude by stream order (Figure 3).

Discussion

The median ecoregion RFI scores (Figure 2) were not consistently explained by any of the individual predictor variables that we examined (Table 4). Herlihy et al. (2020) also reported that the importance of various factors for predicting MMI scores varied by ecoregion and that local factors tended to be more important than catchment factors for predicting index scores. Similar results were reported for midwestern rivers (Wang et al., 2003; Esselman et al., 2015), French rivers (Marzin et al., 2012), and Brazilian streams in the Cerrado, Atlantic Forest and Amazon biomes (Macedo et al., 2014; Terra et al., 2015; Leal et al., 2018). However, RFI scores in all nine ecoregions were most strongly explained by the class of natural geophysical variables occurring in, and differing among, those ecoregions (Table 5). Fausch et al. (1984), Hughes et al. (1987) and Rohm et al. (1987) also reported that fish assemblage composition and species richness varied with ecoregion for midwestern U.S.A., Oregon and Arkansas rivers, respectively. But McCormick et al. (2000), Van Sickle and Hughes (2000) and Herlihy et al. (2019) found that the spatial patterns they recognized for Mid-Atlantic, Oregon and U.S.A. streams were associated most with geographic proximity rather than geographic classifications such as ecoregions, basins, hydrologic units or political units. Clearly, we cannot predict RFI scores accurately from environmental factors and geographical classifications.

There was a tendency for lower RFI scores in several ecoregions with increased levels of fines and sand and fines, decreased bed stability and water quality, increased catchment erodibility, and intensified land uses (dams, agriculture, development, roads, human population) (Table 4). Herlihy et al. (2020) also found that several of those same variables were associated with lower MMI scores. Such relationships have been reflected at basin levels of resolution. For example, in Oregon’s Willamette River basin, an estimated 46% of the stream and river miles in the basin were classified as most disturbed (poor condition), with agricultural land use associated with 62% of the most impaired miles (but representing only 30% of the miles in the basin; Mulvey et al. 2009). As in the Willamette Valley, agriculture was closely linked with negative biological effects on streams or lakes in the upper Mississippi River basin (Deweber et al. 2019), Tennessee-Mississippi basins (Perkin et al. 2019), Kansas River basin (Bruckerhoff and Gido 2019), and Northern Forests, Eastern Temperate Forests and Great Plains ecoregions (Jacobson et al. 2019). Presumably, this is because agriculture is the most widely distributed land use in the nation, there are strong gradients in agriculture across river basins and ecoregions, and its diffuse pollutants (excess sediments and nutrients) are weakly regulated or controlled.

Larger streams and rivers tended to have higher RFI scores (Figure 3). Similarly, Fausch et al. (1984) demonstrated that fish species richness increased with stream order and catchment area in midwestern U.S.A. rivers. McGarvey and Hughes (2008) and McGarvey and Ward (2008) reported that the number of fish species increased with increased discharge in Oregon and Alabama rivers, respectively. Hitt and Angermeier (2008) found increasing numbers of game fish individuals and species with increased proximity to large Mid-Atlantic Highlands rivers and Oberdorff and Hughes (1992) reported increased catch per unit effort with increased river size in the Seine basin, France. Hughes and Gammon (1987), Gammon (1976) and Lyons et al. (2001) included biomass collected per unit effort in the MMIs that they developed for large Oregon and midwestern rivers because of the substantial adult size differences that they found for some fish species in rivers versus those found in smaller streams. Hughes et al. (2020) reported that pristine Alaskan river sites supported more and larger game fish species and individuals than did the river tributary sites. In summary and as expected, larger water bodies tend to yield higher RFI scores because such waters support more and larger game fish, as well as more game fish species.

Although all NRSA MMIs include a non-native species metric, the RFI-MMI correlations were weakly (-0.01) to moderately (-0.60) negative for all ecoregions but the Northern Plains (Table 5). We believe this occurred for four major reasons. 1) MMIs assess all fish species, including many highly sensitive or rare non-game prey species—not only game species. Hughes and Herlihy (2012) described how such species are often replaced in rivers by more tolerant, common and piscivorous game fish species. 2) MMIs are developed and scored by using minimally or least-disturbed reference conditions, whereas the environmental conditions required for supporting recreational fisheries span a broad range of ecological conditions. Hughes and Gammon (1987) and Davies and Jackson (2006) described how sensitive species are replaced by more tolerant and common game fish species as the levels of anthropogenic disturbance increase. 3) RFIs include non-native game fish species, many of which are deliberately introduced, actively sought by anglers, and negatively affect native fish assemblages and the MMIs used to assess them. For example, Oliveira et al. (2009) reported a positive correlation between their coldwater fishery quality index that included no non-native fish and a coldwater MMI, but a negative correlation between their warmwater fishery quality index that included three non-native game fish (Common Carp, Largemouth Bass *Micropterus salmoides*, Pumpkinseed *Lepomis gibbosus*) and warmwater MMIs. Lomnicky et al. (2007) estimated that three non-native salmonid game-fish species (Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, Rainbow Trout *Oncorhynchus mykiss*) occupied 17%, 16% and 14%, respectively, of the stream length assessed in the western USA, and Whittier et al. (2007) included number of non-native species as a negative metric in their western U.S.A. fish MMIs. 4) RFI scores tended to be higher in larger rivers. Although larger rivers tend to support larger game fish, they also tend to be more disturbed (Hughes and Gammon, 1987; Lyons et al., 2001; Mebane et al., 2003; Rinne et al., 2005). Nonetheless, Dietermann et al. (2019) reported that sites with high catch per unit effort of game fish tended to have high MMI scores in rivers of the Eastern Temperate Forest ecoregion of Minnesota, although many sites with high MMI scores had relatively low abundances of game fish. We believe that the moderately positive RFI-MMI correlation in the Northern Plains is a result of two factors. 1) A preponderance of large rivers and relatively few small streams produced many large-bodied native game species in the Northern Plains (Appendix B). 2) In addition, unlike the other ecoregions, the Northern Plains RFI score was strongly associated with its IWI (index of watershed integrity) score (Table 4), which is moderately correlated with higher MMI scores as well (r = 0.30). Nonetheless, RFIs and MMIs often assess markedly different aspects of riverine fish assemblages, just as indicators of ecological integrity markedly differ from indicators of ecosystem services to humans (Hughes 2019).

The weak RFI-site appeal correlations (Table 5) were predicted, indicating subjective evaluations of site attractiveness is poorly related to RFI scores. We presume this occurs because production of some moderately tolerant game fish species tends to increase with moderate levels of disturbance, as reported by Oliveira et al. (2009) for Largemouth Bass and Pumpkinseed as well as by Esselman et al. (2015) for Smallmouth Bass (*Micropterus dolomieu*) and Walleye (*Sander vitreus*). Also, our RFI is based on the fish collected at a site and their costs of culturing—not the attractiveness of a site. However, this is contrary to the assumptions modeled by Ringold et al. (2013) who estimated higher recreational fishery condition in western U.S.A. streams would be associated with higher site appeal.

It is important to indicate what our RFI signifies. First, the species weights are simply the variable costs of producing different sizes of each game fish in hatcheries. The RFI score is a function of those weights times the lengths and numbers of game fish species collected. The numbers and sizes of some game fish are sometimes related to MMI scores and environmental conditions; at other times they are not (Oliveira et al. 2009). Likewise, the scores are not the total economic or subjective value of the recreational fishing experience at a site or in the nation or one of its ecoregions. Those values are calculated by other means, typically by travel cost estimates or willingness to pay studies (Ward and Loomis 1986; Wilson and Carpenter 1999; Bockstael and McConnell 2007; Mendelsohn and Olmstead 2009). In addition, in a national survey, Arlinghaus (2006) found that non-catch attributes of fishing were major motivators for German anglers, despite catch-expectation being the major driver for angler satisfaction. Those studies are important and useful, but generally only provide insights for specific areas and are not directly tied to the production, distribution, size, quality or abundance of fish at a site or in a region.

Conclusions

Because our RFI assessed markedly different aspects of fish assemblages than MMI scores determined from the same site samples, we believe that it would be a useful indicator to add to the USEPA’s National Rivers and Streams Assessments. RFI scores should be of greater interest to traditional state and federal fishery management agencies than are MMI scores because of the RFI focus on game fish variables versus entire fish assemblages that tend to be of greater interest to state and federal environmental quality agencies. Similarly, RFI scores should be of greater interest to the angling public versus ecologists and environmentalists that are more concerned with indicators like MMIs that assess overall ecological condition. There is also a need to determine what should constitute good, fair, or poor RFI scores, such as those used in MMIs, to aid in score interpretation by the public.

Acknowledgments

We thank Karen Blocksom, Alan Herlihy, Marc Weber and Ryan Hill for providing us with the fish and environmental data bases and USEPA contracts C000620098 to RTI International and EP-D-16-021 to CSS for funding. We are also grateful for the many state, federal, and contractor personnel involved with collecting and managing the NRSA data. We appreciate the helpful reviews of earlier manuscripts by Alan Herlihy, Andrew Loftus, James Markwiese, Michael Nye and two journal reviewers. This manuscript was subjected to Agency review prior to submission for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

Appendix

Appendix A.

The 15 most common game fish species found in the National Rivers and Streams Assessment (NRSA). Numbers are percents of total target wadeable stream length (1,438,000 km) or total target boatable river length (123,300 km).

Fish Taxa	Boatable Length (%)	Wadeable Length (%)	Species size class weight range ($US)
Bluegill *Lepomis macrochirus*	60.0	35.4	0.85–4.00
Common Carp *Cyprinus carpio*		49.5	0.12–0.72
Largemouth Bass *Micropterus salmoides*	48.2	21.2	1.41–16.14
Channel Catfish *Ictalurus punctatus*	46.8	-	0.68–4.71
Smallmouth Bass *Micropterus dolomieu*	36.5	-	2.92–33.46
Freshwater Drum *Aplodinotus grunniens*	34.9	-	0.23–1.51
Longear Sunfish *Lepomis megalotis*	33.0	16.7	0.85–4.00
Spotted Bass *Micropterus punctulatus*	30.3	-	0.85–4.00
Green Sunfish *Lepomis cyanellus*	28.6	44.5	0.85–4.00
White Sucker *Catostomus commersonii*	28.3	27.8	1.14–15.88
Golden Redhorse *Moxostoma erythrurum*	24.2	-	1.14–15.88
Rock Bass *Ambloplites rupestris*	24.1	-	0.85–4.00
Flathead Catfish *Pylodictis olivaris*	22.1	-	0.68–15.25
Yellow Bullhead *Ameiurus natalis*	-	23.8	0.80–2.90
Brook Trout *Salvelinus fontinalis*	-	11.8	1.05–10.14

Appendix

Appendix B.

Ecoregions with high and low RFI site scores and number of species collected per size class.

Ecoregion				No. per size class			
	Site (RFI High)	Site (RFI Low)	Species (Common Name)	<15	15–30	31–45	>45
XER	ORR9–0907 (606.62)		Common Carp	0	0	0	1
			Channel Catfish	0	0	8	6
			Rainbow Trout	1	1	0	0
			Smallmouth Bass	43	42	0	0

Ecoregion	Site (RFI High)	Site (RFI Low)	Species (Common Name)	No. per size class <15	15–30	31–45	>45
		NVR9–0910 (0.24)	Common Carp	2	0	0	0
WMT	MTRO-01064 (837.17)		Rainbow Trout	5	29	7	0
			Brown Trout	0	0	2	1
			Bull Trout	0	0	1	1
			Mountain Whitefish	18	90	28	0
			Westslope Cutthroat Trout	0	1	1	0
		ORRF-0108 (0.68)	Chinook Salmon	1	0	0	0
UMV	MNLS-1091 (2256.28)		Green Sunfish	6	0	0	0
			Rainbow Trout	0	2	0	0
			Brook Trout	26	230	29	0
			Brown Trout	0	0	0	1
			Largemouth Bass	0	1	1	0
			White Sucker	127	65	145	0
		WIS9–0926 (0.8)	Yellow Bullhead	1	0	0	0
TPL	SDR9–0913 (3211.8)		RIiver Carpsucker	3	3	42	4
			Common Carp	0	0	4	5
			Freshwater Drum	0	2	1	1
			Goldeye	0	6	22	0
			Channel Catfish	0	3	1	0
			Flathead Catfish	0	0	0	1
			Shortnose Gar	0	0	0	8
			Longnose Gar	0	0	0	15
			Sauger	0	0	5	0
			Walleye	0	1	1	3
			Smallmouth Bass	0	1	0	0
			Shovelnose Sturgeon	0	0	0	26
		ILS9–0922 (0.85)	Green Sunfish	1	0	0	0
SPL	OKRM-1006 (1811.6)		River Carpsucker	6	9	3	2
			Smallmouth Buffalo	0	0	3	8
			Freshwater Drum	12	3	2	0
			White Bass	18	6	1	0
			Green Sunfish	1	0	0	0
			Longear Sunfish	32	0	0	0
			Channel Catfish	3	6	6	6
			Flathead Catfish	0	0	0	2
			Blue Catfish	0	0	0	2
			White Crappie	1	0	0	0
			Largemouth Bass	1	0	0	0

Ecoregion	Site (RFI High)	Site (RFI Low)	Species (Common Name)	No. per size class <15	15–30	31–45	>45
			Longnose Gar	1	0	0	44
			Striped Bass	3	0	0	0
			Golden Redhorse	0	0	0	1
			Shovelnose Sturgeon	0	0	1	7
			Orangespotted Sunfish	3	0	0	0
			Bluegill	5	0	0	0
		NER9–0911 (0.48)	Common Carp	4	0	0	0
SAP	OHR9–0905 (1569.10)		River Carpsucker	0	2	5	0
			Common Carp	0	0	1	21
			Smallmouth Buffalo	2	2	7	8
			Freshwater Drum	3	41	36	5
			White Bass	1	3	2	0
			Green Sunfish	1	0	0	0
			Hybrid Lepomis	1	0	0	0
			Longear Sunfish	1	0	0	0
			Channel Catfish	0	5	14	23
			Flathead Catfish	0	3	1	0
			Black Crappie	0	2	0	0
			Wiper	2	7	2	0
			Largemouth Bass	0	1	1	0
			Longnose Gar	0	0	4	38
			Sauger	0	5	3	1
			Golden Redhorse	0	1	4	0
			River Redhorse	0	0	1	0
			Silver Redhorse	0	0	4	2
			Smallmouth Bass	0	0	1	0
			Black Buffalo	0	0	0	2
			Orangespotted Sunfish	1	0	0	0
			Spotted Bass	4	2	7	0
			Bluegill	0	2	0	0
		ALSS-1065 (0.85)	Green Sunfish	1	0	0	0
NPL	MTRM-1010 (919.27)		Smallmouth Buffalo	0	0	2	0
			Freshwater Drum	0	11	3	1
			Goldeye	33	7	1	0
			White Bass	0	0	1	1
			Channel Catfish	0	3	4	0
			Sauger	2	4	15	0
			Walleye	0	4	9	2
			Shovelnose Sturgeon	0	0	0	4

Ecoregion	Site (RFI High)	Site (RFI Low)	Species (Common Name)	No. per size class <15	15–30	31–45	>45
			Burbot	0	1	0	0
		NELS-1083 (0.12)	Common Carp	1	0	0	0
NAP	NYS9–0930 (1897.87)		Common Carp	0	0	3	15
			White Perch	26	13	2	0
			Yellow Bullhead	0	2	0	0
			Black Crappie	2	1	0	0
			White Crappie	0	1	0	0
			Yellow Perch	0	17	0	0
			Largemouth Bass	10	20	13	1
			Longnose Gar	0	0	2	0
			White Sucker	0	1	2	0
			Muskellunge	0	0	0	1
			Smallmouth Bass	3	6	0	1
			Brown Bullhead	0	3	0	0
			Pumpkinseed	36	134	0	0
			Rock Bass	2	1	0	0
			Bluegill	15	174	0	0
		NYS9–0931 (0.85)	Pumpkinseed	1	0	0	0
CPL	ARR9–0903 (2341.95)		River Carpsucker	0	0	6	10
			Common Carp	0	0	8	45
			Smallmouth Buffalo	0	3	9	6
			Freshwater Drum	8	15	5	1
			White Bass	0	0	2	1
			Green Sunfish	2	0	0	0
			Longear Sunfish	8	0	0	0
			Channel Catfish	4	1	2	2
			Flathead Catfish	4	3	3	6
			Blue Catfish	0	1	6	39
			White Crappie	1	3	0	0
			Largemouth Bass	0	0	1	0
			Shortnose Gar	0	0	1	20
			Spotted Gar	0	0	1	51
			Longnose Gar	0	0	0	10
			Black Buffalo	0	0	0	4
			Orangespotted Sunfish	1	0	0	0
			Spotted Bass	3	0	0	0
			Warmouth	2	0	0	0
			Bluegill	1	0	0	0
		TXSS-1243 (1.6)	Yellow Bullhead	2	0	0	0

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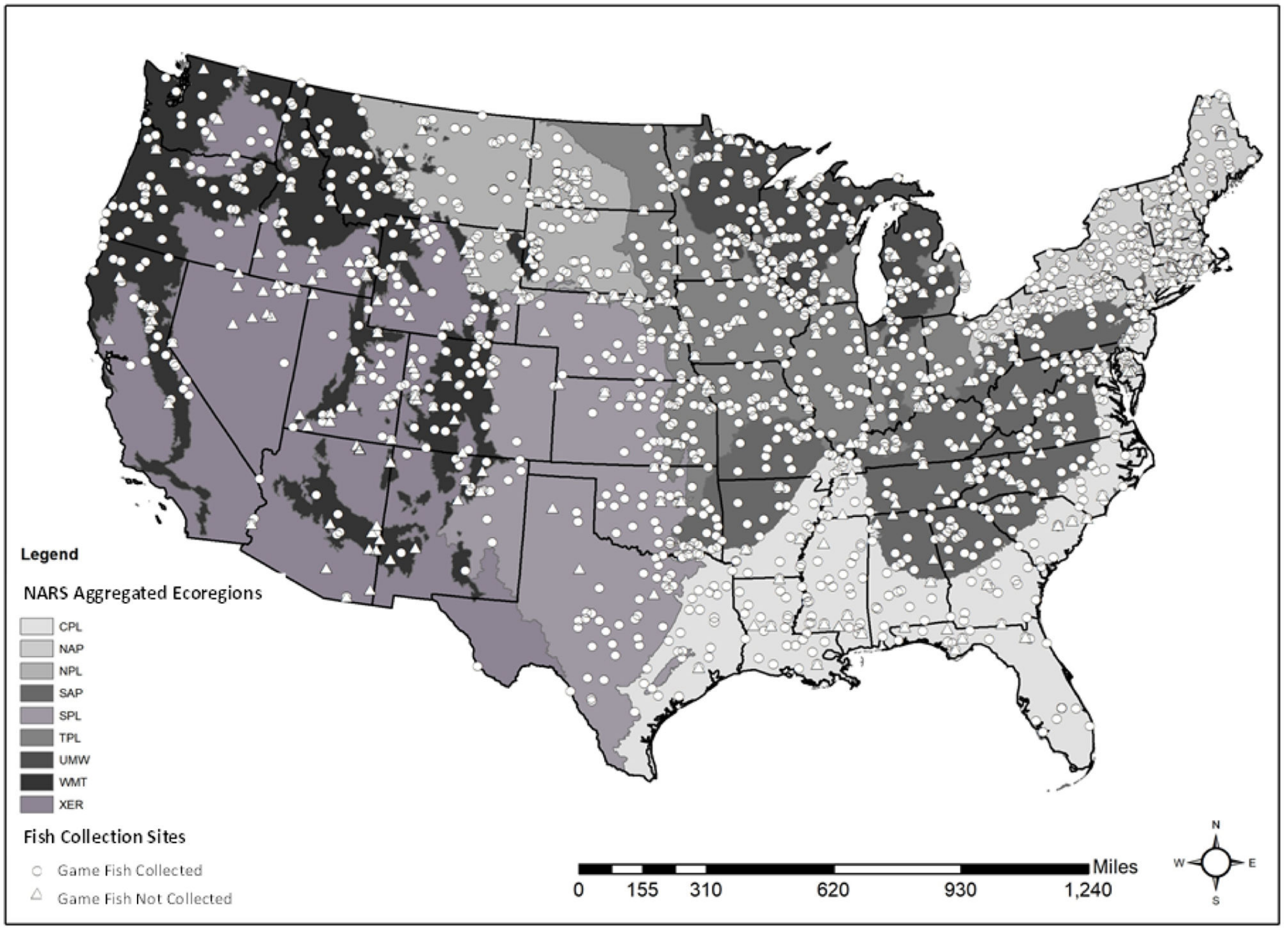

Figure 1.
Locations of the 1,561 NRSA sites with game fish and consistent environmental predictor data by nine ecoregions. Ecoregion codes are defined in Table 1.

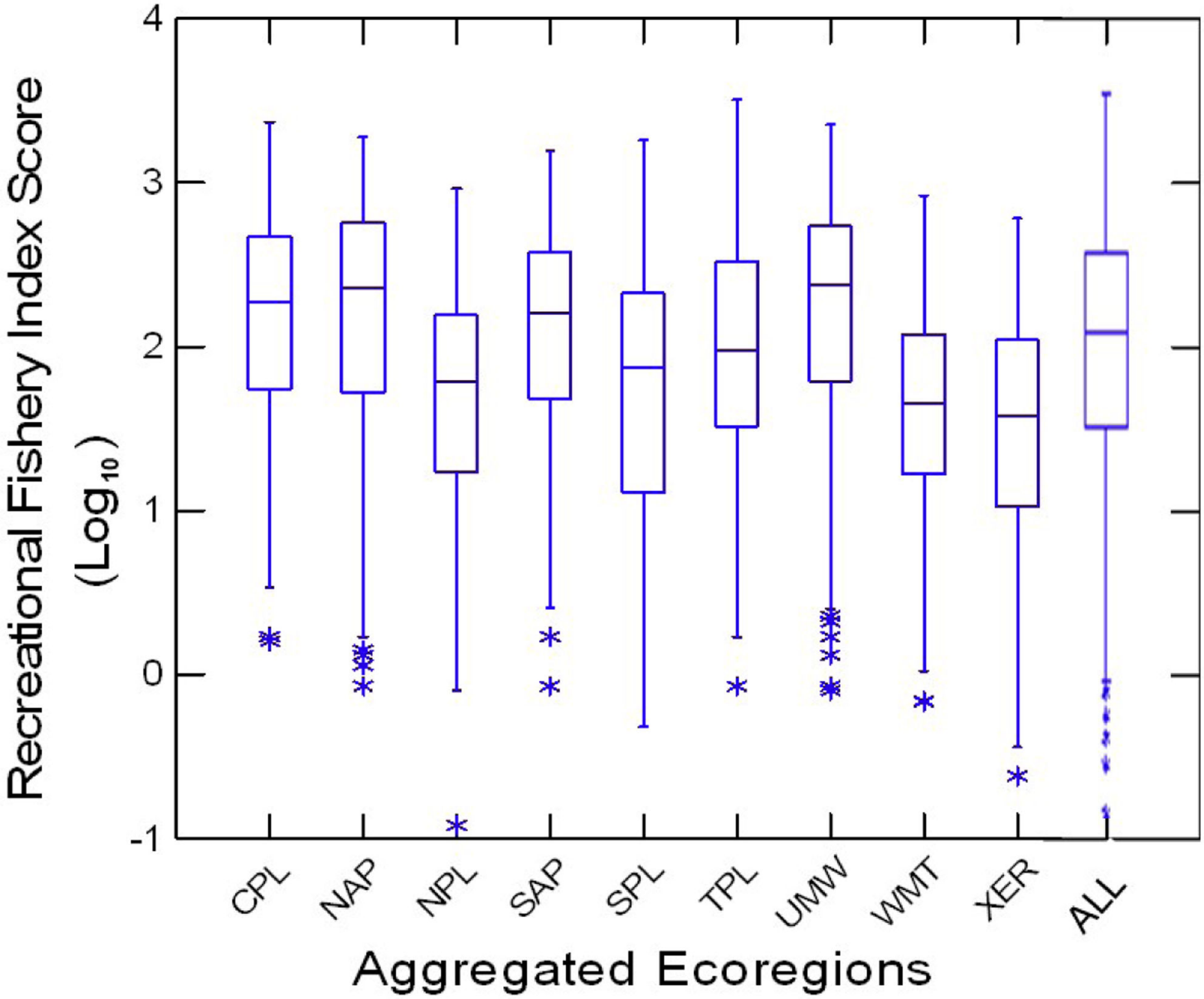

Figure 2.

Recreational fishery index (RFI) scores by ecoregion and for the entire conterminous U.S.A. (ALL). Note that RFI scores are expressed as $\log_{10}$. Horizontal lines are medians and quartiles, vertical lines are ranges, and asterisks are outliers. Ecoregion codes defined in Table 1.

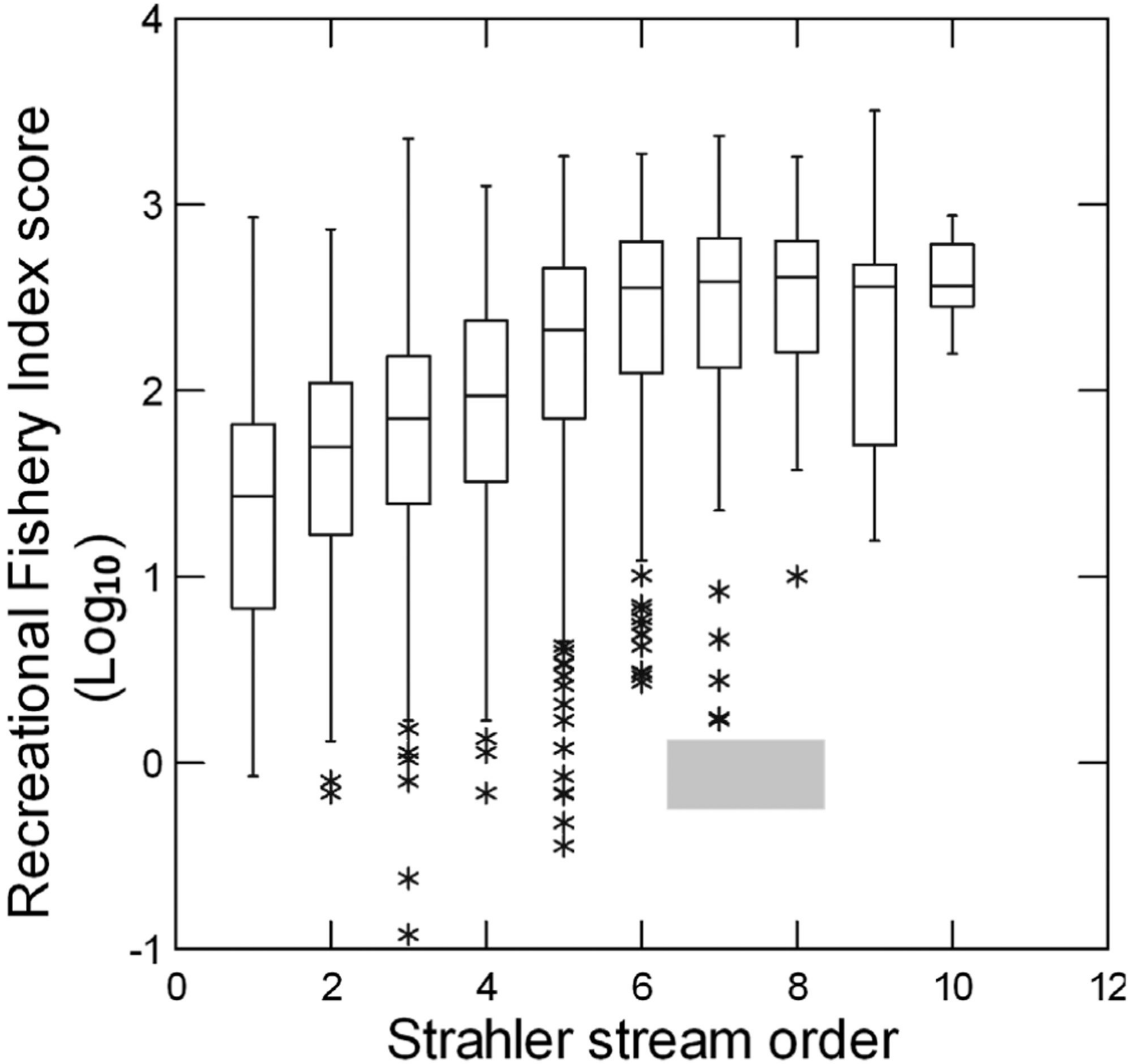

Figure 3.

Recreational fishery index (RFI) scores as a function of Strahler stream order. Note that the RFI scores are expressed as $\log_{10}$ and that zero-order channels are mostly misclassified side channels of larger rivers. Horizontal lines are medians and quartiles, vertical lines are ranges, and asterisks are outliers.

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Table 1.

Number of NRSA sites in each ecoregion with fish RFI scores

Ecoregion	Code	Game Fish Sites
Coastal Plain	CPL	203
Northern Appalachians	NAP	250
Southern Appalachians	SAP	216
Upper Midwest	UMW	156
Temperate Plains	TPL	224
Northern Plains	NPL	132
Southern Plains	SPL	128
Xeric West	XER	88
Western Mountains	WMT	164
Total		1561

Table 2.

Variables used to predict RFI scores and their codes. Variables are ordered by class used for subsequent data interpretation.

Variable (units)	Code	Variable (units)	Code
Water Quality		*Watershed Land Use*	
Total Nitrogen (μg/L)	TN *	Agriculture (%)	AGR_WS
Total Phosphorus (μg/L)	TP *	Developed Land (%)	DEVL_WS
Conductivity (μS)	COND *	Wetlands (%)	WETL_WS
Dissolved Organic Carbon (mg/L)	DOC *	Population Density (#/km^2)	POPDEN *
Chloride (μeq/L)	CL *	Road Density	ROADDEN *
Sulfate (μeq/L)	SO4 *	Dam Disturbance Index	DAM *
Turbidity (NTU)	TURB *	Watershed Integrity Index	IWI
pH	PH	*Climate*	
		Mean Precipitation (cm/yr)	PRECIP *
Physical Habitat Condition		Mean Runoff (cm/yr)	RUNOFF *
Riparian Cover Index	RIPCOV *	Maximum Temperature (°C)	TEMPMAX
Natural Fish Cover (% area)	FISHCOV *	Minimum Temperature (°C)	TEMPMIN
Fast Water Habitat (% length)	FASTPCT		
Pool Habitat (% length)	POOLPCT	*Geophysical*	
Riparian Disturbance Index	RIP_DIST	Latitude (degrees)	LAT
Agricultural Riparian Disturb.	RIP_AGR	Longitude (degrees)	LON
Non-Agricultural Riparian Disturb.	RIP_NOAG	Site Elevation (m)	ELEV *
		Catchment Area (km^2)	WSAREA *
Substrate		Mean Thalweg Depth (cm)	DEPTH *
Fine Substrate (% area)	FINES	Mean Wetted Width (m)	WIDTH *
Sand+Fine Substrate (% area)	SANDFINE	Channel Slope (%)	SLOPE *
Relative Bed Stability Index	RBS	Soil Erodibility Factor	ERODE
Substrate size	DMM	Boatable or Wadeable	LOTIC

* Log_{10}(x+1) transformed for data analysis, except for SLOPE (Log_{10}(x+0.001), and DAM, RIPCOV, and FISHCOV (Log_{10}(x+0.1).

Table 3.

Number of ecoregion sites for each stepwise RFI multiple regression model, adjusted R^2, standard error, F statistic, and degrees of freedom. Ecoregion codes are defined in Table 1.

Ecoregion	N	R^2	SE	F	df
CPL	198	0.635	0.406	69.562	5
NAP	250	0.588	0.465	60.163	6
SAP	205	0.569	0.450	54.772	5
UMW	152	0.695	0.406	35.359	10
TPL	212	0.586	0.449	23.969	13
NPL	132	0.357	0.574	9.077	9
SPL	125	0.454	0.579	18.17	6
XER	87	0.218	0659	8.976	3
WMT	160	0.214	0.596	8.194	6
ALL	1456	0.449	0.553	92.172	13

Table 4.

Variables predicting RFI scores. Numeric values are the stepwise regression coefficients, variable units and transforms are listed in Table 2, -- indicates the variable was not selected in the regression. All variables significant at p≤0.05. Ecoregion codes are defined in Table 1.

Variable		CPL	NAP	SAP	UMW	TPL	NPL	SPL	XER	WMT
Water Quality										
TP	--	−0.2199		--	--	--	--	--	--	--
TN	--	--	--	--	--	--	--	--	0.287	
COND	--	---	--	--	--	−0.434	--	--	0.948	
DOC	--	--	--	−0.732	--	--	--	--	--	
CL	--	--	--	−0.255	--	--	--	--	--	
SO4	--	--	--	--	--	--	−0.224	--		
TURB	--	--	--	−0.329	--	−0.177	--	--	--	
PH	--	--	--	--	0.308	--	--	--	−0.508	
Physical Habitat										
FISHCOV		0.125	--	--	--	−0.205	0.298	--	--	--
FASTPCT		--	−0.005	--	0.004	−0.009	--	--	--	--
POOLPCT	--	--	0.003	--	--	--	--	--	--	
RIP_AGR		--	--	--	--	--	--	0.179	--	--
Substrate										
FINES	--	--	--	--	--	--	--	--	−0.007	
SANDFINE	--	--	−0.003	--	−0.004		−0.011	--	−0.009	--
RBS	--	--	--	--	--	−0.305	--	--	--	
Catchment Land Use										
AGR_WS		--	--	--	--	--	−0.017	0.013	--	--
DEVL_WS	--	--	--	--	--	−0.158	--	−0.142	--	
ROAD_DEN	--	--	−0.785	--	−1.021	--	--	--	--	
DAM	--	--	--	−0.382	--	--	--	--	--	
IWI	--	--	--	−0.476	−3.087	--	0.757	--	--	
Climate										
PRECIP		--	--	--	--	1.228	--	2.281	--	--
RUNOFF		--	−1.406	--	--	--	---	--	--	--
TEMPMIN	0.116	0.044	--	--	--	--	--	--	--	
Geophysical										
LAT	−0.949	--	--	--	--	--	--	--	--	
LON	0.822	--	--	0.032	0.040	--	--	--	--	
ELEV	--	--	--	--	0.885	--	--	--	--	
WSAREA		0.448	--	0.291	0.321	--	-	--	--	--
DEPTH		--	−0.288	-	--	--	--	--	--	--
WIDTH		--	0.598	--	0.502	−0.484	0.721	1.273	--	0.308
SLOPE		--	--	−0.227	--	−0.204	−0.297	--	−0.465	--
ERODE		--	-	-	1.343	−2.691	--	--	--	−2.766

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Variable	CPL	NAP	SAP	UMW	TPL	NPL	SPL	XER	WMT
Model Intercept	−1.910	6.548	0.728	4.442	−0.112	2.659	−5.960	1.717	3.267

Table 5.

RFI multiple regression R^2 for models based only on the variables within each predictor class by ecoregion and correlations (r) by ecoregion for the RFI versus the NRSA fish ecoregion-specific MMI scores. **Bold** signifies >50% variation explained. Ecoregion codes are defined in Table 1.

	CPL	NAP	SAP	UMW	TPL	SPL	NPL	WMT	XER
Water Quality	0.183	0.238	0.291	0.385	0.259	0.249	0.194	0.110	0.097
Physical Habitat	0.193	0.350	0.192	0.192	0.212	0.137	0.075	0.025	0.053
Substrate	0.107	0.103	0.113	0.161	0.060	0.115	0.074	0.036	0.124
Land Use	0.231	0.324	0.270	0.355	0.343	0.174	0.165	0.083	0.145
Geophysical	**0.616**	**0.553**	**0.551**	**0.579**	0.479	0.426	0.302	0.136	0.222
Climate	0.093	0.039	0.045	0.057	0.119	0.186	0.175	0.042	0.101
Correlations (r) MMI X RFI	−0.03	−0.60	−0.46	−0.01	−0.17	−0.09	+0.49	−0.15	−0.01
Site Appeal X RFI	0.305	0.441	0.217	0.394	0.317	0.185	0.267	0.159	0.309