An Index of Biotic Integrity characterizing fish populations and the ecological quality of Flandrian water bodies

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Abstract

A multimetric fish Index of Biotic Integrity (IBI) was composed to assess the biotic integrity of Flandrian water bodies. As fish communities differ substantially between standing waters, running waters of the bream zone and running waters of the barbel zone, eight candidate metrics for each of these water types or zones were identified, representing three major classes of biological attributes. These are species richness and composition, fish condition and abundance, trophic composition. The metrics were tested and modified where needed. The IBI was applied throughout Flanders on 104 locations in standing waters, 500 locations in waters of the bream zone and 257 locations in waters of the barbel zone. Standing waters scored substantially different from running waters. Standing waters rarely contained no fish at all, but their fish communities were very often poor to very poor. Waters of the bream and barbel zone were often fishless (respectively 40% and 35% of all locations contain no fish), but the locations with fish usually scored reasonable to poor. Only 18.5% of all locations were classified as reasonable to excellent (IBI classes 4 or lower on a scale from 1 to 9) and were considered to satisfy the basic ecological quality demands. The Leie-, Dijle-, Dender- and Schelde-basins had a very poor quality (more than 50% of the locations contained no fish). The Maas-, Grote and Kleine Nete-basins scored rather well, with respectively, 44%, 48% and 68% of the locations achieving an IBI of 4 or lower. The IBI is a valuable and complementary tool to assess the ecological quality of water bodies as suggested in the proposal for a Water Framework Directive by the European Commission.

Introduction

Since Karr (1981), analysis of fish communities has become widely accepted in various continents as a tool for the quality assessment of aquatic habitats. His Index of Biotic Integrity (IBI) is based on characteristics of the fish assemblage, such as species diversity, trophic composition, fish biomass and condition. Biotic integrity was defined as: the ability to support and maintain “a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of natural habitat of the region” (Karr & Dudley, 1981).

In North and Central America, applications of the index of biotic integrity was described for several river systems of the Midwestern U.S., e.g.: Fausch et al. (1984) and Karr et al. (1987). Modifications of the original IBI (Karr, 1981) were developed by Steedman (1988) for rivers and streams of South-Ontario. The utility of this method was demonstrated on many more occasions: Leonard & Orth (1986) for streams of West Virginia, Bramblett & Fausch (1991) for rivers of south-eastern Colorado, Osborne et al. (1992) for river basins in Illinois, Fore et al. (1994) for streams of Ohio, Minns et al. (1994) for the Great Lakes of North America, Shields et al. (1995) for streams in Mississippi, Lyons et al. (1995) for streams and rivers in west-central Mexico, Lyons et al. (1996) for Wisconsin cold water streams, Hall et al. (1996) and Paller et al. (1996) for, respectively, Maryland and South Carolina coastal plain streams, amongst others.

In Africa, Hugueny et al. (1996) recently applied the IBI to evaluate fish assemblages in the West African river Konkouré in Guinea. The IBI was adapted to African fish communities, using mormyrid, cichlid and large, benthic siluriform species instead of the American darter, sunfish and sucker species. This application demonstrated the capacity of the IBI to assess the impact of a bauxite treatment plant. Hay et al. (1996) developed an IBI for the Okavango river in Namibia and used it to assess habitat and trophic level degradation, pollution and reduction of the fish stocks while Toham & Teugels (1999) described the use of the IBI in assessing the impact of deforestation in West Africa (river Ntem, Cameroon).

Oberdorff & Hughes (1992) used the IBI to analyse the fish communities of the river Seine. Oberdorff & Porcher (1994) used this fish-based index to assess the impact of salmonid farm effluents in Brittany (France). In Belgium, Didier & Kestemont (1996) discussed variations in IBI scores for several stretches of the river Ourthe with a variety of mesohabitats (Meuse basin). In Flanders, Verbruggen et al. (1996) illustrated the utility of the IBI as an instrument to quantify the degradation resulting from the use of the natural water resources and Maeckelberghe et al. (1998) and De Pauw et al. (1999) gave general overviews of the biotic integrity of the fish stocks in several river catchments in Flanders. Belpaire & Hartgers (1998) illustrated the ability of the multimetric fish Index of Biotic Integrity to assess efficiency of water purification programs.

The plasticity of the IBI methodology is illustrated in Table 1, showing examples of fish based metrics in IBIs adapted to local circumstances. A thorough overview of the use of multimetric indices in biological monitoring is published in Karr & Chu (1999).

The objective in this paper is to provide an overview of the methodology, metrics and scoring criteria used in developing a multimetric fish Index of Biotic Integrity (IBI) adapted to Flandrian water bodies.

Description of sites studied

Most of the data are based on the results of 861 fish assemblage surveys in Flandrian water bodies, carried out during the period 1993–1997. The fish assemblage surveys were mostly carried out by the Institute of Forestry and Game Management (IFGM) (unpublished), but in a number of cases results from published reports were used (Germonpré et al., 1993; Denayer, 1994; Gilson et al., 1994a, b; Belpaire et al., 1998; De Charleroy & Beyens, 1998). For the Nete basin and the old meanders of Schelde and Leie, available data were older (Verheyen et al., 1984, 1985; Samsoen, 1989). The study includes head streams as well as tributaries (stream width ranging from 0.5 m to 40 m), canals, disconnected river meanders, water retaining basins, ponds and lakes, and took place in all of the three major basins in Flanders (IJzer, Schelde and Maas). Stations with running waters were grouped per basin or subbasin. For the basin of the Schelde data on (from west to east) the Leie, Upper and Lower Schelde, Dender, Demer, Dijle and Nete subbasins are presented (Figure 1).

Materials and methods

Techniques used for fish stock analysis varied between research institutions and water types. Fish population surveys carried out by the IFGM were standardised. In general, electrofishing was used, sometimes completed with additional techniques as gill nets, fyke (90 cm diameter and 22 m long) and seine netting (variable sizes). Electrofishing was carried out using a 5 kW generator with an adjustable output voltage of 300–500 V and a pulse frequency of 480 Hz. The number of electrofishing devices and the number of hand-held anodes used depended on the river width. In riverine environments, electrofishing was carried out in upstream direction. When gill nets were used, a set of four monofilament nylon nets was placed (45, 50, 60 and 70 mm mesh size). Further details about sampling methodology are given in Table 2.

All fish were identified and counted. At each station, 200 specimens of each species were individually weighed (Sartørius PT 600 and T 2100) and total length was measured up to 1 mm. Where possible, biomass (kg/ha) and density (individuals/ha) were calculated based on sampling area or using the method of Seber & Le Cren (1967).

Huet's typology (1959), based on riverbed slope and cross section, was used to classify fishing localities of running waters. IBI metrics were defined for standing waters (S1: canals, lakes and isolated river arms) and for running waters of bream (C2) and barbel (C3) zone, comprising, to our estimation, 85–90% of Flanders' surface waters.

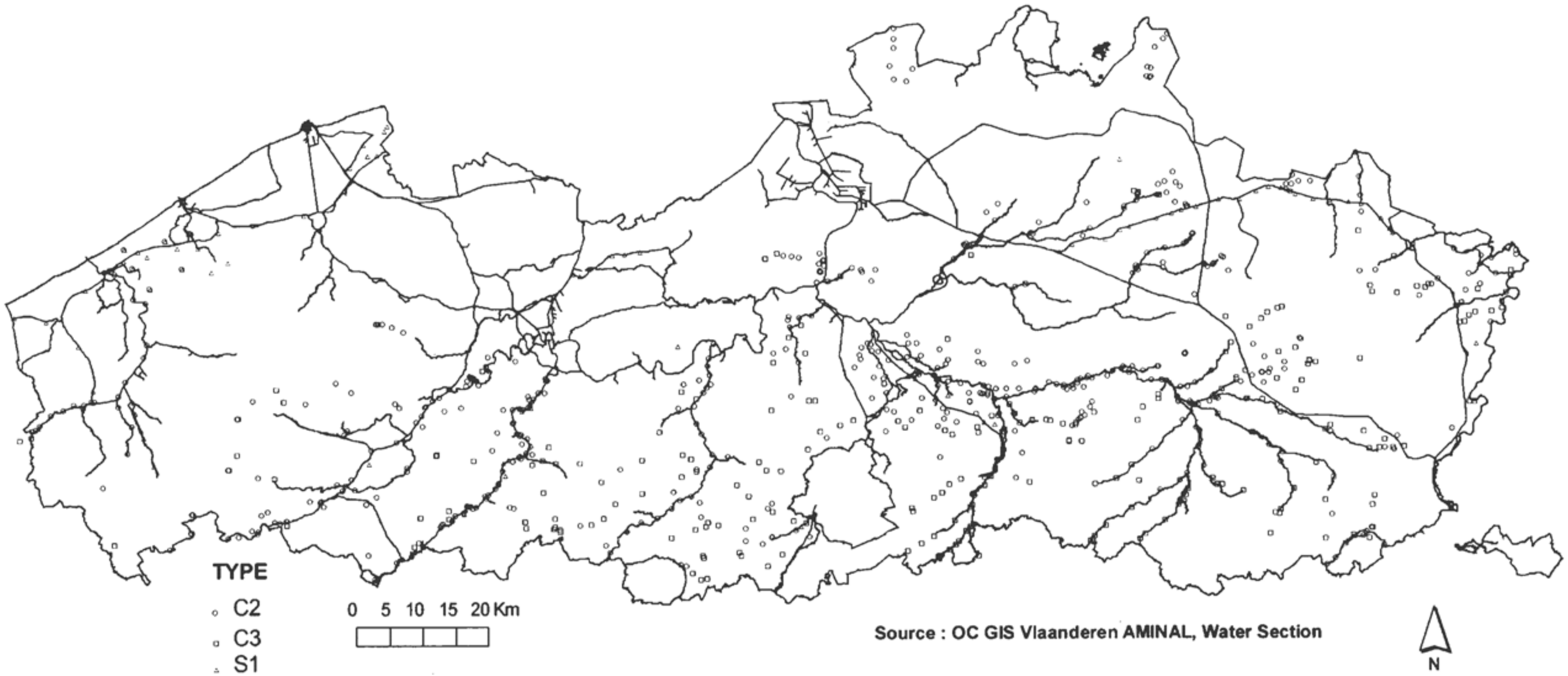

Figure 1. Localisation of sampling localities in Flanders (C2: river waters of bream zone; C3: river waters of barbel zone; S1: standing waters).

Table 1. Use of IBI metrics by various authors adapted to local ecological circumstances (1. Karr (1981), 2. Fausch et al. (1984), 3. Leonard & Orth (1986), 4. Karr et al. (1987), 5. Steedman (1988), 6. Bramblett & Fausch (1991), 7. Oberdorff & Hughes (1992), 8. Osborne et al. (1992), 9. Minns et al. (1994), 10. Oberdorff & Porcher (1994), 11. Shields et al. (1995), 12. Lyons et al. (1995), 13. Hay et al. (1996), 14. Lyons et al. (1996), 15. Hugueny et al. (1996), 16. Paller et al. (1996), 17. Hall et al. (1996), 18. Didier & Kestemont (1996), 19. Toham & Teugels (1999))

Category - Metric	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19
Species composition and richness																		
number of species	*	*	*	*		*	*	*		*	*			*		*	*	*
number of darter and sculpin species					*											*		
species richness and composition of sunfish	*	*		*				*			*				*	*		
number of shiner species																*		
number of native species					*				*			*	*					
benthic species individuals (%)							*			*		*	*				*	
number of species in water-column							*					*					*	
number of centrarchid species						*			*									
number of cyprinid species						*			*									
species richness and composition of darters	*	*	*	*				*			*							
species richness and compostion of suckers	*	*		*				*			*							
% of individuals as sculpin (intolerant species)										*								
% of individuals as eel and roach (tolerant species)										*								
% of expected number of total species															*			
% of expected number of native minnow species															*			
% of expected number of piscivorous species															*			
% of expected number madtom and darter species															*			
percent native minnows															*			
number of mormyrid species														*				
number of cichlid species														*				
number of (large) benthic siluriform species														*				*
proportion of green sunfish	*	*	*	*														
% of sample as *Rhinichtihys* spp.					*									*				
presence/absence of brook trout					*													
presence/absence of Cyprinodontidae																		*
number and composition of Characiformes and Cypriniformes																		*
number of sunfish of trout species					*													
number of sucker or catfish species					*													
% individuals rheophilic species												*					*	
% individuals preferring vegetated areas													*					
% as roach							*											
presence of intolerant species	*	*	*	*			*		*		*	*		*		*	*	*
tolerant species individuals (%)						*			*		*	*		*		*	*	*
year classes in species dominant & intolerant																	*	*
Trophic composition																		
proportion of omnivores	*	*	*	*	*	*	*	*		*	*	*	*			*	*	
proportion of insectivores						*									*	*		
proportion of individuals as pioneering species (%)																*		
proportion of insectivorous cyprinids	*	*	*	*				*			*							
% piscivore biomass					*			*	*		*		*					
% of individuals as omnivores							*			*			*				*	*
% of individuals as invertivores																		*

Continued on p. 21

Table 1. Continued

Category - Metric	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19
% generalist biomass									*									
% specialist biomass									*									
proportion of top carnivores	*	*		*			*							*			*	*
% individuals herbivores													*					
carnivores/non-carnivores																		
Fish condition and abundance																		
biomass of natives (kg)									*	*							*	
number of native individuals									*									
number of individuals in sample	*	*	*	*				*							*			*
catch per unit effort					*	*	*			*	*	*				*		
average number of fish sampled in nets with variable mesh size													*					
brown trout year classes										*								
trout or pike year classes							*											
proportion with disease, tumors, fin damage and other anomalies	*	*	*	*	*	*	*			*	*	*	*		*	*	*	*
proportion of hybrid individuals	*	*		*							*		*					
% individuals as simple lithophilic species																*		
native livebearing species individuals (%)												*						
% of individuals as gravel spawners							*											
% of individuals as phytolithophil (ubiquitious)																	*	
% of individuals as lithophil or phytophil																	*	
exotic species individuals (%)						*						*						

Relations between the individual metrics and between the metrics and the total IBI score were measured using correlation analysis (Pearson correlation coefficient). The significance of the correlation (p value) was tested with the Students t-test (two-tailed test).

Reference sites, metrics and methodology

Accurate historical data on fish populations in undisturbed reference sites in Flanders are scarce. Waters of the pike-tench-roach type, as described by OVB (1988a) and Coussement (1990), were adopted as reference sites for standing waters. For the bream zone, rivers in the Nete basin (De Backer, 1972; Bruylants, 1978) were selected and for the barbel zone the Herk river in the Demer basin (Timmermans, 1957), the Abeek and Warmbeek (Maas basin) (Gilson et al., 1994a, b) were chosen as reference sites. For each water type metrics belonging to 3 categories (1. Species diversity; 2. Trophic composition; 3. Fish biomass and condition) were defined following the general IBI concept (Karr, 1981). Scores for each metric range from 1 (poor) to 5 (excellent) (see Tables 3 and 4).

The methodology, metrics and scoring criteria are summarised in Tables 3 (standing waters) and 4 (running waters of bream and barbel zones) and are briefly discussed.

Species richness and composition

Total number of species

The number of fish species supported by an undisturbed aquatic ecosystem decreases with environmental degradation, as intolerant species will disappear with increasing disturbance (Karr et al., 1986). For standing waters, the scores were assigned, based on the distribution of the total number of species in the 104 standing waters. The upstream–downstream gradient influences species richness, therefore the influence of stream spatial location on this metric was investigated. 4 stream width classes (0–2.9 m, 3–6.4 m, 6.5–8.9 m and over 9 m) were defined. The adopted discrimination boundaries are similar to the divisions suggested earlier by Bruylants (1978) and Vriese et al. (1994). Trendline regression (EXCELL 97, polynome $y = -mx^2 + nx$ on k percentile of data with k=0.95) was used on C2 and C3 waters to define the

Table 2. Description of the techniques used for fish stock analysis in Flandrian water bodies by IFGM

Watertype	Techniques used
Running waters < 1.5 m	100 m electrofishing with 1 anode
Running waters 1.5–4 m	100 m electrofishing with 2 anodes
Running waters 4–6 m	100 m electrofishing with 3 anodes
Running waters 6–8 m	100 m electrofishing with 4 anodes
Running waters > 8 m	Combination of: • 500 m boat electrofishing (2 × 250 m on both river banks) • fykes and/or gill nets
Closed river arms and ponds Polder drainage systems	Combination of: • seine netting • boat electrofishing (both river banks) • fykes and/or gill nets

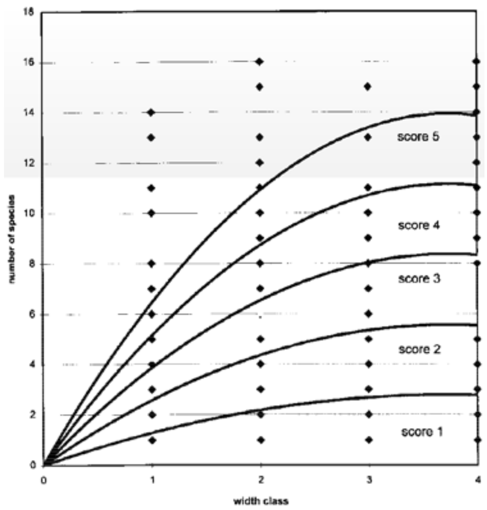

Figure 2. Scoring procedure for the metric 'Total number of species' for C2 waters, determined by the stream width (width class 1 = 0–3 m, 2 = 3–6.5 m, 3 =6.5–9 m and 4 ≥9 m), one dot can represent multiple observations.

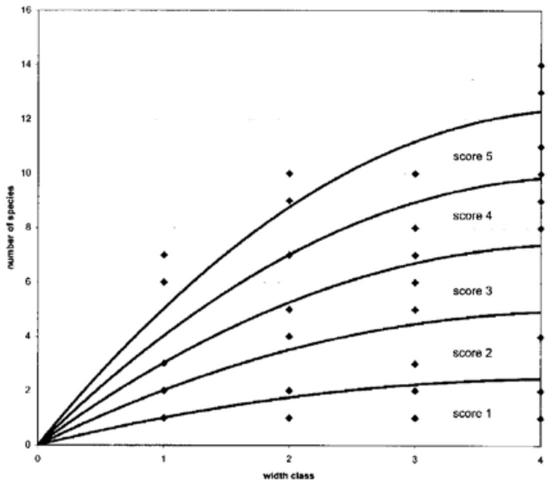

Figure 3. Scoring procedure for the metric 'Total number of species' for C3 waters, determined by the stream width (width class 1 = 0–3 m, 2 = 3–6.5 m, 3 = 6.5–9 m and 4 ≥9 m), one dot can represent multiple observations.

scores corresponding to each width class. Figure 2 shows the effect of stream width on the total number of species and the derived scores for this metric in the bream zone. A similar scoring system was developed for running waters in the barbel zone (see Figure 3).

Mean tolerance value

To each fish species, tolerance values for water quality and habitat quality scoring from 1 (very tolerant) to 5 (very intolerant) were assigned based on information from literature (OVB, 1988b; Reitsma, 1992; Oberdorff & Hughes, 1992; Oberdorff & Porcher, 1994) (Table 5). The individual tolerance value is the mean of the water quality and habitat quality tolerance scores. The final score for the mean tolerance value is calculated as the mean of the tolerance value for each species.

Mean typical species value (C2 and C3 waters only)

In a riverine habitat of good biotic integrity, typical as well as accompanying species should be present. In Flanders, the distribution of different species with changing geographic situation, is documented by Huet (1949, 1954), Bruylants et al. (1989) and Vandelannoote et al. (1998). Different species are considered to be typical of the bream or barbel zone due to adaptations to different stream velocities and structural

Table 3. Definition of metrics and scores for the calculation of the IBI for Flandrian water bodies of type S1 (lakes, ponds and canals).

Metric	Type S1				
Score	5	4	3	2	1
Total number of species	>15	15–12	11–8	7–3	<3
Mean tolerance value	≥2.4	2.39–2	1.99–1.6	1.59–1.2	<1.2
Type species*	≥4.5	4.49–3.5	3.49–2.5	2.49–1.5	<1.5
% Rutilus rutilus	*10–25*	*25.1–35*	*35.1–45*	*45.1–55*	*>55*
		9.9–7.5	*7.4–5*	*2.5–4.9*	*<2.5*
% Scardinius erythrophtalmus	*≥10*	*9.9–5*	*4.9–2*	*1.9–1*	*<1*
% Abramis brama	*0.1–10*	*10.1–20*	*20.1–30*	*30.1–40*	*>40*
					0
Pike recruitment and biomass (kg/ha)**	≥20 (+ recr.)	10–19.9 (+ recr.)	<10 (+ recr.)	≥20 (− recr.)	<20 (− recr.)
Tench recruitment and biomass (kg/ha)**	≥15 (+ recr.)	10–14.9 (+ recr.)	<10 (+ recr.)	≥15 (− recr.)	<15 (− recr.)
Total biomass (kg/ha)	100–349	350–499	500–649	650–799	≥800
		75–99	50–74	25–49	<25
Weight % of non-native species	<1	1–3.99	4–6.99	7–9.99	≥10
Weight ratio piscivores/non-piscivores	0.2–0.14	0.139–0.1	0.09–0.067	0.066–0.05	<0.05
		0.201–0.25	0.251–0.33	0.331–0.5	>0.5

*Score is obtained by taking the mean of the species scores in italics.

** + recr. and − recr. stand for the presence and absence of natural recruitment.

characteristics of the river. Typical species (score 5) are considered to be limited to one single zone. Accompanying species (score 3) are abundant in one zone, but are also often found in other zones. Atypical species for the concerning zone score 1. The metric score is calculated as the mean of the scores for each occurring species (Tables 4 and 5).

Type species

This metric combines the 'typical species' and 'tolerance' features, but it adds extra information on the relative abundance. For each type of water, three typical species were selected: for S1 bream (*Abramis brama*), roach (*Rutilus rutilus*) and rudd (*Scardinius erythrophtalmus)* (OVB, 1988a), for C2 roach, rudd and tench (*Tinca tinca*) (Bruylants, 1978; OVB, 1988a) and for C3 three-spined stickleback (*Gasterosteus aculeatus*), stone loach (*Barbatula barbatula*) (Gilson et al., 1994a, b) and chub (*Leuciscus cephalus*) (OVB, 1988a). Scores were attributed according to relative abundance classes expressed in % of total biomass. For species which are regular restocked, natural recruitment, reflected by the presence of specimens of the first year class (O^+), was taken into account. The final score for this metric was calculated as the mean of the individual scores for each type species (see also Tables 3 and 4).

Fish condition and abundance

*Pike (*Esox lucius*) recruitment and biomass (S1 waters only)*

In standing waters, the presence of good and stable pike populations is considered as an indicator for biotic integrity. Pike prefers a habitat of a good ecological quality (clear oligotrophic waters with a well developed submerged aquatic vegetation) (Billard, 1983; OVB, 1988b; De Nie, 1996). Both biomass and the capacity for natural recruitment (presence of O^+ pike <20 cm) are important criteria indicative for the integrity of a population (see Table 3).

Tench recruitment and biomass (S1 waters only)

Tench can be used as an indicator of good biotic integrity. It prefers a habitat with a wel developed submerged aquatic vegetation (Mann, 1996; Perrow et al., 1996; Copp, 1997). Biomass and natural recruitment (presence of O^+ tench <12 cm) are indicative criteria for the integrity of a population (see Table 3).

Table 4. Definition of metrics and scores for the calculation of the IBI for Flandrian water bodies of type C2 (river habitat corresponding to the bream zone) and type C3 (river habitat corresponding to the barbel zone).

Metric	Type C2					Type C3				
Score	5	4	3	2	1	5	4	3	2	1
Total number of species										
River width < 3 m	*≥7*	*6*	*5–4*	*3–2*	*1*	*≥5*	*4*	*3*	*2*	*1*
River width 3–6.4 m	*≥12*	*11–9*	*8–6*	*5–3*	*≤2*	*≥7*	*6*	*5–4*	*3–2*	*1*
River width 6.5–8.9 m	*≥13*	*12–10*	*9–7*	*6–4*	*≤3*	*≥10*	*9–8*	*7–6*	*5–4*	*≤3*
River width ≥ 9 m	*≥14*	*13–10*	*9–7*	*6–4*	*≤3*	*≥12*	*11–9*	*8–6*	*5–4*	*≤3*
Mean tolerance	≥2.4	2.39–2	1.99–1.6	1.59–1.2	<1.2	≥2.4	2.39–2	1.99–1.6	1.59–1.2	<1.2
Mean typical species value	≥3.3	3.29–3	2.99–2.7	2.69–2.4	<2.4	≥3.1	3.09–2.8	2.79–2.5	2.49–2.2	<2.2
Type species*	≥4.5	4.49–3.5	3.49–2.5	2.49–1.5	<1.5	≥4.5	4.49–3.5	3.49–2.5	2.49–1.5	<1.5
% *Gasterosteus aculeatus*						*<3*	*3–4.9*	*5–6.9*	*7–8.9*	*≥9*
% *Barbatula barbatula*						*≥11*	*10.9–9*	*8.9–7*	*6.9–5*	*<5*
% *Leuciscus cephalus***						*>20*	*20–5*	*<5*	*≥25*	*<25*
						(+ recr.)	*(+ recr.)*	*(+ recr.)*	*(− recr.)*	*(− recr.)*
% *Rutilus rutilus*	*10–25*	*25.1–35*	*35.1–45*	*45.1–55*	*>55*					
		7.5–9.9	*5–7.4*	*2.5–4.9*	*<2.5*					
% *Scardinius erythrophtalmus*	*≥10*	*5–9.9*	*2–4.9*	*1–1.9*	*<1*					
% *Tinca tinca***	*≥15*	*10–14.9*	*<10*	*≥15*	*<15*					
	(+ recr.)	*(+ recr.)*	*(+ recr.)*	*(− recr.)*	*(− recr.)*					
Total biomass (kg/ha)	100–349	350–499	500–649	650–799	≥800	250–349	350–449	450–549	550–649	≥650
		75–99	50–74	25–49	<25		100–249	60–99	20–59	<20
Weight % of non-native species	<1	1–3.99	4–6.99	7–9.99	≥10	<1	1–3.99	4–6.99	7–9.99	≥10
Trophic composition*	5–4.3	4.29–3.5	3.49–2.5	2.49–1.7	<1.7	5–4.3	4.29–3.5	3.49–2.5	2.49–1.7	<1.7
% omnivorous species	*<1*		*1–5*		*>5*	*<1*		*1–5*		*>5*
% invertivorous species	*>45*		*45–20*		*<20*	*>45*		*45–20*		*<20*
% piscivorous species	*3–5*		*2.9–1*		*<1*	*3–5*		*2.9–1*		*<1*
			5.1–7		*>7*			*5.1–7*		*>7*
Natural recruitment (%)	≥85	84.9–70	69.9–55	54.9–40	<40	≥85	84.9–70	69.9–55	54.9–40	<40

*Score is obtained by taking the mean of the species scores in italics. ** + recr. and − recr. stand for the presence and absence of natural recruitment.

Total biomass

For C2 and C3 waters, optimal biomasses were chosen: respectively, 100–350 kg/ha (Bruylants, 1978) and 250–350 kg/ha (Timmermans, 1957). Clear standing waters of the pike-tench-rudd-type contain an optimal biomass of 100–350 kg/ha (OVB, 1988a; Coussement, 1990). As eutrophication increases, the consequent higher primary production will lead to a higher total biomass. Chemical pollution however, will lead to a lower total biomass till the point where eventually there is no fish left. Biomasses higher or lower than the defined optimal biomass are an indication of suboptimal conditions. The metric is, therefore, bi-directional, reducing the scores for biomasses too high or too low compared to the optimal biomass (Tables 3 and 4). In some cases, restocking activities may affect this metric either in a positive or negative way.

Weight percentage of non-native species

Fish assemblages are considered to be biotically integer if no disturbance occurred. The presence of non-native fish species is considered as a disturbance factor (Lyons et al., 1995; Elvira, 1995; Wichert & Rapport, 1998). Consequently, the index of biotic integrity should be negatively correlated with the quantity of non-native fish species present. In Flanders, non-native species are usually very tolerant and some of them are widely distributed e.g. the striped mudminnow (*Umbra pygmaea*), the brown bullhead (*Ameiurus nebulosus*), pumpkinseed (*Lepomis gibbosus*) and so on (Table 5). In some cases, they act as competitors, overcrowding the native fishes. Their presence results from intentional restocking or inadvertent escapement. The latest invader, *Pseudorasbora parva* colonised a wide range of Flandrian waters, even in some riverine systems where the pollution load does not permit

Table 5. Individual tolerance values, typical species values and origin for the different fish species in Flandrian water bodies as used in the IBI. WQ = water quality, HQ: habitat quality, numbers indicate high (= 5), medium (= 3) or low (= 1) demands towards HQ or WQ. Typical species for a specific zone score high (= 5), untypical species score low (= 1), ? indicates no data available.

	Individual tolerance value WQ	Typical species for bream zone HQ	Typical species for barbel zone	
Lampetra planeri	5	5	1	1
Anguilla anguilla	1	3	3	3
Abramis brama	1	1	5	3
Blicca bjoerkna	1	1	3	3
Alburnus alburnus	1	1	3	3
Alburnoides bipunctatus	5	5	1	3
Barbus barbus	3	5	1	5
Carassius carassius	1	3	1	1
Carassius auratus°	1	1	3	3
Carassius auratus gibelio°	1	1	3	1
Chondrostoma nasus	3	5	?	5
Cyprinus carpio	1	3	3	3
Gobio gobio	3	3	1	5
Leucaspius delineatus	?	?	1	1
Leuciscus cephalus	3	3	3	5
Leuciscus idus	3	5	3	5
Leuciscus leuciscus	3	5	1	5
Phoxinus phoxinus	3	5	1	3
Pimephales promelas°	1	1	?	?
Pseudorasbora parva°	1	1	1	3
Rhodeus sericeus	5	3	3	3
Rutilus rutilus	1	1	5	3
Scardinius erythrophthalmus	3	3	5	3
Tinca tinca	3	5	5	3
Cobitis taenia	5	1	3	3
Misgurnus fossilis	1	5	3	?
Barbatula barbatula	3	3	1	3
Ameiurus nebulosus°	1	1	?	?
Esox lucius	3	5	5	3
Umbra pygmaea°	1	1	?	?
Oncorhynchus mykiss°	5	5	1	1
Salmo trutta	5	5	1	3
Lota lota	3	3	3	3
Gasterosteus aculeatus	1	1	3	3
Pungitius pungitius	1	1	3	3
Cottus gobio	5	5	1	?
Lepomis gibbosus°	1	1	3	3
Gymnocephalus cernua	1	1	5	3
Perca fluviatilis	1	1	5	3
Stizostedion lucioperca°	1	1	5	3

°Non-native species

other fish to survive. The presence of non-native species is expressed in weight percentage of the total fish biomass.

Natural recruitment (C2 and C3 waters only)

We tread recruitment as synonymous with natality, but also included immigration (Calow, 1998). The ability of the species to recruit naturally is essential for stable biotic integrity. Natural recruitment was considered positive when O^+ fish of a species were present in combination with individuals of other year classes. We defined the optimum percentage of recruitment (score 5) when 85% of the collected species were considered positive for this metric (Table 4).

Trophic composition

Weight ratio piscivores/non-piscivores (S1 waters only)

An ecosystem is a functional ecological unit in which biological, physical and chemical components of the environment interact (Calow, 1998). A healthy ecosystem is reflected in its ecological pyramid (expressed as pyramid of numbers or biomass) in which the successive trophic levels are in balance. This requires enough predators to control their prey and vice versa. In accordance with OVB (1988a) and Karr & Dionne (1991), an optimal weight ratio between piscivores and non-piscivores of 1/5–1/7 was adopted. Higher or lower ratios create unstable situations and score lower. This metric is bi-directional (Table 3).

Trophic composition (C2 and C3 waters)

The metric ‘trophic composition’ was based on Karr (1981) and Oberdorff & Hughes (1992). We distinguished three different levels, i.e. the percentage of individuals of omnivores, invertivores and piscivores. The final score is the mean of the three levels (see Table 4). A higher omnivorous level is a measure of increasing degradation (<1 scores 5; 1–5 scores 3; >5 scores 1). The invertivorous level decreases with degradation (>45 scores 5; 20–45 scores 3; <20 scores 1) whilst the optimum for the piscivorous level is set at 3–5% (Miller et al., 1988; Steedman, 1988; Schields et al., 1995). The top of the food chain is represented by the amount of predators, this constitutes the piscivorous level which also is sensitive to degradation.

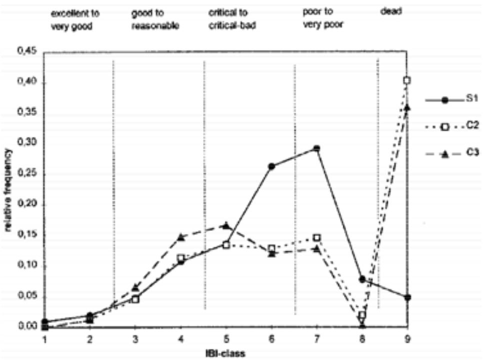

Figure 4. Frequency distribution of the index of biotic integrity for Flandrian water bodies of type S1 (N=104), C2 (N=500) and C3 (N=257).

Total IBI scores and special cases

The overall IBI score for a given site was calculated as the mean of scores for all metrics. IBI classes ranging from 9 (no fish present) to 1 (excellent conditions) were defined. Each IBI score was assigned to an IBI class (as shown in Table 9). In case only stickleback (*Gasterosteus aculeatus* or/and *Pungitius pungitius*) is present, the IBI is overrated due to the high scores for natural recruitment and the absence of non-native species. In this case an IBI class of 7 (poor, see Table 9) was assigned. In case no fish is collected an IBI score of 0 or integrity class 9 (dead water) is attributed.

Results

Overall results

Within the 861 sampled localities, 104, 500 and 257 sites, respectively, belong to S1 (lakes, ponds, closed river arms and canals), C2 (river habitat corresponding to the bream zone) and C3 (river habitat corresponding to the barbel zone). Figure 4 illustrates the frequency distribution of the IBI class for these different types of water bodies. The IBI values have been calculated for each of the 861 locations according to the corresponding methodology.

The frequency distribution of the C2 and C3 zones are very similar. A limited number of locations (5.5%) shows a good to excellent biotic integrity (classes 1, 2 or 3). Most waters containing fish (56.4%), show a ‘reasonable’ to ‘poor’ biotic integrity (classes 4, 5, 6 or 7). However, stagnant waters (S1) score quite differently in the higher classes. Only 5% of the localities contain no fish (class 9), whereas C2 and C3

Table 6. Comparison of the biotic integrity in the different basins in Flanders with indication of the number of stations per basin

Basin	IBI class									Total
	Excellent 1	Very good 2	Good 3	Reasonable 4	Critical 5	Critical – Bad 6	Poor 7	Very poor 8	Dead 9	
IJzer	0%	3%	23%	29%	26%	6%	3%	0%	10%	33
Leie	0%	0%	0%	1%	4%	1%	16%	0%	78%	81
Schelde	0%	0%	5%	7%	4%	8%	17%	1%	59%	120
Dender	0%	0%	0%	5%	11%	8%	21%	2%	53%	62
Demer	0%	0%	1%	14%	23%	28%	12%	3%	18%	178
Dijle	0%	0%	0%	3%	14%	11%	14%	0%	59%	133
Kleine Nete	0%	8%	19%	41%	22%	5%	3%	0%	3%	37
Grote Nete	0%	7%	26%	15%	22%	11%	11%	7%	0%	27
Maas	0%	4%	12%	28%	13%	8%	17%	1%	17%	83
Closed river arms	4%	4%	12%	27%	23%	19%	8%	0%	4%	26
Canals	0%	0%	0%	3%	10%	36%	34%	11%	6%	70
Lakes	0%	12.5%	25%	25%	25%	12.5%	0%	0%	0%	8
Total	1	11	44	104	124	126	132	19	300	861
	0.1%	1.3%	5.1%	12.%	14.4%	14.6%	15.3%	2.2%	34.8%	

Table 7. Pearson correlation coefficients between individual metrics and total IBI score for S1 (lakes, ponds and canals), C2 (bream zone river habitat) and C3 (barbel zone river habitat) waters. All probability values (*p*) were under 0.05

Metric	S1	C2	C3
Total number of species	0.698	0.218	0.261
Mean tolerance	0.766	0.411	0.581
Type species	0.529	0.299	0.341
Pike recruitment and biomass	0.709		
Tench recruitment and biomass	0.685		
Total biomass	0.597	0.561	0.564
weight % of non-native species	0.330	0.556	0.517
Weight ratio piscivores/non-piscivores	0.549		
Mean typical species value		0.253	0.415
Trophic composition		0.422	0.360
Natural recruitment		0.464	0.372

score, respectively, 40 and 35% in class 9. Although usually fish are found in S1 waters (especially in lakes, see Table 6), the fish communities are often degraded, with a low number of species and no intolerant species, like pike or tench. In general, the water quality in S1 waters tends to be better than in C2 and C3 waters, because direct drainage of wastewater into lakes, ponds or canals is minimal, having diffuse drainage as the sole source of pollution. As a result, fish are present and can survive in most of the S1 waters. However, the structural quality of the habitat is often too poor to support a diverse and balanced fish population, especially in the canals. About 81% of the canals show an IBI value corresponding to 'critical-bad', 'poor' or 'very poor' quality (Table 6).

Closed river arms and lakes usually have an acceptable water quality and sufficient structural quality, enabling fish populations of a good to reasonable quality to subsist.

As S1 waters are quite important for angling recreation, restocking regularly occurs. The effects of these restocking activities on fish stocks and on the IBI are not yet fully assessed.

Major differences between different basins in Flanders can be noticed (Table 6). The Leie-basin is considered to be the most degraded basin in Flanders, with 78% of the locations fishless. Also the Dender-, Dijle- and Schelde-basin have over 50% of the locations in IBI-class 9. On the other hand, the Maas-basin, Grote and Kleine Nete-basin score relatively better with, respectively, 44%, 48% and 68% of the locations achieving reasonable to excellent integrity ($IBI \leq 4$).

The correlation of the individual metrics

A correlation analysis was performed on a restricted data series including only waters where fish was present and information was sufficient to calculate all metrics (46 sites of S1, 144 sites of C2 and 127 sites of C3). Table 7 gives an overview of the correlations (Pearson correlation coefficients) between the individual metrics and the final score for the IBI in each water type. The analysis shows clearly that all metrics are positively correlated with the total IBI score, but that apparently not all metrics are contributing to the same extend to the total score. In the standing waters (ponds, lakes and canals), the metrics 'Mean tolerance', 'Pike recruitment and biomass' and 'Total number of species' are the main contributors to the total score whereas 'Weight % of non-native species' has least influence. On the other hand, in running waters 'Total number of species' is contributing the least, whereas total IBI score in bream zones is influenced most by 'weight % of non-native species', 'Total biomass' and 'Natural recruitment' and in barbel zones by 'Mean tolerance', 'Total biomass' and 'weight % of non-native species'. These differences between metric contribution to the IBI in the different water types should be analysed and compared carefully. The metrics and the metric definitions are not identical in all water types. The frequency distributions of the scores for the individual metrics and the IBI are different between water types as different sites and different fish assemblages are involved. The average significant higher correlation between the individual metrics with the IBI in S1 waters than in C2 (Student's *t*-test, T=3.103, p<0.01) and C3 waters (T=2.835, p<0.05) might be explained by variations in distribution patterns of the metrics.

Discussion

As described in our results, the overall status of fish in many waters and especially rivers is poor. This is related to the poor water quality that is mainly the result of a dense human population, with intensively developed agricultural and industrial activities, combined with the long absence of an adapted and adequate environmental legislation. Since environmental regulations recently became more stringent and were coupled with licensing and controlling services, ambitious water purification programmes were set up. The water quality in Flanders is measured since 1989 by the Flemish Environment Agency and is essentially based on chemical and physical measurements (1317 sampling spots in 1996) and on the Belgian Biotic Index (BBI, De Pauw & Vanhooren, 1983) which considers the occurrence of macroinvertebrates (1092 spots in 1996) (De Pauw et al., 1996). Despite these water purification programmes, water quality improvement seems to be limited. In 1997, the physical and chemical water quality (following the Prati Index for Oxygen saturation, PIO) was in 85% of the measured locations poor, very poor or extremely poor. Only 15% of the waters had an acceptable or good quality. In 1997, the biological quality (BBI) was described as very to extremely poor in 27%, poor in 18%, moderate in 38%, and good to very good in only 17% of the cases (Maeckelberghe et al., 1998). This is mainly caused by the fact that only 44% of the domestic waste water in Flanders is purified in wastewater treatment plants before it reaches streams (Maeckelberghe et al., 1998). Despite these figures, there is evidence of recovering fish populations in some parts of important river systems (Belpaire et al., 1998), where a few years ago fish life was absent or restricted to a few tolerant species (e.g. river Dender (Belpaire et al., 1996), river Leie (Van Thuyne et al., 1997), Upper Schelde (Denayer et al., 1997), Lower Schelde (Maes et al., 1997), river Demer (De Charleroy & Beyens, 1998), river IJzer (Denayer & Belpaire, 1997)).

Table 8. Comparison of IBI scores in Flandrian (this study) and Walloon (adapted after Didier, 1997) streams

	Excellent to very good	Good to moderate	Critical to critical-bad	Poor to very poor	Dead
Flanders	1.2%	17.4%	26.9%	25.5%	37.9%
Wallonia	22.6%	49.1%	16%	9.4%	2.8%

Compared to the Walloon situation, the ecological quality of Flandrian streams is poor (Table 8). Didier (1997) sampled 106 stations in the Walloon part of the Meuse basin and developed an IBI for that region (mainly grayling and trout zones following Huet's typology). The biotic integrity in the Walloon part of Belgium is much higher than in the Flandrian part. This is due to the better overall water quality and the less disturbed structural habitat quality. The fact that sampling locations in Flanders were picked at random, including small and obviously heavily polluted river or brook stretches, might to a certain extend have biased the comparison, as the primary aim of Didier (1997) was to study fish population characteristics.

The establishment of an IBI for standing waters (S1) is relatively new especially for Europe. Karr & Dionne (1991) used an Index of Biotic Integrity for the ecological monitoring of Tennessee River Reservoirs. Minns et al. (1994) applied an IBI for fish assemblages in the Great Lakes littoral zone and also MacLeod et al. (1995) used results of Seine netting, electrofishing and spawning habitat survey in an IBI to classify nearshore habitat in the Great Lakes Basin. In southern New England, the fish assemblages of lakes were evaluated using an IBI based on several metrics belonging to species tolerances and trophic guild characteristics (Whittier, 1997). Harig & Bain (1998) emphasised the usefulness of a lake IBI for identifying disturbance in Colorado lakes. Though some factors such as low sampling efficiency and frequent restocking may interfere with some of the obtained results, it is our conviction that the IBI for standing waters might become an important tool for the management and quality assessment of these waters. Due to the importance of recreational angling in Flanders, fish stock management in standing waters is essential. The IBI can be a clear benchmark to which the health of the aquatic ecosystem can be judged.

The development of the IBI matches the current shift of interest from physical or chemical water quality to ecological water quality assessment and management. Ecological water quality is an overall expression of the structure and function of the biological community taking into account natural physiognomic, geographical and climatic factors, as well as physical and chemical conditions, including those resulting from human activities. The stress in the definition of ecological water quality lies not only on physical and chemical conditions, but also on the value of a water body as an ecosystem.

Nixon et al. (1996) provided a framework for the harmonised monitoring and classification of the ecological quality of surface waters in the European Union. In this framework, it is stated that the classification of ecological quality should be made in terms of deviation from a reference site which is a place with pristine chemical and physical quality (high ecological quality). High ecological quality is the quality inherent to a given aquatic ecosystem which was not significantly influenced by human activities. It should be noted that this definition of high ecological quality resembles the definition of biotic integrity as Karr & Dudley (1981) defined. Good ecological quality was originally defined by the European Community as the quality which is suitable for the needs of the ecosystem, taking into account the need to maintain the capacity for self purification. There should be no evidence of elevated levels of disease due to anthropogenic influence. The diversity of the fish population should resemble that of similar water bodies with insignificant anthropogenic disturbance. Key species or taxa normally associated with the undisturbed condition of the ecosystem should be present. There should be no significant hindrance to the passage of migratory fish.

Due to the rapid decline of the ecological quality of European water bodies, the European Commission started working on (developing) a Proposal for a Water Framework Directive (EC, 1998, 1999) to guarantee the ecological quality of surface waters. This directive represents a major new approach to the aquatic environment, focusing for the first time on the integrated protection of the whole ecosystem and associated water uses. One requirement of the proposed directive is to set up and introduce monitoring and classification schemes to determine the ecological quality of surface waters. In the latest proposal (EC, 1999), composition, abundance and (in some cases) age structure of the fish populations have to be used as elements for qualifying the ecological status of rivers, lakes, transitional waters and artificial and heavily modified surface water bodies. The selected monitoring sites should be measured every 3 years. Some specific aspects of the fish assemblages, like aspects of trophic structure, presence of hybrids, diseased fish or fish with anomalies were not withheld in the Water Framework Directive. The need for undisturbed migration of aquatic organisms is only included in the definition of 'high status' in the 'river continuity' quality element for evaluation of river ecological status.

Comparison of IBI values and definitions as described by Karr (1981) with the suggested generalised definitions of ecological quality (EQ) and Ecological Quality Ratio (EQR) for use as a harmonised classification in Europe (Nixon et al., 1996) and the definition for EQ in rivers by the EC Water Framework Directive (EC, 1999) is made in Table 9. Because of this parallel between the IBI and the 'ecological quality' goals, the IBI can be used as a tool to determine the biotic integrity, hence ecological quality, of a water body. With one number, the biotic status of a location can be quantified, giving a complete overview of water quality, as well as structural quality and other deteriorating influences.

On a regional scale, the Flandrian *Commission for the Evaluation of the Environmental Executive Legislation* is proposing the IBI as criterion for basic water quality (CEM, 1998). As basic water quality benchmark an IBI ≤ 6 was proposed whereas good ecological quality is attained with an IBI class ≤ 4

Table 9. Comparison between quality-classes of the generalised definitions of ecological quality (EQ) using the indicative Ecological Quality Ratio (EQR) by Nixon et al. (1996), classes described in the normative definitions of ecological status classification of the EC Water Framework Directive and the Index of Biotic Integrity classes (modified after Karr, 1981) with indication of the IBI class ranges

EQ EQR	Class description Nixon et al. (1996)	EQ	Class description EC Water Framework Directive	IBI class Score	Class description Modified after Karr (1981)
High 0.95–1	'No evidence, or only very minor evidence, of anthropogenic impacts on biological communites and their habitat. The nature (composition and diversity) and status (productivity) of the biota reflect that normally association with the habitat under undisturbed conditions.'	High status	'Species composition and abundance correspond totally or nearly totally to undisturbed conditions. Al the type specific disturbance sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.'	Excellent (class 1) > 4.5–5 to Very good (class 2) > 4–4.5	'Comparable to the best situations without influence of man: all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with full array of age and sex classes; balanced trophic structure.'
Good 0.8–0.95	'Detectable but low-level impacts on biological communities and their habitat. The biota shows signs of disturbance but is fully self-sustaining and deviates only slightly from that normally associated with the habitat under undisturbed conditions.'	Good status	'There are slight changes in species composition and abundance from the type specific communities attributable to anthropogenic impacts on physicochemical and hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.'	God (class 3) > 3.5–4 to Reasonable (class 4) > 3–3.5	'Species richness somewhat below expectation, especially due to loss of most intolerant forms; some species with less than optimal abundance or size distribution; trophic structure shows some signs of stress.'
Fair 0.6–0.8	'Significant impacts on biological communities and their habitats. The biota exhibiting moderate deviations from that normally associated with the habitat under undisturbed conditions.'	Mode-rate status	'The composition and abundance of fish species differ moderately from the type specific communites attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.'	Critical (classs 5) > 2.5–3 to Critical-bad (class 6) > 2–2.5	'Dominated by omnivores, pollution-tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.'
Poor 0.3–0.6	'Severe impacts on biological communities and their habitats. The biota exhibiting large deviations from that normally associated with the habitat under undisturbed conditions.'	Poor status	'Evidence of major alterations to the values of the fish quality elements. Fish communities deviate substantially from those under undisturbed conditions.'	Poor (class 7) > 1.5–2 to Very poor (class 8) 1–1.5	'Few fish present, mostly introduced or very tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.'
Bad 0–0.3	'Only a few stress-tolerant species present or completely lifeless.'	Bad status	'Evidence of severe alterations to the values of the fish quality elements. Fish communities normally associated with the surface water body type under undisturbed conditions are absent.'	Dead (class 9) 0	'No fish found'

(Maeckelberghe et al., 1998). Actually, in the annual Environmental Reports in Flanders, the IBI is used as an instrument to assess water quality (De Pauw et al., 1999). As stated by the Water Framework Directive standardisation of monitoring methods and an intercalibration exercise in the classification of the ecological status between EC countries will be essential.

It has been demonstrated that the IBI concept, which is based on qualifying the integrity of a fish community by evaluating a variety of essential ecological features (species composition, community structure, biological processes (e.g. trophic relationships) and individual health), has a high plasticity and can be used on a variety of aquatic habitats in quite different zoo-geographical regions all over the world.

The advantages of dealing with fish communities to evaluate habitat quality are multiple. Compared to the physicochemical Prati Index and the biological Belgian Biotic Index (based on macroinvertebrates), the Index of Biotic Integrity does reflect a wider range of habitat disturbance factors (e.g. the presence of a dam on a river stretch will have a negative effect on the IBI score of the upstream part, whereas PIO and BBI probably will remain stable). Fish are sensitive to a variety of disturbance factors, some species to a different degree. They are present in most of the aquatic habitats and are easy to identify. They have representatives on all trophic levels and thus show an integrated view of an ecosystem. In comparison with other (lower) organisms, most of the species live considerably longer, so even on a long term disturbances may be detected. Using fish as indicators for aquatic habitat quality is a generally accepted idea in public's opinion and the sampling is considered to be non-destructive. The metrics which were chosen in these IBI applications were in concordance with the original ecological framework as designed by Karr (1981), including metrics describing species diversity, habitat guilds, trophic composition, recruitment and the presence of non-native species. Elements of condition, diseases and/or presence of fish with anomalies were not included, mainly due to practical difficulties in assessing these metrics in an accurate and unambiguous way. Most of the metrics we have described are identical or very similar with the metrics used in other European IBI applications as summarised by Hughes & Oberdorff (1999). However, some new metrics – or variations on existing ones – were included. The 'mean typical species value' metric (running water) matches the need to integrate the expected species composition in a river habitat adapted to the different zonations of the river. This value declines with increasing environmental degradation. In the metric 'mean tolerance value', an attempt was made to define the individual species tolerance value as a combination of both water quality and habitat quality tolerance scores based on literature research. Further research on the tolerance status of fishes of Western Europe should refine this. In the metric 'type species', the abundance scores of species with contrasting tolerances are combined. In standing waters, the abundance of pike and tench was believed to be important enough to be used as individual metrics. For these metrics, we combined the abundance and recruitment. This regional adaptation of the abundance metric avoids too strong positive effects of restocking on the total IBI score.

Conclusion

The IBI, with its' merits and constraints, has a high value for the management and conservation policy of aquatic ecosystems. It should not be considered as an alternative to physical or chemical water quality indices, but rather as a complementary instrument to help local, national and international policy makers, fisheries managers and administrations to justify and support decisions related to issues of aquatic or fisheries policy. It is a clear benchmark to judge a water system and to identify waters most in need of protection or restoration. The index may also be useful for the protection of endangered species that require healthy and unperturbed ecosystem conditions. We believe that the development of a fish-based IBI for Flandrian water bodies is a first step to meet the requirements as stated by the European Commission to assess and monitor the ecological quality of surface waters.

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