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# Fish zonation in a Mediterranean stream: Effects of human disturbances

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**Abstract.** The fish assemblage and limnological features along twelve sites from the Terri River basin (Catalonia, Spain) were sampled quarterly from August 1999 to May 2000. Twelve fish species were captured, of which four were native and eight exotic. Correspondence analysis revealed that spatial variation accounted for most of the variation (73.7%) in fish species composition. The upstream, urban area was dominated by chub (*Leuciscus cephalus*) and common carp (*Cyprinus carpio*) with some exotic species coming from nearby Lake Banyoles, whereas Mediterranean barbel (*Barbus meridionalis*) predominated in the rest of the Terri River. Along the longitudinal gradient, fish assemblage displayed discontinuous variation and disappearance in more polluted areas. Fish abundance was significantly correlated with summer oxygen concentration and decreased in downstream sampling sites. Species richness was higher in downstream sampling sites due to the proximity of the Ter River. Common carp size increased progressively along the course of the Terri River, whereas the pattern for the eel was the opposite, with the smallest found in downstream sampling sites and a gradual increase in size in the upper reaches. The natural zonation in the fish assemblage of the Terri River is presently altered to a high degree by habitat degradations, pollution, and dispersal of exotic species.

**Key words.** Fish assemblage; size structure; water quality; native species; exotic species.

## Introduction

Numerous studies of fish in streams and rivers reveal variation in fish species composition along longitudinal gradients within individual rivers, suggesting adaptation to habitat conditions associated with upstream versus downstream variation in water depth, current velocity and substratum (Gorman and Karr, 1978; Schlosser, 1982; Moyle and Vonderacek, 1985; Bain et al., 1988; Lobb and Orth, 1991; Pires et al., 1999). This observation has been used to formulate river classification schemes based on zones in which a number of discernible and characteristic species assemblages inhabit different river reaches. Typically, there are no sharp limits between zones and species composition changes gradually along a river gradient (Cowx and Welcomme, 1998).

In most European rivers, 'trout', 'grayling', 'barbel' and 'bream' zones are recognised along river continua (Cowx and Welcomme, 1998). Many European freshwater fish such as grayling or bream, however, are not native to the Iberian Peninsula (see e.g., García-Berthou and Moreno-Amich, 2000a). Consequently, 'trout', 'barbel' and 'eel' zones are distinguished for most Iberian rivers (Sostoa et al., 1990; Doadrio et al., 1991). Considerable complementarity occurs in the distribution of large and small fish along longitudinal gradients, with small fish generally predominant in shallow upstream or lateral habitats (Welcomme, 1985; Power, 1987; Schlosser, 1987; Moore and Gregory, 1988) with large fish becoming more abundant in deeper downstream habitats (Welcomme, 1985; Schlosser, 1987; Pires et al., 1999). Asso-

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ciated with this longitudinal gradient, several studies show that species richness, fish density and biomass increase from the headwaters to downstream (Schlosser, 1990; Pires et al., 1999).

The main purposes of this study are: 1) to report the first data on species composition, abundance and size structure of the fish assemblage from Terri River, the outlet from Lake Banyoles to Ter River, two very well studied areas (Sostoa et al., 1990; García-Berthou, 1999a, 1999b; García-Berthou and Moreno-Amich, 2000a, 2000b, 2000c; Vila-Gispert and Moreno-Amich, 1998, 2000; Aparicio et al., 2000); 2) to show that over a short distance transect (15 km) that varies in slope less than 100 m, the fish assemblage displayed fragmented distribution and disappearance in polluted areas, which caused the community to deviate from natural zonation pattern; and 3) to assess the dispersal of exotic species from Lake Banyoles, the first site of introduction to the Iberian Peninsula of many exotic fish species (García-Berthou and Moreno-Amich, 2000a).

## Materials and methods

### Study area

Samples were taken from one site in the main inflow stream (Morgat stream) of Lake Banyoles, three sites near an outlet of the lake and nine sites along the course of the Terri River (Catalonia, Spain) (Fig. 1). The Terri River originates as the drainage outlet of Lake Banyoles and

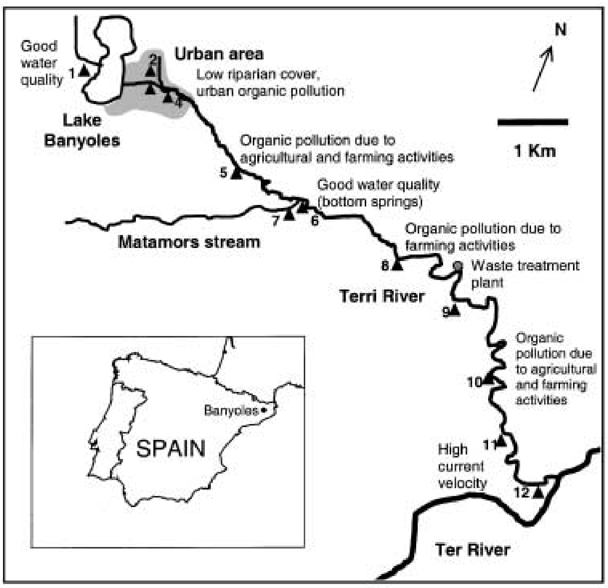


**Figure 1.** Location of sampling sites, water quality and potential pollution sources in the study area: 1, Morgat stream; 2, Canaleta; 3, Figuera de'n Xó; 4, Canaleta-Major; 5, Mas Riera; 6, Borgonyà: Terri River; 7, Borgonyà: Matamors stream; 8, Sords; 9, Santa Llogaia; 10, Sant Andreu; 11, Pla d'Olivars; 12, Terri mouth.

flows into Ter River. The Terri basin covers a drainage area of approximately 105.35 $km^2$ and is fed both by water coming from Lake Banyoles and by rainfall (900 $mm\,yr^{-1}$). The mean lake outflow in 1991 was 0.57 $m^3\,s^{-1}$, with a maximum of 0.88 $m^3\,s^{-1}$ in January and a minimum of 0.54 $m^3\,s^{-1}$ in July (Figueras and Frigoler, 1992). Predominant land use in this area is row-crop agriculture, intensive farming and urbanisation. Detailed information about locations of potential pollution sources, the wastewater plant and areas of good water quality are summarised in Figure 1. Sampling sites 2, 3 and 4 were located in Banyoles town, under the influence of urban activities. The rest of the sampling sites along the course of the Terri River suffered predominatly the impact of agricultural and farming activities. In addition, between sampling sites 8 and 9, there was a waste water plant that often could not complete the waste water treatment causing nutrient and organic matter enrichment of the Terri River. However, sampling site 11 was characterised by high current velocity that contributed to increased oxygen availability.

Lake Banyoles is a natural lake situated at 172 m a.s.l. on a karstic system close to the city of Banyoles (Catalonia, Spain) at 42°06′N 02°46′E. The water supply is mainly subterranean through several bottom springs. Water outflow is through five streams.

The fish assemblage of Lake Banyoles is dominated by introduced species: largemouth bass *Micropterus salmoides* (Lac.), pumpkinseed sunfish *Lepomis gibbosus* (L.), and mosquitofish *Gambusia holbrooki* (Gir.) in the littoral zone; roach *Rutilus rutilus* (L.) and common carp *Cyprinus carpio* (L.) in the limnetic zone (García-Berthou, 1999a, 1999b; García-Berthou and Moreno-Amich, 2000a, 2000b, 2000c; Vila-Gispert and Moreno-Amich, 1998, 2000). The most common native species are chub *Leuciscus cephalus* (L.) and the freshwater blenny *Blennius fluviatilis* (Risso). The size structure of the current fish assemblage is dominated by large fish, particularly for carp and chub. In contrast to the intensely studied Lake Banyoles, the only data available on the fish assemblage of the Terri River comes from a single site (Aparicio et al., 2000).

### Sampling methods

From August 1999 to May 2000, we sampled abiotic variables and fishes from the twelve sites on a quarterly basis. In each sampling site and date eight limnological variables were measured: conductivity ($\mu s\,cm^{-1}$), dissolved organic matter ($mg\,L^{-1}$, only measured in autumn), oxygen concentration ($mg\,L^{-1}$), water temperature (°C), pH, riparian cover, stream width (m), and stream depth (cm). Physicochemical measures (conductivity, oxygen concentration, water temperature and pH) were taken at subsurface of the midpool at each sampling site using a

Hydrolab DS3 multiparametric probe. Dissolved organic matter was measured as Total Organic Carbon (TOC) using a TOC analyser. Riparian cover was measured as a percentage of wooded bank cover.

Fishes were sampled by electrofishing from 50 m sections of the river. Transects were blocked with barrier nets and electrofishing was performed in an upstream direction. Electrofishing was conducted by foot using 200–350 V, 2–3 A AC. A consistent sampling scheme was used among different dates and sites.

Fish fork length (to the nearest mm) and total weight (to the nearest g) were measured *in situ*. Fish were anaesthetised with benzocaine, measured, and released.

### Statistical analyses

Limnological variables were analysed by principal component analysis (PCA) to describe the main sources of variation. Principal component analysis is an ordination method that allows a multidimensional swarm of correlated data points to be viewed within a few orthogonal axes (Pielou, 1984). PCA was applied to the matrix of 7 limnological variables and 47 samples (12 sites by 4 seasons, except 1 dry site). To improve linearity, conductivity, dissolved organic matter and oxygen concentration were log-transformed ($\log_{10}$). We extracted the factors with eigenvalues larger than 1, which were much larger than the rest according to a scree plot (Norušis/SPSS 93 : 55). Varimax rotation was used to ease interpretation. The measure of sampling adequacy of Kaiser-Meyer-Olkin (Norušis/SPSS 93 : 52) was 0.62, indicating that the variables were clearly interdependent and that PCA was thus suitable. PCA axes were further interpreted correlating PCA sample scores with site number (ordinal variable) by means of Spearman's rank correlation ($r_S$).

Correspondence analysis (CA) was used to describe the main sources of fish community variation. CA is an ordination technique that reduces a species x sample matrix to a few dimensions that explain most of the variation. For community ecology data, CA generally performs better than principal component analysis, due to the unimodal response of species abundance to environmental gradients (Ter Braak, 1987). A direct gradient analysis through the program CANOCO 4.0 did not provide a better understanding of this data set as compared to CA. All statistical analyses were performed with SPSS 7.5 for Windows.

## Results

### Water quality

Seasonal and spatial variation of the limnological variables along the Terri River is shown in Figure 2. The Terri River naturally becomes wider and deeper downstream, albeit with seasonal variation and minimal levels in summer. Water temperature varied from 10 °C to 15 °C in winter and from 18 °C to 27 °C in summer. Oxygen concentration tended to vary inversely with temperature and was lowest in summer and highest in winter. Conductivity increased along the course of the river, while dissolved organic matter showed that the most contaminated stretch was by the waste water treatment plant, between sampling sites 8 and 9. Riparian cover was minimal in the urban area of Banyoles town (sampling sites 2, 3 and 4), which, in contrast to other sampling sites, lacked wooded banks. The Borgonyà zone (sampling sites 6 and 7) had better water quality due to underground springs. As in the Morgat stream (sampling site 1), this led to less seasonal variation in temperature and oxygen concentration, and no hypoxia in summer. Sampling site 1 (Morgat stream) showed limnological characteristics that corresponded well to the upstream areas of most rivers: low conductivity, low dissolved organic matter, well-developed riparian cover, narrow stretches and shallow waters.

pH was highest in the urban area of Banyoles, because of poorly developed riparian cover and abundant algae due to nutrient runoff, which raised pH through photosynthesis. In contrast, pH was lowest in the Borgonyà area, where, because of shading of well-developed riparian cover and low nutrient input, algae abundance was reduced and the breakdown of organic detritus (mainly leaves) also lowered pH.

Since many of the physico-chemical variables were significantly correlated (Table 1), a PCA analysis gave a synoptic view that accounted for most of the variation. A scree plot suggested extraction of the first two components of the PCA that had eigenvalues greater than 1, and hence explained the greater part of the variation (35.7% and 32.5% respectively).

The first dimension summarised seasonal variation of individual sampling sites. In summer, water temperature and riparian cover were at their highest, while oxygen concentration and pH were at their lowest; in winter the situation was reversed, while spring and autumn had intermediate scores on the first dimension (Fig. 3).

The second dimension of the PCA corresponded to river zonation (Fig. 3), since the factor sample scores for the second dimension were significantly correlated with sampling site ($r_S = 0.87$, $n = 47$, $P < 0.0005$), unlike for the first dimension of the PCA ($r_S = 0.11$, $n = 47$, $P = 0.48$). Width, depth and conductivity increased along the course of the Terri River.

### Fish assemblage

Twelve fish species were captured in the study area, of which four were native and eight exotic (Table 2). Species richness was highest in the downstream sampling site 11 (Fig. 4) due to the proximity of the Ter River and likely

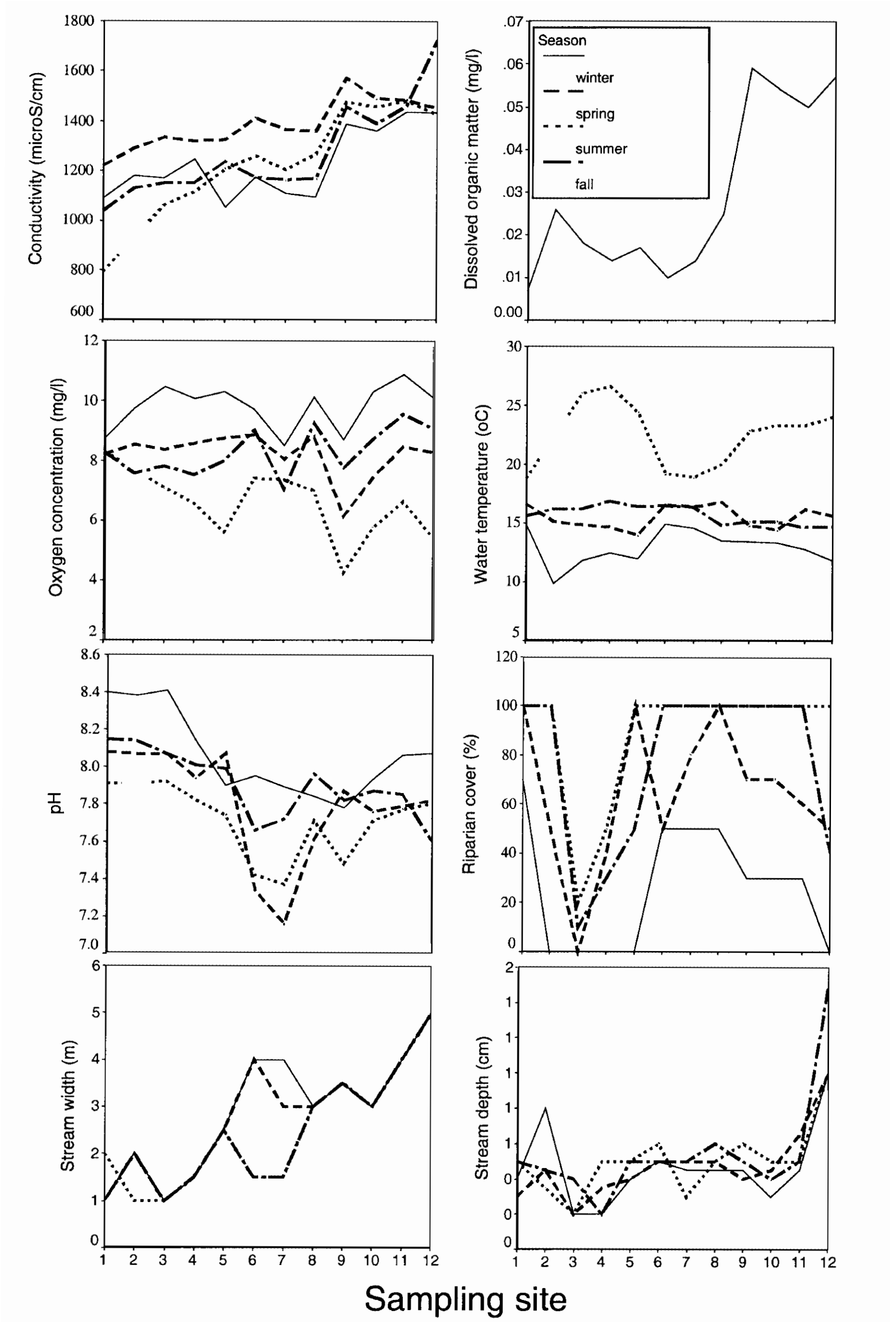


**Figure 2.** Seasonal variation of limnological variables along the Terri River. Dissolved organic matter was only measured in autumn.

**Table 1.** Correlation matrix (Pearson's correlation) of the limnological variables along the Terri River in the 4 sampling dates. $n = 47$ except for correlations with dissolved organic matter ($n = 12$).

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1. Conductivity (log) | | | | | | | |
| 2. Dissolved organic matter (log) | 0.80** | | | | | | |
| 3. Oxygen concentration (log) | – 0.16 | 0.33 | | | | | |
| 4. Water temperature | – 0.06 | – 0.40 | – 0.80** | | | | |
| 5. pH | – 0.33* | – 0.36 | 0.39** | – 0.41** | | | |
| 6. Riparian cover | 0.05 | – 0.35 | – 0.50** | 0.45** | – 0.43** | | |
| 7. Stream width | 0.62** | 0.52 | – 0.02 | – 0.05 | – 0.33* | 0.05 | |
| 8. Stream depth | 0.40** | 0.34 | – 0.07 | 0.09 | – 0.21 | 0.06 | 0.66** |

* = $P < 0.05$; ** = $P < 0.01$.

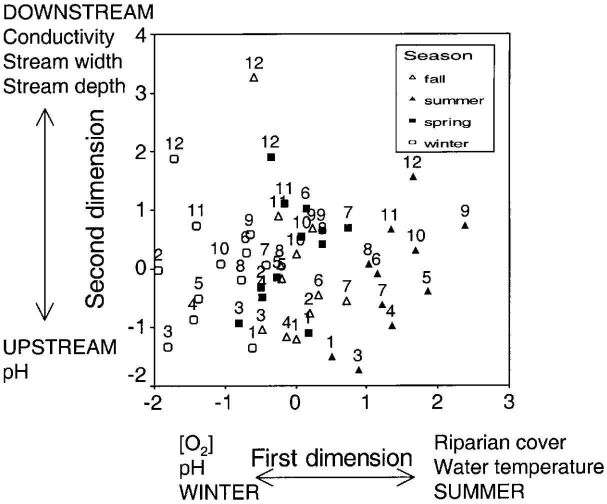


**Figure 3.** PCA sample scores for the first two dimensions by season and sampling site. The number above the symbol corresponds to the sampling site in Figure 1.

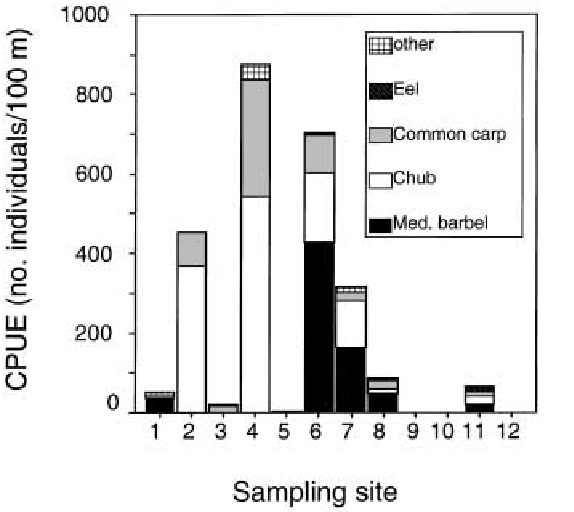


**Figure 4.** Fish species abundance (catch per unit effort, CPUE) by sampling site.

better water quality than in surrounding sampling sites. Common barbel, eel, mosquitofish, and freshwater blenny were not considered for correspondence analysis (CA), because they dominated the first solutions as outliers due to their dominance in a few samples. The first two dimensions were considered (eigenvalues = 0.69 and 0.29, explained 73.7% and 12.9% of the variation, respectively), although the first dimension accounted for most of the variation, with the second axis seeming to show an arch effect (a distortion of the first dimension).

The sample factor scores for the first dimension of the CA correlated significantly with the sampling site ($r_S = -0.29$, $n = 48$, $P < 0.05$), unlike for the second dimension ($r_S = 0.049$, $n = 48$, $P = 0.74$). Therefore, the first dimension of the CA seems to differentiate the urban sites in the upstream area (sampling sites 2, 3, and 4), dominated by chub and common carp with some exotic species present (pumpkinseed sunfish and largemouth bass), from the rest of the Terri River and the Morgat stream, that were dominated by Mediterranean barbel (Fig. 5).

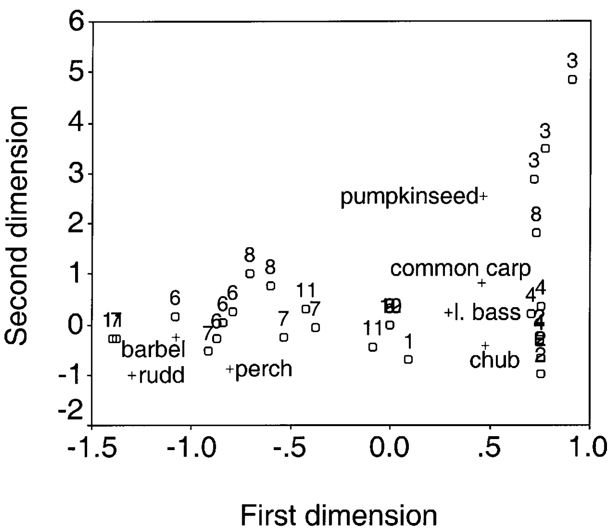


**Figure 5.** CA biplot of species and site scores. The number above the symbol corresponds to the sampling site in Figure 1.

**Table 2.** Fish species captured in the study area (N = native, E = exotic).

| Common name | Scientific name | Family | Status | Mean length (mm) | Length range (mm) | n |
|---|---|---|---|---|---|---|
| Eel | *Anguilla anguilla* | Anguillidae | N | 242 | 144–580 | 22 |
| Mediterranean barbel | *Barbus meridionalis* | Cyprinidae | N | 94 | 28–269 | 764 |
| Freshwater blenny | *Blennius fluviatilis* | Blenniidae | N | 59 | 37–81 | 9 |
| Chub | *Leuciscus cephalus* | Cyprinidae | N | 185 | 31–431 | 705 |
| Common barbel | *Barbus graellsii* | Cyprinidae | E | 161 | 147–176 | 2 |
| Common carp | *Cyprinus carpio* | Cyprinidae | E | 266 | 47–597 | 281 |
| Rudd | *Scardinius erythrophthalmus* | Cyprinidae | E | 123 | | 1 |
| Mosquitofish | *Gambusia holbrooki* | Poeciliidae | E | 33 | 16–50 | 387 |
| Pumpkinseed sunfish | *Lepomis gibbosus* | Centrarchidae | E | 118 | 107–131 | 7 |
| Perch | *Perca fluviatilis* | Percidae | E | 333 | | 1 |
| Largemouth bass | *Micropterus salmoides* | Centrarchidae | E | 223 | 84–399 | 24 |

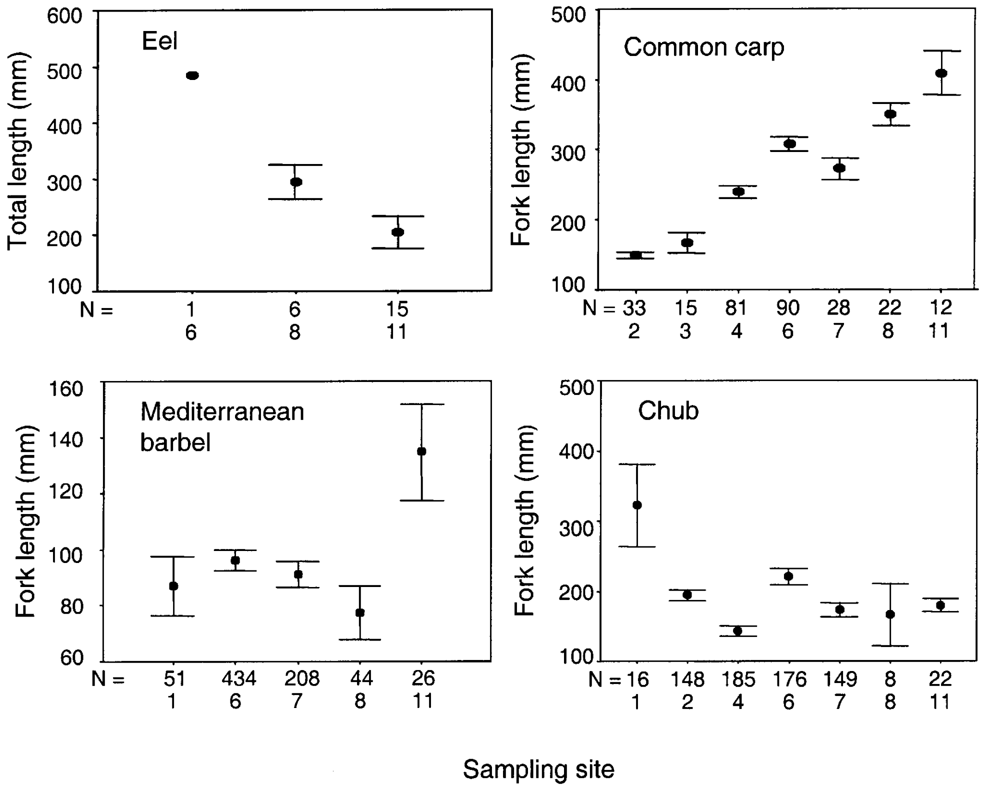


**Figure 6.** Size structure of the most abundant fish species along the Terri River course. Mean ±1 SE are shown.

Fish abundance was greatest in the Canaleta (sites 2 and 4) and Borgonyà areas (sites 6 and 7), in the upstream and middle reaches of the Terri River, and was lowest in the downstream sampling sites (Fig. 4). There were several stretches where fish were totally absent (sites 5, 9, 10, and 12). Eel were more abundant in the final stretches of the Terri River. In summer, we found a significant relationship between fish abundance and oxygen concentration ($r_S = 0.71$, $n = 12$, $P = 0.01$).

Several fish species showed notable differences in size structure along the Terri River (Fig. 6). The Mediterranean barbel exhibited considerably larger specimens in site 11, while the largest chub was found in the Morgat stream (site 1) due to the proximity of Lake Banyoles. Common carp size increased progressively along the course of the Terri River ($r_S = 0.61$, $n = 281$, $P = 0.001$). In contrast, eel showed the opposite pattern, with the smallest fish found close to the Ter River and a gradual increase in size in the upper reaches of the Terri River ($r_S = -0.64$, $n = 24$, $P = 0.001$).

## Discussion

### Water quality and fish assemblage

Fish assemblages in rivers are typically structured by habitat complexity, environmental variables (e.g., temperature, oxygen concentration, etc.) and periodic phenomena, such as low-flows and floods and associated shifts in water quality (Gorman and Karr, 1978; Schlosser, 1987, 1990; Cowx and Welcomme, 1998). In many river systems, habitat complexity increases as width and depth increase; and fish density, biomass and fish diversity increase in downstream areas (Schlosser, 1990; Pires et al., 1999). Water temperature raises from headwaters to downstream, contrary to what occurs with oxygen concentration and flow (Cowx and Welcomme, 1998). As longitudinal gradients of physico-chemical variables exist in rivers, habitat preferences of fish species are often translated into zonation patterns of fish species assemblages in rivers. In our study, in addition to the marked seasonal variation in water flow and physico-chemical variables (Fig. 2), fish assemblage structure varied dramatically along the longitudinal gradient of the Terri River. In the sampling sites from the urban zone of Banyoles (upstream area), the fish assemblage was dominated numerically by chub and common carp, with some exotic species present (pumpkinseed sunfish and largemouth bass), coming from Lake Banyoles. By contrast, in the rest of the Terri River, Mediterranean barbel predominated, particularly in the Borgonyà area and in the Morgat stream. Sampling sites from the urban zone of Banyoles were characterized by low depth and width, poorly developed riparian cover, high pH, and pronounced seasonal variation of water temperature and oxygen concentration. In contrast, the Borgonyà sites (6–7) and the Morgat stream (site 1) showed the opposite attributes. Mediterranean barbel require oxygen-saturated waters and are more sensitive than common carp and chub to pollution and physical changes (Lelek, 1980; Bianco, 1995; Changeux and Pont, 1995).

Overall, fish abundance tended to decrease in the downstream area of the Terri River (Fig. 4), contrary to what would be expected in undisturbed systems (Schlosser, 1990; Pires et al., 1999). This could be associated with an increase in organic pollution, as shown by the increase of dissolved organic matter and oxygen depletion (Fig. 2). In summer, we found a significant relationship between fish abundance and oxygen concentration. Oxygen levels below 4 mg $L^{-1}$ can result in fish deaths (Matthews, 1987; Lohr and Fausch, 1997). In our study, sampling sites where fish had disappeared showed oxygen levels ranging from 4–10 mg $L^{-1}$ but they are lower at night and in the early morning due to reduced photosynthetic activity.

### Size structure, zonation and dispersal of exotic species

Marked patterns in size structure of fish occurred along the course of the Terri River. Small common carp individuals were found in urban sampling sites that were characterised by shallow depths and low habitat volume. The abundance of large specimens increased gradually along the river. The absence of small-sized common carp in the downstream area is due to the fact that carp spawn in the urban area of Banyoles (personal observation) that contain shallow and vegetated habitats that are crucial for spawning and recruitment (Balon, 1975; Lelek, 1980; Crivelli, 1981). Eel showed the opposite pattern probably as a result of the introduction by humans of a large number of small eels in downstream sampling sites (C. Feo, personal communication).

It is well known that fish assemblage structure varies along an upstream-downstream gradient in lotic systems (Schlosser, 1982, 1987, 1990; Angermeier and Schlosser, 1989; Pires et al., 1999; Godinho et al., 2000). This variation suggests that water depth, current velocity and substratum are key factors that control fish assemblage structure (Cowx and Welcomme, 1998). In undisturbed lotic systems, fish density and biomass increase from headwaters to downstream (Schlosser, 1990; Pires et al., 1999). Our results suggest that fish assemblage structure in the Terri River was rather affected by anthropogenic disturbances, particularly from organic pollution due to agriculture, intensive farming and urbanisation. In the downstream sampling sites fish abundance was extremely low or there were no fish. In addition, Mediterranean barbel have disappeared from upstream areas, being replaced by species such as common carp and chub, typical of the middle and lower reaches of most rivers (Sostoa et al., 1990; Doadrio et al., 1991; Cowx and Welcomme, 1998), more resistant to organic pollution and altered habitats. Mediterranean barbel only persisted in habitats with high water quality. This pattern of habitat fragmentation due to heavily polluted stretches might hinder recolonization following catastrophic events such as floods, and increases vulnerability of fish populations (Detenbeck et al., 1992; Noss and Csuti, 1994).

Apart from common carp, other exotic fish species are also present in the Terri River. Pumpkinseed sunfish and largemouth bass were restricted to upstream areas, whereas common barbel were found only in the downstream area of the Terri River. Centrarchids have dispersed or been transported from Lake Banyoles and were mostly found in pools. Common barbel have dispersed from the Ter River but the high organic pollution of the downstream sampling sites may have contributed towards deterring barbel dispersion through the Terri River.

It is well known that the introduction of exotic species has had harmful effects on native Iberian fishes (Elvira, 1998; Godinho and Ferreira, 1998). Collares-Pereira et al. (1998) found that when exotics such as pike and largemouth bass remain in pools, endemic fish populations decline or even disappear. The Mediterranean barbel has already disappeared from the main body of Lake Banyoles due to fish introduction (García-Berthou and Moreno-Amich, 2000a).

The fish assemblage of the Terri River is largely influenced by anthropogenic disturbance which produces a decrease in fish species abundance, especially in the downstream area, and a shift in fish species composition. Management measures should focus on preventing further degradation of habitats, and controlling organic pollution and the dispersal of exotic species coming from Lake Banyoles or Ter River.

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