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Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France

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Abstract

The Index of Biotic Integrity (IBI) is a measure of fish assemblage 'health' that has been used to assess catchment and stream quality throughout North America. It reflects human perturbations on natural environmental structures and processes. While preserving the ecological foundation of the original North American metrics, we have modified and adapted the IBI to the mainstem Seine River and its major tributaries in France. This successful modification of the IBI to a considerably different fish fauna on a different continent further supports its wider use outside the midwestern United States. Using data collected in 1967, 1981, and 1988–1989 from a total of 46 sites, we show spatial and temporal variation in the Seine as indicated by IBI scores. Statistically significant relationships were found between IBI and catchment area but insignificant relationships existed between IBI and an independent Water Quality Index (WQI) based on water chemistry. Comparisons between the IBI and the WQI indicate that the former is a more sensitive and robust measure of water body quality. Our results demonstrate that the IBI, combined with a statistically designed national monitoring program, would offer a reliable means of assessing spatial patterns and temporal trends in water body improvement or degradation in France. The more primitive fish families in the Basin were affected first by perturbations. These families include all the diadromous species found in the Seine and suggest serious disruption of their life histories.

Introduction

The French Water Quality law of 1964 and its 1971 and 1978 amendments mandate maintenance of the biological integrity of surface waters in France. Although this objective is fundamentally biological, efforts to assess water body integrity were dominated until 1981 by nonbiological chemical and physical measures. Since 1981, a biotic index based on number and type of benthic macroinvertebrates taxa (Verneaux & Tuffery, 1967) has been used at a few permanent stations, but there has been little ecological monitoring of fish assemblages despite a fish index proposed by Verneaux (1976a, b). A major disadvantage of Verneaux's fish model is that it considers only qualitative aspects of fish assemblages; in addition, it is based essentially on the distribution and dominance of species or families and can only indicate when an expected assemblage is absent. Similarly, Metcalfe (1989) found Verneaux's macroinvertebrate indices insensitive to changes in water quality, first, because organisms were analyzed at the family and class level, and second, because the indices were not designed for use in low gradient rivers.

Another tool for assessing stream and river quality based on fish assemblage attributes is the Index of Biotic Integrity (IBI), the subject of this article. The IBI was designed to integrate information from individual, population, assemblage, ichthyogeographic, and ecosystem levels into a single index of the quality of water bodies (Karr *et al.*, 1986). Originally proposed by Karr (1981) and later refined by Fausch *et al.* (1984) and Karr *et al.* (1986), the IBI combines 12 fish assemblage metrics classified into 3 groups: (1) species richness and composition, (2) trophic composition, and (3) fish abundance and health.

Ideally, environmental conditions at the site in question are compared with the attributes expected in undisturbed streams or rivers of similar size and habitat type located in a similar geographic region. When there are no undisturbed sites, the least impacted regional sites can be used as standards (Hughes *et al.*, 1986). A rating of 5, 3, or 1 is then assigned to each metric, according to whether its value approximates (5), deviates moderately from (3), or strongly deviates from (1) the value expected at the reference sites. The IBI is the sum of the 12 ratings and varies from 12 to 60 in 5 quality classes: excellent (58–60), good (48–52), fair (40–44), poor (28–34), and very poor (less than 24). A classification of 'no fishes' is assigned when repeated sampling finds no fish.

Although developed for streams in the midwestern USA, the IBI has been tested in several other regions of North America (Leonard & Orth, 1986; Moyle *et al.*, 1986; Thompson & Fitzhugh, 1986; Fausch & Schrader, 1987; Hughes & Gammon, 1987; Steedman, 1988; Crumby *et al.*, 1990). These applications have shown that the IBI concept is useful, but that metrics must be modified, deleted, or added to reflect regional differences in fish distribution and assemblage structure (Miller *et al.*, 1988).

This study was designed to analyze existing ichthyology books and data based on fish distributions, ecological tolerances, and trophic guilds in order to (1) develop an Index of Biotic Integrity for fish assemblages of the Seine Basin, (2) examine the spatial and temporal variation of this IBI in the basin, and (3) assess the response of the IBI to varying levels of physical and chemical degradation. We first adapted the IBI metrics for use in France and then developed scoring criteria from those proposed by Karr *et al.* (1986) and from criteria we developed for the Seine Basin. We calculated IBI scores from available historical data and evaluated spatial and temporal patterns. The IBI scores were also compared with independent rankings of water degradation.

Methods

Study area

The Seine Basin is underlain by sedimentary deposits, in particular by permeable chalk, limestone, sandstone, sand, and gravel. Drained by five major river systems (Seine, Marne, Oise, Yonne, and Aisne), it slopes from the southeast to the northwest, where it joins the English Channel (Fig. 1). High-quality water has become a rare and fragile resource for the Seine Basin. Demographic and economic growth, intensive agricultural and industrial production, and increasing urbanization (particularly near Paris) accentuate the problem of inadequate water resources in this particular region.

Sampling procedure

We used data from 1967, 1981, and 1988–1989 for the analyses of the IBI (Table 1). In 1967, data were collected by seining, electrofishing, and a variety of other techniques at 17 sites in 11 rivers of the Seine Basin. These data resulted from an

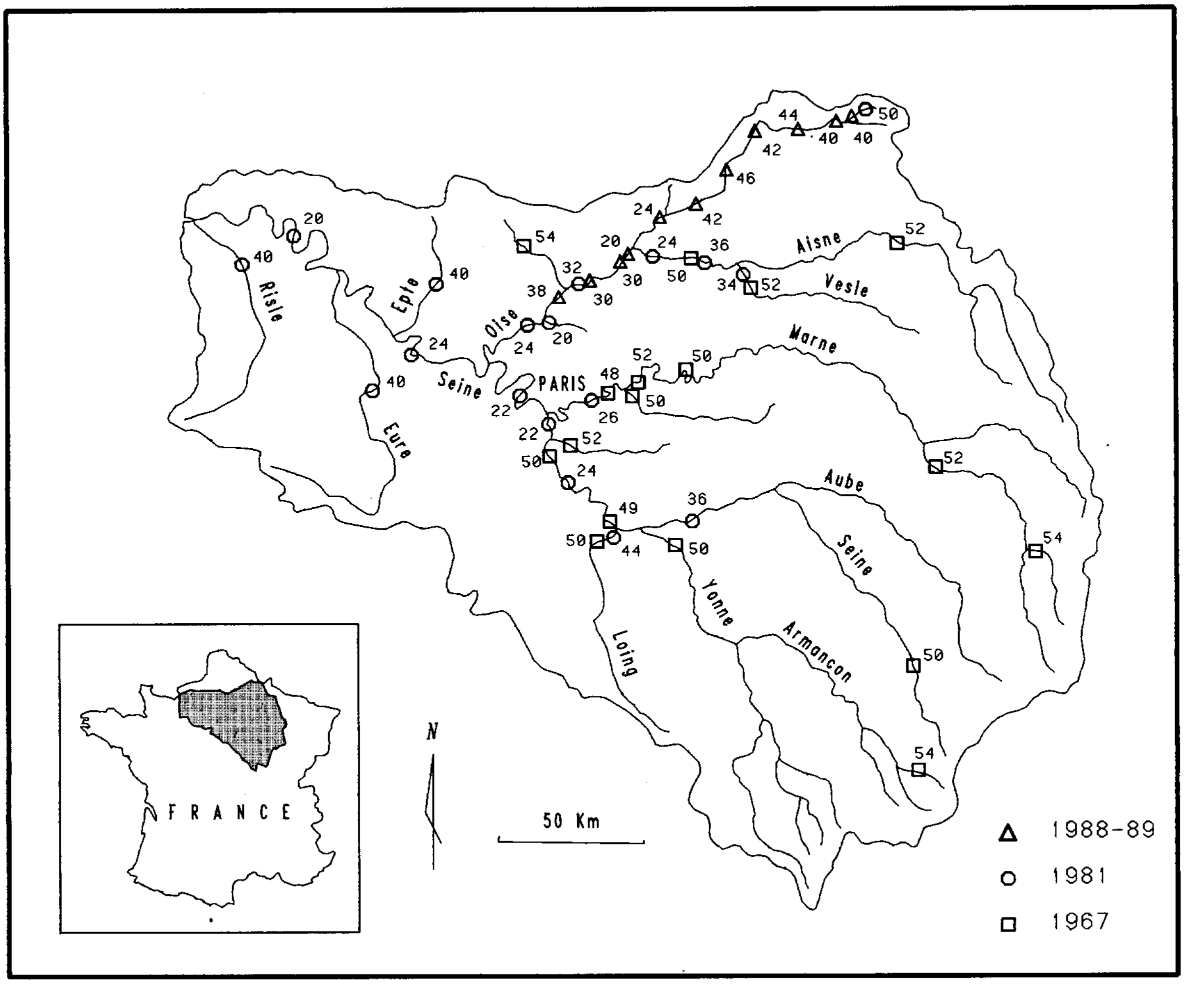

Fig. 1. The Seine Basin and its location in France.

intensive inventory of fish assemblages performed by the Muséum National d'Histoire Naturelle and the Associations de Pêche et Pisciculture du Bassin de la Seine. In 1981, fish were collected by electrofishing at 18 sites in 9 rivers of the Seine Basin. These data were collected by the Conseil Supérieur de la Pêche to evaluate the fish assemblages. The data for 1988–1989 were collected by electrofishing from 11 sites of the river Oise in the Seine Basin, also by the Conseil Supérieur de la Pêche. Only nearshore areas were sampled for all 46 sites. Although this approach may not have yielded a complete inventory of all species, it did result in sample sizes large enough to permit comparisons among sites (an average of 140 fishes per site).

Calculation of catchment area and statistical analyses

The catchment area (Table 1) for each site was measured with a digital planimeter on a 1 : 1,000,000-scale map of the Seine Basin provided by the Agence Financière de Bassin Seine-Normandie (the local water authority responsible for the Seine Basin). Statistical analyses (simple linear regressions, multiple regressions, and main

Table 1. Catchment area and number of stations sampled during 1967, 1981, and 1988-1989, and considered in this study.[a]

Catchment	Total area (km^2)	Number of sample stations		
		1967	1981	1988-1989
Major systems				
Seine	73,800	3	6	0
Oise	17,000	0	4	11
Marne	13,000	3	1	0
Yonne	11,000	2	0	0
Aisne	8,000	2	2	0
Minor systems				
Eure	6,000	0	1	0
Loing	4,200	1	1	0
Risle	2,000	0	1	0
Vesle	1,600	1	1	0
Epte	1,480	0	1	0
Grand Morin	1,200	1	0	0
Yerres	1,000	1	0	0
Rognon	711	1	0	0
Brêche	650	1	0	0
Vaux	114	1	0	0

[a] Stations differed each year; in 1988-1989, sampling focused on the River Oise only.

effects analyses of variance models) were performed on a microcomputer with JMP SAS statistical software (SAS Institute Inc., 1989).

Modifying the IBI for the Seine Basin

Some of the metrics originally used for the IBI (Karr *et al.*, 1986) required modification for application in the Seine Basin.

Species composition. Two of the original six metrics of Karr were retained: 'total number of species' and 'number of intolerant species'. Total number of species is a measure of the species richness component of diversity and it decreases with increased degradation. The number of species intolerant of various chemical and physical habitat perturbations distinguishes high and moderate quality sites. Intolerant species are usually the first species to disappear after a disturbance. Species were selected by examining ichthyological books and data bases for species that were once widely distributed but are now restricted to the highest quality water bodies. Three metrics specific to North America ('number of darter species', 'number of sunfish species', and 'number of sucker species') were replaced with 'number of water column species' and 'number of benthic species', because these two metrics are strongly responsive to changes in water quality and habitat structure. Water column species are active swimmers that typically feed on drifting and surface invertebrates or other fishes. Benthic species, for the most part, are sensitive to siltation and benthic oxygen depletion because they feed and reproduce in benthic habitats.

We replaced '% of individuals as green sunfish' with '% of individuals as roach'. Roach (*Rutilus rutilus* L.) was selected to replace green sunfish as a tolerant species in this region because it is common in medium to high gradient rivers and appears tolerant of many pollutants. This metric is the complement to 'number of intolerant species' and distinguishes low and moderate quality waters. The percentage of roach increases with degradation and the species becomes dominant in highly disturbed sites.

Another metric was added, based on local indicator species: 'presence or absence of juvenile or adult trout or pike'. Because the study area had both medium gradient/warm water and high gradient/cool water, pike and trout, respectively, were used as indicators of high quality water. These species include large, long-lived individuals and also offer a substitute for Karr's 'number of sucker species' metric. Steedman (1988), Hughes & Gammon (1987), and Moyle *et al.* (1986) successfully used a similar metric. Both trout (*Salmo trutta* L.) and pike (*Esox lucius* L.) are sensitive to physical and chemical habitat degradation and they are important species to fishermen.

Trophic composition. All three original metrics were retained, '% of individuals as omnivores', '% of individuals as insectivores (invertivores)', and '% of individuals as top carnivores'. The omnivore metric is designed to measure increasing levels of environmental degradation due to a disruption of the food base. Omnivores are defined as species that consistently feed on substantial proportions of plant and animal material, but do not include filter feeding species such as lamprey ammocoetes. Because invertivores are the dominant trophic guild in most streams and rivers, this metric is designed to be sensitive over the middle range of biotic integrity. We prefer the more general term, 'invertivore', because these fishes typically eat crustaceans, oligochaetes, and mollusks, as well as insects. A low abundance of invertivores typically reflects a degradation of the invertebrate food base of a stream (Karr *et al.*, 1986). Top carnivores are species that feed, as adults, primarily on fish, other vertebrates, or large invertebrates such as crayfish. Many of these species are popular sport fish and the metric discriminates between high and moderate quality systems.

Fish health and abundance. Two of the original three metrics were unchanged: 'Catch per unit of effort' (CPUE) and '% of individuals with disease'. As noticed by Steedman (1988) working in the Toronto, Ontario, metropolitan area, very high CPUE was often associated with warm, enriched rivers and low CPUE more often with strongly degraded systems. Unusually low CPUE often indicates toxicity, making this metric most sensitive at the low end of the biological integrity scale. Although no disease data were available for this study, we retained the metric for future investigations because it is easy to apply in the field and seems to reflect highly degraded areas. We deleted '% of individuals as hybrids' because this metric is difficult to apply in most regions, it is inconsistently related to habitat degradation (Pflieger, 1975; Ohio EPA, 1988), and available data on

Table 2. Guilds for common freshwater cyclostomes and fishes of the Seine Basin.[a]

Family species	Trophic guild	Species tolerance	Non-native species	Extirpated species	Water column or benthic species	Gravel spawner
Petromyzontidae						
Petromyzon marinus L.	PA	IS	–	E	B	GS
Lampetra fluviatilis L.	PA	IS	–	E	B	GS
Lampetra planeri Bloch	FF	IS	–	–	B	GS
Acipenseridae						
Acipenser sturio L.	I	IS	–	E	B	GS
Anguillidae						
Anguilla anguilla L.	I/P	–	–	–	B	–
Clupeidae						
Alosa alosa L.	I	IS	–	E	WC	–
Alosa fallax Lacepede	I	IS	–	E	WC	–
Salmonidae						
Salmo salar L.	I/P	IS	–	E	WC	GS
Salmo trutta fario L.	I/P	IS	–	–	WC	GS
Salmo trutta L.	I/P	IS	–	E	WC	GS
Oncorhynchus kisutch Walbaum	I/P	–	NN	–	WC	GS
Oncorhynchus mykiss Walbaum	I/P	–	NN	–	WC	GS
Esocidae						
Esox lucius L.	P	IS	–	–	WC	–

Table 2. (Continued).

Family species	Trophic guild	Species tolerance	Non-native species	Extirpated species	Water column or benthic species	Gravel spawner
Cyprinidae						
Phoxinus phoxinus L.	I	–	–	–	WC	GS
Gobio gobio L.	I	–	–	–	B	–
Leuciscus leuciscus L.	I	–	–	–	WC	GS
Leuciscus cephalus L.	I/P	–	–	–	WC	–
Chondrostoma nasus L.	O	–	–	–	WC	GS
Barbus barbus L.	I	–	–	–	B	GS
Cyprinus carpio L.	O	–	NN	–	B	–
Tinca tinca L.	I	–	–	–	B	–
Abramis brama L.	I	–	–	–	B	–
Blicca bjoerkna L.	I	–	NN	–	WC	–
Rutilus rutilus L.	O	–	–	–	WC	–
Scardinius erythrophthalmus L.	O	–	–	–	WC	–
Rhodeus sericeus Bloch	H	–	–	–	WC	–
Alburnoides bipunctatus Bloch	I	IS	–	–	WC	GS
Alburnus alburnus L.	I	–	–	–	WC	–
Cobitidae						
Cobitis taenia L.	I	–	–	–	B	–
Noemacheilus barbatulus L.	I	–	–	–	B	–
Ictaluridae						
Ictalurus melas Rafinesque	I	–	NN	–	B	–
Gadidae						
Lota lota L.	P	IS	–	–	B	GS
Gasterosteidae						
Gasterosteus aculeatus L.	I	–	–	–	WC	–
Pungitus pungitius L.	I	–	–	–	WC	–
Centrarchidae						
Lepomis gibbosus L.	I	–	NN	–	WC	–
Micropterus salmoides Lacepede	P	–	NN	–	WC	–
Percidae						
Perca fluviatilis L.	I/P	–	–	–	WC	–
Stizostedion lucioperca L.	P	–	–	–	WC	–
Gymnocephalus cernua L.	I	–	–	–	B	–
Cottidae						
Cottus gobio L.	I	–	–	–	B	–

[a] I = invertivore; FF = filter feeder; PA = parasite; P = piscivore; O = omnivore; H = herbivore; IS = intolerant species; NN = non-native; E = extirpated; GS = gravel spawner; WC = water column; B = benthic. Fishes of the estuarine zone are not included.

hybrids are lacking for the Seine Basin. One metric was added, '% of individuals as gravel spawners', as suggested by Ohio EPA (1988), because these species use particular habitats for reproduction and are sensitive to degradation of these habitats.

Species assignments

Before computing IBI scores, we determined the niche, habitat, and status of each species (Table 2). We made species assignments after consulting regional ichthyological books (Spillmann, 1961; Muus & Dahlström, 1968; Gregoire, 1983; Philippart & Vranken, 1983) and making personal observations. A species was regarded as intolerant of anthropogenic changes if its general abundance or geographical distribution has been dramatically reduced in this century and if it is restricted to high quality sites. Selection of these species was based on data from a comparison of fish community collections in two rivers of the Seine Basin between 1927 and 1967 by the Féderation Départementale des Associations de Pêche et de Pisciculture and from the above books.

Calculation of IBI metrics

The IBI was calculated for each sample site according to methods outlined in Karr *et al.* (1986). Measures of species composition (total species, number of water-column species, number of benthic species, number of intolerant species) were scored from Maximum Species Richness Lines (MSRL) (Fausch *et al.*, 1984), which indicate potential species richness for the sample as a function of catchment area (Fig. 2). Species richness was plotted against catchment area, which gives a more reliable measure of water body size than does stream order (Hughes & Omernik, 1981, 1983). This relationship is assumed to be log linear because of the great range in catchment size and the much smaller range in species richness (Fausch *et al.*, 1984, Mahan, 1984). The MSRL was fitted by eye to include about 95% of the sites and it indicates the number of species expected in relatively undisturbed sites of various sizes. Fausch *et al.* (1984) judged that such a line was a more meaningful measure of potential species richness than one provided by linear regression, especially when data are lacking for small streams. The area under the MSRL was trisected to determine the ratings. A station scored maximum points (5) if species richness was 0.67 MSRL or higher, 3 points for 0.33 to 0.67 MSRL, and 1 point for less than 0.33 MSRL.

We used the same approach to assess fish abundance (catch per minute of sampling). For this metric, the Line of Maximum CPUE was defined as a 'fair' fish community, because we noticed that high CPUE was associated with relatively degraded sites and increased abundance of tolerant species like roach. A station scored a maximum of points (5) if CPUE was 0.33 to 0.67 of that predicted by the Line of Maximum CPUE, 3 points for 0.67 or greater, and 1 point for less than 0.33; Steedman (1988) used a similar scoring approach.

For all the other metrics, we used as a standard the least disturbed regional sites for the years 1967 and 1981 (sites with a high number of species and high number of intolerant species). As no data were available for the metric '% of individuals with disease', a rating of 3 was arbitrarily assigned to this metric. We also attributed a rating of 3 to the metric CPUE for the IBI in the year 1967 because these data were missing. Karr *et al.* (1986) recommended a score of 5 for metrics with missing data, but this tends to overestimate quality and Karr (pers. comm.) now believes that 3 is best for all but hybrid and disease metrics. Criteria for scoring the IBI are summarized in Table 3.

Testing contribution of IBI metrics

We used multiple regression of each metric to test its relative contribution to the IBI. A model containing total number of species, % of indi-

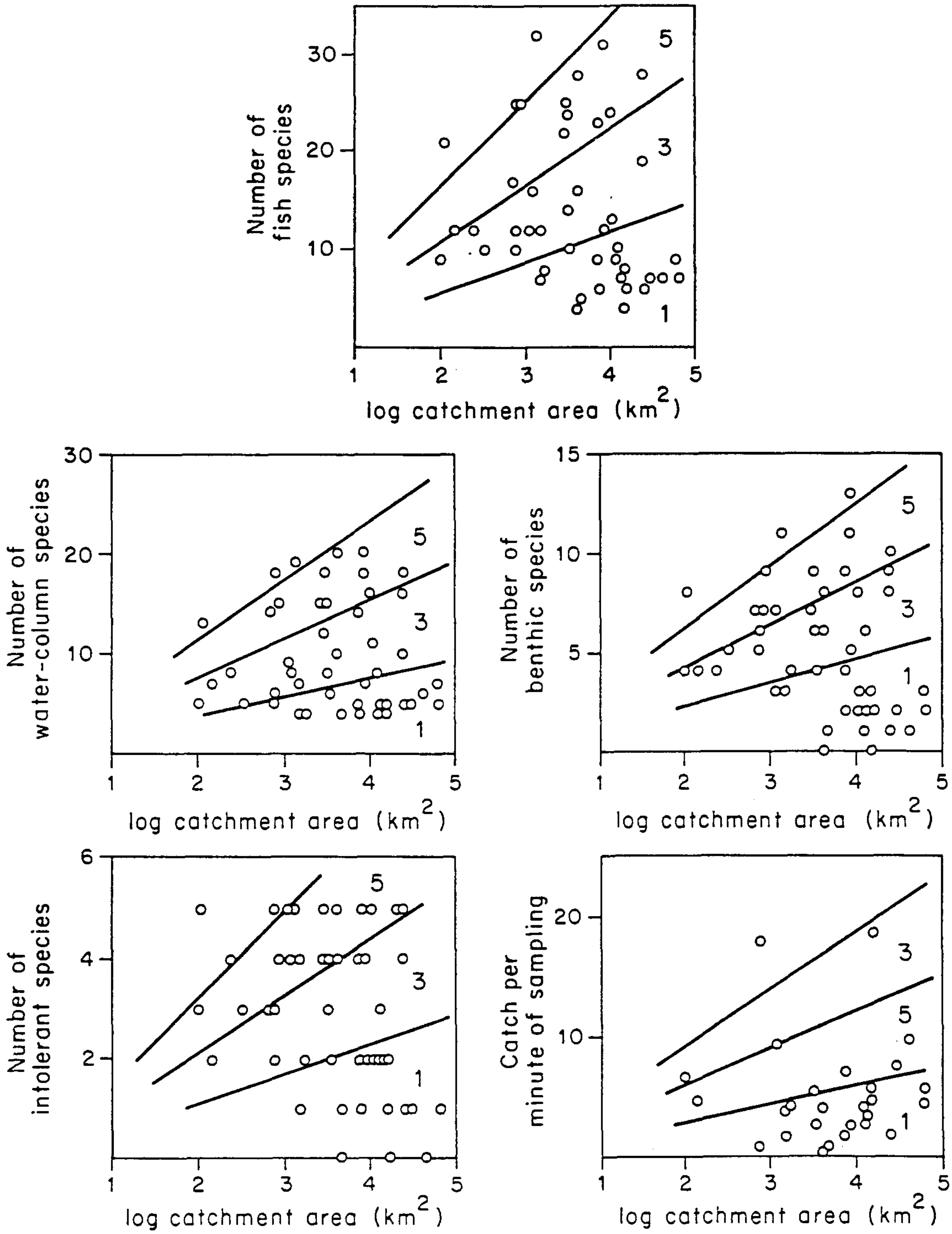

Fig. 2. Maximum species richness lines (MSRL) and catch per unit of effort (CPUE) lines used in determining IBI metric scores.

Table 3. Criteria for scoring Index of Biotic Integrity metrics adapted for this study.[a]

Category	Metric	Scoring criteria		
		5	3	1
Species richness and composition	1. Total number of species (% MSRL)	>67	33–67	<33
	2. Number of water column species (% MSRL)	>67	33–67	<33
	3. Number of benthic species (% MSRL)	>67	33–67	<33
	4. Number of intolerant species (% MSRL)	>67	33–67	<33
	5. % of individuals as roach	<30	30–60	>60
	6. Trout or pike year classes	0+–>2+	0+–2	0
Trophic composition	7. % of individuals as omnivores[b]	<1	1–5	>5
	8. % of individuals as invertivores	>35	20–35	<20
	9. % of individuals as top carnivores	>5	1–5	<1
Fish health and abundance	10. % of individuals as gravel spawners	>10	5–10	<5
	11. % of individuals with anomalies (disease, tumors, fin damage)	–	–	–
	12. Catch per minute of sampling (% of line of maximum CPUE)	33–67	>67	<33

[a] A metric scored 1 represents the lowest quality; 3 is intermediate; 5 is highest quality.
[b] Excludes *Rutilus rutilus*.

viduals as invertivores, trout or pike year classes, and % of individuals as gravel spawners explained 96% of the IBI variation (Table 4). We did not test the variable CPUE, because it was missing data from 1967, nor the % of individuals with anomalies, because it lacked data for all three years.

Table 4. Results of multiple regression of IBI on 10 of the 12 metrics for all the stations.[a]

	Number of metrics in model									
	1	2	3	4	5	6	7	8	9	10
	TNS	TNS	TNS	TNS	TNS	TNS	TNS	TNS	TNS	TNS
		IAI	IAI	IAI	IAI	IAI	IAI	IAI	IAI	IAI
			TOP	TOP	TOP	TOP	TOP	TOP	TOP	TOP
				IAG	IAG	IAG	IAG	IAG	IAG	IAG
					IAC	IAC	IAC	IAC	IAC	IAC
						NIS	NIS	NIS	NIS	NIS
							IAO	IAO	IAO	IAO
								NIR	NIR	NIR
									NWS	NWS
										NBS
r^2	0.75	0.90	0.93	0.96	0.97	0.97	0.98	0.98	0.99	1.00

[a] $n = 46$; all analyses used a maximum r^2 algorithm; metrics are listed in order of decreasing significance: TNS = total number of species; IAI = % of individuals as invertivores; TOP = trout or pike year classes; IAG = % of individuals as gravel spawners; IAC = % of individuals as top carnivores; NIS = number of intolerant species; IAO = % of individuals as omnivores; NIR = number of individuals as roach; NWS = number of water column species; NBS = number of benthic species.

Performance of the IBI relative to known perturbations

We compared River Oise (1988–1989) IBI scores against an independent measure of pollution. We used Water Quality Index (WQI) scores provided by the Agence de Bassin Seine-Normandie. This WQI used 5 qualitative values (excellent, good, fair, mediocre, bad) to integrate the influence of 12 variables (temperature, dissolved oxygen, pH, % of oxygen saturation, 5-d biological oxygen demand, nitrates, phosphates, ammonia, heavy metals, turbidity, chlorophyll, and fecal coliforms).

Results and discussion

Analysis of biodiversity

We observed a strong relationship between extirpated species and their degree of primitiveness. Twenty-two percent of the total native species included in this study were classified as extirpated. All belonged to the six most primitive families and represented 70% of the total number of native species of these small families (Fig. 3).

Spatial and temporal variation in the IBI

Temporal variation in the IBI during the period studied is illustrated by Fig. 4. The highest IBI

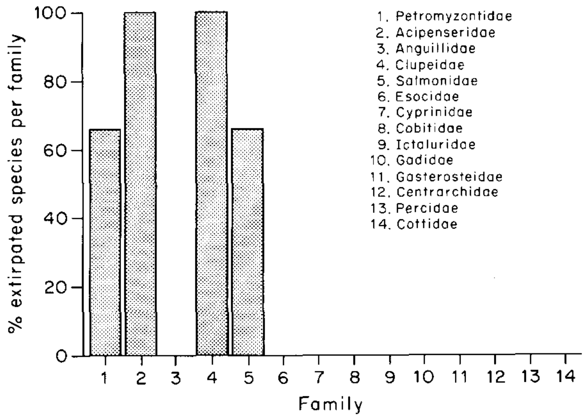

Fig. 3. Percent of extirpated species in each fish family by order of primitiveness.

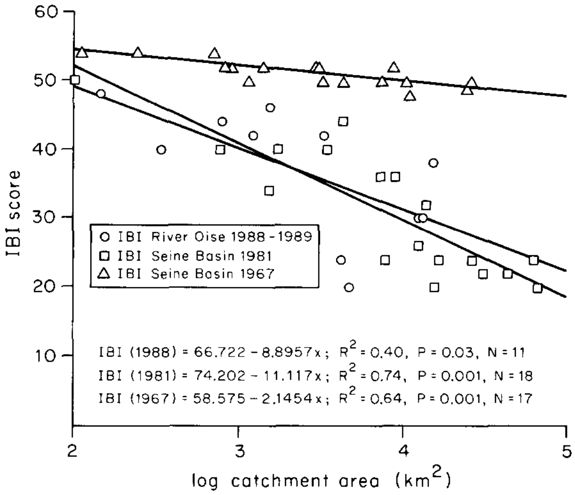

Fig. 4. IBI as a function of catchment area for the Seine Basin in 1967 and 1981, and for the River Oise in 1988–1989.

values occurred during 1967, with an index value classified as good for all the stations (variation of the IBI from 55 to 50). In the two other years, IBI values varied respectively from 50 to 20 (good to very poor) for 1981 and from 49 to 20 (good to very poor) for 1988–89. These differences do not represent temporal degradation, because the data were not collected from the same sites in the same manner each year. They are presented here only as examples of how the IBI can be used to evaluate river quality, given a suitable sampling design. Linear regressions were used to test the correlation between IBI and catchment area. For all three years, IBI values decreased significantly in a downriver direction ($r^2 = 0.64$, $P = 0.001$ for 1967; $r^2 = 0.74$, $P = 0.001$ for 1981; $r^2 = 0.40$, $P = 0.03$ for 1988–1989). This phenomenon was more apparent for 1981 and 1988–1989 than for 1967.

The IBI for the River Oise (1988) relative to known perturbations

We plotted midpoints of the qualitative scores of IBI and WQI to assess comparability (Fig. 5). The IBI classes were always lower than the WQI, except for one upriver station. One explanation

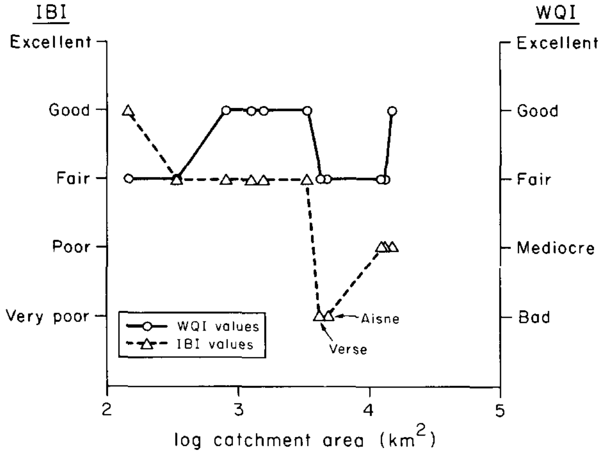

Fig. 5. Variation of the IBI and of the WQI for the River Oise in 1988–1989. Arrows indicate two stations with low IBI corresponding to the confluence of two tributaries of the River Oise.

for this phenomenon was that the IBI was biased for scoring higher upriver than downriver. We rejected this hypothesis because results from 1967 show relatively constant IBI values as a function of catchment area (Fig. 4). However, it is possible that sampling was less adequate in the lower reaches than in the upper reaches in 1981 and 1988–1989. Another explanation is that the IBI integrates factors such as flow alterations and physical habitats, unlike the WQI, which considers only water quality. In upriver sites, anthropogenic perturbations do not yet modify physical habitat and fish assemblages to the degree they do downriver. On the other hand, at downriver sites, increasing degradation from channelization, dams, agricultural lands, urbanization, and industrialization tend to strongly alter the biotic integrity and may explain the lower values of the IBI. Using a regression model, we found that IBI was successfully predicted by catchment area alone ($P = 0.009$, $r^2 = 0.54$, $n = 11$), and by WQI and catchment area, using the following model:

$$\text{IBI} = 3.755 + 0.641\ \text{WQI} - 1.042 \log \text{CA}$$
$$(r^2 = 0.67, n = 11),$$

where CA = catchment area with $P = 0.0063$ and WQI = Water Quality Index, with $P = 0.011$.

For the same WQI value, variation of the IBI was directly influenced by the catchment area, with IBI values decreasing as catchment area increased. Compared with the WQI, which assesses only conventional water quality variables, the IBI is a more robust tool for assessing quality of the entire water body because of its ability to integrate the biological, physical, and chemical effects of surface water perturbations.

We analyzed two stations with very low IBI (20–24) and fair WQI scores (Fig. 5). The Verse and the Aisne enter the River Oise at these two stations. Just before its confluence with the River Oise, the Verse traverses the city of Noyon and receives effluent from a sewage treatment plant and storm water discharges. At its confluence with the River Oise, the River Aisne water quality is considered 'bad' because of low dissolved oxygen and high nitrogen and ammonia. Despite a flow ratio of 1 : 20 and 1 : 2, respectively, between Stream Verse/River Oise and River Aisne/River Oise, the biotic integrity of the River Oise seems to have been drastically perturbed near these confluences. The WQI did not detect these perturbations. Ohio EPA (1988) found similar discrepancies between chemical and biological evaluations of water body quality.

Analysis of the fish assemblage metrics (Fig. 6) for the two stations indicates how IBI metrics

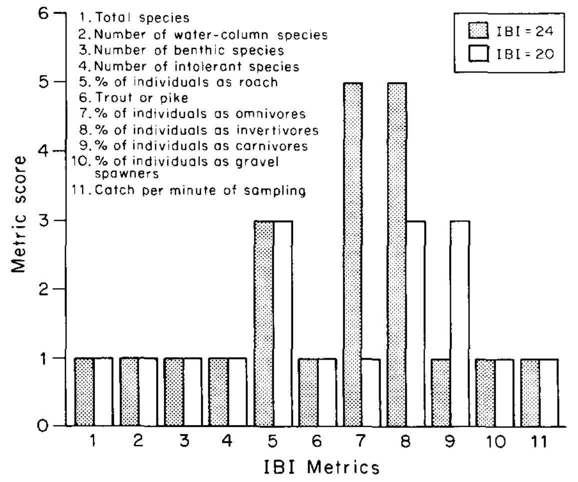

Fig. 6. Metric behavior for two stations of the River Oise with low IBI scores (1988–1989).

respond to water body condition. The values for species composition and richness and fish abundance metrics are consistent with river degradation. Values of the trophic composition metrics failed to support the predicted decreasing trend with increasing pollution. This inconsistent response probably results from the small number of fish captured (10 and 20) at the two sites. Ohio EPA (1988) found a similar pattern in sites seriously impacted by toxic chemicals and scored proportional metrics as 1 when CPUE reached specific cutoff points.

Conclusions

There are at least four reasons for increased biological monitoring and assessment in the Seine Basin.

1. Diadromous fish species have been rapidly extirpated in recent years, presumably because of overfishing and dams.
2. Declining IBI scores with increasing catchment size, especially in later years, suggest continued deterioration of the rivers despite efforts to control point sources of pollution.
3. Comparisons between the IBI and a chemically based water quality index reveal that the former offers more protective assessments of water body quality.
4. A biological evaluation such as the IBI provides a means to quantify ecological changes that result from the combination of chemical, physical, and biological stressors.

The fact that IBI concepts based on community or assemblage ecology can be applied to the differing fish faunas of two different continents (23 out of 40 species differ) offers support for its wider use.

It is interesting to note that the extirpated species are those that normally are characterized by extinction resistant traits (broad geographic distribution, high dispersal potential). Why then might they have been eliminated from the Seine basin? The six primitive families, as determined by cladistic analysis by Lauder & Liem (1983), contain all the anadromous and catadromous species found in the Seine Basin, that is, all migrate between fresh and salt water. Some of these migrations attract commercial fishermen. More importantly for diadromous species, dams hinder their migrations and prevent them from reproducing and feeding in preferred environments. Finally, most of these species require clean substrata for spawning and clear water for feeding. The relationship between primitiveness and extirpation is by no means a general rule. Although Lelek (1989) demonstrated declines in all species in the same primitive families for the Rhine River, he also found that some species in more advanced families had disappeared. In North America, Williams *et al.* (1989) did not demonstrate greater tendency for extirpation among primitive families.

Data used during our study covered only seven decades but showed that six species and two families of fishes have been eliminated from the Seine basin. Similar declines in the fish fauna for the Rhine (Lelek, 1989), for other large rivers (Dodge, 1989), and for Iran (Coad, 1980) and North America (Williams *et al.*, 1989) have been reported. These large-scale biodiversity declines lead to depletion of genetic variability (for the entire fish assemblage), then to a decline in the assemblage's ability to adjust to short- and long-term stressors, and finally to species extinction.

The results of this study and that of Hughes & Gammon (1987) and Ohio EPA (1988) indicate that the IBI can be a useful and sensitive measure for monitoring biotic integrity in large rivers. Such an index, when combined with a statistically defensible monitoring design, could provide a useful means of assessing and reporting on status and spatial and temporal trends in European rivers. With such an approach, the biological quality of entire rivers or all the rivers of a nation or continent could be evaluated and communicated to the public and to decision makers.

Efforts to protect and restore water resources need to combine chemical and physical criteria with indices and biological criteria that measure the health or integrity of biological communities (fish, invertebrates, algae). Continued biological monitoring and biological criteria provide a direct and effective way to determine if actions taken result in improvements in the water resource system (Hughes *et al.*, 1990; Karr & Dudley, 1981; Karr, 1987; Karr, 1990). Although this first use of the IBI in Europe was successful, we encourage other ichthyologists and ecologists to test the concept further, particularly in large rivers and near-coastal marine waters. These ecosystems, though highly impacted, are capable of considerable recovery, and current chemical monitoring alone is inadequate for assessing the quality of the resource.

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References

Coad, B. W., 1980. Environmental change and its impact on the freshwater fishes of Iran. Biol. Cons. 19: 51–80.

Crumby, W. D., M. A. Webb & F. J. Bulow, 1990. Changes in biotic integrity of a modified river in north central Tennessee. Trans. am. Fish. Soc. 119: 885–893.

Dodge, D. P. (ed.), 1989. Proceedings of the international large river symposium. Can Spec. Publ. Fish. aquat. Sci. 106, 629 pp.

Fausch, K. D. & L. H. Schrader, 1987. Use of the index of biotic integrity to evaluate the effects of habitat, flow, and water quality on fish communities in three Colorado Front Range streams. Final Report to Kodak-Colorado Division and the Cities of Fort Collins, Loveland, Greeley, Longmont, and Windsor. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO, USA, 53 pp.

Fausch, K. D., J. R. Karr & P. R. Yant, 1984. Regional application of an index of biotic integrity based on stream fish communities. Trans. am. Fish. Soc. 113: 39–55.

Gregoire, P., 1983. Contribution à la connaissance de la répartition des poissons d'eaux douce en France. D.E.A. d'écologie de l'Université Paris VI. Paris, France, 141 pp.

Hughes, R. M. & J. R. Gammon, 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Trans. am. Fish. Soc. 116: 196–209.

Hughes, R. M. & J. M. Omernik, 1981. Use and misuse of the terms, watershed and stream order. In L. A. Krumholz (ed.), The Warmwater Streams Symposium. Am. Fish. Soc., Bethesda, MD, USA, 320–326.

Hughes, R. M. & J. M. Omernik, 1983. An alternative for characterizing stream size. In T. D. Fontaine III & S. M. Bartell (eds), Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, MI, USA, 87–102.

Hughes, R. M., D. P. Larsen & J. M. Omernik, 1986. Regional reference sites: a method for assessing stream potentials. Envir. Mgmt 10: 629–635.

Hughes, R. M., T. R. Whittier, C. M. Rohm & D. P. Larsen, 1990. A regional framework for establishing recovery criteria. Envir. Mgmt 14: 673–684.

Karr, J. R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6: 21–27.

Karr, J. R., 1987. Biological monitoring and environmental assessment: a conceptual framework. Envir. Mgmt 11: 249–256.

Karr, J. R., 1990. Biological integrity: a long-neglected aspect of water resource management. Ecol. Appl. 1: 66–84.

Karr, J. R. & D. R. Dudley, 1981. Ecological perspective on water quality goals. Envir. Mgmt 5: 55–68.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant & I. J. Schlosser, 1986. Assessing biological integrity in running waters: a method and its rationale. I11. Nat. Hist. Surv. Spec. Publ. 5, Urbana, IL, USA, 28 pp.

Lauder, G. V. & K. F. Liem, 1983. The evolution and interrelationships of the actinopterygian fishes. Bull. Mus. comp. Zool. 150: 95–197.

Lelek, A., 1989. The Rhine River and some of its tributaries under human impact in the last two centuries. In D. P. Dodge (ed.), Proceedings of the international large river symposium. Can. Spec. Publ. Fish. aquat. Sci. 106: 469–487.

Leonard, P. M. & D. J. Orth, 1986. Application and testing of an index of biotic integrity in small, coolwater streams. Trans. am. Fish. Soc. 115: 401–415.

Mahan, R., 1984. Divergent structure in fish taxocenes of north temperate streams. Can. J. Fish. aquat. Sci. 41: 330–350.

Metcalfe, J. L., 1989. Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. Envir. Pollut. 60: 101–139.

Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniels, K. D. Fausch, G. A. Fitzhugh, J. R. Gammon, D. B. Halliwell, P. L. Angermeier & D. J. Orth, 1988. Regional applications of an index of biotic integrity for use in water resource management. Fisheries 13: 12–20.

Moyle, P. B., L. R. Brown & B. Herbold, 1986. Final report on development and preliminary tests of indices of biotic integrity for California. Final report to the U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR, USA, 22 pp.

Muus, B. J. & P. Dahlström, 1968. Guide des poissons d'eau douce et pêche. Delachaux et Niestlé. Paris, France, 242 pp.

Ohio EPA, 1988. Biological criteria for the protection of aquatic life. Ohio Environmental Protection Agency, Division of Water Quality Monitoring and Assessment, Columbus, OH, USA, 343 pp.

Pflieger, W. L., 1975. The fishes of Missouri. Missouri Department of Conservation, Jefferson City, MO, USA, 343 pp.

Philippart, J. C. & M. Vranken, 1983. Atlas des poissons de Wallonie. Distribution, écologie, éthologie, pêche, conservation. Cahiers d'Ethologie Appliquée. Vol. 3. Suppl. 1–2. Université de Liège, Liège, Belgique, 395 pp.

SAS Institute Inc., 1989. Preliminary documentation for the JMPTM user's guide. SAS Institute Inc., Cary, NC, USA, 464 pp.

Spillmann, C. J., 1961. 65 poissons d'eau douce. In P. Lechevalier (ed.), La faune de France. Paris, France, 304 pp.

Steedman, R. J., 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Can. J. Fish. aquat. Sci. 45: 492–501.

Thompson, B. A. & G. R. Fitzhugh, 1986. A use attainability study: an evaluation of fish and macroinvertebrate assemblages of the lower Calcasieu River, Louisiana. Center for Wetland Resources, Coastal Fisheries Institute, Louisiana State University, Baton Rouge, LA, USA, 143 pp.

Verneaux, J., 1976a. Application de la méthode des 'indices biotiques' à l'échelle d'un réseau hydrographique: cartographie de la qualité biologique des eaux. In P. Pesson (ed.), La pollution des eaux continentales. Gauthier-Villars, Bordas, Paris, France, 221–228.

Verneaux, J., 1976b. Fondements biologiques et écologiques de l'étude de la qualité des eaux continentales – principales méthodes biologiques. In P. Pesson (ed.), La pollution des eaux continentales. Gauthier-Villars, Bordas, Paris, France, 229–285.

Verneaux, J. & G. Tuffery, 1967. Une méthode zoologique pratique de détermination de la qualité biologique des eaux courantes. Indices biotiques. Ann. Sci. Univ. Besancon, Zool. 3: 79–89.

Williams, J. E., J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro-Mendoza, D. E. McAllister & J. E. Deacon, 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14: 2–20.