Ecological traits of fish assemblages from Mediterranean Europe and their responses to human disturbance

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Abstract Mediterranean river systems are characterised by more diverse fish assemblages and regional ecological processes compared with the rest of Europe. A data set from Mediterranean France, Iberia and Greece (~2000 sites) was used to describe the characteristics of fish assemblages, explore their responses to anthropogenic disturbance and analyse the implications for river quality assessment. There was a southwards decline in species richness per site, but endemicity and proportion of alien species increased. Sites in the eastern Mediterranean had higher endemicity, lower site richness and lower number of alien species than sites in western Mediterranean Europe. Assemblage composition differed between Mediterranean sub-regions, but was dominated by three major fish types: a salmonid fish type common throughout the study area and two cyprinid-dominated fish types (in some sub-regions, *Salmo trutta* L. is present but not numerically dominant), corresponding to a gradient in hydrological and temperature regimes. Metric responses to perturbation were compared with those found at the European (larger scale) and basin (smaller scale) levels. Overall metric response was weaker in this Mediterranean application. The best responses to human pressure were usually obtained with abundance-based metrics and included the contribution of naturalised alien species. Some widespread alien species contributed to the response to anthropogenic alteration (notably *Cyprinus carpio* L. and *Lepomis gibbosus* (L.)).

KEYWORDS: alien species, fish metrics, fish types, guilds, human impacts, Mediterranean streams.

Introduction

Hydrological variability of Mediterranean-type regions profoundly determines the life forms and life cycles of aquatic organisms, as well as ecological processes (Blondel & Aronson 1999; Gasith & Resh 1999). Fish fauna from these heterogeneous ecosystems must frequently survive under alternating scenarios of too much or too little water with a few intermediate but crucial periods of investment in recruitment and growth. Under these conditions, fishes tend to have short life spans, rapid growth rates, high fecundity and early sexual maturity and spawning, as well as generalist and opportunistic feeding strategies (e.g. Granado-Lorencio 1996; Pires, Cowx & Coelho 2001; Vila-Gispert, Moreno-Amich & García-Berthou 2002).

The spatial and temporal environmental variability is exacerbated by a long history of human-induced pressures. Mediterranean-type regions generally experience limited water availability during part of the year, usually overcome by water storage in reservoirs, water abstraction from ground and surface sources and water transfers (Davies, Thoms, Walker, O'Keefe & Gore 1994). Compared with more northern European rivers, anthropogenic disturbance frequently focuses on water quality and habitat modification; in Mediterranean ecosystems, these alterations are determined or amplified by human-related changes in the amount and periodicity of water availability to organisms. The robustness of these aquatic ecosystems and of their biological assemblages to naturally harsh and variable hydrological conditions make them resilient in the short-term to human pressure. However, over longer time periods they are vulnerable to continuous and cumulative human-induced changes (Matthews & Marsh-Matthews 2003). It is therefore important to develop reliable indicators of ecosystem health for Mediterranean rivers.

The European FAME project developed a multi-metric index based on fish assemblages to assess the ecological quality of European rivers, including the Mediterranean region (Pont, Hugueny, Beier, Goffaux, Melcher, Noble, Rogers, Roset & Schmutz 2006). However, the taxonomic variability of fish assemblages found in these systems was so high that it reduced the number of available reference sites per fish type to a point that a site-based approach could not be applied in southernmost areas of Iberia and Greece (Pont *et al.* 2006). Previous attempts to develop metric indices for the Mediterranean regions also dealt with this limitation (Ferreira, Cortes, Godinho & Oliveira 1996; Oliveira & Ferreira 2002) with various degrees of success, but only at smaller regional scales. To provide an accurate assessment of the ecological status of rivers in the Mediterranean region, it is necessary to establish their characteristics and fish assemblages, and whether or not they present a common pattern.

The paper describes an approach to address this need using fish assemblage data from a range of Mediterranean rivers. The response of Mediterranean fish assemblages to human disturbance was also assessed using metrics developed within the wider European FAME project (Noble, Cowx, Goffaux & Kestemont 2007; Roset, Grenouillet, Goffaux, Pont & Kestemont 2007), as the foundation for further

development of fish-based ecological quality assessment in the Mediterranean region.

Methods

Data on fish assemblages, environmental characteristics and human impacts were collected from 1989 sites representing 15 river regions from Portugal, Spain, France and Greece (Fig. 1). Although not distributed evenly, the available sites represent a wide range of Mediterranean conditions, covering large areas in western, central and north-eastern Iberia, southern France and western Greece. About half of the sites were truly Mediterranean (after Blondel & Aronson 1999) (Fig. 1). Mediterranean sites retained for the analyses were generally characterised by small- to medium-size catchments (less than 500 km^2), mean annual temperature (MAT) ranging from 10 to 18 °C, mean annual rainfall (MAR) ranging from 600 to 1300 mm and an altitude below 800 m. Fish were sampled by electric fishing according to CEN 14011 standards (CEN 2003), and all sites were wadeable. Environmental and human impact variables were collected either *in situ* or from national geographical information systems.

To establish reference conditions of species assemblage types, hierarchical cluster analysis was performed on a group of low impacted (termed calibration) sites. These have a low human pressure classification of 1 and 2 (range 1–5) on each of five core variables (as defined by Degerman, Beier, Breine, Melcher, Quataert, Rogers, Roset & Simoens 2007): connectivity of the river segment, hydrological regime, morphological condition of the site, level of toxic and acidic substances and level of nutrients and organic matter. Overall, 293 low impacted sites were available. Fish density data were log $(x + 1)$ transformed and analysed using squared Euclidean distance and Ward's method of clustering.

Multiple discriminant analysis was used to allocate non-calibration sites to river types. Environmental data were transformed to ensure normality and the homogeneity of variance tested. The environmental variables retained in the model were catchment size, altitude, longitude, latitude, MAT, MAR, gradient and wetted width of the river channel. Spearman rank correlations were used to study the response to disturbance of the selected metrics for: (a) an European fish-based index (Pont *et al.* 2006); (b) the European spatially based approach (Melcher, Schmutz, Haidvogl & Moder 2007); and (c) a data set from Iberia (Ferreira, Caiola, Casals, Oliveira & Sostoa 2007). The rank correlation was complemented by Mann–Whitney *U*-tests to confirm significant differences between minor-to-slight alteration (classification of 1–2) and moderate-to-severe alteration (classification > 2). All analyses were performed using STATISTICA 6.0 software (StatSoft, Inc., Tulsa, OK, USA).

Results

Fifty-one percent of the sites (1004) were considered to belong to the Mediterranean bioclimatic region. Ninety-one fish species were caught (87 in Mediterranean only sites), of which 17 were alien. Most native species were endemic (Table 1). There is a southwards decrease in richness per site, but an increase in endemicity and in the proportion of alien species. The eastern Mediterranean area, represented by 110 Greek sites, presented a higher endemicity (50%) and a lower number of alien species than in western Mediterranean Europe (Table 1).

In the western Mediterranean, most minimally disturbed sites had four or less species, while in the eastern Mediterranean most sites had only one or two species (Fig. 2). Assemblage composition differed between and within Mediterranean sub-areas (Fig. 3), probably in accordance with physical and physiographic heterogeneity of the river systems. Mediterranean France supported more widely distributed species, while only a few species occur in more than 20% of sites in more southern areas, indicating a higher degree of basin-specific assemblages, especially for Greece. Salmonid-type sites (those where *Salmo trutta* L., was present or dominant) were common throughout the Mediterranean area (Fig. 3). Different species of cyprinids, e.g. of the genera *Barbus*, *Chondrostoma*, *Leuciscus*, *Rutilus*, *Squalius*, *Pseudophoxinus* and *Tropidophoxinellus*, characterised the cyprinid-type fish assemblages. In France, the absence of physical barriers promoted the occurrence of typical central European species such as *Barbus barbus* (L.) and *Rutilus rutilus* (L.).

Superimposed on this scenario is a strong influence of alien species (Table 1), notably *Lepomis gibbosus*


Figure 1. Location of sites from Southern Europe database. Also shown is a line roughly separating the Mediterranean part according to Blondel & Aronson (1999).

Table 1. Total number of sites (and available calibration sites), total number of species, percentage of endemic species in total of natives, average richness per site (and range) and average alien species per site in total of species, for Europe (FIDES database, Beier, Degerman, Melcher, Rogers & Wirlöf 2007), Southern Europe and only Mediterranean sites (MED database)

	Number of sites (calibration sites)	Total number of species	Endemic species (%)	Site richness (range)	Alien species (%)
All Europe (FIDES)	12 679 (2418)	329	30.9*	5.0 (0–29)	15.4
Southern Europe	1989 (868)	91	45.9	2.8 (0–19)	18.7
Mediterranean Europe	1014 (293)	87	47.9	3.4 (0–19)	19.6
France	154 (83)	42	7.1	5.1 (0–19)	35.7
Spain	491 (74)	42	39.5	2.3 (0–10)	23.9
Portugal	249 (72)	34	36.0	4.3 (0–12)	23.5
Greece	110 (64)	28	50.0	2.5 (0–6)	10.7

Data for specific countries are only for Mediterranean sites. Calibration sites (= sites having conditions of minimal disturbance) are those scoring 1 or 2 in the five core variables used to evaluate human pressure (see *Methods* for explanation).
*Average endemicity from European ichthyoregions (Melcher *et al.* 2007).
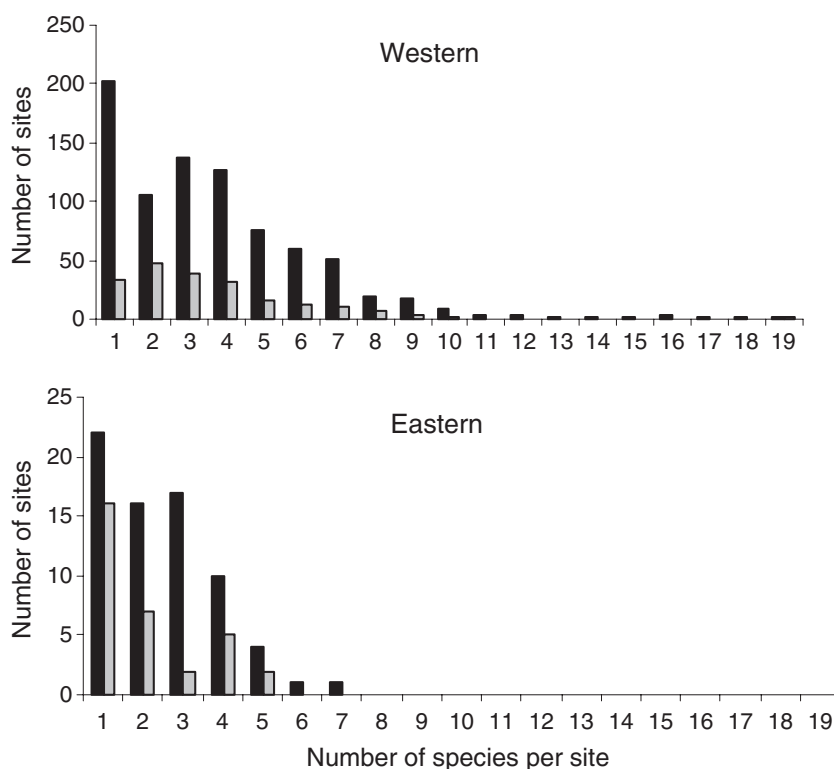
Figure 2. Fish richness in all sites (bold) and in calibration sites (shaded) in western Mediterranean (France and Iberia) and eastern Mediterranean (Greece).

(L.), which is particularly widespread in western Iberia, even in relatively unimpacted sites (Fig. 3). The number of alien species generally increased with human pressure (e.g. *L. gibbosus* and *Cyprinus carpio* L.) and its proportion in the calibration sites was significantly lower than in the non-calibration sites (Mann–Whitney U rank test, $P < 0.05$). Alien species seemed to be additive to natives in western Mediterranean rivers but not in eastern Mediterranean ones. At a considerable

proportion of the Mediterranean sites (11.2%), some of which were pre-classified as minimally impacted, all native species have been replaced by aliens.

Three large groups and five subgroups were discriminated by clustering (Fig. 4 and Table 2). *Salmo trutta* occurs as exclusive or dominant in group 1 (which is present in all countries and all parts of the Mediterranean area). Group 2 includes fish assemblages from France, eastern Spain and Greece
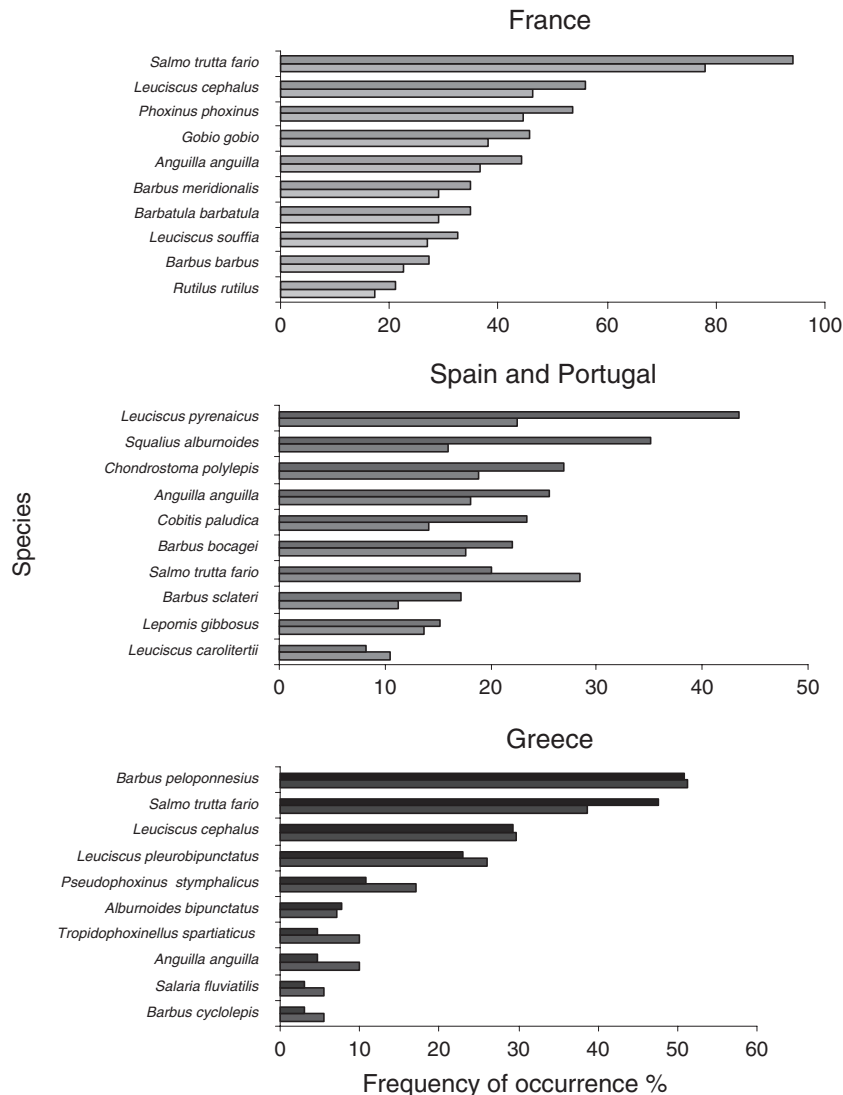
Figure 3. Ten top species having the highest frequency of occurrence (as the percentage of sections where the species was recorded) in the Mediterranean parts of France, Iberia and Greece. Black bars represent the calibration sites and shaded bars the total number of sites.

dominated by cyprinids, such as *Barbus meridionalis* Risso, *Phoxinus phoxinus* (L.), *Leuciscus cephalus* (L.) or *Leuciscus souffia* Risso; in this group, *S. trutta* can be present but is not numerically dominant. Group 3 includes sites from western, central and southern Iberia, dominated by various basin-specific cyprinid species such as *Barbus bocagei* Steindachner, *Barbus microcephalus* Almaça, *Leuciscus pyrenaicus* (Günther) and *Squalius alburnoides* (Steindachner). Overall, the three groups and their subdivisions displayed altitudinal and climatic gradients (Fig. 5) because Mediterranean areas include both cold water and warm water (permanent or intermittent) reaches. In addition, zoogeographical factors act simultaneously with the

environmental drivers – groups G3A and G2A include sites only from Portugal and France respectively.

The best discriminant (canonical standardised) coefficients were altitude (−0.78), MAT (0.82) and MAR (−0.76) for axis 1, and MAR (0.72) for axis 2. Environmental correlation with the canonical axes was higher with MAR (−0.54) and gradient (−0.49) for axis 1, and MAT (0.46) for axis 2. The first two axes were significant ($P < 0.01$) and their cumulative variance was 79%. The percentage of predicted/observed ratio allocation of sites was 81% for group 1, 70% for group 2 and 78% for group 3.

Overall, metric response was weak (Table 3), especially in group 3. The metrics showing the strongest
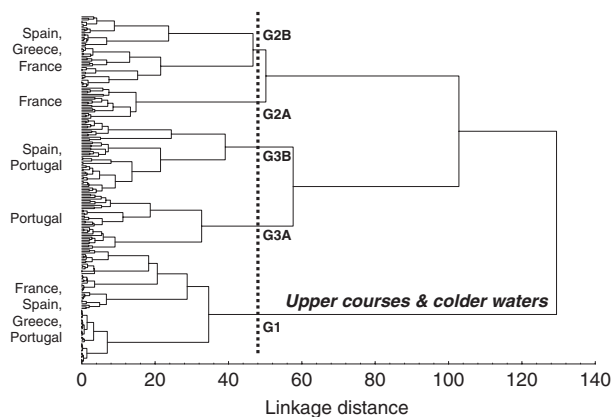
Figure 4. Fish-based groups for the Mediterranean calibration data set, using log $X + 1$-transformed abundances, squared Euclidian distance and Ward's clustering. All caps indicate a dominance of sites from a specific country.

responses were limnophilic, omnivorous and long-lived species (positive) for group 1 assemblages and tolerant species (positive), rheophilic and lithophilic species (negative) for group 2 assemblages. These metrics presented significant differences between calibration and non-calibration sites ($P < 0.01$). The feeding guild (e.g. influenced by introduced piscivorous species such as *Micropterus salmoides* (Lacépède, 1802)) and the tolerance guild (influenced by alien species such as *C. carpio*, *L. gibbosus* and *Gambusia holbrooki* Girard 1859) exhibited significant differences (Mann–Whitney U-tests, $P < 0.05$) when all species and only native species were compared.

Discussion

Low species richness per site, a high degree of endemicity, as found in eastern Mediterranean fish assemblages, and basin-specific taxa assemblages, are problematic for developing biotic indices (Miller, Leonard, Hughes, Karr, Moyle, Shrader, Thompson, Daniels, Fausch, Fitzhugh, Gammon, Halliwell, Angermeier & Orth 1988; Moyle & Marchetti 1999). In Mediterranean Europe, additional difficulties include: (1) uncertainty about existing cyprinid taxa units; (2) insufficient knowledge of the ecological preferences of some species (e.g. Ribeiro, Cowx, Tiago, Filipe, Moreira da Costa & Collares-Pereira 2003); and (3) a wide tolerance of many native taxa to abiotic variability (Granado-Lorencio 1996; Magalhães, Batalha & Collares-Pereira 2002). Low richness per site is

Table 2. Frequency of occurrence (FO%) and average relative abundance as species individuals ha^{-1} (RA%) in each of the five fish types obtained in the cluster analysis using only calibration sites

Species	FO (%) in each Fish Type					RA (%) in each Fish Type				
	G1	G2A	G2B	G3A	G3B	G1	G2A	G2B	G3A	G3B
Anguilla anguilla (L.)	19	35	31	9	28	3.9	1.2	11.9	0.5	0.3
Barbatula barbatula (L.)	1	*83*	0	0	0	0.4	10.8	0	0	0
Barbus barbus (L.)	3	45	11	0	0	0.7	9.1	1.1	0	0
Barbus bocagei Steindachner	0	0	0	*63*	0	0	0	0	12.7	0
Barbus meridionalis Risso	21	*65*	42	0	0	*18.9*	4.4	*19.1*	0	0
Barbus microcephalus Almaça	0	0	0	0	34	0	0	0	0	*21.4*
Barbus peloponnesius Val.	0	0	29	0	0	0	0	8.6	0	0
Barbus sclateri Günther	0	0	0	0	*60*	0	0	0	0	3.2
Chondrostoma lemmingii Steindachner	0	0	0	6	21	0	0	0	0.9	7.6
Chondrostoma polylepis Steindachner	0	0	0	*89*	0	0	0	0	8.4	0
Chondrostoma willkommii Steindachner	0	0	0	0	38	0	0	0	0	6.2
Cobitis paludica de Buen	0	0	0	19	36	0	0	0	1.1	4.0
Cottus gobio (L.)	10	15	6	0	0	12.6	9.6	0.6	0	0
Gobio gobio (L.)	6	*70*	0	16	0	2.7	3.2	0	4.0	0
*Lepomis gibbosus** (L.)	0	5	0	9	30	0	0.4	0	13.6	0.9
Leuciscus carolitertii Doadrio	0	0	0	28	0	0	0	0	16.8	0
Leuciscus cephalus (L.)	1	*95*	*73*	0	0	0.5	6.2	12.0	0	0
Leuciscus pyrenaicus (Günther)	0	0	0	*60*	*62*	0	0	0	15.8	4.2
Leuciscus souffia Risso	3	*65*	9	0	0	1.5	*23.9*	12.8	0	0
Phoxinus phoxinus (L.)	17	*80*	20	0	0	*22.8*	13.5	*31.7*	0	0
Salmo trutta fario (L.)	*100*	*90*	20	50	0	*36.1*	17.7	2.5	5.7	0
Squalius alburnoides (Steindachner)	0	0	0	*53*	45	0	0	0	*20.2*	*52.1*

Only species with FO > 5% are shown. In italics, FO > 50% and RA > 17.5%. Only calibration sites.
*Alien species.
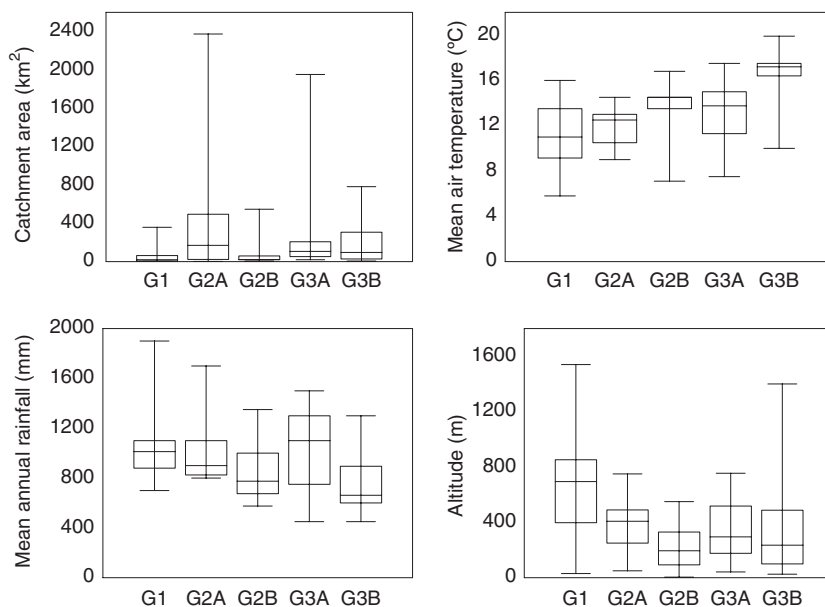
Figure 5. Variability in catchment area (km^2), mean air temperature (°C), mean annual rainfall (mm) and altitude (m), for the five groups of sites obtained for the Mediterranean data set.

common in other European waters, especially upper rhithral streams (Melcher *et al.* 2007); their bio-assessment relying upon absolute abundances of key (sentinel) species and other population parameters.

Many Mediterranean-type reaches include a high proportion of alien species (Moyle 1995; Aparicio, Vargas, Olmo & Sostoa 2000; Corbacho & Sánchez 2001; Kennard, Arthington, Pusey & Harch 2005), and alien species were dominant over native populations at some weakly impacted sites, such as some salmonid streams from Greece (colonised mostly by *Oncorhynchus* sp. escaped from trout farms) and small lowland streams in Iberia. Factors important in the invasive process include human-driven dispersal, physical and biological characteristics of the aquatic systems, and different establishment phases of the alien species populations (Ross 1991; Lozon & MacIsaac 1997; Meador, Brown & Short 2003). However, it is not always easy to understand the relative contribution of each.

Whether or not alien species should be considered in ecological quality assessment in Mediterranean rivers is debatable. At the European level, metrics using only native species did not perform much better than the whole community response, but the number and abundance of alien species is generally lower and they are more widespread. In Iberia, however, some metrics responded to disturbance using only native taxa, namely species richness, abundance and individuals categorised as invertivorous, water column and phyt-

ophylic (Ferreira *et al.* 2007). Kennard *et al.* (2005) demonstrated that alien fishes were good indicators of disturbance intensity in Mediterranean-like subtropical streams in Queensland, Australia, and can account for river health.

Considering the naturally small number of native species per site and the contribution to disturbance assessment of some alien species, should these be allowed on future metric indices? If the purpose of bio-assessment, *senso* the Water Frame Directive (WFD; EC 2000), is to evaluate the status of ecosystems with the best and most reliable biological indicators, these should include aliens. Furthermore, from a practical point of view, it will be difficult to control long-established alien species, which are virtually impossible to eradicate in most freshwater systems (Smith, Lonsdale & Fortune 1999).

Metric responses to perturbation across Mediterranean areas were poor, and weaker than those used at the European level, both using fish-based or spatially based models (Pont *et al.* 2006; Melcher *et al.* 2007). Metric responses were also poorer in this large-scale Mediterranean bioassessment than previously found in smaller scale studies, in which fish types were obtained mostly at the basin level (Ferreira *et al.* 2007). Furthermore, local indices (frequently incorporating local expert knowledge of the species ecology) tend to perform better. In warm water streams of Virginia (USA), Angermeier & Winston (1999) reported that each drainage–physiography combination supported a

Table 3. Significant Spearman rank correlations (*P* < 0.05) between human pressure and selected metrics for the three major fish-based groups of sites (from Fig. 4) and for all Mediterranean sites pooled

Candidate metrics	Group 1 (*n* = 235)	Group 2 (*n* = 311)	Group 3 (*n* = 371)	All (*n* = 917)
Taxonomic				
N_sp_all[†,‡]	0.19	−0.12	0.12	0.11
N_sp_native[†,‡]		−0.19		
N_ha_sp_all[†,‡]	0.24			
Perc_N_sp_total[†,‡]				0.28
Tolerance				
N_ha_sp_tol[†,‡]	0.30			0.27
Perc_N_sp_intol[†,§]	−0.32	−0.25*		−0.31*
Perc_N_sp_tol[†,§]		0.49**		0.39**
Habitat				
N_sp_li[†]	0.35**	0.26*		0.18
N_sp_rh[†,§]		−0.33**		−0.09
N_sp_wc[†]		−0.17		
N_sp_b[§]	0.26		0.12	0.16
N_ha_sp_b[†]	0.29			
Perc_N_sp_rh[†]	−0.18	−0.58**		−0.34**
Perc_N_sp_eury[†]		0.32*		0.20
Reproduction				
N_sp_lith[†]	0.14	−0.31*	−0.13	−0.11
N_sp_phyt[†]	0.15	0.14	0.24	0.24
Perc_N_ha_sp_lith[‡,§]	−0.15	−0.50**	−0.23	−0.40**
Feeding				
N_sp_inse[†]		−0.14		−0.18
N_sp_omni[†]	0.34*		0.16	0.17
N_ha_sp_omni[†,‡,§]	0.23			
Perc_N_sp_omni[†]	0.32*	−0.12		0.13
Perc_N_sp_inse[†]	−0.17	−0.21	−0.18	−0.31*
Life cycle				
N_ha_sp_sl[†,‡]	0.17		0.14	0.10
N_ha_sp_ll[†]	0.23		−0.11	
N_sp_ll[†]	0.38**			0.13
Perc_N_sp_sl[†]		0.14	0.21	0.07
Perc_N_sp_ll[†]	0.35**		−0.12	0.08
Migration				
N_ha_sp_long[†]	−0.15			0.09
N_sp_pota[†,§]	0.30	−0.27*		
N_sp_long[†,§]	−0.20	0.16	0.19	0.20
Perc_N_sp_long[†]	−0.20	0.37**	0.10	0.22

Significant differences (*P < 0.01 and **P < 0.001) between calibration and disturbed sites using Mann–Whitney *U* rank tests.
[†]Selected metrics for the European spatially based approach (Melcher *et al.* 2007).
[‡]Selected metrics for the Iberian ecoregion (Ferreira *et al.* 2007).
[§]Selected metrics for the European fish-based index (Pont *et al.* 2006).

distinctive type of fish community with particular metric responses. In Mediterranean-type stream eco-systems of California, metric response was dependent on site-specific characteristics of streams, resulting in distinct watershed-wide metrics (Moyle & Randall 1998; Moyle & Marchetti 1999).

In conclusion, there are considerable differences in fish community patterns between Mediterranean region and other parts of Europe. Moreover, there are also considerable within-region differences (particularly concerning the eastern Mediterranean area), related to micro-scale fluctuating environments, macro-scale landscape patchiness and ichthyo-geographic heterogeneity. Thus, it will be difficult to implement a fish-based approach at the large Mediterranean scale, with any degree of accuracy. Alternatively, the spatially based modelling approach may overcome these drawbacks. In both cases, metric reactions that can be used for quality assessment should be based in the abundance of the few native species present.

Acknowledgments

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