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[Article]

A Preliminary Fishery Quality Index for Portuguese Streams

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Abstract.—There is a need to quantify the multivariate quality of a recreational fishery at the site scale to better communicate the relative quality among sites to the public and anglers. Borrowing on the general approach of multimetric indices of biotic integrity (IBIs), we developed fishery quality indices (FQIs) from species quality indices (SQIs) based on measures of fish abundance and size structure for northern and central Portuguese streams. Our FQIs showed regional patterns indicating a range in fishery quality. Higher coldwater FQI scores were mostly found in the northwestern (Minho and Lima), northeastern Douro, and northern Tagus basins. Higher warmwater FQI scores occurred in the eastern Tagus basin. The species that contributed the most to warmwater FQI scores were largemouth bass *Micropterus salmoides*, pumpkinseed *Lepomis gibbosus*, the cyprinid *Luciobarbus bocagei*, chubs *Squalius carolitertii* and *S. pyrenaicus*, and nases *Pseudochondrostoma duriense* and *P. polylepis*. The chubs, nases, and brown trout *Salmo trutta* contributed the most to coldwater FQI scores. As expected, our indices were correlated with river size and with disturbance at the catchment, segment, and site scales. Regression models for separate coldwater and warmwater FQIs were stronger than those for the individual SQIs and for an all-site FQI. The correlation was positive between the coldwater FQI and a coldwater IBI but negative between the warmwater FQI and warmwater IBIs. The proposed FQIs offer a quantitative approach for assessing relative fishery quality among sites and for making regional assessments given an appropriate study design. The component SQIs and SQI metrics of the FQIs can be disassociated to determine the population and species characteristics most affected by various environmental variables.

Indices of biotic integrity (IBIs) are commonly used for assessing the ecological health or condition of entire fish assemblages in North America (Miller et al. 1988; Simon and Lyons 1995) and internationally (Hughes and Oberdorff 1999; Roset et al. 2007) because they combine multiple variables into a single number easily comprehended by fishery administrators and the public. Despite the popularity of the multimetric IBI approach, few fishery managers have adopted comparable explicit multimetric indices for assessing key game fish assemblages, although they may consider such information implicitly and for specific populations. Qualitative assessments hinder rigorous statistical comparisons among sites as well as analyses of how environmental factors affect fishery quality. One notable exception is the Oregon Department of Fish and Wildlife (2006), which employs multiple metrics for evaluating the status of populations of coho salmon *Oncorhynchus kisutch*, but these metrics are not quantitatively combined into a single score. Also, Hickman (2000) proposed a sportfishing

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index for reservoir populations, but his index uses rank scores of 5, 10, or 15 for each of four qualitative population characteristics (angler quantity and quality, population quantity and quality), while each of the five components of the population quality characteristic was scored 1, 2, or 3. Such scoring increases the variance of indices as compared with continuous metric and index scoring (Hughes et al. 1998; Pont et al. 2006).

Researchers have examined the reasons people fish because angler motivations affect the types of catch- and noncatch-related benefits anglers seek (Fedler and Ditton 1994; Arlinghaus 2006). In fact, recreational fishing is a multifaceted outdoor activity in which anglers do not seek just to catch fish; they also seek relaxation, escape, and enjoyment of the outdoors, among other things (Pollock et al. 1994; Arlinghaus 2006). Although motivational studies have shown that catching fish was generally not as important to anglers as were noncatch motivations (Arlinghaus 2006), activity specific elements (Arlinghaus 2006) are far from being negligible in recreational fisheries. Ditton and Hunt (1996) reported that 50–60% of Texas anglers were more satisfied if they caught both more fish and more-challenging game fish. A good catch was also important to almost 50% of anglers in a Belgian province (Frank et al. 1998). Spencer (1993) concluded that fishing success and targeted species affected angler satisfaction on Lake Miltona, Minnesota. Lichtkoppler et al. (2008) also reported that abundance and size of targeted species were major objectives of charter fishermen on Lake Erie (Ohio).

Although many noncatch elements of a recreational fishery may contribute to angler motivations, we assume that more and larger individuals of a greater number of desired species are important factors in fishery quality. Therefore, our objective in this paper is to develop a fishery quality index (FQI), calculated from species quality indices (SQIs) for fish assemblages in Portuguese streams, where fishing remains a popular recreational activity and source of food. We define fishery quality as the sum of one or more species quality index scores, which, in turn, incorporate population measures of recruitment, maximum size, overall abundance, and abundance of legally catchable individuals. We do not assume that our indices should be the only guides to classify fishing quality. Rather, our indices simply summarize key biological aspects of the quality components of recreational fisheries.

There are at least six reasons that a fishery management agency may want to use an FQI or SQI in fluvial systems. First, an agency may often have only one sample of 100 m or so from a set of sites, which represents too few data for developing rigorous stock–recruitment models and quantitative population management. However, such samples can suffice for developing SQIs and FQIs. Second, these SQIs and FQIs can be used as a coarse tool for screening general fishery quality pattern across large regions, followed by subsequent intensive sampling and population modeling. With the proper study designs, FQIs, like IBIs or multimetric indices, can also be used by agencies for making regional or national fishery assessments as well as assemblage (Stoddard et al. 2005; Paulsen et al. 2008) and ecosystem service (Costanza et al. 1997; Limburg et al. 2002) assessments. Third, single-species management has been increasingly shown to be problematic where there are strong interactions (predator–prey, competition, nonnative invasives) among fish species (Ross 1991; Moyle and Light 1996; Hughes et al. 2005). Fourth, despite having low IBI scores, sites with high SQI or FQI scores may warrant increased water body protection or management to protect the fishery. Availability of both FQIs and IBIs also will aid managers to quantify and compare fishery quality with overall fish assemblage condition. Although both endpoints are of public concern, occasionally they appear contradictory (Whittier et al. 1997; USEPA 2000; Godinho 2002). Fifth, FQIs are useful for rating fishery quality for nonspecialized (family, children) fishing as opposed to specialized anglers seeking a specific species. Sixth, because FQIs can be disassociated to determine species scores (SQIs), these tools are also useful for rating fishing quality for anglers seeking specific species. Our FQI and SQI approaches should be applicable in any nation or state that collects similar game fish data, regardless of species.

Methods

Study species.—Based on a national survey of Portuguese anglers, Oliveira (unpublished data) found that the primary game species sought by Portuguese anglers are native brown trout *Salmo trutta*, the cyprinid *Luciobarbus bocagei* (hereafter termed barbel), the chubs *Squalius carolitertii* and *S. pyrenaicus*, and the nases *Pseudochondrostoma duriense* and *P. polylepis*, plus the nonnative common carp *Cyprinus carpio*, pumpkinseed *Lepomis gibbosus*, and largemouth bass *Micropterus salmoides* (Table 1). Consequently, these are the species included in our SQIs and FQIs.

Data collection and analyses: fish data.—We selected data from fish samples of northern and central Portuguese streams collected by a consortium of Portuguese national universities 1996–2006 (Figure 1). Over 400 sites were screened to ensure that they were sampled according to CEN (2003), the standard

European protocol for electrofishing. The resulting 202 sites cover the range of natural conditions and human impacts occurring across the study areas. Although 5–73 sites per basin were sampled, we did not assess sampling variability because site widths ranged from 1 to 60 m in our data set, and we lacked revisit samples; consequently, we could not evaluate the effects of interannual or seasonal variability on our preliminary index scores. However, one certainly can expect some of our target species to vary temporally. In addition, sites were not selected through use of a probabilistic sampling design; therefore, the sites are not statistically representative of all streams in any basin (Herlihy et al. 2000), and the results cannot be inferred statistically beyond the site lengths that were sampled (e.g., see Olsen and Peck 2008).

Each site was classified as warmwater or coldwater depending on its potential to support brown trout. During spring–summer base flow, sites were electrofished (DC, 300–700 V, or pulsed DC, 400–1,000 V) once. Electrofishing distances followed CEN (2003) standards to encompass repeating habitat types (riffles, pools) and the home ranges of dominant fish species expected. This distance was at least 20 times the mean wetted width of the channel. The entire widths of wadeable streams were fished by walking slowly upstream and using one anode for every 5 m of stream width. Block nets were used only when riffles or other natural obstructions were absent, and only in wadeable streams. Rivers with mean depths exceeding 0.5 m were electrofished by boat moving downstream, again sampling all habitat types, but focusing on the margins. Most fish were identified and measured in the field and returned alive to the water, but voucher specimens were preserved from each site for subsequent documentation or taxonomic verification. Total lengths were measured to the nearest centimeter and assigned to length-classes: less than 8 cm (class 1), 8–19 cm (class 2), and greater than 19 cm (class 3) for brown trout (minimum legal length [MLL] = 19 cm); less than 8 cm (class 1), 8–20 cm (class 2), and greater than 20 cm (class 3) for barbel, common carp, and largemouth bass (MLL = 20 cm); and less than 8 cm (class 1), 8–10 cm (class 2), and greater than 10 cm (class 3) for chubs, nases, and pumpkinseed (MLL = 10 cm).

Environmental data.—For each site, environmental data were obtained at catchment, segment, and site scales and, where appropriate, ranked according to Pont et al. (2006). Kaufmann et al. (1999) reported that qualitative physical habitat estimates had greater variances than quantitative measurements, but that those variances could be reduced through use of a set of five ranks.

Catchment.—Drainage area (DRAIN) and distance from headwaters (SOURCE) were derived from digital elevation models. Percentages of agricultural land (AGRIC) and forest and seminatural land (NATUR) were obtained from a land cover shape file of the site's catchment based on Corine Land Cover 2000 imagery (Bossard et al. 2000).

Segment.—Human disturbance was evaluated subjectively from available data and professional judgment, and variables were scored to the degree they deviated from minimally disturbed conditions (from 1 for no deviation, to 5 for highly degraded; Table 2). Land use (LAND) was estimated as less than 10% of nonnatural land use (1) to more than 40% of intensively cultivated land, intensive silviculture, or both (5). Urbanization (URBAN) was estimated as less than 1% (1) to greater than 25% (5) urban. Riparian disturbance (RIPAR) was evaluated, and ranged from no or minor impacts (1) to complete riparian vegetation removal and urban or agricultural land use (5). Morphological alteration (MORPH) was evaluated from negligible (1) to complete channelization and bank hardening (5). Sediment load (SEDIM) was estimated as having less than 5% (1) to greater than 75% (5) of the bottom with fine sediment deposits, and little to high turbidity.

Site.—Elevation (ELEV) and channel slope (SLOPE) were derived from digital elevation models. Mean annual precipitation (MAP) and mean annual air temperature (MAT) were determined from climate models based on time series between 1941 and 1942, and 1990 and 1991, from 554 Portuguese weather stations (MESP 2002). Water conductivity (COND) and physical habitat data (collected from 3 to 10 cross-sectional transects depending on distance fished [i.e., about one transect per 30 m of electrofishing distance]) were measured in the field. Transect data were used to measure mean wetted width (WIDTH), mean depth (MEDEP), and maximum depth (MADEP). Hydrological disturbance (HYDR) was evaluated as having little (1) to extreme (5) deviation from the natural annual flow regime as a function of the number, proximity, and size of hydroelectric power plants upstream from the site (most of these structures operate in a similar way, imposing an "on-off" pattern of flow that depends on electricity demands). Nutrient and organic contamination (NUTORG) ranged from class A (unpolluted; 1) to class E (extremely polluted; 5) as measured by the Portuguese water quality classification system (SNIRH: http://snirh.pt/). Based on SNIRH data, dissolved oxygen concentration (OXYG) was evaluated as having no (1) to extreme (5) deviation from the natural seasonal variation.

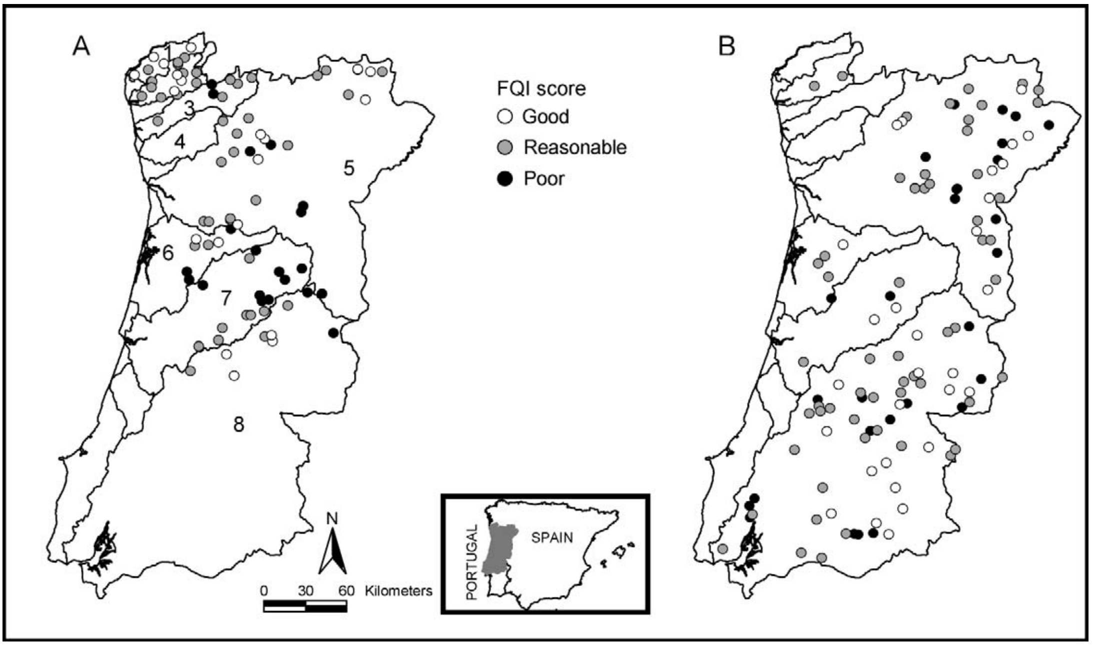

FIGURE 1.—Patterns of FQI scores for **(A)** coldwater streams and **(B)** warmwater streams across northern and central Portuguese river basins (1 = Minho, 2 = Lima, 3 = Cávado, 4 = Ave, 5 = Douro, 6 = Vouga, 7 = Mondego, and 8 = Tagus). The data set was trisected to provide differing fishery quality groups. Clusters of sites with higher coldwater FQI scores occur in the northwestern basins (Minho and Lima), northeastern Douro basin, and northern Tagus basin. Clusters of sites with higher warmwater FQI scores occur in the eastern Tagus basin.

Fishery quality index calculation.—To develop our FQI, we first developed SQIs for the primary game species collected at each site (Table 1). Our SQIs were based on the average of four biological metrics commonly related to the performance and fishery quality of a species, and each SQI was treated as an independent variable in subsequent analyses. These metrics included recruitment (class 1 catch per unit effort [CPUE]), abundance of legally catchable specimens (MLL, class 3 CPUE), a measure of large specimens (maximum individual total length of a species at a site), and an estimate of overall abundance (species total CPUE). Before SQI calculation, each metric for each species was standardized so it ranged from zero to one as follows:

$$Y_{abc} = y_{abc}/y_{ab}^{\max},$$

where Y is the standardized value of metric a for species b at site c, and $y_{ab}^{\max}$ is the maximum value for metric a and species b, along all sites c.

The general equation for an SQI is

$$\mathrm{SQI}_{bc} = \left(\sum_{a=1}^{4} Y_{abc}\right)/4.$$

We used the percentage of anglers that prefer each species to weight the SQIs (J. M. Oliveira, unpublished data). Thus, the SQIs of chubs, nases, and pumpkinseed were single weighted (preferred by $< 10\%$ of the anglers), the SQIs of barbel and common carp were double weighted (preferred by 10–20% of the anglers), and the SQIs of brown trout and largemouth bass were triple weighted (preferred by 20–30% of the anglers). Paukert et al. (2007) also reported that black basses were the most or second most sought after taxa by anglers in 27 of 42 reporting U.S. and Canadian states and provinces, respectively. Brown trout is a highly valued game species in several European countries (Hickley and Tompkins 1998). We calculated FQIs as the sum of the SQIs (e.g., if a site contained brown trout, barbel, and chubs, its FQI was calculated as FQI $= 3\mathrm{SQI}_{\text{brown trout}} + 2\mathrm{SQI}_{\text{barbel}} + \mathrm{SQI}_{\text{chubs}}$).

In order to examine regional patterns of the FQI scores, both the warmwater and coldwater FQI scores were evaluated as follows: high fishery quality sites (values greater than the upper quartile), reasonable fishery quality sites (values within the interquartile range), and poor fishery quality sites (values less than the lower quartile). We also determined the SQIs that contributed most to the higher warmwater and cold-

TABLE 1.—General ecology and life history traits of primary Portuguese riverine game fish species.

Species	Family	Maximum total length (cm)	General tolerance	Adult trophic guild	Preferred habitat
Largemouth bass	Centrarchidae	70	Tolerant	Piscivore	Limnophilic, warm, cover
Pumpkinseed	Centrarchidae	20	Tolerant	Invertivore–piscivore	Limnophilic, warm, macrophytes
Barbel	Cyprinidae	100	Tolerant	Omnivore	Limnophilic, warm, benthic
Chubs	Cyprinidae	30	Moderately sensitive	Invertivore	Eurytopic, cool–warm, macrophytes
Nases	Cyprinidae	50	Moderately sensitive	Omnivore	Rheophilic, cool–warm, benthic
Common carp	Cyprinidae	70	Tolerant	Omnivore	Limnophilic, warm, benthic
Brown trout	Salmonidae	50	Sensitive	Invertivore–piscivore	Rheophilic, cold, cover

water FQI scores, calculating the percent contribution of each single SQI score to each respective FQI score.

Statistical analyses.—We used multiple linear regression (MLR) to analyze relations between SQIs, FQIs, and environmental variables. The dependent variables were SQI_b (for all sites with species *b*, and for warmwater or coldwater sites [or both] supporting and preferred by species *b*) and FQI (for all, warmwater, and coldwater sites). To avoid overfitting regression models, Harrell (2001) recommended that the number of candidate predictor variables be less than 10% of the total sample size, and Tabachnick and Fidell (2001) argued that the final number of predictor variables be less than 6% of the sample size. Therefore, before MLR we used Spearman correlation to determine potential predictor variables and to avoid multicollinearity. To reduce the influence of multicollinearity, we inspected associations among all the environmental variables, and between those variables and each index. Variables insignificantly related to the indices were rejected and those with between-variable correlations greater than $|0.75|$ were considered redundant. When variables were redundant, we selected the most responsive variable. Quantitative data were tested for normality using the Kolmogorov–Smirnov test. When nonnormality was indicated, data were transformed to ensure linear relations between the response and predictor variables and to fulfill MLR assumptions. For example, we $\log_{10}$ transformed index scores and catchment variables. We used Akaike's information criterion (AIC) to select the best MLR model for each SQI and FQI from a set of candidates. Akaike's information criterion is a model performance statistic that balances statistical fit with model parsimony, which is useful for determining the appropriate maximum number of variables for a model and for selecting among candidate models (Burnham and Anderson 2004). We used standardized residuals and

TABLE 2.—Criteria for scoring qualitative variables related to human disturbance. Variables were scored to the degree they deviated from minimally disturbed conditions (from 1 for no deviation to 5 for highly degraded). Variable abbreviations are defined in Methods.

Class	LAND	URBAN	RIPAR	MORPH
1	<10% nonnatural	<1% urban	No or minor impacts	Negligible morphological alteration
2	<40% nonnatural, low impact	<15% urban, low impact	75–90% of the streambank vegetation and immediate riparian zones in natural state	Most of natural channel form maintained, all habitats present
3	<40% nonnatural, moderate impact	<15% urban, moderate impact	50–75% of the streambank vegetation and immediate riparian zones in natural state	Channelized, some natural habitat types missing
4	>40% cultivated land–silviculture, strong impact	15–25% urban	<50% of the streambank vegetation and immediate riparian zones in natural state	Channelized, most natural habitat types missing
5	>40% intensively cultivated land–intensive silviculture, severe impact	>25% urban	Complete riparian vegetation removal; immediate riparian zones with urban or agricultural land use	Canal; bank hardening

[a] SHPP = small hydroelectric power plant (<15 m high or $<0.5 \times 10^6$ m^3 storage); LHPP = large hydroelectric power plant.
[b] Measured according to the Portuguese water quality classification system (SNIRH data).

TABLE 1.—Extended.

Species	Reproductive guild
Largemouth bass	Guarder, nest spawner polyphil
Pumpkinseed	Guarder, nest spawner polyphil
Barbel	Nonguarder, lithophil, potamodromous
Chubs	Nonguarder, lithophil
Nases	Nonguarder, lithophil, potamodromous
Common carp	Nonguarder, phytophil
Brown trout	Nonguarder, brood hider, lithophil

Cook's distance to check models for outliers and eliminated them to increase model accuracy.

We used Spearman correlation to determine whether ecological assessments based on IBI scores and fishery assessments based on FQI scores differed among 85 sites. Because of markedly different fish assemblages and species richness, we used the European Fish Index (Pont et al. 2006) to estimate the ecological status of coldwater and warmwater sites in two northern basins (Douro and Minho), and we employed an IBI developed by Oliveira and Ferreira (2002) to assess the ecological status of warmwater sites in the Tagus basin. No validated IBI was available to perform this kind of evaluation for the remaining 117 sites, which were in the Lima, Vouga, and Mondego basins, and the coldwater Tagus streams.

Results

Sites of good, reasonable, and poor fishery quality were spread throughout the study area (Figure 1). This dispersion of fishing quality was expected because stream sites respond to heterogeneous and variable environmental conditions (both "natural" and anthropogenic) at regional and national scales. However, higher coldwater FQI scores generally were found in the northwestern basins (Minho and Lima), northeastern Douro basin, and the cold waters of the Tagus basin (Figure 1A). All but three sites in these regions scored high FQIs largely because of their high quality populations (more and larger fish) of brown trout as well as chubs, nases, or both. In fact, the SQI scores of these species contributed most to the higher coldwater FQI scores (percent contribution of SQIs in the higher fishery quality sites [$n = 20$; mean $\pm$ SD]: SQI brown trout [68.02 $\pm$ 26.50], SQI nases [12.65 $\pm$ 9.47], and SQI chubs [11.67 $\pm$ 10.90]).

Higher warmwater FQI scores occurred in the eastern Tagus basin (Figure 1B). This region has a wide variety of medium-to-large rivers (typically 8–30 m wide at base flow), with species-rich fish assemblages that include several nonnative and native game fishes. The SQI scores for largemouth bass, pumpkinseed, barbel, chubs, and nases contributed most to the higher warmwater FQI scores (percent contribution of SQIs in the higher fishery quality sites [$n = 28$; mean $\pm$ SD]: SQI barbel [32.85 $\pm$ 16.10], SQI nases [14.88 $\pm$ 8.68], SQI largemouth bass [13.83 $\pm$ 20.04], SQI chubs [13.02 $\pm$ 10.54], and SQI pumpkinseed [11.56 $\pm$ 11.20]).

Environmental variables related to site size (drainage area, distance from headwaters, elevation, channel slope, mean wetted width, mean depth, and maximum

TABLE 2.—Extended.

Class	SEDIM	HYDR[a]	NUTORG[b]	OXYG[b]
1	<5% of the bottom with fine sediments, and little turbidity	Little influence of SHPPs or LHPPs on the natural annual flow regime	Class A (unpolluted)	No deviation of oxygen levels from the natural seasonal variation
2	5–25% of the bottom with fine sediments, and little turbidity	Slight influence; distance > 30 km from an SHPP, or distance > 60 km from an LHPP	Class B (almost unpolluted)	Occasional deviation from natural (<20% of the total available data)
3	26–50% of the bottom with fine sediments, and little turbidity	Moderate influence; distance 10–30 km from an SHPP, or distance 20–60 km from an LHPP	Class C (slightly polluted)	Frequent deviation from natural (20–50% of the total available data)
4	51–75% of the bottom with fine sediments, or moderate turbidity	Strong influence; distance < 10 km from an SHPP, or distance < 20 km from an LHPP	Class D (polluted)	Strong deviation from natural (51–80% of the total available data)
5	>75% of the bottom with fine sediments, or high turbidity	Extreme influence; sites located immediately downstream from a hydroelectric power plant	Class E (extremely polluted)	Extreme deviation from natural (>80% of the total available data)

TABLE 3.—Spearman correlations between all the environmental variables and both species quality indices (SQIs) and fishery quality indices (FQIs), and between FQIs and indices of biotic integrity (IBIs) (bold italics denote r-values $\geq |0.25|$ with $P <$ 0.10). Variable abbreviations are defined in Methods. For the subsequent multiple linear regressions, variables that were insignificantly related to the indices were rejected, as were those with between-variable correlations greater than |0.75|, which were considered redundant (underlining denotes rejected redundant variables).

		SQI						
				Barbel		Chubs		
Variables	Median (range)	Largemouth bass (n = 17)	Pumpkinseed (n = 39)	Warm (n = 94)	All (n = 118)	Warm (n = 96)	Cold (n = 57)	All (n = 153)
Catchment								
DRAIN (km^2)	89 (2–4,654)	0.23	0.02	***0.47***	***0.50***	−0.16	0.07	0.06
SOURCE (km)	20 (2–125)	0.34	−0.02	***0.42***	***0.44***	−0.15	0.07	0.06
AGRIC (%)	19 (0–99)	***0.51***	0.08	0.12	−0.13	−0.17	0.01	−0.12
NATUR (%)	78 (0–100)	***−0.53***	−0.05	0.12	0.12	0.15	−0.13	0.08
Segment								
LAND (1–5)	2 (1–5)	0.23	0.27	−0.07	0.00	−0.07	0.19	0.03
URBAN (1–5)	1 (1–5)	−0.18	0.18	−0.09	−0.06	0.09	0.12	0.07
RIPAR (1–5)	2 (1–5)	−0.08	0.18	−0.08	−0.01	0.03	0.00	0.04
MORPH (1–5)	1 (1–4)	0.04	0.16	−0.08	−0.05	0.03	0.07	0.04
SEDIM (1–5)	2 (1–5)	***0.51***	***0.32***	0.14	0.24	−0.14	0.02	−0.06
Site								
ELEV (m)	250 (10–1,034)	−0.32	−0.14	−0.07	−0.08	0.09	−0.07	0.01
SLOPE (%)	0.8 (0–17)	−0.33	−0.25	***−0.38***	***−0.41***	0.11	−0.10	−0.04
MAP (mm)	930 (450–3,000)	−0.19	−0.11	−0.09	−0.18	0.15	0.03	−0.07
MAT (°C)	13 (8–18)	0.36	***0.50***	−0.06	0.04	0.03	0.08	0.14
COND (µS cm^{-1})	73 (10–1,300)	***0.54***	0.14	0.13	***0.26***	0.01	0.11	0.16
WIDTH (m)	7 (1–60)	0.24	0.06	0.21	0.19	***−0.26***	0.15	−0.09
MEDEP (m)	0.45 (0.13–2.00)	***0.46***	***0.32***	***0.28***	***0.25***	−0.23	0.10	−0.10
MADEP (m)	1.00 (0.20–4.80)	0.21	***0.36***	0.22	***0.27***	−0.14	0.10	−0.01
HYDR (1–5)	1 (1–4)	−0.07	−0.03	0.01	0.10	***−0.26***	0.06	−0.08
NUTORG (1–5)	1 (1–5)	0.34	***0.33***	0.00	0.14	−0.05	***0.27***	0.13
OXYG (1–5)	2 (1–4)	−0.07	***0.35***	−0.07	0.07	0.06	0.10	0.12
IBIs								
All sites (n = 85)								
Warm sites (n = 62)								
Cold sites (n = 23)								

depth) often were relatively strongly correlated with SQI and FQI scores, suggesting better angling in larger rivers as expected (Table 3). Disturbances at the catchment (agricultural land, forest, and seminatural land), segment (land use, sediment load, urbanization), and site (hydrological disturbance, nutrient and organic contamination, dissolved oxygen concentration) scales were about equally often correlated with SQI scores. The fact that all three scales were similarly correlated with SQI scores indicates the importance of all three spatial scales of environmental data to the SQI and FQI scores.

Multiple linear regression results revealed the same general patterns as the correlations, although site-scale variables predominated in the SQI and FQI models (Table 4), but AIC restricted the number of predictor variables to 1–3. Although the MLR models were significant, the variability explained by them only ranged from 15% to 47%. Increased sedimentation and turbidity were associated with increasing SQI scores for largemouth bass, and both increased sediment load and decreased mean depth were associated with increasing pumpkinseed SQI scores. While higher warmwater SQI scores for barbel were associated with greater drainage area and greater mean depth, higher all-site SQI scores for barbel were associated with greater drainage area, lower channel slope, and higher conductivity. Increased warmwater SQI scores for chubs were associated with lower mean depth and lower hydrological disturbance. Increased mean annual precipitation was linked with higher coldwater SQI scores for nases. The coldwater SQI scores for brown trout increased with decreasing mean wetted width and increasing mean annual air temperature, but the coldwater FQI scores increased with increasing mean wetted width and increasing mean annual air temperature. As expected from the correlations, higher warmwater FQI scores were linked with increasing drainage area, increasing mean depth, and decreasing channel slope, and higher all-site FQI scores were associated with increasing mean wetted width, decreasing channel slope, and decreasing elevation. The

TABLE 3.—Extended.

	SQI							
	Nases			Brown trout		FQI		
Variables	Warm (n = 83)	Cold (n = 41)	All (n = 124)	Cold (n = 70)	All (n = 84)	All (n = 202)	Warm (n = 116)	Cold (n = 86)
Catchment								
DRAIN (km^2)	0.15	0.24	***0.28***	−0.05	−0.19	***0.33***	***0.43***	***0.33***
SOURCE (km)	0.17	0.09	***0.26***	−0.19	***−0.32***	***0.29***	***0.39***	0.22
AGRIC (%)	***−0.25***	***0.26***	−0.14	0.21	0.15	−0.03	−0.13	0.14
NATUR (%)	0.24	***−0.29***	0.12	−0.21	−0.16	0.03	0.12	−0.13
Segment								
LAND (1–5)	−0.09	***0.26***	0.03	0.11	0.06	0.00	−0.07	0.13
URBAN (1–5)	−0.14	0.17	0.00	0.04	0.03	0.07	−0.06	0.24
RIPAR (1–5)	−0.17	0.17	−0.03	0.04	−0.02	0.00	−0.11	0.12
MORPH (1–5)	−0.15	0.17	−0.06	0.00	0.00	−0.02	−0.12	0.11
SEDIM (1–5)	−0.07	0.01	−0.02	0.10	0.12	0.10	0.06	0.15
Site								
ELEV (m)	−0.02	***−0.34***	−0.15	0.00	0.05	−0.18	−0.07	***−0.31***
SLOPE (%)	0.01	−0.13	−0.09	0.12	0.16	***−0.31***	***−0.39***	***−0.26***
MAP (mm)	0.06	***0.44***	−0.02	0.06	0.17	0.00	−0.08	0.14
MAT (°C)	−0.12	0.01	0.03	***0.25***	0.10	0.11	0.01	***0.31***
COND (μS cm^{-1})	0.03	0.05	0.12	0.20	0.06	0.10	0.00	***0.27***
WIDTH (m)	0.00	***0.28***	0.12	***−0.26***	***−0.29***	***0.32***	***0.32***	***0.35***
MEDEP (m)	0.03	0.00	0.04	−0.19	−0.16	0.21	***0.42***	0.00
MADEP (m)	−0.21	0.15	−0.03	−0.02	−0.08	***0.26***	***0.35***	0.14
HYDR (1–5)	−0.14	0.09	0.00	0.05	−0.15	0.05	0.04	0.07
NUTORG (1–5)	0.02	0.17	0.15	0.00	−0.13	0.10	0.09	0.11
OXYG (1–5)	−0.07	0.22	0.08	0.06	−0.01	0.11	0.06	0.18
IBIs								
All sites (n = 85)						***−0.26***		
Warm sites (n = 62)							***−0.38***	
Cold sites (n = 23)								***0.39***

models for chubs in cold water and all sites and for nases in warm water and all sites were not significant ($P > 0.05$).

The models for the warmwater and coldwater FQIs were slightly stronger than those for the individual SQIs, revealing one value of incorporating multiple species in an FQI (Table 4). These patterns did not hold true for the all-sites FQI model, which had a lower correlation coefficient than the SQIs or the separate coldwater and warmwater FQI models, thereby supporting separate application of coldwater and warmwater FQIs.

Correlation between the IBI and the coldwater FQI was positive ($r = 0.39$; $n = 23$; $P < 0.10$), but correlations between the IBIs and both the warmwater FQI ($r = -0.38$; $n = 62$; $P < 0.05$) and all-sites FQI ($r = -0.26$; $n = 85$; $P < 0.05$) were negative (Table 3). Those FQI–IBI correlations indicate that high-quality fishing and assemblage health or condition are corroborative to some degree in coldwater Portuguese systems, but not in warmwater Portuguese systems.

Discussion

The existence of a standard European electrofishing protocol greatly facilitated use of fish data collected by colleagues throughout Portugal. That same standard method has enabled Europe-wide assessments of fish assemblage condition (Pont et al. 2006, 2007), despite sampling by diverse entities. A different standard method and a probabilistic study design allowed a rigorous assessment of nearly all western U.S. streams and rivers (Whittier et al. 2007; Pont et al. 2009). Clearly, standard sampling methods are essential for spatially extensive assessments of fish populations and assemblages (Bonar and Hubert 2002; Hughes and Peck 2008; Bonar et al. 2009).

We generally found higher SQI and FQI scores in larger rivers. Fausch et al. (1984) and subsequent IBI developers (e.g., Dauwalter et al. 2003) also found that accurate scoring of IBI species richness metrics required calibration for river size. McCormick et al. (2001) found that abundance plus selected trophic, habitat, and reproductive metrics were affected by river

TABLE 4.—Multiple linear regression results for the species quality indices (SQIs) and fishery quality indices (FQIs). Variable abbreviations are defined in Methods. Only models with $P < 0.05$ are presented. Note that the number of sites in the FQI all-sites model does not equate with the sum of sites in the FQI-cold and FQI-warm models because different outliers were removed from each model as explained in Methods.

					Model results			
Dependent variable	AIC	Predictor	Standardized coefficient	*P*	Adjusted R^2	df	*F*	*P*
SQI								
Largemouth bass, all sites ($n = 17$)	−3.26	Intercept		0.0023	0.21	1, 15	5.31	<0.0359
		SEDIM	0.511	0.0359				
Pumpkinseed, all sites ($n = 36$)	−25.93	Intercept		<0.0001	0.26	2, 33	7.02	<0.0029
		MEDEP	−0.463	0.0039				
		SEDIM	0.400	0.0112				
Barbel, warm sites ($n = 87$)	−54.75	Intercept		<0.0001	0.26	2, 84	15.73	<0.0001
		DRAIN	0.304	0.0045				
		MEDEP	0.310	0.0038				
Barbel, all sites ($n = 116$)	−54.34	Intercept		<0.0001	0.29	3, 112	16.47	<0.0001
		DRAIN	0.381	<0.0001				
		SLOPE	−0.188	0.0294				
		COND	0.215	0.0079				
Chubs, warm sites ($n = 94$)	−27.21	Intercept		<0.0001	0.15	2, 91	9.33	<0.0002
		MEDEP	−0.215	0.0292				
		HYDR	−0.315	0.0017				
Nases, cold sites ($n = 35$)	−48.46	Intercept		<0.0001	0.47	1, 33	16.45	<0.0001
		MAP	0.609	<0.0001				
Brown trout, cold sites ($n = 66$)	−31.34	Intercept		0.0004	0.16	2, 63	7.27	<0.0145
		MAT	0.333	0.0047				
		WIDTH	−0.262	0.0248				
FQI								
Warm sites ($n = 114$)	1.16	Intercept		0.0007	0.30	3, 110	16.37	<0.0001
		DRAIN	0.253	0.0134				
		MEDEP	0.258	0.0044				
		SLOPE	−0.197	0.0378				
Cold sites ($n = 80$)	6.00	Intercept		<0.0001	0.31	2, 77	18.55	<0.0001
		MAT	0.463	<0.0001				
		WIDTH	0.299	0.0021				
All sites ($n = 193$)	21.75	Intercept		0.5984	0.17	3, 189	14.15	<0.0001
		ELEV	−0.126	0.0743				
		SLOPE	−0.231	0.0021				
		WIDTH	0.216	0.0027				

size as well. In addition, predictive IBI models include measures of river size for richness metrics (Oberdorff et al. 2002; Pont et al. 2006). We chose not to calibrate FQIs or SQIs for river size because of our focus on absolute, versus river size-relative, fishery quality. Calibrating SQIs and FQIs to river size could possibly improve model associations with predictor disturbance variables if that were one's objective. However, Whittier et al. (2006) reported that size calibration produces even weaker associations when evaluating disturbance at large regional scales because many variables, especially land use, covary with catchment size. More importantly, informing anglers that sites in small and large rivers have comparable calibrated SQI and FQI scores creates the illusion that those sites have comparable fishing qualities, which defeats the purpose of such indices. On the other hand, if fisheries managers desired to report SQI and FQI scores for small, medium, and large rivers separately, that might clarify regional patterns and aid some anglers in deciding where to fish.

Others interested in fish assemblage assessments found assemblage condition related at various degrees to catchment versus site conditions (Allan et al. 1997; Brown et al. 2005; Hughes et al. 2006). Our FQI and SQI scores were correlated with predictor variables at all three spatial scales (catchment, segment, site). As explained by Wang et al. (2006), this concordance among spatial scales occurs when relatively wide ranges in variability and comparable levels of disturbance occur across catchments, reaches, and sites.

The multispecies coldwater and warmwater FQI models were slightly stronger than the single species SQI models. Likely, reduced within-site variability of species metrics (noise), increased among-site variability (signal), or both provided stronger correlations between predictor variables and FQIs than for SQIs. Hughes et al. (1998) and Mebane et al. (2003) reported that their IBIs had greater among-site versus within-site variability (signal/noise) than the metrics forming them. But Hughes et al. (2004) and Whittier et al.

(2007) found that the signal/noise ratios for their IBIs were intermediate between those of their IBI metrics.

The all-sites FQI model had a lower correlation with its predictor variables than the SQI models or than the separate coldwater and warmwater FQIs did with their predictor variables. The IBI literature also supports use of separate coldwater and warmwater IBIs (Lyons et al. 1996; Mundahl and Simon 1999; Ferreira et al. 2007; Whittier et al. 2007). However, predictive IBI modeling (which calibrates for natural gradients in size, temperature, and elevation) does not necessarily require separation into warmwater and coldwater models (Oberdorff et al. 2002; Pont et al. 2006, 2009).

Correlation between FQI and IBI scores was positive for coldwater sites, primarily because brown trout is a popular coldwater game species, intolerant, and an abundant species in minimally disturbed coldwater Portuguese streams. A similar pattern may be expected between fishery quality and the coldwater IBIs of Mundahl and Simon (1999), Mebane et al. (2003), and Hughes et al. (2004), which included salmonid size, abundance, recruitment metrics, or a combination thereof. Additionally, reduction in or absence of brown trout, as well as chubs and nases (both moderately sensitive), in moderately to highly disturbed cold waters is not associated with the presence of other game fishes sought by Portuguese anglers. Increasing coldwater FQI scores were associated with wider coldwater streams because these systems produce higher quality populations (more and larger fish) of brown trout, nases, and chubs. In fact, mostly good–reasonable quality sites included in the minimally disturbed and forested regions of the Minho and Lima basins, the northeastern Douro basin, and the northern Tagus basin were in intermediate-to-low altitude streams with gentle slopes.

We assume that the negative correlation between the warmwater FQI and IBI scores results partly from higher FQI scores in medium to large rivers that are commonly impounded and moderately to highly polluted in Portugal (and elsewhere). These larger rivers produce more and larger game fish (largemouth bass, pumpkinseed, common carp, barbel), all of which are limnophilic and generally tolerant to pollution and habitat degradation. Larger streams with higher-quality fisheries are certainly the pattern of the eastern Tagus, an agricultural area that includes some of the longest and largest streams in the basin, which are also altered by agricultural practices and river impoundment.

However, it is not surprising for improved fishing or FQI scores to be associated with lower assemblage condition or IBI scores. The IBI of Oliveira and Ferreira (2002) has two metrics (percent native individuals and percent tolerant individuals) that will reduce IBI scores with increased numbers of tolerant nonnative game fish species (higher FQI scores). Lyons et al. (1996) noted that an IBI score does not indicate fishery quality because stocked fish in Wisconsin streams may yield high quality fisheries, despite having low or intermediate IBI scores. Whittier et al. (1997) reported that piscivores, especially nonnative piscivores introduced to improve fishing, were associated with lower minnow species richness (lower IBI scores) in northeastern U.S. lakes. Many other authors have also raised concerns about the association of nonnative game fish—deliberately introduced to improve fisheries—with declines or extirpation of native fishes (e.g., Miller et al. 1989; Rahel 2002; Sanderson et al. 2009). Clearly, fishery quality is often a fundamentally different ecological endpoint or ecosystem service than fish assemblage condition as measured by an IBI or by native species richness.

Less-disturbed warmwater rivers could yield lower SQI metric scores (lesser abundances, sizes, and recruitment) for the four tolerant species listed above, thereby producing lower FQI scores and higher IBI scores. On the other hand, those sites could reflect higher SQI metric scores (greater abundances, sizes, and recruitment) of nases and chubs, subsequently higher FQI scores, and higher IBI metric scores (e.g., more native and rheophilic species, and higher percentages of native individuals, water column invertivore individuals, and lithophilic species). For example, Lyons (2005) and Yoder et al. (2005) reported higher IBI scores at high-quality sites than at low-quality sites in large, warmwater Wisconsin and Ohio rivers. On the other hand, slightly enriched sites are expected to support more and larger tolerant game species, not declining until physical and chemical habitat is excessively degraded (Davies and Jackson 2006).

Although Moyle and Light (1996) noted that nonnative species often have little effect on the invaded assemblages, they concluded that (1) invasions are most successful in anthropogenically altered ecosystems or where species richness is low, (2) piscivores and omnivores are more likely to be successful invaders than other guilds, and (3) piscivores are the most likely to alter fish assemblages. All three conditions describe warmwater Portuguese streams, and they are issues of concern because the native fish fauna is species depauperate and lacks a native piscivore (Godinho and Ferreira 1998).

The fact that slightly enriched sites are expected to support more and larger fishes may be why the brown trout SQI and the coldwater FQI scores both increase with increasing mean annual temperature and conductivity. As long as temperatures remain cold enough for trout reproduction and growth, increased temperatures that also increase metabolism and food supply are likely to increase trout production (Warren 1971; Elliott 1975). In addition, studies like ours that include streams with wide variation in ionic strength are likely to indicate a positive correlation between trout production and fertility of stream water (Kwak and Waters 1997). The growth of moderately sensitive Iberian cyprinids also seems to be generally higher in more-productive and wider water bodies (e.g., Granado Lorencio et al. 1985).

We encourage others interested in quantifying fishery quality at the species and multispecies levels to evaluate and adapt our SQI and FQI approach to their fisheries in streams and lakes. The Oregon Department of Fish and Wildlife (2006) developed a related approach in streams for coho salmon but did not convert multiple metric scores to a single index score. Like us, Oregon Department of Fish and Wildlife employed recruitment and abundance metrics, but also included distribution and density metrics because of concerns with Endangered Species Act listing. The latter metrics would be appropriate for basin- versus site-scale FQIs and SQIs.

In conclusion, we stress that ours is a preliminary fishery quality index. Other pertinent metrics and SQIs may be added, other scoring mechanisms may be employed, and the development of the index for other aquatic systems may be considered, just as Karr's (1981) original IBI was adapted for local and regional applications by various ecologists. In addition, it would be important to validate our indices with angling measures such as the frequency that anglers fish those sites, and their judgment of fishing success. However, we believe the general multimetric and multispecies index approach has merit for assessing fisheries quality, and, like the IBI, each FQI can be analyzed directly or disassociated to determine those variables most responsive to environmental factors.

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