

# Natural and anthropogenic variations in a channelized water course in Centre of Portugal

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## ABSTRACT

The present study took place in the Mondego River, located in the Centre of Portugal. The lower sector of the river (Lower Mondego) is largely man-made due to regularization and rectification of the channel. The objective was to assess the impacts on the aquatic communities (fishes and benthic invertebrates). Fauna inventories were performed in June and September of 2000 and 2001, together with habitat characterization. Three sampling sites were selected in this segment and compared to a reference site located upstream. It is concluded that the presence of structures such as submerged weirs and riprap, promoted the diversity, due to the physical complexity, which they introduced into the system. The dramatic flood peaks that occurred in the winter of 2000/01 also caused substantial changes in the fluvial dynamics and in the habitats: the large amount of suspended solids transported resulted in a riverbed of unstable fine materials, and in a subsequent biological impoverishment. However, both communities displayed a high resilience to these changes; the inter-annual differences being obscured by the seasonal ones on macroinvertebrate communities.

**Keywords:** benthic invertebrates, fishes, channelization, fluvial dynamics, floods.

## RESUMEN

*El presente trabajo tuvo lugar en el río Mondego, localizado en el Centro de Portugal. El tramo bajo del río (Bajo Mondego) se encuentra intensamente transformado debido al regularización y rectificación del cauce. El objetivo fue evaluar los impactos en las comunidades acuáticas (peces e invertebrados bentónicos). Se realizaron inventarios de fauna en Junio y Septiembre de 2000 y 2001, junto con la caracterización del hábitat. Se seleccionaron tres localidades en este segmento fluvial y se compararon con una localidad de referencia localizada aguas arriba. Se concluye que la presencia de varias estructuras como los azudes sumergidos y enrocamientos, promovió la diversidad, derivado de la complejidad física que ellos introdujeron en el sistema. Las riadas dramáticas que ocurrieron en el invierno de 2000/01 también causaron cambios sustanciales en la dinámica fluvial y en los hábitats: la gran cantidad de sólidos en suspensión transportada dio lugar a un sustrato constituido por materiales finos inestables, y al empobrecimiento biológico consecuente. Sin embargo, ambas comunidades mostraron una elevada resiliencia a estos eventos, quedando las diferencias interanuales ocultas por las diferencias estacionales en las comunidades de invertebrados.*

**Palabras clave:** invertebrados bentónicos, peces, canalización, dinámica fluvial, riadas.

## INTRODUCTION

Unlike some other European countries such as Denmark and England (Brookes, 1988), Portugal has only few extensions of channelized river segments, most of which are set in urban environments (Aguiar *et al.*, 2001). These segments are located on large floodplains, in order to maxi-

mize crop production through irrigation. In these cases, the riverbed has been lowered, while riparian land is periodically cleared of trees and riverbank edges are cleaned (Aguiar *et al.*, 2001).

The objectives of this study carried out in the terminal part of the Mondego River (Centre of Portugal) were to characterize the macroinvertebrate communities and fish (abundance and

diversity) in different sectors of the river, comparing channelized segments with natural ones. An additional objective was to evaluate the effects of the floods that occurred during the study period (January of 2001) in these same sectors, and which caused a large impact on the river habitats. In channelized sectors, the influence of hydraulic structures on the diversity of organisms was also assessed.

## MATERIAL AND METHODS

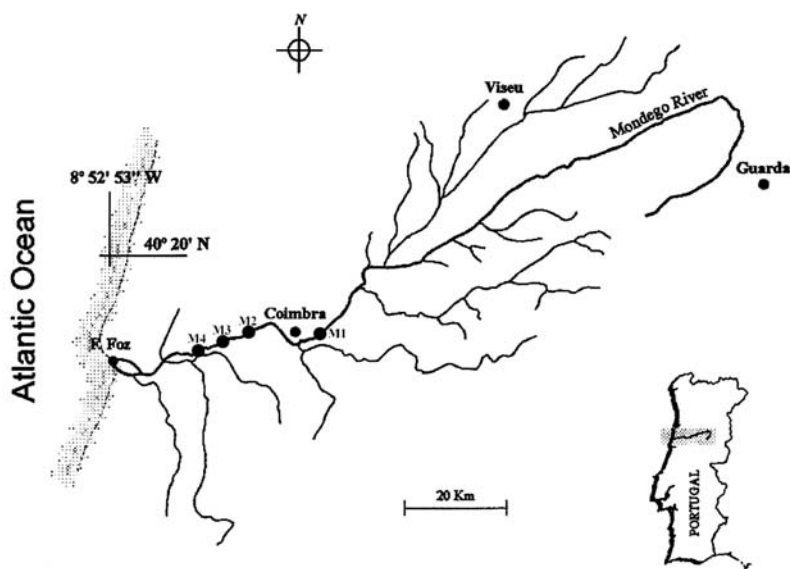
### Study area and channelization activities

The Mondego River flows in an E-W direction from the “Serra da Estrela” mountains (1547 m) for about 227 km until “Figueira da Foz”. The influence of the Atlantic increases the relative humidity of the air and affects temperatures and precipitation. The catchment area has 6671 km<sup>2</sup> and a medium altitude of 375 m, with a mean annual precipitation of 1130 mm. We may divide the longitudinal profile into different segments, according to the morphometric characteristics. The segment located in the lowest part is

called the Lower Mondego and is fully regulated and channelized. The Lower Mondego runs along an extensive alluvial plain of Cenozoic materials that extends from Coimbra to Figueira da Foz (37.5 km), with altitude levels between 0 m and 16 m (Vieira & Ferreira, 1997).

The main purpose of the channelization of Lower Mondego was flood control (to a limit of 1200 m<sup>3</sup>/s for a recurrence period of 100 years) and the enlargement of the agricultural area. The design of an entirely new river channel was coupled with two dams upstream of Coimbra, to regulate the flows from the main river and the tributaries. Specifically the channelization of the Lower Mondego consisted in resection the riverbed and in the construction of extensive longitudinal dykes, constraining this river segment in a entirely new channel with artificial banks, trapezoidal shaped in cross section. Submerged weirs and riprap were also constructed to reduce the hydraulic energy, to settle the transported sediments and to stabilize the riverbanks.

In December and January of 2000/01 an extremely high precipitation in the NO and SE slopes of the basin occurred. Cumulative precipitation for the two months registered return



**Figure 1.** Location of the sampling sites within the Mondego Basin. M1– Reference site; M2, M3 and M4 - Sites on channelized sector. *Localización de las estaciones de muestreo en la Cuenca de Mondego. M1– Localidad de referencia, M2, M3, M4 – localidades en el tramo canalizado.*

periods of 250 and 300 years respectively (Rodrigues *et al.*, 2001). The high saturation level of the soil increased the superficial flow in the catchment, which exceeded the storage capacity of the reservoirs. Consequently, the flood events of January 26 and 27 caused the rupture of the dykes downstream of Coimbra.

### Sampling sites

Three sampling sites were set in the regularized Central Bed of the Mondego River (M2, M3, M4), between Coimbra and the river mouth (Figueira da Foz), and one located approximately 14 Km upstream of Coimbra (M1) - (Fig. 1). This last one, was a control site since it was not affected by channelization, although it is located approximately 20 Km downstream of the Dam of Aguieira. This site has well developed riparian vegetation on the left bank. In contrast, the right bank presents scarce vegetation due to vegetation clear cutting and to the high deposition of materials (small stones, gravel and sand). The sites in the artificial segment exhibit extensive riprap along the banks, with constant slope of 45°, partially colonized by shrubs and trees (mainly *Populus* spp.). Medium fraction materials (stones and gravel) dominated the riverbed, but were replaced by a lower grain size fraction in the second part of the study after the flood events. M2 shows a semi-disaggregated submerged weir with resulting shear stress in the wet channel. A more detailed description of the different characteristics of each meso-habitat is in table 1.

Macroinvertebrate (M) and fish (F) sampling was carried out simultaneously in June (6) and September (9) of 2000 and 2001. Physical and chemical parameters (dissolved oxygen, pH, temperature, conductivity, alkalinity and total suspended solids) were also analysed at the sampling sites for the same periods (Table 2).

### Benthic macroinvertebrates communities

Benthic invertebrates were collected from reaches of approximately 100 m in length during a fixed time of 5 minutes (CPUE) by disturbing

the substratum upstream of the net using a vigorous kicking and/or feet action. The sampling was performed using a 350 µm mesh net with 600 cm<sup>2</sup> aperture and embraced all the existent biotopes with an effort proportional to the relative importance of each habitat (Table 1). The nets were washed carefully between collections. The contents of the hand-net were placed in labeled containers, transported to the laboratory, and the specimens sorted alive. For preservation 70% ethanol was used for subsequent identification. Wherever possible, identification was done to species level using the available keys (except Diptera and Oligochaeta).

### Ichthyic communities

In contrast with benthic collections, fish sampling allowed the discrimination between habitat types in order to detect the influence of hydraulic structures and erosion sedimentation processes (Table 1). Fish were captured using an Electrocatch apparatus, model WFC7-HV, powered by a generator (Honda GX160) of 4.0 KW. Electrofishing used DC current and the voltage was set between 150 to 200 V in order to produce a current from 2.5 to 4 A. This fact, together with a constant capture effort of 7 minutes in each meso-habitat (CPUE), allowed comparable results among the different inventoried habitat types. Electrofishing captures were complemented by 30 x 2.5 m static multimesh gill net (mesh types: 32 mm, 43 mm, 50 mm, 65 mm and 85 mm), which was placed in the deeper pools for 3-4 hours.

### Data treatment

To compare sites and periods for both sampled communities, the total number of individuals and Shannon diversity index were computed through PRIMER 5.2.2 (Clarke & Gorley, 2001).

Multivariate methods were used to detect the spatial and temporal patterns underlying the biotic and abiotic data. Metric Dimensional Analysis (MDS) was used through the package SYN-TAX 2000 (Podani, 2001) and non-Metric

**Table 1.** Characterization of habitats in each sampled site and aquatic communities that were inventoried in each sector: F – fishes; M – macroinvertebrates. Example: M1006 means reference site (M1) sampled in 2000 (second and third code's cypher) in June (fourth code's cypher). The last code refers to habitat type: D- right bank; E- left bank; T- submersed weirs; R- nets; N- rip rap; I- sand bank. *Caracterización de hábitats en cada localidad y las comunidades acuáticas que se inventariaron en cada sector. Ejemplo: M1006 significa que se trata de la estación de referencia (M1), muestreada en el año 2000 (segunda y tercera cifra del código) en el mes de Junio (cuarta cifra del código). La última cifra del código designa el hábitat: D- margen derecha; E- margen izquierda; T- azude sumergido; R- redes; N- enrocamento; I- banco de arena.*

Habitat	Mean depth (m)	Dominant substrate	Current (m s <sup>-1</sup> )	Bank structure	Communities
M1006D	1.20	Stones	0.28	Natural, smooth profile with tree clumps.	F; M
M1009D	1.20		0.28	Natural, smooth profile with tree clumps.	F; M
M1009E	2.50		0.28	Natural with a vertical profile. Riparian vegetation without interruptions.	F
M1016D	1.20		0.28	Natural, smooth profile with tree clumps.	F; M
M1016E	2.50		0.28	Natural with a vertical profile. Riparian vegetation without interruptions.	F
M1019D	1.20		0.28	Natural, smooth profile with tree clumps.	F; M
M1019E	2.50		0.28	Natural with a vertical profile. Riparian vegetation without interruptions.	F
M2006E	0.50	Gravel	0.20	Artificial embankment. 45° slope. Dense riparian vegetation.	F; M
M2006T	0.40	Stones	0.84	Semi-disintegrated submersed weir with stone blocks.	F
M2006R	2.50	Gravel	1.05		F
M2009T	0.40	Stones	0.84	Semi-disaggregated submersed weir with stone blocks.	F
M2009E	0.50	Gravel	0.20	Artificial embankment. 45° slope. Dense riparian vegetation.	F; M
M2016E	0.50	Gravel	0.20	Artificial embankment. 45° slope. Dense riparian vegetation.	F; M
M2016T	0.40	Stones	0.84	Semi-disaggregated submersed weir with stone blocks.	F
M2016R	2.50	Gravel	0.95		F
M2019E	0.50	Gravel	0.20	Artificial embankment. 45° slope. Dense riparian vegetation.	F; M
M2019T	0.40	Stones	0.84	Semi-disaggregated submersed weir with stone blocks.	F
M2019R	2.50	Gravel	1.02		F
M3006D	1.20	Stones	0.15	Artificial embankment. 45° slope. Riparian vegetation with interruptions.	F
M3006N	0.60	Stones	0.25	Rip rap with stone blocks.	F
M3006R	2.00	Gravel	0.55		F
M3009D	1.20	Stones	0.15	Artificial embankment. 45° slope. Riparian vegetation with interruptions.	F; M
M3009N	0.60	Stones	0.25	Rip rap with stone blocks.	F
M3016D	1.20	Stones	0.15	Artificial embankment. 45° slope. Riparian vegetation with interruptions.	F; M
M3016N	0.60	Stones	0.25	Rip rap with stone blocks.	F
M3016R	2.00	Gravel	0.49		F
M3019D	1.20	Stones	0.15	Artificial embankment. 45° slope. Riparian vegetation with interruptions.	F; M
M3019N	0.60	Stones	0.25	Rip rap with stone blocks.	F
M3019R	2.00	Gravel	0.54		F
M4006E	0.70	Sand	0.06	Sand bank with herbaceous vegetation.	F; M
M4006I	1.00	Sand	0.10	Stabilized sand bank with herbaceous and shrubby vegetation.	F
M4006D	1.50	Stones	0.06	Artificial embankment. Riparian vegetation with interruptions.	F
M4006R	2.50	Sand	0.10		F
M4009D	1.50	Stones	0.06	Artificial embankment. Riparian vegetation with interruptions.	F
M4009E	0.70	Sand	0.06	Sand bank with herbaceous vegetation.	F; M
M4009I	1.00	Sand	0.10	Banco de areia estabilizado com vegetação herbácea	F
M4016D	1.50	Stones	0.06	Artificial embankment. Riparian vegetation with interruptions.	F
M4016E	0.70	Sand	0.06	Sand bank with herbaceous vegetation.	F; M
M4016R	2.50	Sand	0.15		F
M4019D	1.50	Stones	0.06	Artificial embankment. Riparian vegetation with interruptions.	F
M4019I	1.00	Sand	0.10	Sand bank with herbaceous vegetation.	F
M4019E	0.70	Sand	0.06	Sand bank with herbaceous vegetation.	F; M
M4019R	2.50	Sand	0.16		F

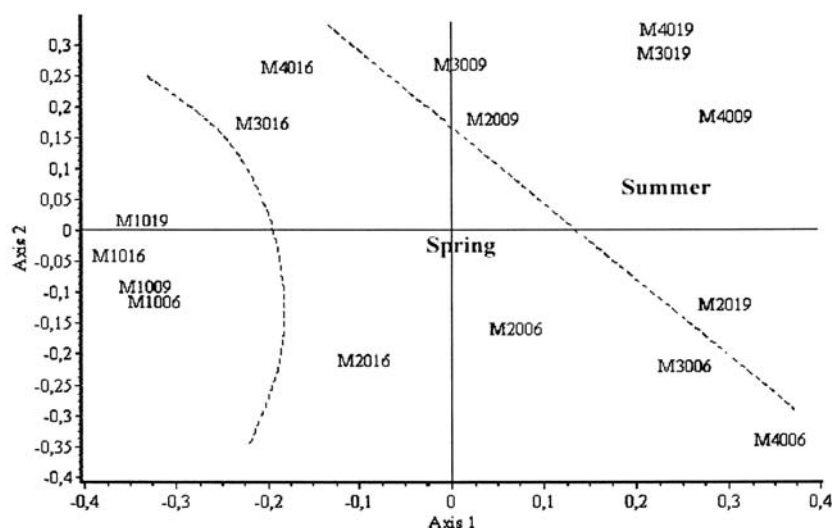
**Table 2.** Physical and chemical parameters at the 4 sampling sites in June/September 2000 and 2001. *Parámetros físicos y químicos a las 4 localidades en 2000 y 2001 (Junio/Septiembre).*

Sampling site	D.O. (mg·L <sup>-1</sup> )	pH	Temp. (°C)	Cond. (μS·cm <sup>-1</sup> )	Alkalinity (mg·L <sup>-1</sup> CaCO <sub>3</sub> )	TSS (mg·L <sup>-1</sup> )
M1006	9.5	6.5	18.6	76.1	11.8	3
M1009	8.4	7.0	20.6	78.2	14.4	1
M1016	10.2	6.3	22.8	76.3	13.8	3
M1019	9.0	6.5	22.4	79.8	9.30	0
M2006	8.9	6.7	21.1	120.1	22.9	5
M2009	9.1	7.6	23.4	103.0	20.5	1
M2016	6.7	6.4	22.1	128.9	26.4	8
M2019	7.0	7.0	22.3	113.0	18.3	8
M3006	8.6	7.4	25.5	123.5	24.8	8
M3009	10.2	7.7	24.3	149.0	27.7	2
M3016	10.4	8.1	29.0	136.7	31.9	8
M3019	9.6	7.3	25.0	120.9	19.8	5
M4006	9.2	6.9	23.9	149.0	31.8	7
M4009	6.6	6.6	22.4	137.0	35.4	2
M4016	10.4	8.1	24.9	161.0	40.1	20
M4019	7.9	7.2	23.8	129.0	20.9	20

Dimensional Analysis (n-MDS) through PRIMER 5.2.2 (Clarke & Gorley, 2001). N-MDS operated on a sample similarity matrix of the Bray-Curtis coefficient instead of the original data matrix, converting the similarity values to rank order (in order to preserve the original relationships between samples). MDS is a rela-

ted technique, in the sense that it also uses a distance or dissimilarity matrix but, on the contrary, assumes the existence of linear relationships between variables.

The data files were not transformed to enhance the effect of the density variation of organisms among sites.

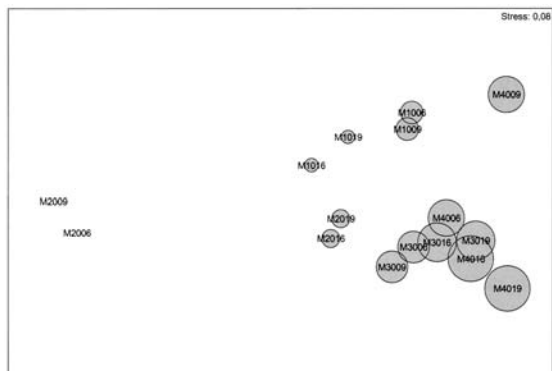


**Figure 2.** MDS ordination of sampling sites based on benthic invertebrates. Example: M1006 means reference site (M1) sampled in 2000 (second and third code's cypher) in June (last code's cypher). *Ordenación por MDS de las estaciones de muestreo con base en los invertebrados bentónicos. Ejemplo: M1006 significa que se trata de la estación de referencia (M1), muestreada en el año 2000 (segunda y tercera cifra del código) en el mes de Junio (última cifra del código).*

## RESULTS

### Macroinvertebrates communities

The differences between the reference site and the channelized sector and the potential effects of the floods in the macroinvertebrate communities were assessed through MDS ordinations of sampling sites. Figure 2 shows a clear separation of the reference site (M1) relative to the channelized ones. This site presents then, a specific benthic assemblage, characterized by different caddisflies (*Polycentropus* sp., *Plectrocnemia* sp., *Tinodes waeneri*) and stoneflies (*Leuctra fusca*) taxa. On the contrary, some Heteroptera (e.g.: *Gerris lateralis* and *Micronecta* sp.) show a preference for the modified sector. A clear seasonal separation of the sampling sites is another important aspect displayed by figure 2. This fact demonstrates the high capacity of recovery of the system since inter-annual differences are obscured by seasonal ones. The importance of riverbed materials in explaining the dynamics of benthic assemblages is illustrated by figure 3. Here, we can link these changes to the winter peak flows, which cause an extensive deposition of fine sediments, especially clear in site M2.



**Figure 3.** n-MDS ordination of sampling sites based on benthic fauna. In each site was overlapped one circle with proportional radius at relative importance of the sand on the substrate. Abbreviations of the sampling sites are given in figure 2. Ordenación n-MDS de las estaciones de muestra con base en la fauna bentónica. Sobre cada estación se instaló un círculo de radio proporcional a la importancia relativa de arena en el substrato. Las abreviaciones de las localidades de muestreo están en la figura 2.

**Table 3.** Total individuals and Shannon's diversity index for macroinvertebrate communities of the 4 sampling sites in 2000 and 2001 (June/September). Total de individuos y el Índice de diversidad de Shannon para las comunidades de macroinvertebrados de las 4 localidades en 2000 y 2001 (Junio/Septiembre).

Sampling sites		Total individuals	Shannon's diversity
M1	2000	324/385	1.99/2.54
	2001	338/486	1.83/1.93
M2	2000	1615/491	2.81/1.93
	2001	680/4661	2.14/1.44
M3	2000	978/155	0.84/1.23
	2001	305/1276	2.59/2.50
M4	2000	4334/2326	1.50/1.44
	2001	293/830	2.02/2.24

The reduced *stress* value obtained by the n-MDS ordination (0.08) demonstrates a good representation of the global variance.

In the reference site the diversity of benthic organisms was, in general, superior when compared to the channelized sites before the flood events. After this phenomenon, diversity decreased in the reference site, while the total number of individuals did not suffer great variations. However, in the channelized sites (M2, M3 and M4), the extreme flows were probably responsible for the drastic reduction in invertebrate abundances, as shown in Table 3. Nevertheless, the diversity was not substantially changed in these sites.

A taxonomic list of macroinvertebrates determined in the sampling sites is shown in Annex 1.

### Ichthyic communities

A total of thirteen *taxa*, of which six were cyprinids, were recorded (Table 4). This family, besides barbel (*Barbus bocagei*), includes three Iberian endemisms (Iberian nase - *Chondrostoma toxostoma*, Portuguese roach - *Rutilus rutilus*, and goldfish - *Carassius auratus*), and two introduced species (goldfish - *Carassius auratus*, gudgeon - *Gobio gobio*). *Cobitis paludica* was also recorded. Aside from these, two other exotic species were recorded: eastern mosquitofish (*Gambusia holbrooki*),

**Table 4.** List of ichthyic species captured in the sampling sites in 2000 (00) and 2001 (01) in June (6) and September (9). *Lista de especies de peces capturados en las localidades en 2000 (00) y 2001 (01) en Junio (6) y Septiembre (9).*

Specie	M1006	M1009	M1016	M1019	M2006	M2009	M2016	M2019	M3006	M3009	M3016	M3019	M4006	M4009	M4016	M4019
<i>Alosa fallax</i>	0	0	0	0	0	0	1	0	0	0	0	0	3	0	1	0
<i>Anguilla anguilla</i>	0	8	0	0	7	9	5	7	4	8	12	7	11	2	1	10
<i>Barbus bocagei</i>	0	2	5	6	56	39	63	55	29	1	12	40	16	34	21	31
<i>Carassius auratus</i>	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	1
<i>Chondrostoma polylepis</i>	0	5	30	50	14	3	25	29	12	6	9	8	5	1	4	2
<i>Cobitis paludica</i>	4	2	4	1	13	2	12	3	11	4	8	0	39	2	2	2
<i>Gambusia holbrooki</i>	0	0	0	0	0	0	0	0	0	0	2	0	2	1	0	3
<i>Gobio gobio</i>	3	14	16	13	13	0	0	5	2	4	0	5	10	4	0	9
<i>Lepomis gibbosus</i>	1	1	1	5	0	1	0	1	0	3	1	2	2	4	3	1
<i>Squalius carolitertii</i>	12	13	2	0	0	0	0	0	1	0	1	1	0	2	0	1
<i>Liza ramada</i>	0	0	0	0	1	0	5	9	5	2	15	1	6	1	1	0
<i>Petromyzon marinus</i>	0	0	0	0	0	0	0	2	0	0	0	2	0	0	1	1
<i>Rutilus macrolepidotus</i>	29	8	27	52	2	1	0	0	3	2	0	4	0	0	0	0

**Table 5.** Total individuals and Shannon's diversity index for ichthyic communities of the meso-habitats inside the 4 sampling sites in 2000 and 2001 (June/September). *Total de individuos y el Índice de diversidad de Shannon para las comunidades de peces en los meso-hábitats de cada una de las 4 localidades en 2000 y 2001 (Junio/Septiembre).*

	Sampling sites		Total individuals	Shannon's diversity
M1	2000	D	49/18	1.11/1.66
		E	-/35	-/1.48
	2001	D	29/72	1.33/1.02
		E	56/55	1.37/1.02
M2	2000	E	15/18	1.46/1.13
		T	67/37	1.23/0.61
		R	24/-	0.83/-
	2001	E	16/23	0.70/1.75
		T	55/61	0.57/0.94
		R	40/27	1.08/1.07
M3	2000	N	10/19	1.28/1.65
		D	26/11	1.23/1.47
		R	31/-	1.12/-
	2001	N	29/25	1.72/1.83
		D	8/37	0.97/1.05
		R	24/9	1.01/0.96
M4	2000	E	19/13	0.63/1.78
		D	21/26	1.22/0.48
		I	30/12	0.77/0.87
		R	24/-	1.30/-
	2001	E	17/23	1.81/1.63
		D	8/22	0/0.66
		R	11/6	0.89/1.24
		I	-/10	-/0.90

and the centrarchid pumpkinseed (*Lepomis gibbosus*). The migratory diadromous fish species identified were the anadromous sea lamprey (*Petromyzon marinus*), the twaite shad (*Alosa fallax*), the catadromous European eel (*Anguilla anguilla*), and the thinlip mullet (*Liza ramada*).

The influence of floods and channelization on the abundance and diversity of ichthyic communities was not conclusive (Table 5). However, figure 4 suggests that the two types of sites (channelized *versus* non-channelized) support different communities. In fact, *Rutilus macrolepidotus*, *Gobio gobio* and *Squalius carolitertii* are more represented in the reference site, whereas *Barbus bocagei* and *Chondrostoma polylepis* are common in both sectors (channelized/ non-channelized). The other species (including the exotic ones) are restricted to the artificial segment of the Mondego. The fish populations were discriminated by the meso-habitat in each station, which is also represented in figure 4. We may conclude from this the lack of inter-annual differences, demonstrating a high resilience of fish populations to extreme hydrological events. It is also possible to see from this figure and from Table 5 that a higher number of species exhibit preferences for the meso-habitats T and N (submerged weir and riprap, respectively). Similarly, a higher density of the majority of species is observed precisely in these habitats.



fluvial dynamics. The elevated transport of solid material originated a strong sedimentation of unstable fine materials, leading to a biological impoverishment and alterations in the functioning of the system. Macroinvertebrate communities underwent a substantial reduction of abundance, with larger incidence in channelized sectors, where sedimentation was higher. Nevertheless, despite the floods, macroinvertebrate communities displayed a high resilience. Identical results were obtained by Ortega *et al.* (1991) after a flood in the basin of River Segura (Spain). The resilience of the benthic community is not, however, so surprising if we take into account that floods are natural phenomena that have occurred throughout the evolutionary history of aquatic insects (Ward, 1992). Macroinvertebrates respond to spatial and temporal variability by changes in the structure of their communities. They show tremendous diversity in their life history patterns, including variation in life cycle length, developmental strategies, and seasonality of the various life history stages (Greenwood & Richardot-Coulet, 1996). Such traits explain also the seasonal variations, which were very clear in the Lower Mondego, probably because in changing environments there is a dominance of short-lived species (Hershey & Lamberti, 1998).

The ichthyic communities did not show clear inter-annual or seasonal differences; moreover, the natural hydrological disturbances seemed to produce a low impact. Roux & Copp (1996) argue that the importance of hydrological variation is necessary to complete the biological cycles and that only frequent flow peaks disrupt these communities.

Channelization of river courses, because of simplification of the channel environment, leads to a decrease in microhabitats, therefore mitigation structures providing habitat heterogeneity must be installed immediately after channelization (Brookes, 1988; Armitage, 1995). Submersed weirs diversify the habitat by impounding a greater depth of water above the structure, and by increasing the velocity downstream to erode a scour pool (Brookes, 1988). Other struc-

tures built to absorb fluvial erosion such as brushing, logwalling, rock riprap, etc., may create specific habitats propitiating larger faunal diversity, due to the physical heterogeneity that is associated with them (Torre, 2001). For instance, Reeves *et al.* (1998) in a small stream in western Oregon observed abundance increases of dace with increasing levels of habitat complexity. Likewise, Vieira & Ferreira (1997) argue that the use of submersed weirs and riprap in the Lower Mondego was environmentally positive. All these mitigation structures in channelized reaches increase the heterogeneity of available habitats for the aquatic communities and have been applied to restore streams all over Europe (Nijland & Cals, 2000). In the present case we can assess the positive effects of submersed weir and riprap in improving the habitat, with consequences on diversity of fish populations.

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**Annex 1.** List of macroinvertebrates present in the sampling sites. *Lista de invertebrados presentes en las localidades muestreadas.*

Taxon	M1006	M1009	M1016	M1019	M2006	M2009	M2016	M2019	M3006	M3009	M3016	M3019	M4006	M4009	M4016	M4019
Hydracarina	152	100	53	83	132	8	0	35	0	0	2	10	0	21	0	2
Diptera																
<i>Hemerodromia</i> sp.	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eusimulium</i> sp.	2	0	0	0	6	5	2	12	0	0	0	0	0	0	0	0
Ephydriidae gen. sp.	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1
<i>Hydrellia</i> sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Ephydra subocapa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Stratiomyidae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Tipula</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tipula strepens</i>	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dicranomyia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
<i>Limnophora</i> sp.	1	0	0	0	1	1	0	0	0	0	0	0	3	11	0	0
<i>Atrichops</i> sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Atherix</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Empididae gen. sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini gen. sp.	4	3	51	24	99	49	15	79	7	8	32	120	55	22	21	19
Tanypodinae gen. sp.	3	17	110	49	12	3	17	6	0	1	15	7	3	3	1	0
Orthoclaadiinae gen. sp.	9	19	9	8	194	11	38	54	766	15	16	12	2368	9	10	24
Tanytarsini gen. sp.	0	11	11	9	49	10	22	27	13	2	100	47	31	3	124	15
Hemedromiinae gen. sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Dolichopodidae gen. sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Tipulidae gen. sp.	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	1
Limoniidae gen. sp.	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	8
<i>Chironomus gr. plumosus</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Simulium pseudequinum</i>	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Simulium erythrocephalum</i>	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
<i>Simulium bezzii</i>	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0
<i>Simulium sergenti</i>	0	0	0	0	5	1	0	2	0	0	0	0	0	0	0	0
<i>Simulium ruficorne</i>	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0
<i>Simulium quadrifila</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Sciomyzidae gen. sp.	0	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0
<i>Syrphus</i> sp.	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
<i>Sepedon tenuicornis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Sepedon</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Anthomyiidae gen. sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
<i>Melanocheilia riparia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Pericoma</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Culicidae gen. sp.	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Ceratopogonidae gen. sp.	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bezzia</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dixella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Atrichopogon</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
<i>Dimecoenia spinosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mollusca																
<i>Unio</i> sp.	0	0	0	0	0	0	11	0	1	0	0	0	0	0	0	0
<i>Anodonta cygnea</i>	0	0	0	0	0	0	11	1	0	0	0	0	0	0	0	0
<i>Pisidium</i> sp.	50	60	0	0	100	50	100	52	36	3	2	3	0	0	3	27
<i>Margaritifera margaritifera</i>	0	0	0	0	50	0	28	5	13	0	0	0	0	0	1	0

**Annex 1.** (Continuation.)

Taxon	M1006	M1009	M1016	M1019	M2006	M2009	M2016	M2019	M3006	M3009	M3016	M3019	M4006	M4009	M4016	M4019
<i>Sphaerim</i> sp.	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
<i>Pisidium casertanum</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
<i>Ferrissia wautieri</i>	0	0	0	0	5	0	0	10	0	0	0	0	0	1	0	1
<i>Bithynia tentaculata</i>	0	0	0	0	3	0	0	0	7	1	0	0	0	0	0	0
<i>Physella acuta</i>	0	0	0	0	36	5	7	54	2	0	19	64	38	193	0	177
<i>Gyraulus crista</i>	0	0	0	0	0	0	0	59	0	0	0	0	0	0	0	0
<i>Gyraulus</i> sp.	0	0	0	0	5	2	0	0	0	0	0	0	18	599	0	0
<i>Lymnaea peregra</i>	0	1	0	0	1	0	0	0	0	0	0	0	1	2	0	0
<i>Zonitoides nitidus</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
<i>Bythinella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
<i>Ancylus fluviatilis</i>	6	4	0	0	5	0	0	2	0	0	0	0	0	0	0	0
<i>Potamopyrgus jenkinsi</i>	4	0	0	0	401	1	37	9	0	0	10	4	0	0	0	0
<i>Oxylom elegans</i>	1	0	0	0	3	0	0	12	0	0	0	14	0	55	0	60
Oligoqueta																
<i>Eiseniella tetraedra</i>	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Enchytraeidae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	2
Lumbricidae gen. sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lumbriculidae gen. sp.	25	34	0	3	1	0	0	2	0	0	0	23	0	1	0	5
Tubificidae gen. sp.	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Branchiura sowerbyi</i>	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Naididae gen. sp.	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Colembola																
Sminthuridae gen. sp.	3	0	1	1	12	14	0	3300	0	0	3	2	299	13	7	2
Poduridae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Isotomidae gen. sp.	0	0	77	207	0	0	0	1	0	0	0	0	1	0	1	0
Coleoptera																
<i>Rhantus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Helichus substriatus</i>	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
<i>Limnius</i> sp.	1	0	0	9	0	0	1	0	0	0	0	0	0	0	0	0
<i>Laccophilus</i> sp.	0	0	0	0	3	0	0	0	0	0	0	0	54	1	0	0
<i>Stenelmis canaliculata</i>	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0
<i>Dryops</i> sp.	0	0	1	2	0	0	0	9	0	0	0	0	0	0	1	6
<i>Hydaticus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Copelatus</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Potamophilus acuminatus</i>	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Oulimnius</i> sp.	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
<i>Oulimnius troglodytes</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Curculionidae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	1075	0	0	0
<i>Hydrous</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Enochrus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	59	7	0	0
<i>Laccobius</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2
<i>Helophorus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	0
<i>Hydrobius</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Hydraena</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
<i>Guignotus pusillus</i>	0	0	0	0	0	0	0	0	0	0	0	0	3	0	4	0
<i>Helochares</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
<i>Agabus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Berosus</i> sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Bidessus pusillus</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Bidessus</i> sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Meladema coriacea</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Taxon	M1006	M1009	M1016	M1019	M2006	M2009	M2016	M2019	M3006	M3009	M3016	M3019	M4006	M4009	M4016	M4019
Trichoptera																
<i>Enomus</i> sp.	0	0	0	0	0	0	0	1	0	0	0	11	0	0	0	0
<i>Hydropsyche</i> sp.	1	2	0	0	74	29	20	162	0	0	2	0	0	0	0	0
<i>Ceraclea</i> sp.	1	0	0	0	9	1	6	0	0	0	8	0	0	0	1	0
<i>Pseudoneuroclipsis lusitanicus</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Polycentropus</i> sp.	3	3	0	0	1	0	2	0	0	0	0	0	0	0	0	0
<i>Plectrocnemia</i> sp.	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Mystacides azurea</i>	0	1	0	0	4	1	0	1	0	0	0	0	0	0	0	0
<i>Oecetis testacea</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Chimarra marginata</i>	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
<i>Lype auripilis</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Hydroptila</i> sp.	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
<i>Diplectrona felix</i>	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0
<i>Hydropsyche lobata</i>	0	4	0	1	21	4	35	123	0	0	1	0	0	0	0	0
<i>Padoniella vandeli</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tinodes waeneri</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Psychomyia</i> sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Gomphus pulchellus</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Gomphus simillimus</i>	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata																
<i>Calopteryx virgo</i>	0	2	0	0	1	1	0	1	0	0	0	0	0	1	0	0
<i>Platicnemis latipes/acutipennis</i>	0	0	0	0	1	0	0	0	2	0	0	0	1	2	0	0
<i>Ischnura graellsii</i>	0	0	0	0	3	0	0	8	0	0	0	0	0	0	0	0
<i>Trithemis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Pyrrhosoma nymphula</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Coenagrion puella</i>	0	0	0	0	0	0	0	49	0	0	0	0	1	3	0	0
<i>Corduliidae</i> gen. sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Coenagrion mercuriale</i>	0	0	0	0	0	0	0	9	0	0	0	0	4	0	0	0
<i>Calopteryx</i> sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Platicnemis</i> sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ischnura elegans</i>	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
<i>Boyeria irene</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Crustacea																
<i>Atyaephyra desmarestii</i>	28	38	1	61	136	259	0	346	122	112	7	195	125	1274	50	171
<i>Bragasellus cortesii</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Procambarus clarkii</i>	0	0	0	0	5	0	0	0	0	1	10	2	0	0	20	1
Ephemeroptera																
<i>Caenis luctuosa</i>	4	14	0	1												

Annex 1. (Continuation.)

Taxon	M1006	M1009	M1016	M1019	M2006	M2009	M2016	M2019	M3006	M3009	M3016	M3019	M4006	M4009	M4016	M4019
<i>Centropitilum luteolum</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Pseudocentropitilum pennulatum</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<hr/>																
Triclades																
<i>Dugesia polychroa</i>	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
<i>Planaria torva</i>	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
<i>Dugesia lugubris</i>	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0
<hr/>																
Heteroptera																
<i>Aquarius najas/cinereus</i>	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0
<i>Aquarius najas</i>	0	0	0	0	0	7	2	2	0	0	8	3	0	0	0	0
<i>Aquarius cinereus</i>	0	0	0	0	1	2	1	10	0	0	0	156	0	0	0	0
Gerridae gen. sp.	0	0	0	0	2	2	0	0	0	0	6	0	1	0	0	0
<i>Micronecta minuscula</i>	0	0	0	2	0	0	0	65	0	0	1	161	0	0	4	19
<i>Micronecta scholtzi</i>	0	0	0	0	8	0	0	16	0	0	7	198	8	0	7	211
<i>Micronecta</i> sp.	0	0	0	0	0	0	0	7	0	0	0	145	0	0	0	39
<i>Naucoris maculatus</i>	0	0	0	0	4	0	0	0	0	0	0	0	2	0	0	0
<i>Ochterus marginatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Corixidae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
<i>Sigara</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
<i>Sigara semistriata</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6
<i>Mesovelgia vittigera</i>	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
<i>Hydrometra stagnorum</i>	0	1	0	0	0	0	0	5	0	0	0	0	1	0	0	0
Notonectidae gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Gerris lateralis</i>	0	1	0	0	0	0	297	0	0	0	0	0	0	0	0	1
<i>Nepa cinerea</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
<i>Gerris thoracicus</i>	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
<i>Hydrometra stagnorum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<hr/>																
Plecoptera																
<i>Leuctra aurita</i>	0	1	0	0	5	0	0	0	0	0	0	0	0	0	0	0
<i>Leuctra fusca</i>	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
<i>Leuctra</i> sp.	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leuctra geniculata</i>	0	0	0	0	0	0	2	2	0	0	7	0	0	2	0	0
<i>Perlodes microcephala</i>	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
<hr/>																
Acheta																
<i>Helobdella stagnalis</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Erpobdellidae gen. sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Erpobdella monostrata</i>	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0
<i>Glossiphonia complanata</i>	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0