UNIVERSIDADE DE ÉVORA

Influência dos obstáculos de pequena dimensão na estruturação dos agrupamentos piscícolas

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The impact of small physical obstacles on the structure of freshwater fish assemblages

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Orientação:

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Esta tese não inclui as críticas e sugestões feitas pelo júri.

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The impact of small physical obstacles on the structure of freshwater fish assemblages

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ABSTRACT

Many studies have assessed the effects of large dams on fishes but few have examined the effects of small obstacles. Fishes were sampled and environmental variables were characterized at 28 sites in two Iberian streams, 14 located immediately downstream, upstream and between five small obstacles at River Muge and 14 at River Erra, considered as the reference stream. Multivariate analysis indicated that habitat variables like current velocity and depth, but not physicochemistry, were the main responsible for site groups' discrimination in both streams. The reference stream exhibited a longitudinal gradient of current velocity that, however, wasn't strong enough to cause significant changes in the fish assemblage's composition and structure. By successive and drastically repeating this gradient near each structure, the obstacles stream presented differences in fish fauna between the three site types. Lentic upstream sites presented higher density of limnophilic, omnivorous and exotic species, like gudgeon *Gobio lozanoi*, who are well adapted to this type of habitat. Downstream and between obstacles sites were characterized by the dominance of rheophilic and invertivorous *taxa*, especially barbel *Luciobarbus bocagei*. Richness metrics did not differ among site types, but diversity was higher in sites located between the obstacles away from its direct influence, where the habitat diversity was higher. Contrarily to upstream sites, downstream and between obstacles sites were similar in many of the studied features to the reference stream, implying that this type of structures cause a higher modification in the upstream fish community. This study suggests that the effects of small obstacles on habitat and fishes are similar, in some extent, to those reported for larger dams, providing important considerations for riverine ecosystem conservation efforts.

KEYWORDS: Fish assemblages, small physical obstacles, habitat fragmentation, connectivity, ecological guilds, Portugal.

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RESUMO

O efeito das grandes barragens na comunidade piscícola vem sendo documentado por numerosos estudos, enquanto o número de trabalhos que incidem sobre o efeito dos obstáculos de pequena dimensão é bastante mais reduzido. A comunidade piscícola foi amostrada e as variáveis ambientais foram caracterizadas em 28 locais divididos por dois cursos de água da Península Ibérica, 14 dos quais localizados imediatamente a montante, jusante e entre cinco pequenos obstáculos na Ribeira de Muge e 14 na Ribeira de Erra, considerada a linha de água de referência. Através de análise estatística multivariada foi possível verificar que variáveis de habitat como a velocidade de corrente e a profundidade, e não as variáveis físico-químicas, foram as principais responsáveis pela discriminação dos vários grupos de locais nas duas ribeiras. A ribeira de referência exibiu um gradiente longitudinal de velocidade de corrente que, contudo, não era suficientemente forte para causar alterações significativas na composição e estrutura dos agrupamentos piscícolas. Através da sucessiva e drástica repetição deste gradiente junto a cada estrutura, a ribeira com obstáculos apresentou diferenças na fauna piscícola entre os três tipos de locais. Os troços lênticos a montante apresentavam uma densidade mais elevada de espécies limnofílicas, omnívoras e exóticas, como o góbio (*Gobio lozanoi*), que estão bem adaptadas a este tipo de habitat. Os locais de amostragem situados a jusante e entre os obstáculos caracterizavam-se pela dominância de *taxa* reófilos e invertivoros (i.e. barbo, *Luciobarbus bocagei*). As métricas relacionadas com a riqueza especifica não apresentaram diferenças entre os três tipos de locais, ao contrário da diversidade que foi mais elevada nos pontos situados entre os obstáculos, afastados da sua influencia directa, onde a diversidade de habitats também é mais elevada. Contrariamente aos locais a montante, os troços a jusante e entre os obstáculos apresentaram similaridades, em muitas das características estudadas, com a ribeira de referência, sugerindo que este tipo de estruturas provoca uma alteração mais significativa na comunidade piscícola a montante. Este estudo sugere que os efeitos dos pequenos obstáculos no habitat e na ictiofauna são, em parte, semelhantes aos descritos para as grandes barragens, fornecendo considerações importantes para os esforços de conservação dos ecossistemas ribeirinhos.

PALAVRAS-CHAVE: Agrupamentos piscícolas, pequenos obstáculos, fragmentação de habitat, conectividade, *guilds* ecológicas, Portugal.

INTRODUCTION

Historically, rivers and adjacent areas have been used by human populations more than any other type of ecosystem (Jungwirth, 1998). Humans have exploited the resources provided by rivers and their flood plains and drastically modified them to reduce the threat to urban areas (Arthington & Welcomme, 1995; Jungwirth, 1998). As a result from this sometimes unruled use, very few water courses maintain their original integrity (Jungwirth, 1998; Jager *et al.*, 2001). By the early 1900s, most large rivers in temperate regions had already been modified, and nearly all large rivers in the world are now impounded by hydroelectric power plants and other hydraulic structures (Welcomme, 1995). Fragmentation and loss of aquatic habitat originated by the construction of artificial barriers such as dams, weirs, roads or bridges are some of the most important anthropogenic actions in this type of ecosystem, at a global scale (Dynesius & Nilsson, 1994; Jungwirth *et al.*, 2000; Morita & Yokota, 2002; Nilsson, 2005). In rivers, fragmentation is easy to accomplish since a single damming event is enough to isolate adjacent river segments (Jager *et al.*, 2001).

Unlike many groups of animals, fish movement is limited to within watercourses. Because of their high mobility and stage-specific movement patterns, as well their distinct habitat requirements, stream-dwelling fish populations are severely affected by the disruption of the longitudinal continuum, proving to be sensitive indicators for assessment of the highly variable connectivity conditions of running waters over space and time (Jungwirth *et al.*, 2000; Morita & Yokota, 2002).

The impacts of large dams (i.e. height>15m defined by Poff & Hart, 2002) on fish are well documented. The obstruction of the dispersal and migration of organisms is its most discussed effect (i.e. Saunders *et al.*, 1991; Dynesius & Nilsson, 1994; Peter, 1998; Nilsson, 2005), being directly linked to loss of populations and entire species of freshwater fishes, but it is easy to find studies reporting other significant impacts of these structures on the aquatic ecosystems, namely the changes on the habitat characteristics from a lotic to a lentic environment (i.e. Martinez *et al.*, 1994; Godinho *et al.*, 1997; Rodriguez-Ruiz, 1998; Guenther & Spacie, 2006), consequently benefiting the nonnative species, and degradation of the water quality resulting from the high nutrient accumulation and primary production growth (i.e. Godlewska & Swierzowski, 2003; Carol *et al.*, 2006). Contrary to the extensive literature that exists about the large dams, the effects of small obstacles such as weirs, low-head dams, road crossings, culverts and bridges have received less attention. Most of the studies that have investigated the impact of such small barriers mainly concern with fish migrations (Lucas & Frear, 1997; Warren & Pardew, 1998; Winter & Van Densen, 2001; Ovidio & Phillipart, 2002), populations isolation (Morita & Yokota, 2002; Meldgaard *et al.*, 2003) or its application as a method for preventing the invasion of migratory exotic species (Thompson & Rahel, 1998; McLaughlin *et al.*, 2007). However, studies addressing the impact of small obstacles on fish community structure remain scarce and have been carried out mainly in France and U.S.A (Cumming, 2004; Tiemann *et al.*, 2004; Gillette *et al.*, 2005; Poulet, 2007).

Small obstacles designs could vary from simple, low-water fords to massive concrete or earth-filled structures (Warren & Pardew, 1998; Gibson *et al.*, 2005). Some of them may act as semipermeable or seasonal barriers to fish movement, similar to shallow riffles, others may preclude all movements by fishes, similar to the effects of dams (Winston *et al.*, 1991). Regardless of their size and complexity, the presence of these structures is often associated to local changes in the physical structure of the rivers, mainly the homogenization of several micro-habitat characteristics such as current velocity, depth, substrate, among others (Hagglund & Sjoberg, 1999; Dodd *et al.*, 2003; Santucci *et al.*, 2005; Poulet, 2007). The native fish fauna of a lotic ecosystem is generally well adapted to natural fluctuations of the environmental conditions

(Gehrke & Harris, 2001) but there are clear evidences of an evolution in the way to exploit specific habitat features, which include for example, highly adapted body forms and mouth position. Any type of change to the habitat stability could alter the life-cycle of fish species and consequently the local structure patterns of its assemblages (Welcomme *et al.*, 2006).

The native freshwater fish fauna of the Iberian Peninsula is characterized by a low number of families, with most of the species belonging to the family Cyprinidae, a high degree of diversification at the species level, and the greatest European percentage of endemism (Doadrio, 2001; Clavero *et al.*, 2004; Rogado *et al.*, 2005). As in other Mediterranean peninsulas, the Iberian fluvial network is complex, comprising a high number of independent river basins where the different species populations are strongly isolated and highly vulnerable to habitat alterations (Collares-Pereira *et al.*, 2000; Corbacho & Sanchez, 2001; Clavero *et al.*, 2004). Iberian ichthyofaunas have received little attention, specially the ones from small rivers, even though an urgent need for conservation and plans of action are required (Corbacho & Sanchez, 2001). In this context, a comprehensive assessment of fish biodiversity and their possible relationship with environmental variables and river alterations should be carried out as an important management tool for its conservation. In this work it is presented a comparative analysis of the fish assemblages' structure of two Iberian streams with similar original characteristics but different levels of impact from the presence of small physical obstacles. The aim of this study was to evaluate the hypothesis that the habitat alterations originated by the presence of this type of structures will promote changes on the structure of fish assemblages.

MATERIALS AND METHODS

Study area

In the beginning of 2008, a field survey was conducted in order to find watercourses with similar abiotic and biophysic characteristics but with different levels of impact from the presence of small obstacles. The southern basins of the country were avoided to reduce the structuring effect of their harsh intermittent hydrological regime, as well rivers with a high regulated flow, caused by the presence of large dams or other hydroelectrical structures. Rivers were selected using a criterion of minimum evidence of human disturbance (presence or absence of small obstacles aside) such as major point-source pollution or agricultural run-off (Dodd *et al.*, 2003). After this survey, two rivers were selected for this study: River Erra and River Muge (Figure 1). These rivers belong to the River Tagus basin, considered Europe's fifth major basin in terms of area and the third on the Iberian Peninsula, covering a total surface of about 80629 km^2, of which 24800 km^2 (30%) are in Portuguese territory (INAG, 2008a). Being located near each other in a low altitude (≈ 54m), reduced slope (4-8%) and high mineralization area on the sedimentary deposits of the Tagus basin (INAG, 2008a), these rivers are very similar in what concerns to environmental and climate features. The area is characterized by a low annual rainfall, nearly 730 mm±118.30 (mean±s.d.), and a high mean annual temperature (15.5°C±0.38). Both rivers have a low mean annual drainage, which can vary between 100-200 mm (INAG, 2008a).

The River Muge is severely affected by the presence of small obstacles, most of them consisting of bridges for the passage of people and/or vehicles, with elevated bases similar to small weirs or low-head dams. In this third order river, a reach of 17.5 km of length (with the river's total length being 55 km) with five structures of the described type was selected as the "Obstacles stream". For a more detailed description of the studied obstacles, please check Appendix I. The River Erra (total length of 37.5

km), being significantly less affected by habitat fragmentation, was elected as the "Reference stream" and a reach of similar order and length but without the presence of any obstacle was considered for the study (Figure 1).

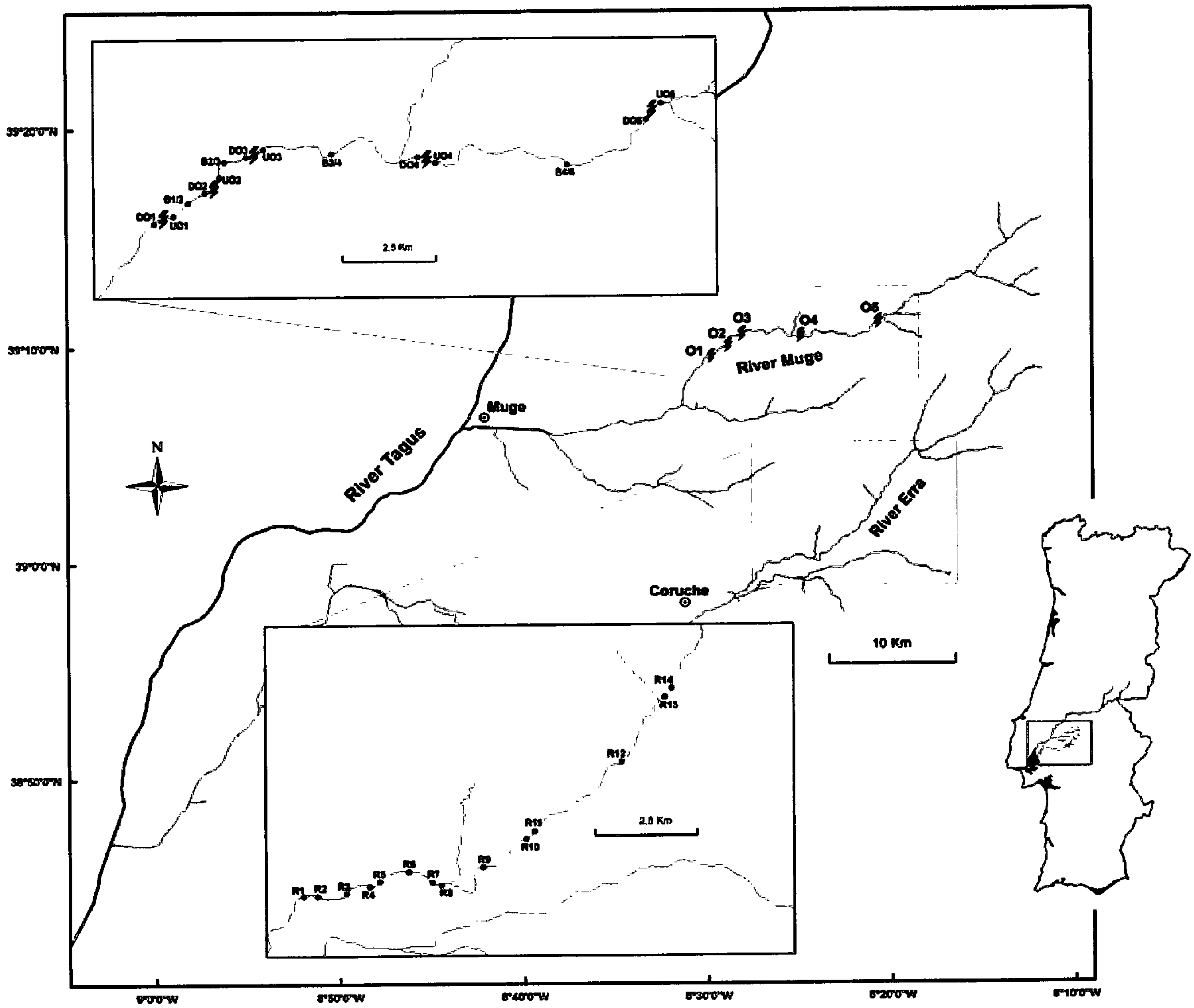

Figure 1. Location of the study area and sampling sites (•) in the "Obstacles stream" (River Muge) and in the "Reference stream" (River Erra). Obstacles are identified by lightening (⚡). DO, UO and B abbreviations represent respectively the sampling sites located downstream, upstream and between the obstacles, while R represents the sampling sites in the reference stream.

Sampling procedure

In the obstacles stream, sampling was done in three types of sites: immediately downstream from the obstacles (DO), immediately upstream from the obstacles (UO) and between obstacles, away from its direct influence (B), in a total of 14 sites. An equal number of sites were sampled in the reference stream (R), respecting the same arrangement and distance between them. In similar studies, reference and non-reference sites were selected and compared in the same watercourse (i.e. Tiemann *et al.*, 2004; Poulet, 2007). Considering the longitudinal continuum of the lotic ecosystems and the linkage between all of its components (see Vannote *et al.*, 1980), selecting the two types of reaches in different rivers allows to reduce the indirect effect of the obstacles on the reference sites (Dodd *et al.*, 2003).

During May 2008, fishes were collected with a backpack electrofishing device (Hans Grassl ELT60II HI, 500V DC, 10A), following an adaptation of the standard sampling protocol defined by INAG (2008b) in the scope of the Water Framework Directive. According to this protocol, the minimum length of the sampling reach should be 20 times its mean width, never being less than 100 m. In this study, this was the length sampled in all sites because none of them had more than 5 m of width. Each site was blocked off, at its downstream and upstream limits, with 20 mm knot to knot mesh size nets that were secured to the stream bed to prevent the escape or entry of any fish. For a better estimation of fish abundance, a removal method with at least three passes was completed at each site. Regardless of the higher simplicity and cost-effectiveness of the single-pass method, which is mostly recommended for simple monitoring programs, this procedure has proven to be more accurate on successfully determine the fish abundance in this type of studies (Meador *et al.*, 2003; Peterson *et al.*, 2004). After each pass, fishes were identified and counted allowing a break of 1/2h to let the system recover and the fishes retake their normal behaviour. Additional electrofishing passes were made if necessary until the catch per pass declined by 75% or more between successive passes (Peterson *et al.*, 2004). At the end of each pass, nets were cleaned of debris and inspected to ensure they were barriers to fish passage. All block nets remained in position until electrofishing sampling was concluded. All captured fish were placed in oxygenated live wells and held at stream margins. Only after the conclusion of all passes fishes were returned alive to their natural environment. Considering the specific daily variation on the spatial occupation of each *taxon*, the sampling procedure was completed at a similar hour and climate conditions in all sites.

For each site sampled, water temperature (ºC), dissolved oxygen (mgL^{-1}), conductivity (µS/cm) and pH (Sorensen scale) were recorded, using a calibrated multi parameter probe (*YSI* 600 XLM-M) coupled to a data logger viewer (*YSI* 650 MDS) and a pH probe (*pH 197* WTW). Current velocity (ms^{-1}) was measured using a *Valeport* current meter (*Model 105*) and mean depth was obtained by taking measurements (precision of 0.01 m) several times at each sampling site (minimum of 3 measurements). Dominant type of substrate in each site was characterized considering 5 different classes: silt; sand; gravel; pebbles; blocks. The biophysic features of each site were characterized by direct observation, namely the following parameters: shade (provided by the riparian habitat) and aquatic cover (provided by aquatic vegetation, debris and rocks) proportions (5 classes: 0-20%; 20-40%; 40-60%; 60-80%; 80-100%).

Data analysis

All abiotic and biotic variables were log-transformed before being statistically analysed to reduce normality deviations. Before the application of any parametric analysis, normality and homogeneity of variances were tested for each variable, using Shapiro-Wilk *W*-statistic and the Levene test, respectively.

Sampled sites on both streams were grouped by their abiotic and biophysic characteristics using a hierarchical classification with a linkage between groups' method and the Euclidean distance as measure, as recommended for abiotic data (Sokal & Rohlf, 1981). An arbitrary cut-off level was used, such that separate groups could be chosen. This analysis was complemented with a stepwise discriminant function analysis (DFA; Wilks's λ method, F entry: 3.840, F removal: 2.710) to identify the variables significantly responsible for the group discrimination. These analyses were performed and resulting plots displayed using SPSS 12.0.

After the application of a multiple pass removal method in the sampling procedure, fish species' abundance in the sampled sites was estimated with Leslie's census method (Cowx, 1983) by plotting capture *per* unit of effort (CPUE, expressed in number of fishes caught *per* minute) against cumulative removal and estimating the total number of fishes that would be removed when the CPUE tends to zero. In the resulting graphic, designated by Leslie's representation (Appendix II), the estimative of the initial population's dimension (N_∞) corresponds to the point in the abciss when CPUE=0 and it can be calculated by dividing the regression line's intercept by its slope (capturability coefficient) [N_∞= - (a/b)]. All the assumptions for using this method were satisfied in the study design. With the estimated abundance values, and knowing the area of the sampled sites (mean width of the reach x sampled length), each species' density was calculated and expressed in number of fishes caught *per* 100 m^2. The lamprey's ammocoetes (genera *Lampetra*) and the mosquitofish (*Gambusia holbrooki* Girard, 1859) captured in both streams were removed from the subsequent analysis due to their ecological features and response to the sampling methodology. The first ones have very specific habitat requirements, forming large accumulation areas commonly known as ammocoetes beds (Almeida & Quintella, 2002), which can cause disturbance in the field sampling and bias in the data analysis. As for the mosquitofish, its small size and shoaling behaviour allows these specimens to escape in high number from the net blocking, reducing its capture efficiency.

The association between fish community composition (mean N_∞ values of each species) and site types within each stream was tested by using a *G*-test of independence (Sokal & Rohlf, 1981).

A Canonical Correspondence Analysis (CCA Ter Braak, 1987) was used to characterise and compare the relation between the spatial variability of the captured fish species (expressed in density) and the environmental parameters in both studied rivers, (CANOCO 4.5). The result of this analysis is an ordination diagram, where symbols represent fish species and sites sampled, and vectors correspond to the environment variables. The vectors indicate the direction of maximum variation of the correspondent environmental variable. Environmental variables, whose projection in a particular axis is extended, are strongly correlated with the referred ordination axis (Ter Braak, 1987). The statistical significance of the relation between the fish species density and the set of environmental variables was assessed through a Monte Carlo global permutation test (999 permutations) (Ter Braak, 1987). Poorly represented species (occurring only in three or less samples and total density below 5 fishes *per* 100 m^2) were removed from this analysis.

For each sampling site, total fish species-richness (i.e. *TR*, the number of fish species in each sample), introduced species-richness (*IR*), native species-richness (*NR*), species diversity (*H*, Shannon-Wiener Index) and density of introduced individuals (*DI*) were determined. The captured species were classified according to its habitat requirements (rheophilic, *DRheo*; eurytopic, *DEury*; limnophilic, *DLimno*) and its trophic ecology (invertivorous, *DInve*; piscivorous; omnivorous, *DOmni*) (Michel and Oberdorff, 1995; Welcomme *et al.*, 2006; Kottelat & Freyhof, 2007), and the density of these guilds in each sample was determined. Because the piscivorous species were poorly represented in our samples (only large-mouth bass, *Micropterus salmoides* Lacepède, 1802) its density was very low and this guild was excluded from the statistical analysis.

Several studies describe the distance from the source as a key factor on determining the fish assemblages' structure in lotic environments, being specially related with the species-richness (i.e. Angermeier & Schlosser, 1989; Gillette *et al.*, 2005; Poulet, 2007). Thus, for both studied streams, the relationship of the composition and structural metrics (*TR*, *NR*, *IR*, *DI* and *H*) and guilds density with distance from the source was investigated using Pearson or Spearman correlations, whether the data were parametric or not (SPSS 12.0). If this was significant ($P<0.05$), an analysis of covariance (ANCOVA) was performed in order to test the differences in metrics and guilds structure between the two streams and between the groups of sites within each stream. This method, performed with the program BIOMstat for Windows (Version 3.0), allows to adjust the values of the related metrics and guilds (dependent variables) so that one can estimate the mean and variance that would have been obtained if the distance from the source (covariate) had not varied within a sample (Sokal & Rohlf, 1981). If the correlation was not significant, a one-factor analysis of variance (ANOVA), followed by a post-hoc Gabriel test for multiple comparisons, or in case of non parametric data a Kruskall-Wallis test with a Simultaneous Test Procedure (STP) (Siegel & Castellan, 1988) for multiple comparisons, were conducted with the same objective. These analyses were performed using SPSS 12.0.

RESULTS

Abiotic characterization

During the sampling period, physicochemical parameters, such as water temperature, dissolved oxygen, conductivity and pH, showed little variation between the two studied rivers and among sampling sites within each river (Table 1). On the other hand, environmental features directly related with stream morphology and hydrodynamics, such as current velocity and mean depth, and with biophysic characteristics, like shade and aquatic cover, exhibited some variation between the two watercourses and sampling sites within (Table 1). Substrate was reasonably homogeneous throughout the two studied reaches, being mainly composed of sand.

Table 1. Abiotic and biophysic characteristics of the studied area on both streams

	River Erra – "Reference Stream"				**River Muge – "Obstacles stream"**			
	Mean	S.D.	Minimum	Maximum	Mean	S.D.	Minimum	Maximum
Water temperature (°C)	16.3	1.3	14.3	18.2	17.3	1,4	15.6	20.2
Dissolved oxygen (mgL^{-1})	9.63	0.62	8.47	10.67	9.54	0.49	8.18	10.01
Conductivity (µS/cm)	0.330	0.012	0.318	0.366	0.358	0.023	0.323	0.398
pH (Sorensen scale)	7.1	0.3	6.6	7.7	6.9	0.2	6.4	7.4
Current velocity (ms^{-1})	0.42	0.06	0.32	0.52	0.48	0.16	0.27	0.74
Mean depth (m)	0.42	0.10	0.30	0.68	0.54	0.23	0.30	1.00
Shade (%)	61.4	15.6	40.0	90.0	72.1	5.4	60.0	80.0
Aquatic cover (%)	50.7	6.2	40.0	60.0	57.1	5.8	50.0	70.0

S.D. - Standard Deviation.

Hierarchical clustering of the 14 sites of the reference stream identified two groups of sites (Figure 2). Group 1 included eight sampled sites (R1-R8), located in a downstream area of the river, and Group 2 included the upstream remaining six sites (R9-R14). The discriminant function analysis (DFA) conducted for this stream identified current velocity (within-group correlation with the DFA function = -0.53) as the environmental gradient significantly separating the two groups (Wilks λ = 0.11, F = 44.820, P <0.001). Cross-validation (leave-one-out method) procedure revealed that the DFA correctly predicted the status of 100% of the cases.

The hierarchical classification of the sampled sites within the obstacles stream identified three groups (downstream from obstacles – DO, upstream from obstacles – UO and between the obstacles – B), clearly separated according to their position relatively to the obstacles (Figure 2). DFA conducted for the three site types of this stream revealed a gradient of current velocity (within-group correlation with the first DFA function = 0.99) that separates DO and B sites, with faster current, from the UO sites with slower current (Figure 3). The second discriminant axis of DFA separated UO sites with higher mean depth (within-group correlation with the second DFA function = 0.91) from DO and B sites with lower depth. The DFA procedure was highly significant (Wilks λ = 0.21, F = 29.733, P <0.001) and correctly predicted the status of 100% of the cases.

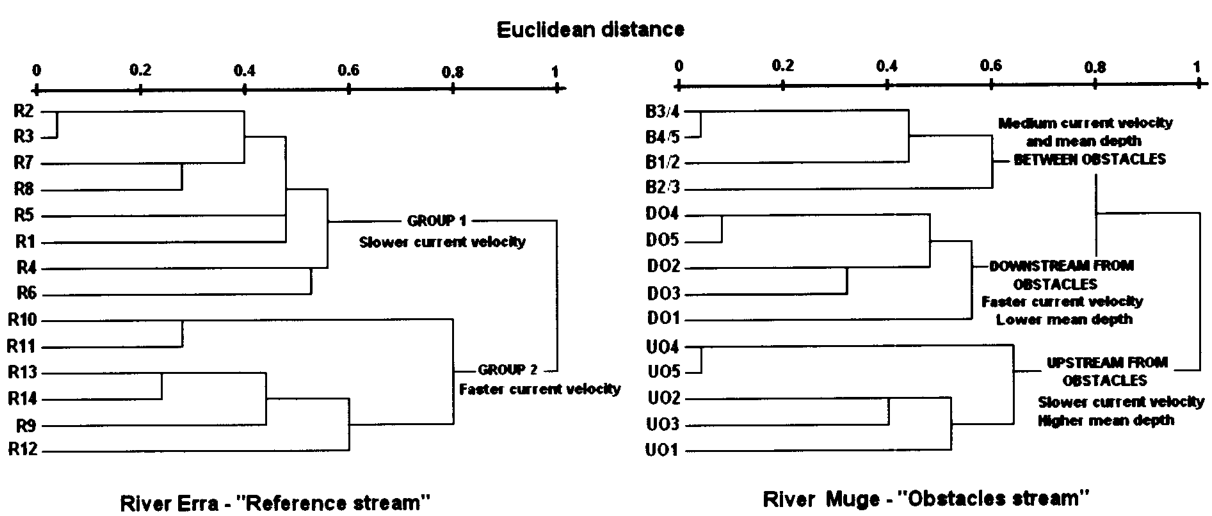

Figure 2. Hierarchical classification of sampled sites on both studied rivers, based on their abiotic and biophysic characteristics.

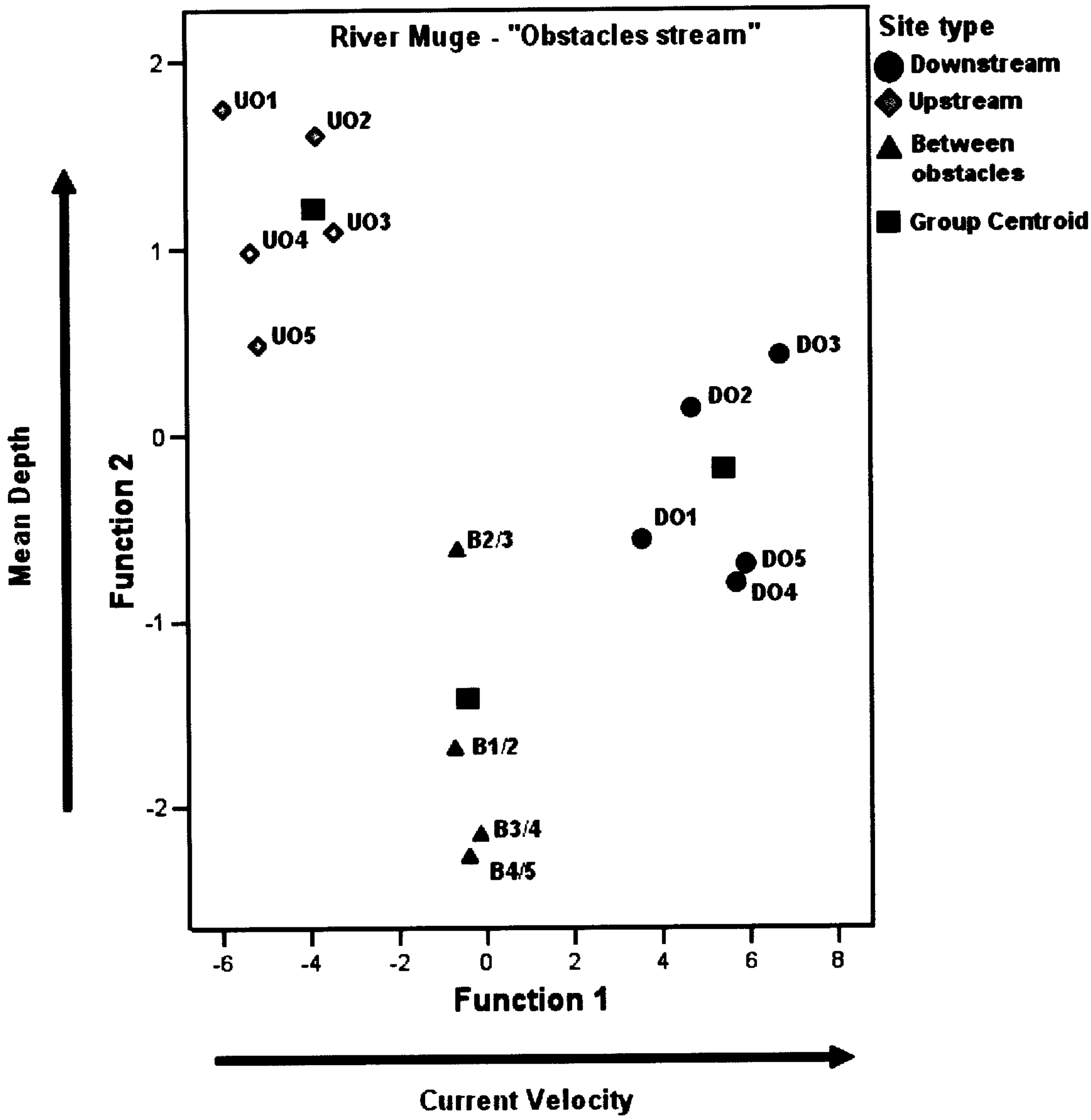

Figure 3. Sampling sites scores (by site type) on the two discriminant function (DFA) axes for River Muge – "Obstacles stream".

When considering all the sampled sites of both streams, the hierarchical clustering identified two major groups, assembling DO and B sites of the obstacles stream with Group 2 of the reference stream and UO sites with Group 1 (Figure 4). DFA conducted for all the sampled sites identified current velocity (within-group correlation with the DFA function = 0.81) as the main environmental gradient significantly separating the two groups (Wilks λ = 0.18, F = 77.181, P <0.001). Cross-validation procedure revealed that this DFA correctly predicted the status of 100% of the cases.

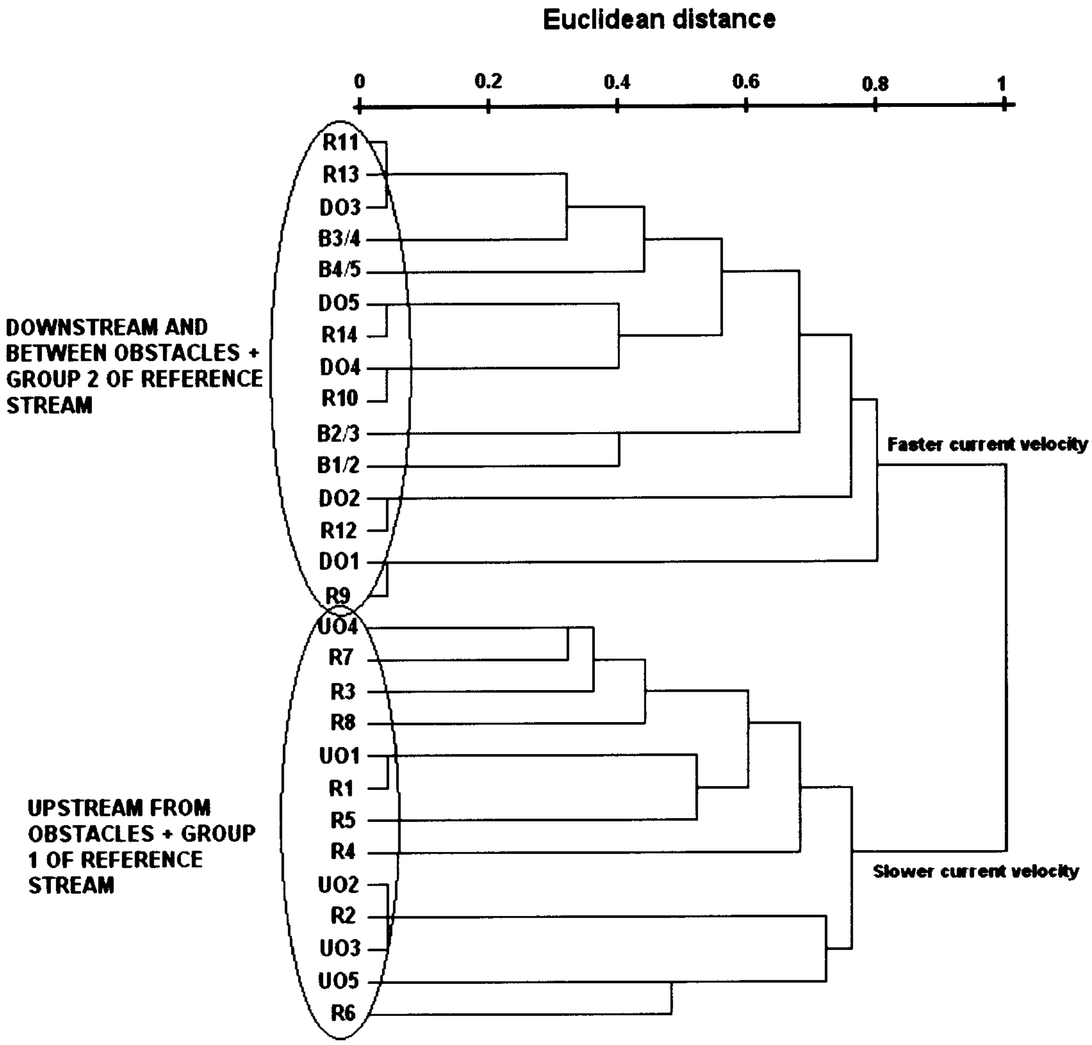

Figure 4. Hierarchical classification of all sampled sites on both rivers, based on their abiotic and biophysical characteristics.

Fish-species composition and environmental relationships

A total of 11 fish-species were sampled (Table 2). Their majority were captured on both streams, except large-mouth bass and roach (*Iberocypris alburnoides* Steindachner, 1866) that were only present in the obstacles stream. Among the 11 species, four were classified as introduced (36.4%). In terms of ecology, 27.3% of the species sampled were rheophilic, the same proportion eurytopic and 45.5% limnophilic (most of them introduced). Concerning their feeding habits, most of the species were omnivorous (45.5%), 36.4% were invertivorous and only one was classified as piscivorous. Due to the reasons described in the methodology section, mosquitofish and the specimens of the genera *Lampetra* were not considered in the following analyses.

Table 2. Status, ecological and trophic guilds of the fish-species sampled

Scientific name (*acronym*)	**Common name**	**Status**	**Ecological guild**	**Thophic guild**
Anguilla anguilla (L.) (*Aang*)	Eeel	N	Eurytopic	Omnivorous
Cobitis paludica (de Buen) (*Cpal*)	Loach	N	Limnophilic	Omnivorous
Gambusia holbrooki (Girard) (*Ghol*) *	Mosquitofish	I	Limnophilic	Omnivorous
Gobio lozanoi (L.) (*Gloz*)	Gudgeon	I	Limnophilic	Omnivorous
Iberocypris alburnoides (Steindachner) (*Ialb*)	Roach	N	Eurytopic	Invertivorous
Lampetra spp. (*Lamp*) *	Lampreys	N	Reophilic	Filter-feeding
Lepomis gibbosus (L.) (*Lgib*)	Pumpkinseed	I	Limnophilic	Invertivorous
Luciobarbus bocagei (Steidachner) (*Lboc)*	Barbel	N	Reophilic	Omnivorous
Micropterus salmoides (Lacepède) (*Msal*)	Large-mouth bass	I	Limnophilic	Piscivorous
Pseudochondrostoma polylepis (Steidacnher) (*Ppol*)	Nase	N	Reophilic	Invertivorous
Squalius pyrenaicus (Gunther) (*(Spyr*)	Chub	N	Eurytopic	Invertirvorous

N – Native, I – Introduced.
* These species were removed from the analyses due to the reasons described on the methodology section.

Overall, the studied rivers presented statistically similar fish assemblages, dominated by cyprinid species, with gudgeon, barbel and chub exhibiting the highest values of mean density (Figure 5). The rarest species in these watercourses were roach, eel and large-mouth bass. Regardless of the abiotic distinction observed between the two groups of sites within the reference stream, their fish-species composition was statistically similar and independent from the sample group (P >0.05), so the reference stream was always compared as a whole. Despite of the independence test results (Table 3), the separated analysis of the three site types of the obstacles stream was maintained because this was the treatment stream. In the sites sampled immediately downstream from the obstacles (DO), the highest values of mean density were exhibited by barbel (dominating species), gudgeon and chub. The fish-species proportions in this type of sites did not differed significantly from the ones in the reference stream (Table 3). In the same way, sampling sites located between the studied obstacles (B) were characterized by a high density of the same three most abundant species, but without the clear dominance of none of them. The *G*-tests revealed non significant differences between the fish composition of B sites and the ones from DO sites and reference stream. Gudgeon, an introduced species, exhibited the highest mean density value in the sites located immediately upstream from the obstacles (UO), clearly being the predominant species in this type of sites. Species that were abundant in other locations, barbel and chub, presented low values of density, both being surpassed by another introduced species, i.e., pumpkinseed. Contrarily to what was being observed among the other site types and whole streams, the fish species composition of UO sites was significantly different from the DO and B sites in River Muge and from the reference stream. The significance of this differences was higher between the sites within the same river ($P < 0.001$) than the one observed against the whole reference stream ($P < 0.05$).

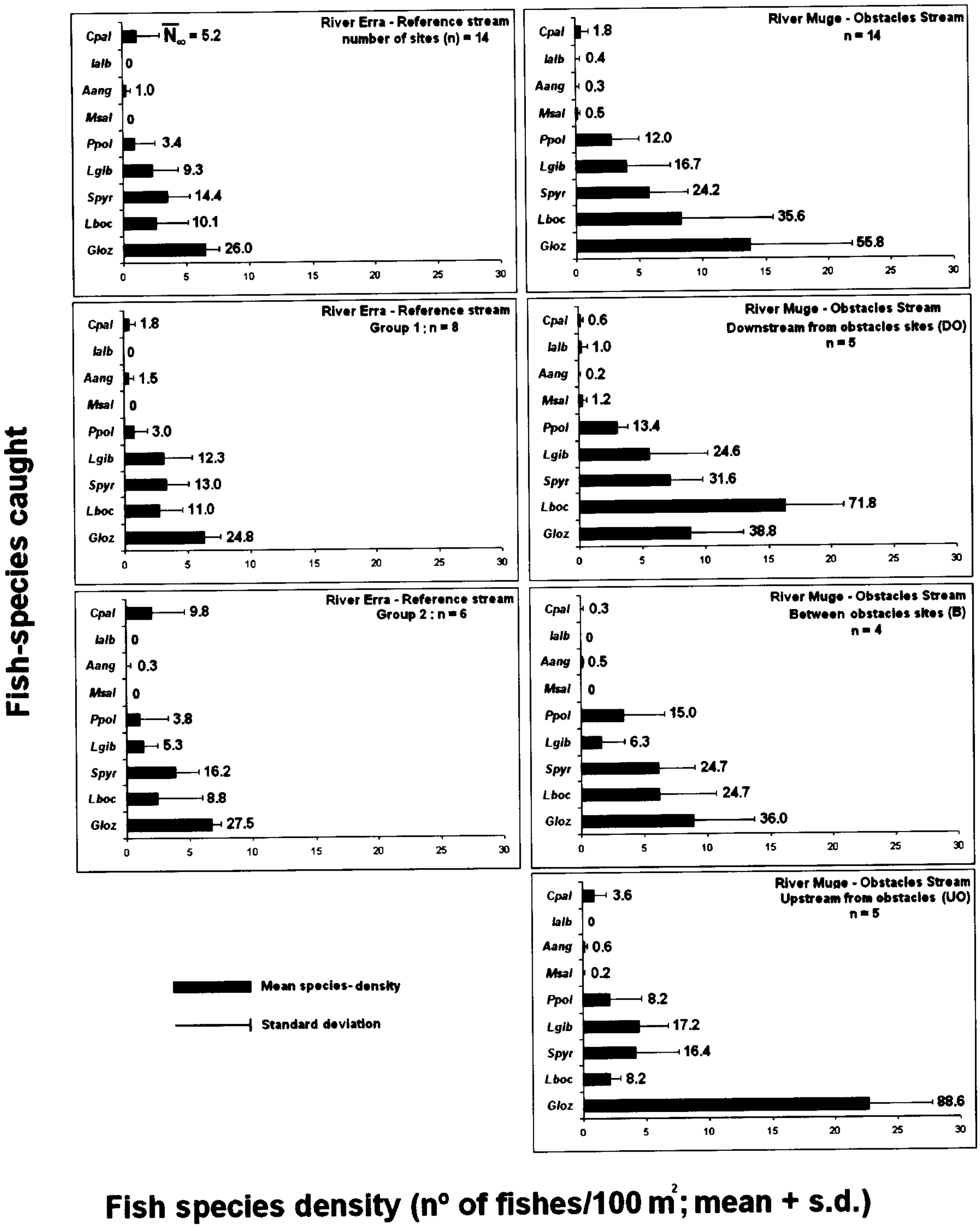

Figure 5. Fish-species density (n° of fishes/100 m^2; mean + s.d.) and mean estimated N_∞ values for each species sampled in the studied streams and groups of sites within.

Table 3. Results of G – tests of independence on the fish-species composition (mean estimated N_∞ values) of both studied stream and groups of sites within

	River Erra "Reference stream"	**River Muge "Obstacles stream"**	**Group 1 "Reference stream"**	**Group 2 "Reference stream"**	**DO sites "Obstacles stream"**	**B sites "Obstacles stream"**	**UO sites "Obstacles stream"**
River Erra "Reference stream"	-						
River Muge "Obstacles stream"	$G = 11.6$ n.s.	-					
Group 1 "Reference stream"	*	†	-				
Group 2 "Reference stream"	*	†	$G = 11.22$ n.s.	-			
DO sites "Obstacles stream"	$G = 12.8$ n.s.	*	†	†	-		
B sites "Obstacles stream"	$G = 11.15$ n.s.	*	†	†	$G = 12.15$ n.s.	-	
UO sites "Obstacles stream"	$G = 15.5$ $P < 0.05$	*	†	†	$G = 86.57$ $P < 0.001$	$G = 40.77$ $P < 0.001$	-

* Groups of sites were not tested against the rivers they are within it.

† Fish-species composition of Group 1 and Group 2 (Reference stream) was statistically independent of the sample ($P > 0.05$), so the River Erra was compared in its whole.

The Canonical Correspondence Analyses (CCA) showed that the fish-species assemblages of the studied rivers were differently structured, regarding their relationships with the environmental features (Figure 6). In the reference stream CCA, of the nine abiotic and biophysic variables initially considered (variables from Table 1 plus Distance from the source) only six were retained for the analysis by the forward selection procedure (Table 4). The first two axis of this CCA ordination explained 39.9% of the fish assemblage spatial variability and 78.5% of the relation between fish-species density and the selected environmental variables. The high correlation coefficients between species and environmental variables, obtained for the first two axes (0.82 and 0.73 respectively), suggest that environmental variables explain the variability associated with fish-species density. The high correlation of aquatic cover and shade with the first canonical axis, and current velocity and mean depth with the second canonical axis, identified the main environmental gradients for each axis in the reference stream (Table 4). The global permutation test (*F*-ratio = 3.00) showed that the first canonical axis was statistical significant ($P < 0.05$). The test based on the sum of all canonical eigenvalues led to an *F*-ratio of 2.88, demonstrating that the relation between fish-species density and environmental variables was also significant ($P < 0.05$). This CCA ordination separated the sampled sites in two main groups, in a similar way to the respective hierarchical clustering. Sites located in the downstream area of the study reach (R1-R8) were characterized by higher mean depth, shade and aquatic cover, and were mostly differentiated by an elevated density of pumpkinseed. On the other side of the horizontal axis (Axis II), the sites located upstream in the sampling reach (R9-R10) were mainly represented by native species like nase and chub, and were associated to a faster current velocity. The most abundant species, barbel and gudgeon, were not clearly associated to any of the resulting groups, being common throughout the sampled reach.

In the obstacles stream CCA, the same six environmental variables were retained by the selection procedure (Table 4). The first two axis explained 48.7% of the fish assemblage spatial variability and 78.1% of the relation between fish-species density and the selected environmental variables. The first two axes obtained high correlation values of 0.97 and 0.69, respectively. Mean depth, current velocity and shade exhibited high correlations with the vertical axis (Axis I), representing the main environmental gradients structuring the fish assemblages in the obstacles stream. All canonical axes were statistical significant (*F*-ratio = 2.42, $P < 0.05$). The vertical axis clearly separates the sampling sites of this stream in two opposite groups, according to its location relatively to the obstacles. The UO sites were grouped and characterized by a higher mean depth and slower current velocity. The fish-species associated to this type of sites were the pumpkinseed, gudgeon and loach. The DO and B sites were represented together, exhibiting faster current velocities, shallower habitats and a higher percentage of shade, where species like barbel, chub and nase were more abundant.

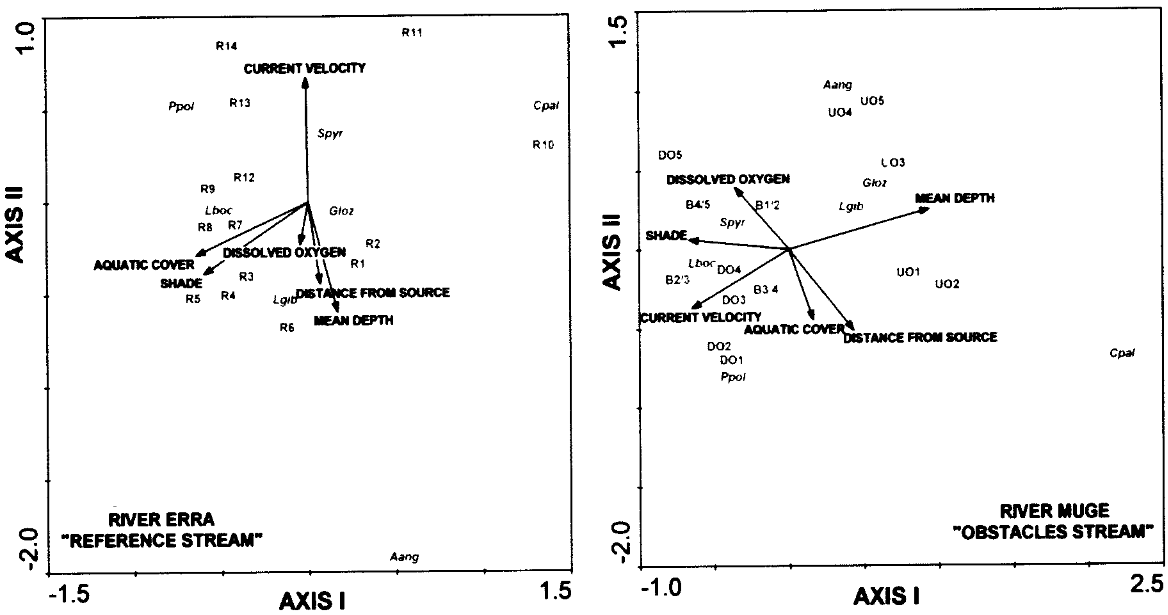

Figure 6. Canonical correspondence analysis (CCA) biplot for fish-species and environmental variables (with indication of samples) assessed for both studied rivers. Environmental variables are represented by arrows that point towards the direction of maximum variation.

Table 4. Results of the ordination by CCA of fish-species density data: eigenvalues, species-environment correlation coefficients, and intraset correlation of environmental variables with the first two canonical axes

	River Erra – "Reference Stream"		**River Muge – "Obstacles Stream"**	
	Axis I λ = 0.10	Axis II λ = 0.05	Axis I λ = 0.06	Axis II λ = 0.02
Species-environment	0.82	0.73	0.97	0.68
Aquatic cover	-0.58	-0.26	0.15	-0.37
Current velocity	-0.10	0.62	-0.60	-0.31
Dissolved oxygen	-0.10	-0.21	-0.33	0.33
Distance from source	0.16	-0.40	0.40	-0.43
Mean depth	0.15	-0.54	0.88	0.21
Shade	-0.53	-0.35	-0.62	0.05

Community structure

On the studied streams, of all the metrics and guilds analysed, only *TR* ("Reference stream": Pearson r = 0.32, $P<0.05$; "Obstacles stream": Pearson r = 0.41, $P<0.05$) and *NR* ("Reference stream": Pearson r = 0.54, $P<0.05$; "Obstacles stream": Pearson r = 0.44, $P<0.05$) were significantly related with distance from the source, so an ANCOVA was applied to these variables.

From the studied metrics and guilds, only *NR* and *IR* were significantly different between the two streams in its whole (Table 5), with the obstacles stream exhibiting a higher number of introduced species and, consequently, a lower native richness than the reference stream (Figure 7). None of the variables tested presented significant differences between the two groups of sites within the reference stream, so this river was always compared as a whole.

Within the obstacles stream, *H*, *DI* and all the ecological and trophic guilds presented significant differences between the three site types (Table 5). *DRheo* and *DEury* were similar between DO and B sites but higher than in UO sites. *DI*, *DOmni* and *DLimno* exhibited an inverse pattern, exhibiting higher values at UO sites (Figure 7). Species-diversity *(H)* was significantly higher in B sites than in UO and DO, a pattern similar to the one observed for *DInve*. In the obstacles stream, none of the richness metrics was significantly different among site types.

When testing the three site types of the obstacles stream against the whole reference reach, the richness metrics did not exhibited significant differences, with the exception of *IR* that was constantly higher in all site types of the impounded stream (Figure 7). In the reference stream, *H* was similar to the values observed in B sites and higher than in UO and DO. *DI*, *DLimno* and *DOmni* were significantly higher in UO sites with the reference stream exhibiting lower values, similar to the ones observed in DO and B sites. *DRheo* was significantly lower in UO and reference sites, when compared to DO and B (Table 5). *DEury* and *DInve* were not significantly different between the three site types of the obstacles stream and the whole reference stream.

Table 5. Results from the statistical analyses applied to test the differences in composition and structural metrics and guilds density between the two streams and groups of sites within

	Tests Performed § †							
Metrics/ Guilds	**Reference stream *vs* Obstacles stream**	**Group 1 *vs* Group 2 (Reference stream)**	**DO *vs* UO sites (Obstacles stream)**	**DO *vs* B sites (Obstacles stream)**	**UO *vs* B sites (Obstacles stream)**	**Reference stream *vs* DO sites**	**Reference stream *vs* UO sites**	**Reference stream *vs* B sites**
TR	ANCOVA Intercepts F=0.93, P=0.35 Slopes F=0.01, P=0.91	ANCOVA Intercepts F=0.26, P=0.62 Slopes F=1.23, P=0.29	ANCOVA Intercepts F=0.24, P=0.64 Slopes F=0.11, P=0.75	ANCOVA Intercepts F=1.19, P=0.32 Slopes F=0.18, P=0.69	ANCOVA Intercepts F=0.88, P=0.39 Slopes F=0.05, P=0.84	ANCOVA Intercepts F=0.76, P=0.36 Slopes F=0.48, P=0.59	ANCOVA Intercepts F=1.01, P=0.38 Slopes F=0.26, P=0.62	ANCOVA Intercepts F=0.99, P=0.35 Slopes F=0.21, P=0.62
NR	ANCOVA Intercepts F=18.31*, P<0.05 Slopes F=1.02, P=0.32	ANCOVA Intercepts F=0.05, P=0.82 Slopes F=0.54, P=0.48	ANCOVA Intercepts F=0.20, P=0.68 Slopes F=1.20, P=0.32	ANCOVA Intercepts F=0.57, P=0.48 Slopes F=1.69, P=0.25	ANCOVA Intercepts F=0.73, P=0.43 Slopes F=0.69, P=0.45	ANCOVA Intercepts F=5.35, P<0.05 Slopes F=0.00, P=0.96	ANCOVA Intercepts F=10.75, P<0.05 Slopes F=1.65, P=0.22	ANCOVA Intercepts F=11.45, P<0.05 Slopes F=2.54, P=0.13
IR	ANOVA F=38.37*, P<0.01	Kruskall-Wallis χ^2=0.98, P=0.52		Kruskall-Wallis χ^2=1.97, P=0.72			Kruskall-Wallis χ^2=23.53*, P<0.001 DO=UO=B >Reference stream	
H	Kruskall-Wallis χ^2=3.97, P=0.14	ANOVA F=4.64, P=0.06		Kruskall-Wallis χ^2=5.82*, P<0.05 B>DO=UO			Kruskall-Wallis χ^2=11.75*, P<0.01 B=Reference stream>DO=UO	
DI	Kruskall-Wallis χ^2=2.16, P=0.34	ANOVA F=0.45, P=0.51		ANOVA F=10.63*, P<0.01 UO>DO=B			ANOVA F=6.09*, P<0.01 UO>DO=B=Reference stream	

§ Groups of sites were not tested against the rivers they are within it.

† Metrics and guilds were always statistically similar (P >0.05) between Group 1 and Group 2 (Reference stream), so the River Erra was compared as a whole.

* Significant; ** Highly significant.

Table 5 (cont.). Results from the statistical analyses applied to test the differences in composition metrics and guilds density between the two streams and groups of sites within

	Tests Performed § †							
Metrics/ Guilds	**Reference stream *vs* Obstacles stream**	**Group 1 *vs* Group 2 (Reference stream)**	**DO *vs* UO sites (Obstacles stream)**	**DO *vs* B sites (Obstacles stream)**	**UO *vs* B sites (Obstacles stream)**	**Reference stream *vs* DO sites**	**Reference stream *vs* UO sites**	**Reference stream *vs* B sites**
DRheo	Kruskall-Wallis χ^2=3.46, *P*=0.18	ANOVA *F*=2.27, *P*=0.12		ANOVA *F*=16.16*, *P*<0.01 DO=B>UO			ANOVA *F*=6.89*, *P*<0.01 DO=B>UO=Reference stream	
DLimno	Kruskall-Wallis χ^2=4.06, *P*=0.13	ANOVA *F*=0.09, *P*=0.76		ANOVA *F*=11.23*, *P*<0.01 UO>DO=B			ANOVA *F*=5.05*, *P*<0.01 UO>DO=B=Reference stream	
DEury	Kruskall-Wallis χ^2=3.32, *P*=0.19	ANOVA *F*=0.16, *P*=0.70		ANOVA *F*=6.24*, *P*<0.05 DO=B>UO			ANOVA *F*=2.19, *P*=0.10	
DOmni	ANOVA *F*=0.96, *P*=0.39	ANOVA *F*=1.27, *P*=0.28		ANOVA *F*=3.24*, *P*<0.05 UO>B>DO			ANOVA *F*=8.32**, *P*<0.001 UO>B=Reference stream>DO	
DInve	Kruskall-Wallis χ^2=1.86, *P*=0.40	Kruskall-Wallis χ^2=1.21, *P*=0.29		Kruskall-Wallis χ^2=4.49*, *P*<0.05 B>DO=UO			ANOVA *F*=2.13, *P*=0.11	

§ Groups of sites were not tested against the rivers they are within it.

† Metrics and guilds were always statistically similar (*P* >0.05) between Group 1 and Group 2 (Reference stream), so the River Erra was compared as a whole.

* Significant; ** Highly significant.

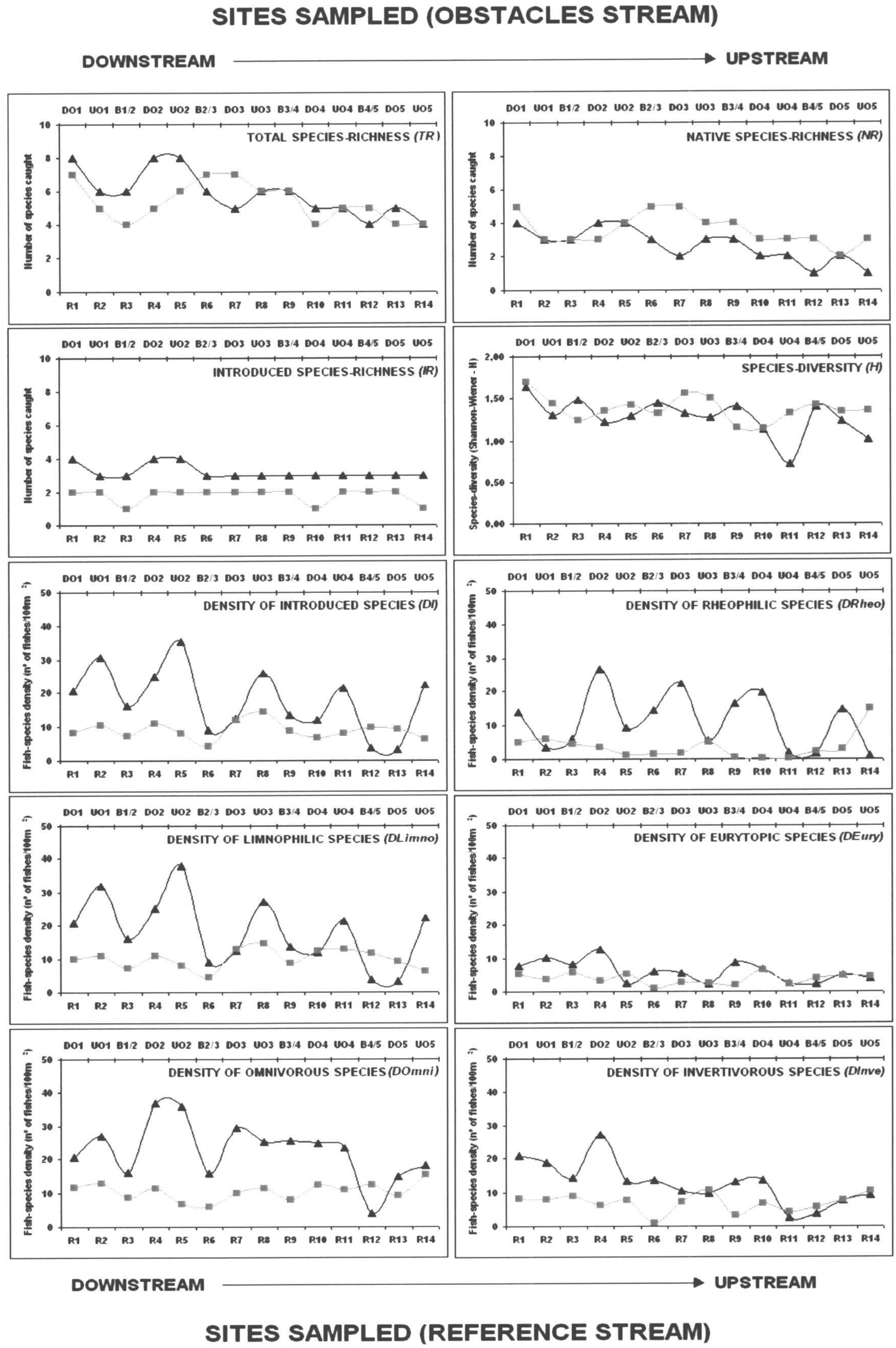

Figure 7. Variation of community structural metrics (*TR*, *NR*, *IR*, *H* and *DI*) and guilds density (rheophilic, limnophilic, eurytopic, omnivorous and invertivorous species) on both studied rivers: River Erra – "Reference stream" —■— ; River Muge – "Obstacles stream" —▲—.

DISCUSSION

A strong correlation exists between habitat variables and fish assemblages, which imply that fragmentation and modification of riverine habitat can have profound effects on biotic integrity (Dynesius & Nilsson, 1994; McLaughlin *et al.*, 2006; Harford & McLaughlin, 2007). The protection and conservation, as well as restoration and management of running water environments, requires an exact knowledge of the ecological demands of the most important species in order to genuinely understand the influence of the habitat alterations at a local scale (Jungwirth *et al.*, 2000). This study demonstrates the influence of the presence of small physical obstacles on habitat arrangement and, consequently, fish assemblages' structure.

As a stream portion is deepened, water velocity is decreased and its ability to carry sediment in the water column is reduced, generally resulting in increased sedimentation of the substrate (Kondolf, 1997). On the same way, when a stream reach is narrower, the water velocity tends to increase. In this study, the river stretch considered as reference was separated in two groups of sampling sites discriminated by their current velocity. Sites located in an upstream area had faster current velocities than the downstream sites. This gradient, probably related with natural features like water depth, width, local geology and slope, is corroborated by the river continuum theory (Vannote *et al.*, 1980) and is similar to the results described by other authors for typical undammed lotic ecosystem (Gorman & Karr, 1978; Angermeier & Schlosser, 1989). In the obstacles stream, the three types of sampling sites previously defined were statistically different, being discriminated by current velocity and mean depth. The DO sites were characterized by low depth and high current velocity, contrarily to the UO sites which were deeper and had a slower current. Sites located between the obstacles, away from its direct influence, exhibited higher habitat diversity, similar to the one generally observed throughout the reference stream. The obstacles caused a homogenization of the aquatic habitat in the adjacent areas, with DO dominated by riffles and UO changed into a lentic environment, which is an effect commonly associated with the presence of these structures (Snodgrass & Meffe, 1998; Hagglund & Sjoberg, 1999; Cumming, 2004; Gillette *et al.*, 2005). These authors also describe changes in the substrate composition due to the presence of the obstacles, with an increase in the siltation at the lentic upstream reaches. In this study, substrate was not considered for analysis because it was very similar throughout the sampled reaches. Physicochemistry variables exhibited little variation along the two studied reaches and were not predictive of any of the groups formed by the clustering analysis. Unlike large dams (Wildhaber *et al.*, 2000), the studied obstacles did not seem to affect physicochmestry. Based on their current velocity, similarities were observed between DO and B sites and the upstream portion of the reference stream, and between UO sites and the downstream area of the natural reach. Considering these results, it could be assumed that the natural current velocity gradient observed in the reference stream is being repeated near each obstacle on the fragmented river. Nonetheless, these environmental changes seem to happen in a smoothly way in the reference stream where, contrarily to the obstacles stream, they were not strong enough to cause significant differences in the fish community composition.

The two streams, in its whole, presented a similar fish-species composition, implying that all the differences observed on the assemblages' structure were probably related with the presence of the obstacles instead of natural dissimilarities on the fish community, which was an assumption of this study. Between its two groups of sites, the reference stream did not exhibit significant differences on the fish-species composition. Regardless of the evident current velocity gradient, the most abundant species, like barbel and gudgeon, were common and equally proportioned throughout the sampling reach, not showing a clear association with any of the site groups. Other species such as chub and nase were more abundant at the higher velocity sites and species like eel and pumpkinseed were mostly captured at the downstream, well vegetated and shaded sites. However, these results, being probably related with specific ecological requirements of the described *taxa*, were not sufficient to clearly identify a zonation pattern along the reference stream. For natural Iberian streams, Vila-Gispert *et al.* (2002) described a variation on the fish assemblages' structure along an upstream-downstream gradient based on environmental features like current velocity and water depth. In our study, the fish community of the reference stream did not follow these results, probably due to the reduced length of the studied reach. In the obstacles stream, due to the accentuated variation of the environmental features caused by the presence of these structures, significant differences were found between the fish species composition of DO/B sites, dominated by barbel, nase and chub, and UO sites where gudgeon, loach and pumpkinseed were the most abundant species. Some authors describe the higher swimming capacity and aerobic resistance to current velocity of potamodromous riverine species like barbel and nase (Lucas & Batley, 1996; Lucas & Frear, 1997, Mateus *et al.*, 2008) while Tudorache *et al.*, (2008) classifies gudgeon as a "weak" swimmer, incapable of resist to faster currents, thus explaining these species distribution throughout the obstacles stream.

When comparing the two studied streams in its whole, in spite of the statistically similar total richness, the obstacles stream exhibited a higher number of introduced species, and consequently, a lower native richness. Although the difference is solely based in one species with low abundance (largemouth-bass), this result is similar to the one described by some authors for dammed rivers (Corbacho & Sanchez, 2001; Jager *et al.*, 2001; Tiemann *et al.*, 2004). None of the richness metrics showed significant differences between the groups of sites within each stream, despite the existence of studies describing a variation of the total richness in different habitat types of natural rivers (Angermeier & Schlosser, 1989) and a higher value for this metric in the sites located downstream from obstacles (Porto *et al.*, 1999; Cumming, 2004; Poulet, 2007). However, Tiemann *et al.*, (2004) had a similar result, not finding differences on the total species richness between different site types in a dammed river. Within the obstacles stream, the presence of such structures was not influencing the number of exotic species between the three site types, but their density, which was higher in UO sites than in DO, B and the whole reference stream. These structures modified the physical habitat, increasing depth so that water velocity was reduced, creating a lentic habitat that usually favours this type of species (Hagglund & Sjoberg, 1999; Gillette *et al.*, 2005; Poulet, 2007).

In the obstacles stream, the sites located away from these structures exhibited higher species diversity, similar to the values of the reference stream, which is probably related with the higher habitat diversity of this reaches (Gorman & Karr, 1978; Angermeier & Schlosser, 1989). Habitat heterogeneity is important to the conservation of aquatic biodiversity in rivers because abundance and distribution of stream fishes are strongly affected by individual or combinations of microhabitat variables (Santucci *et al.*, 2005). Free-flowing areas in both streams were made up of a variety of physical features that provided a wide array of water depths and current velocities. In contrast, impoundment areas were more homogeneous, restricting the occurrence of many fish species with distinct habitat requirements.

The fish species requirements in terms of current velocity and their resistance to extreme situations determined the reophilly pattern throughout the studied rivers. In Iberian streams, the introduced species are generally limnophilic whereas most of the native species are rheophilic. Naturally, the density of limnophilic species was higher in the lentic habitat created upstream from the obstacles than in free-flowing and downstream sites of the obstacles river, in which rheophilic species were more abundant. This result is commonly described by several other authors (Tiemann *et al.*, 2004; Gillette *et al.*, 2005; Poulet, 2007) as being related with the drastic gradient of current velocity and mean depth caused by the presence of the obstacles. According to Gillette *et al.* (2005) fish species with ecological characteristics between this two, namely the eurytopic species, should be more abundant in free-flowing sites, away from the obstacles. Our study followed in part this results since these species were more abundant, not only in B sites and in the reference stream, but also downstream from obstacles. The upstream habitat modifications in the obstacles stream probably changed the macroinvertebrate fauna from a lotic to a lentic species community and increased the detritus accumulation, as reported by Stanley *et al.* (2002), which tend to benefit omnivorous species (i.e. gudgeon, barbel, loach) that usually feed on substratum-dwelling invertebrates and other organic material, rather than invertivorous species (i.e. chub, nase). Our results are similar to the ones described by Poulet *et al.* (2007), who also find significant differences on the abundance of invertivorous and omnivorous species in a fragmented river.

The habitat preferences of the ecological and trophic guilds described for undammed rivers usually follow the same pattern that was found in the obstacles stream considered in this study (Gorman & Karr, 1978; Didier & Kestemont, 1996), but this happens at a microhabitat scale and not in a successive way, like near each structure in the impounded stream. In the reference stream, despite the longitudinal changes in the current velocity, none of the guilds exhibited significant differences between the two groups of sites. The same result was found for the other metrics and for the species composition, corroborating the hypothesis that the habitat modifications induced by the presence of the obstacles, despite of focusing in the abiotic features that also vary in natural rivers, such as current velocity and mean depth, are much more severe and highly influential of the fish assemblages' structure.

Despite the differences in some environmental features, the sites sampled immediately downstream from the obstacles were very similar to the sites located between the studied structures, not only in terms of fish species composition, but also considering their assemblages' functional structure. Besides that, these site types were also similar, in some community features, to the reference stream, contrarily to the sites upstream from the impoundment. Based in these results, it can be assumed that, as it is described by other authors (Hagglund & Sjoberg, 1999; Tiemman *et al.*, 2004: Gillette *et al.*, 2005; Poulet, 2007), the upstream habitat and, consequently, its fish community structure are more affected by the presence of the obstacles.

CONCLUSIONS

This study suggests that small physical obstacles cause changes in habitat immediately upstream and downstream, producing effects on fish assemblages that are similar to, but with less extent than, the ones from large dams. Contrarily to the smoothly longitudinal changes in the free-flowing stream habitat, the obstacles in this study were associated with drastic differences in water depth and current velocity that appear to affect fish assemblages' composition and structure. The study contributes insights into the effects of small obstacles on riverine habitat and fish community structure of two Iberian streams with different levels of impact from the presence of these structures. Additional studies in other basins, with different faunas and environmental conditions and different types of obstacles, should be conducted to gain a better understanding of how the biology and hydrology of these ecosystems are affected by these human constructions. Also, another study, this time considering the length distribution and age structure of the affected fish assemblages, should be conducted in order to assess the effect of these obstacles in fish populations' fragmentation.

Knowledge of the effects of these barriers can be used in the conservation and protection of riverine biotic integrity.

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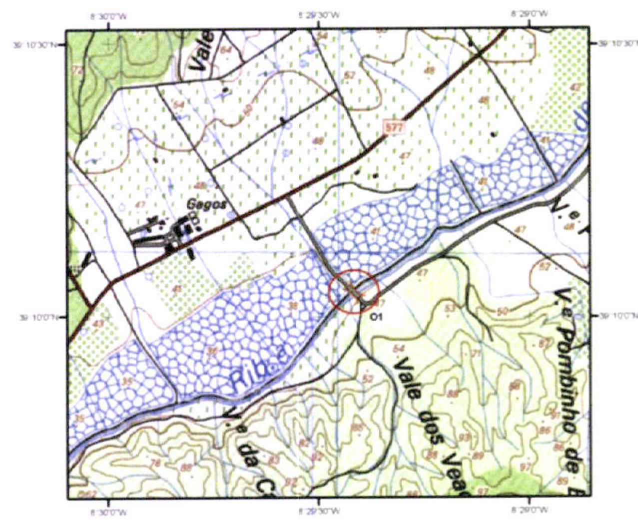
Appendixes

Appendix I – Characterization of the obstacles studied in River Muge

Code: O1

Coordinates: 08º 29' 25''W
39º 10' 02''N

Description: Bridge built for vehicle or people passage with elevated bottom. Each column has a vertical rail in both sides used to low the wood slabs that will prevent the water passage. These plates are lowered in an alternating way, always leaving at least one of the passages open. The lentic upstream area is often used for water abduction with agriculture purposes.



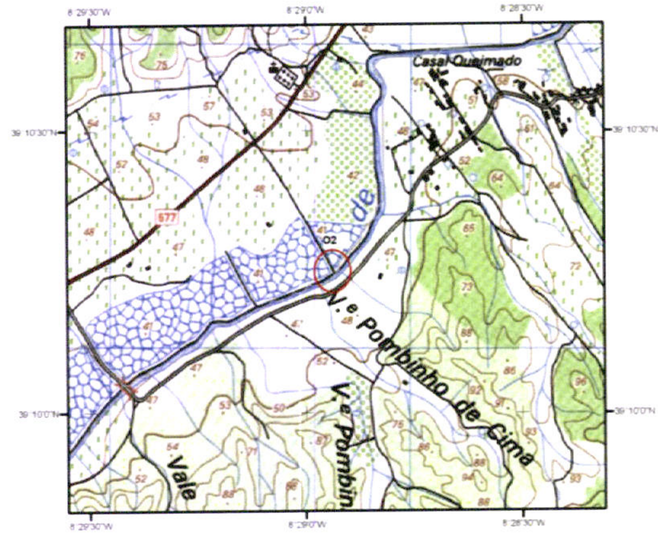
1:10.000

Code: O2

Coordinates: 08° 28' 89''W

39° 10' 25''N

Description: Small weir used for upstream water retention with agricultural purposes. The bridge above was built only to allow the access to the structure. The columns have vertical rails to insert the slabs that will stop the water passage.



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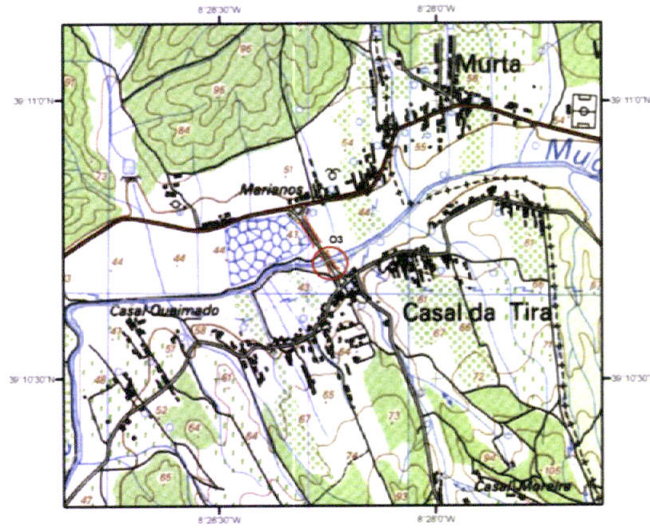
Code: O3

Coordinates: 08° 28' 14''W

39° 10' 42''N

Description: Low-head dam below the Alfredo Bento Calado bridge. The bridge has a mechanical structure that allows to low the steel slabs in order to stop the water passage. At the moment of the field survey, the flood-gates were down resulting in an accumulation of organic material with large dimension (i.e. trees). During the sampling, some barbels were captured while trying to negotiate this structure.



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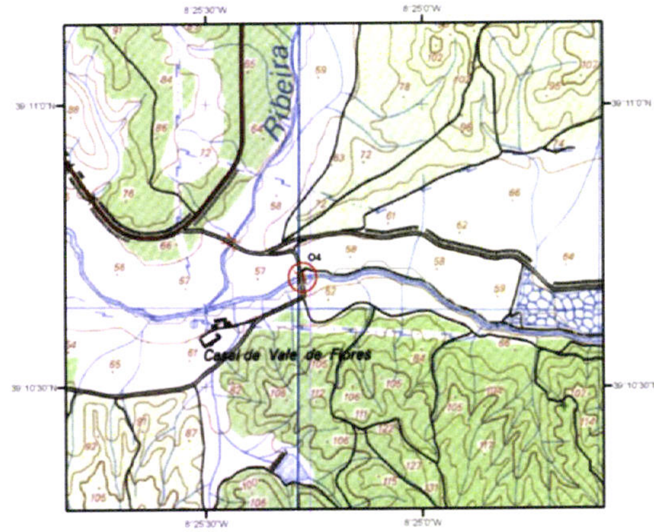
Code: O4

Coordinates: 08º 25' 17''W

39º 10' 41''N

Description: Small weir with similar characteristics and purposes of O1 and O2. The exception in this structure seems to be the more rudimentary system of water retention, without the use of slabs or other mechanism. The bridge is for passage of people and vehicles.



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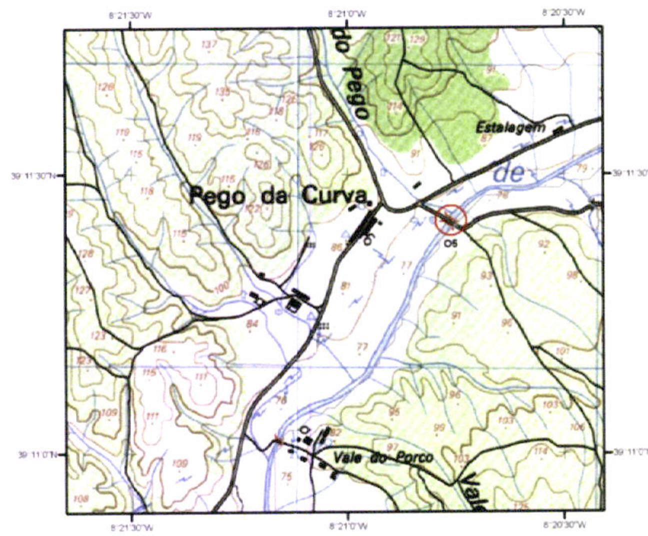
Code: O5

Coordinates: 08° 20' 46''W

39° 11' 25''N

Description: Bridge for vehicles passage with elevated bottom. Like O4, this obstacle doesn't have any water retention mechanism. Its exploitation for agricultural use is solely based on the effect of the base.



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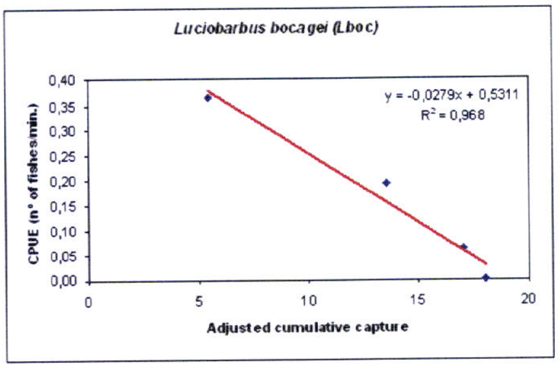
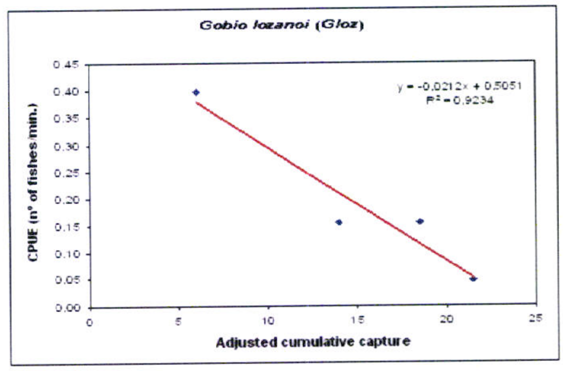
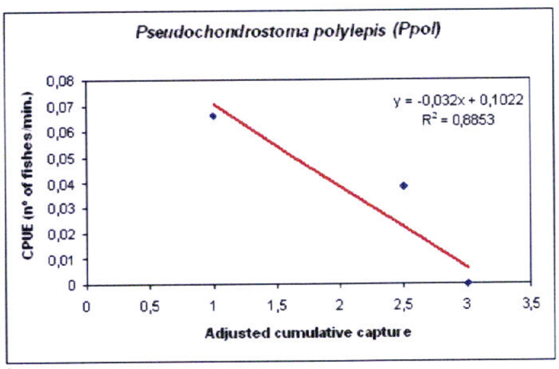
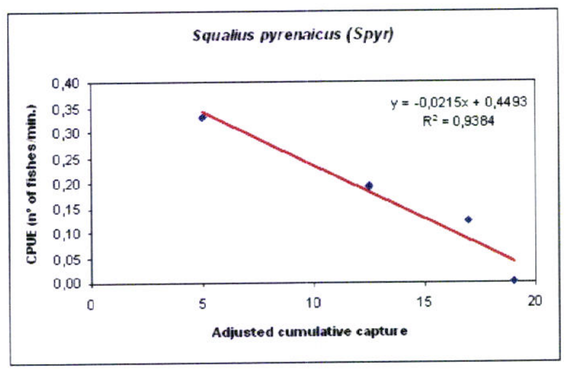
Appendix II – Leslie's representations for estimative of the population's N_∞

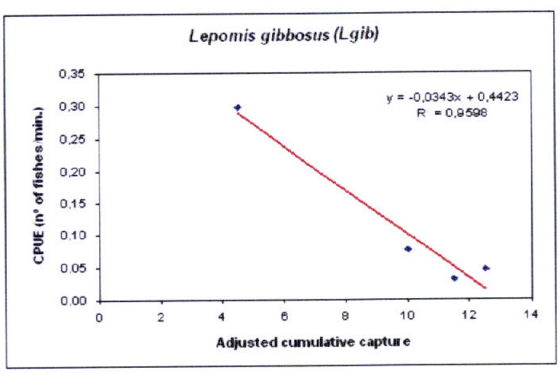
RIVER ERRA (REFERENCE STREAM) – R1

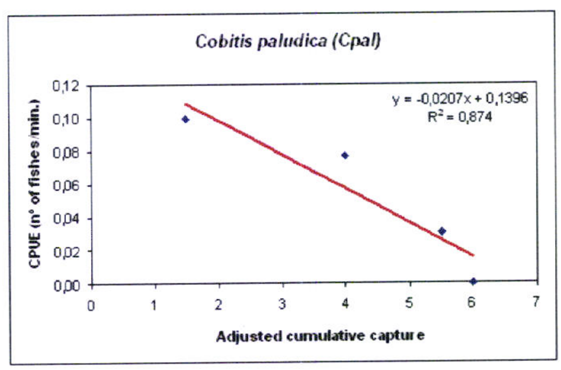


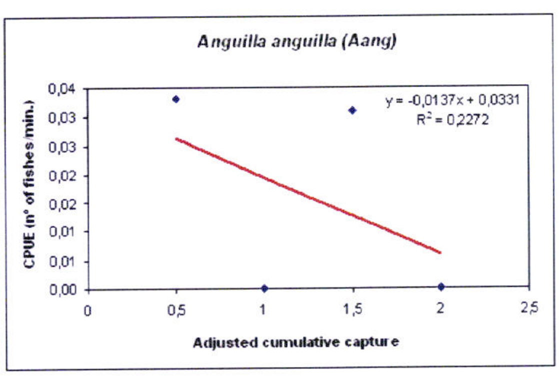




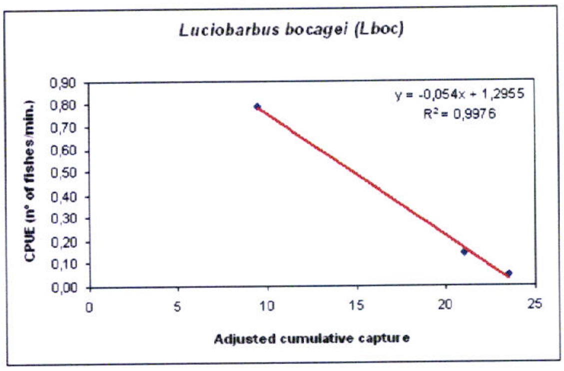


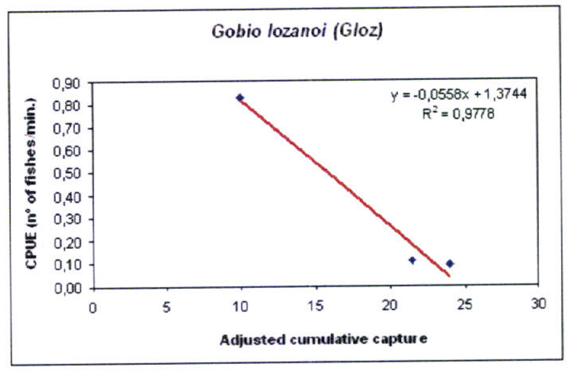


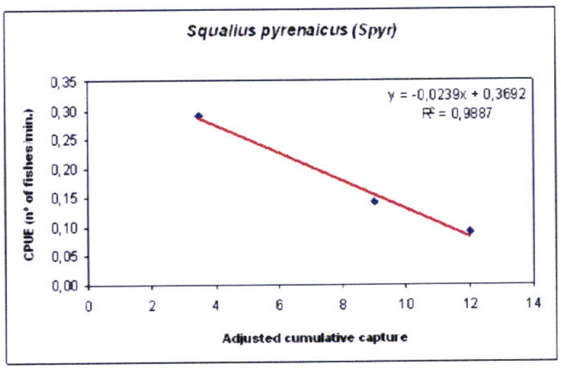


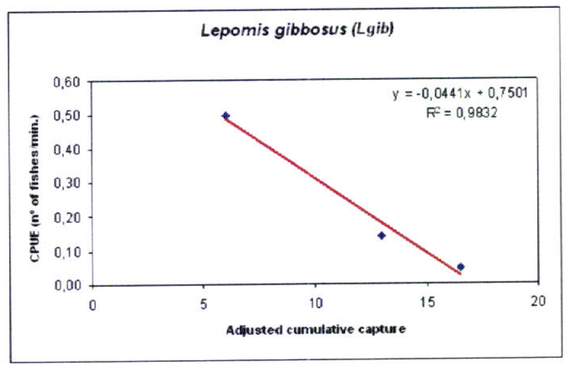


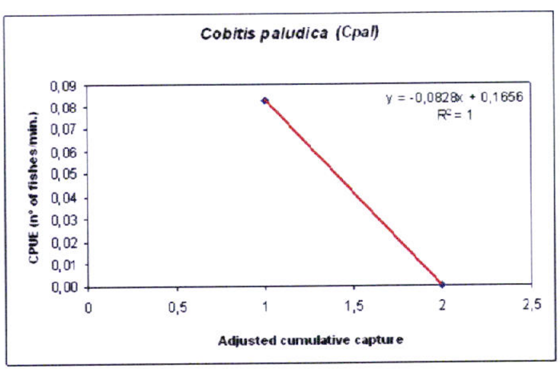
RIVER ERRA (REFERENCE STREAM) – R2



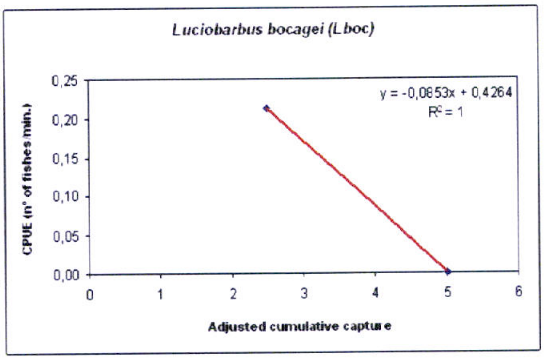


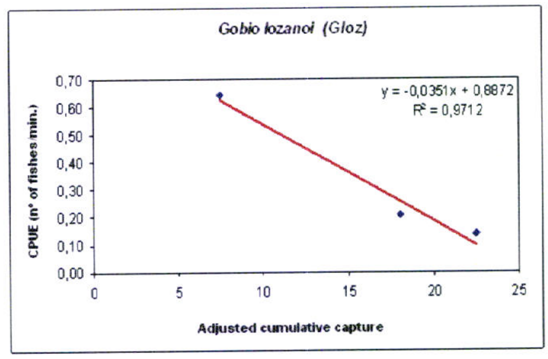


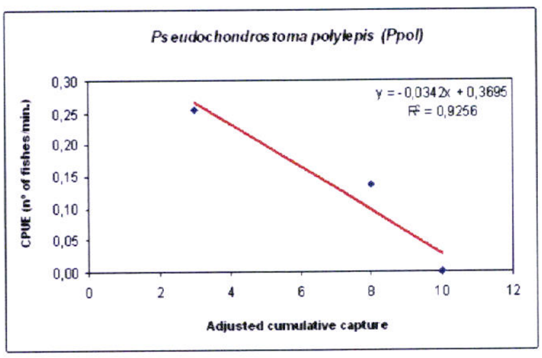


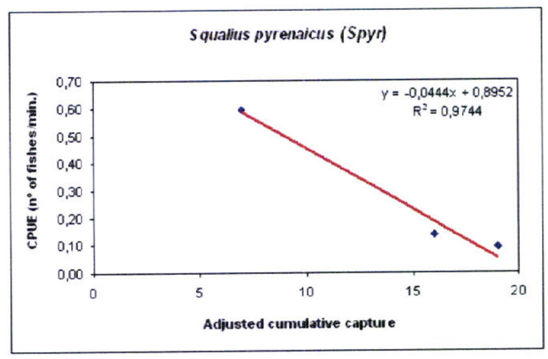


RIVER ERRA (REFERENCE STREAM) – R3

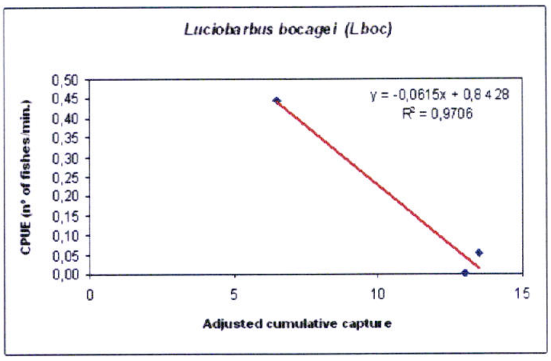


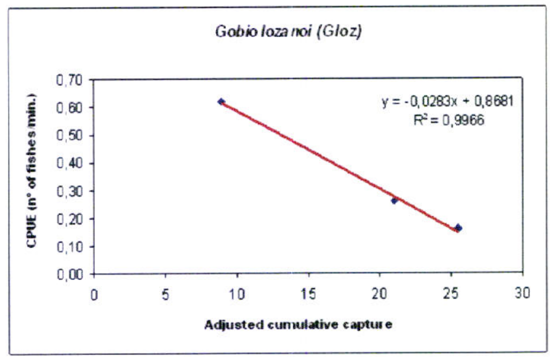


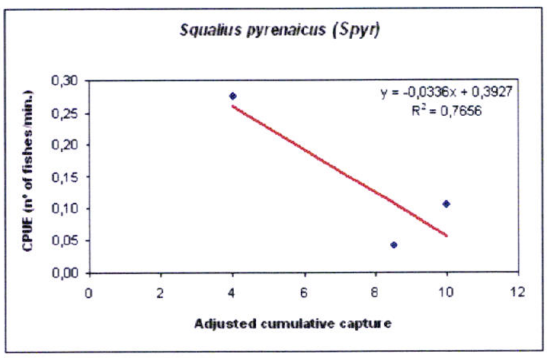


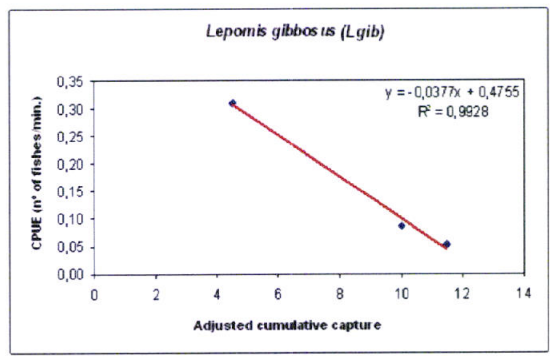


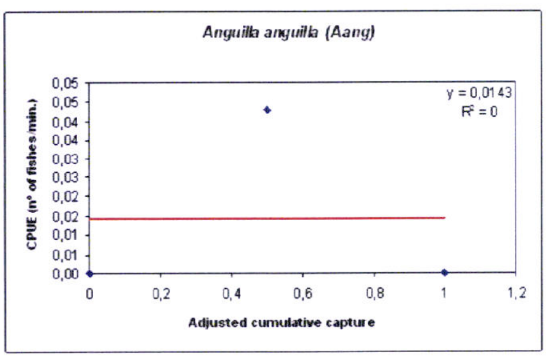
RIVER ERRA (REFERENCE STREAM) – R4



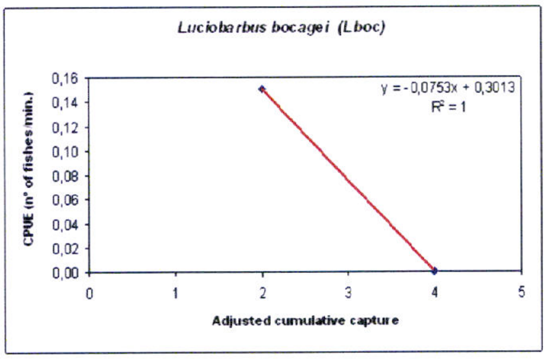


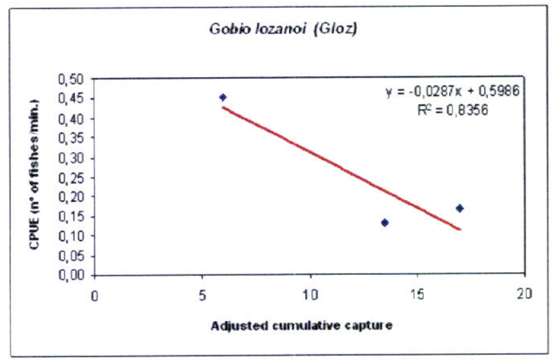


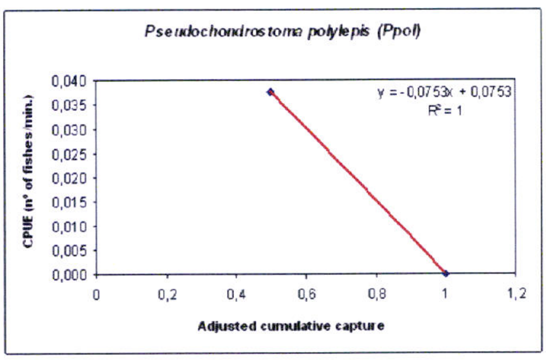


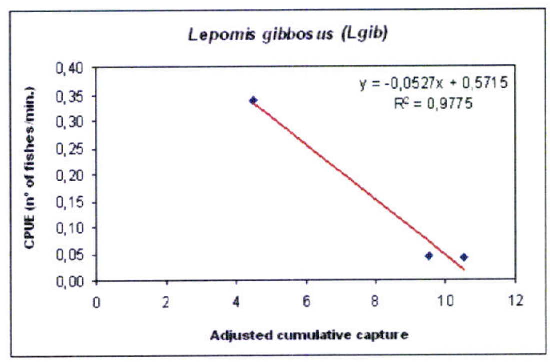


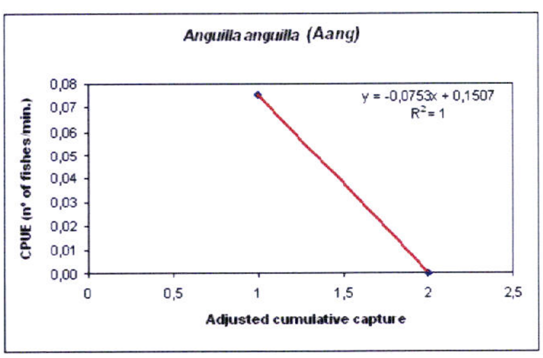
RIVER ERRA (REFERENCE STREAM) – R5



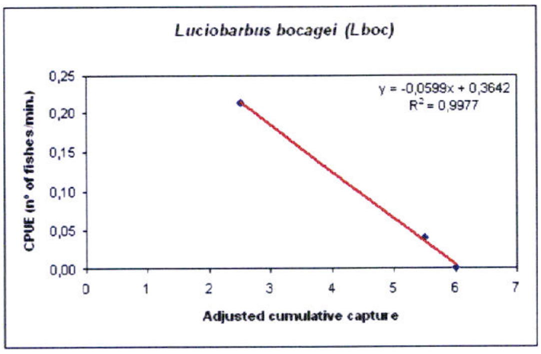


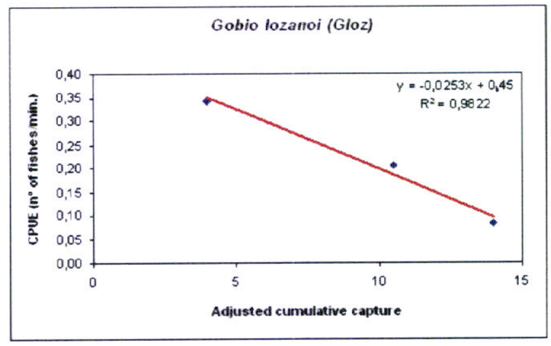


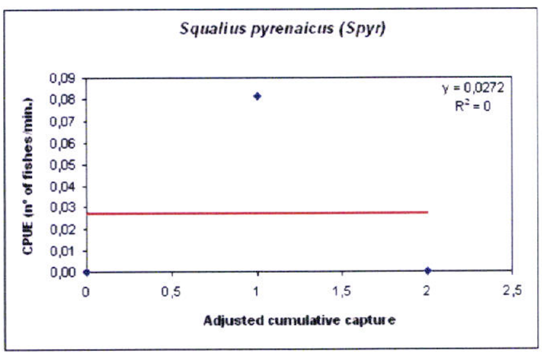


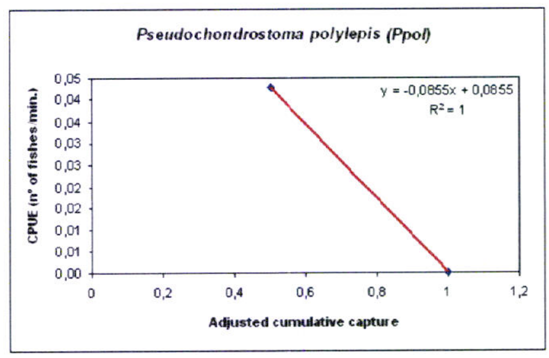


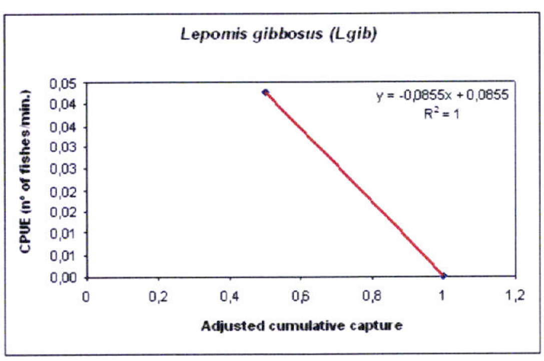
RIVER ERRA (REFERENCE STREAM) – R6

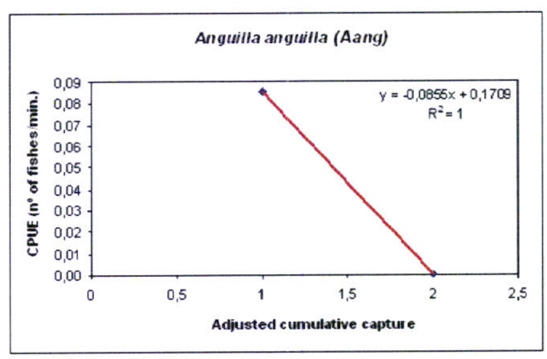




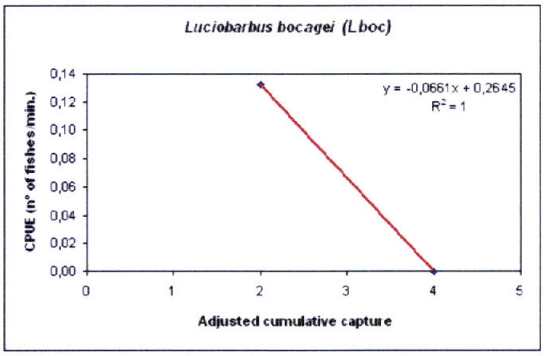


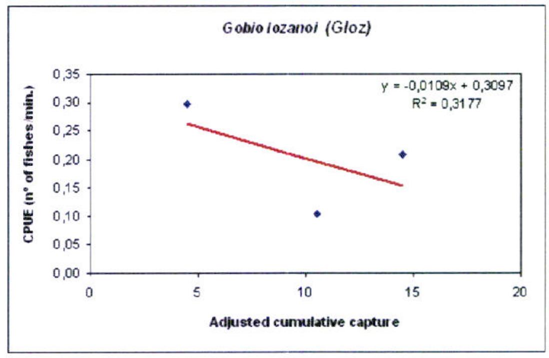


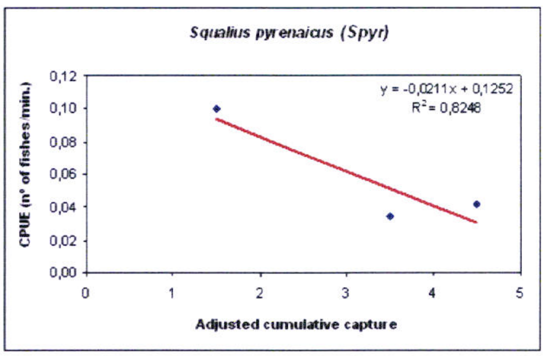


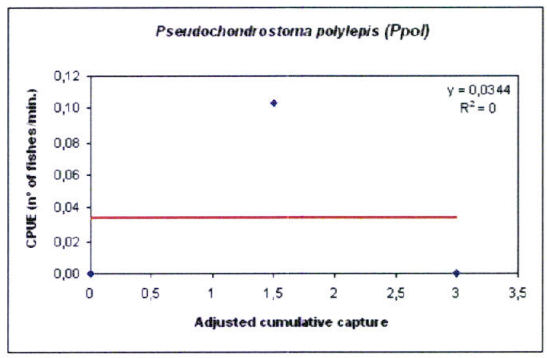


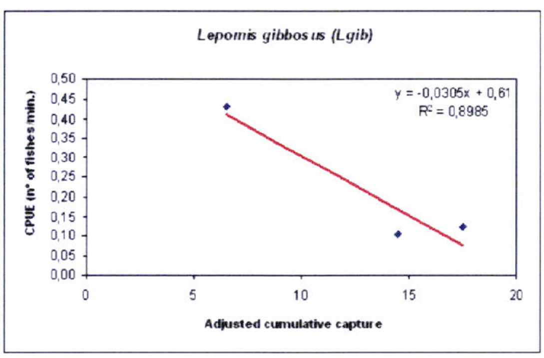
RIVER ERRA (REFERENCE STREAM) – R7

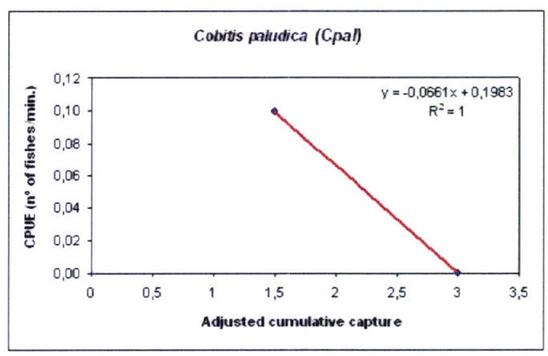


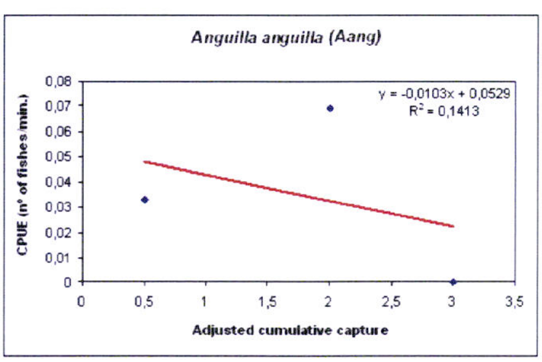




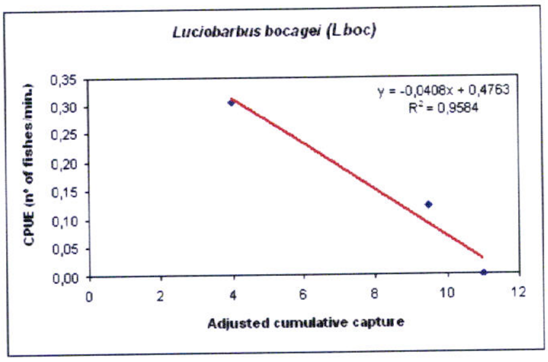


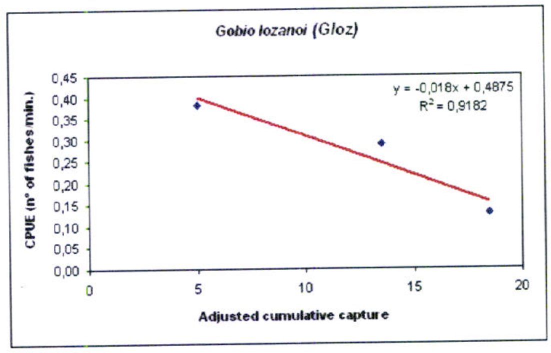


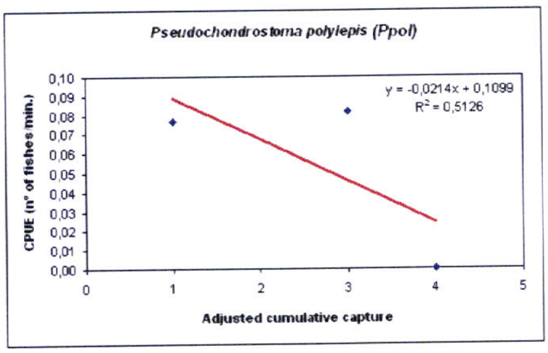


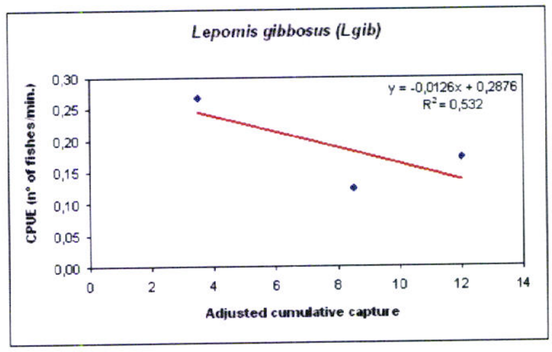


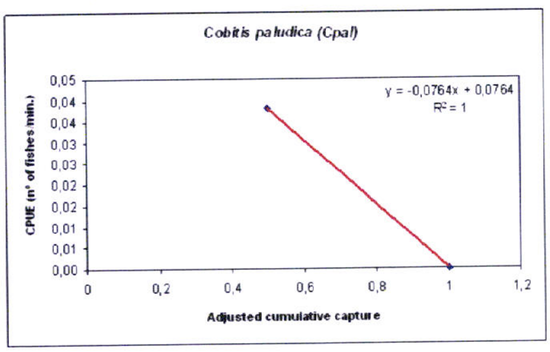
RIVER ERRA (REFERENCE STREAM) – R8



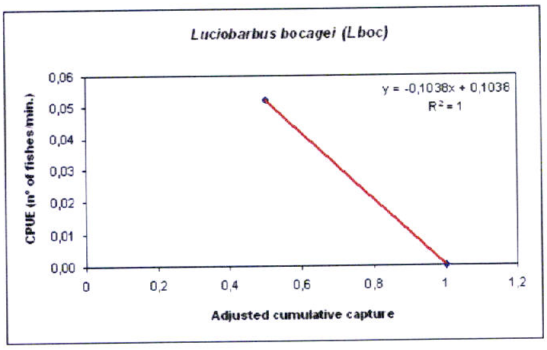


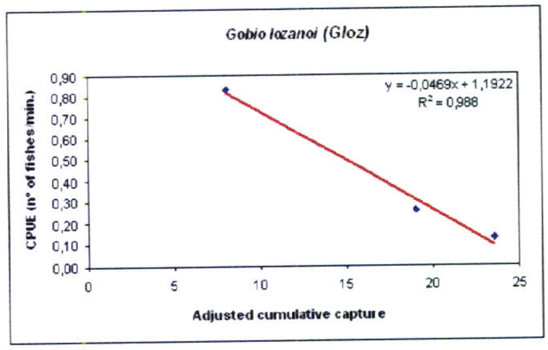


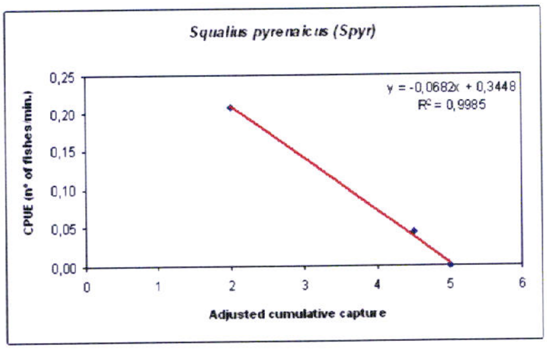


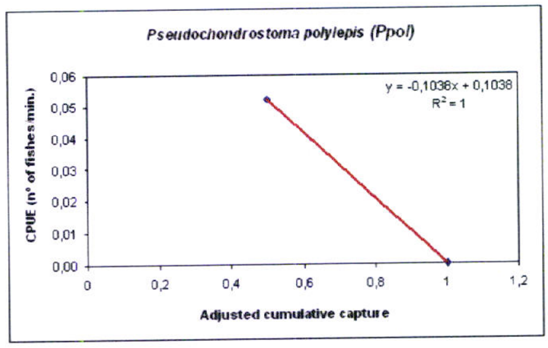


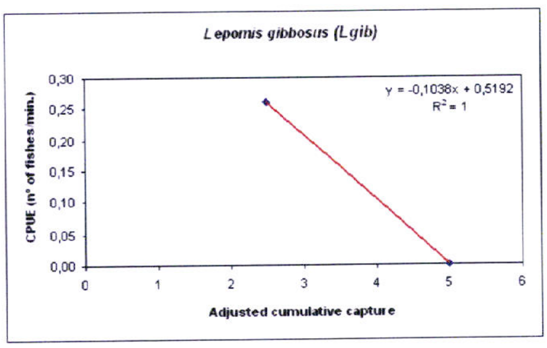
River Erra (Reference stream) – R9

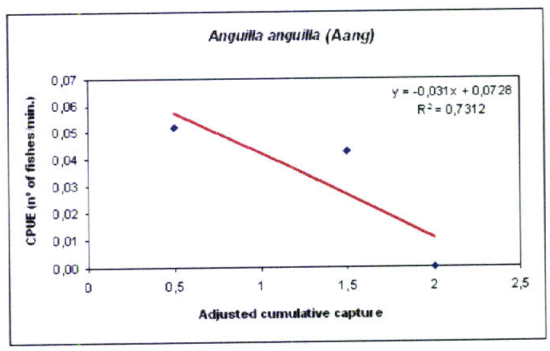




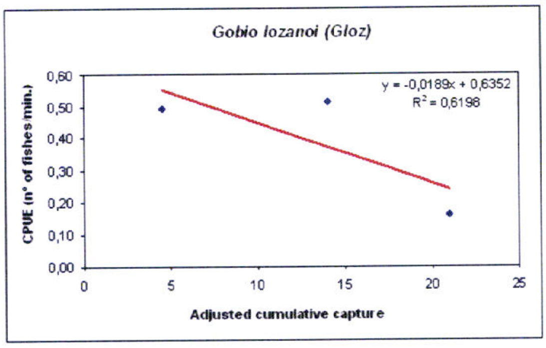


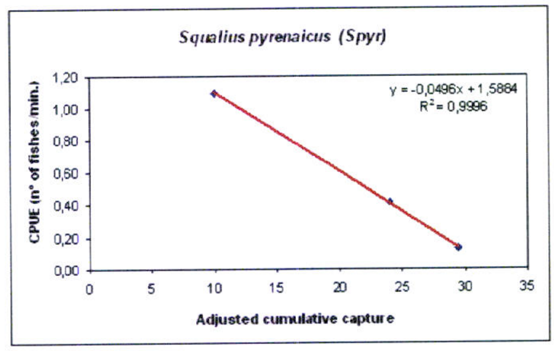


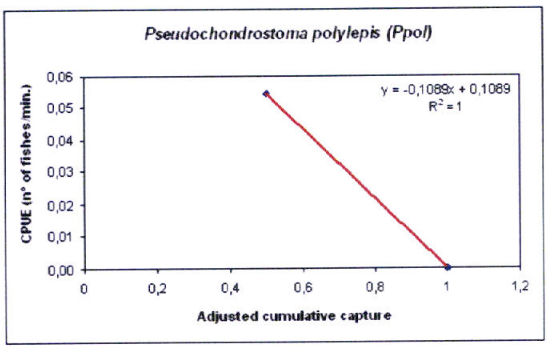


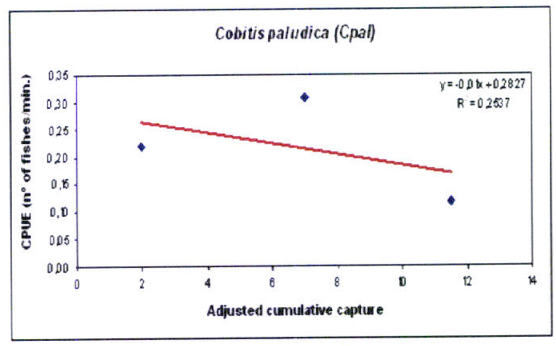


RIVER ERRA (REFERENCE STREAM) – R10

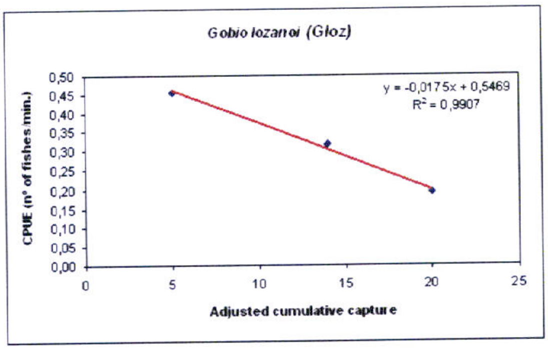


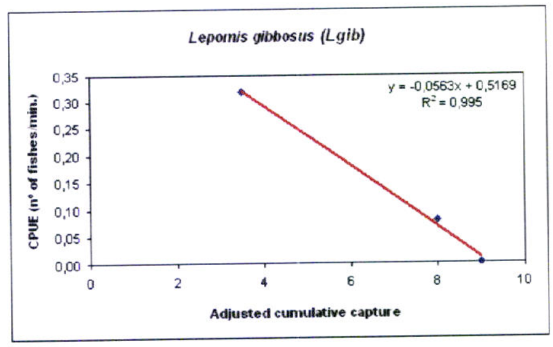


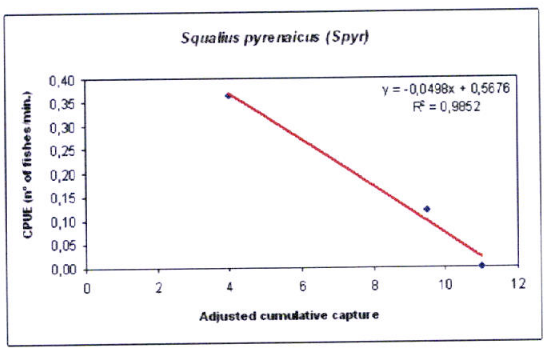


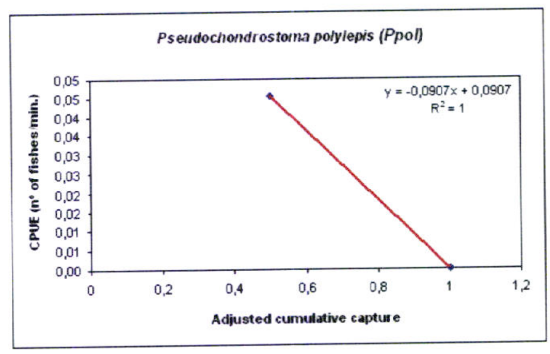


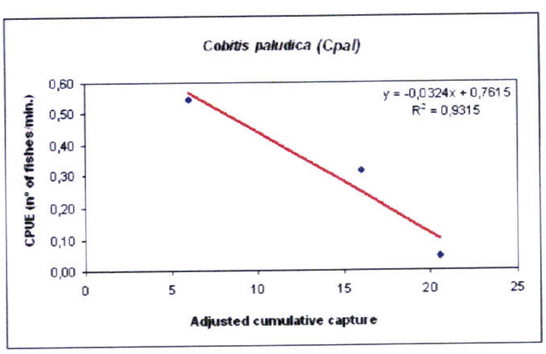
RIVER ERRA (REFERENCE STREAM) – R11



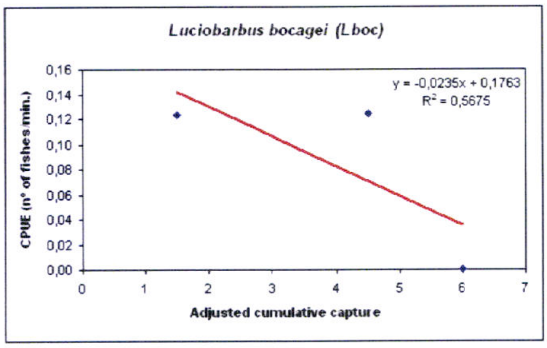


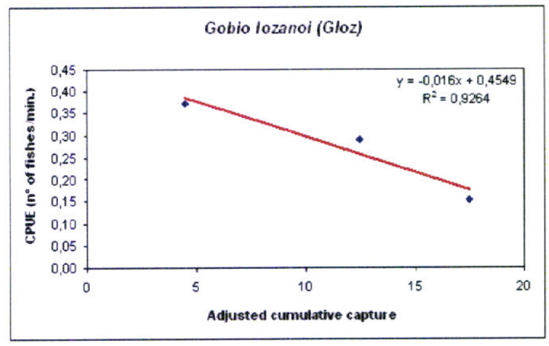


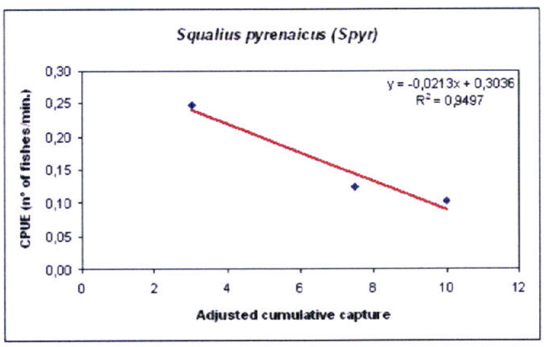


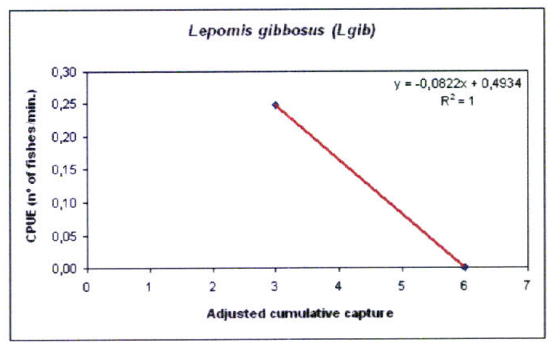


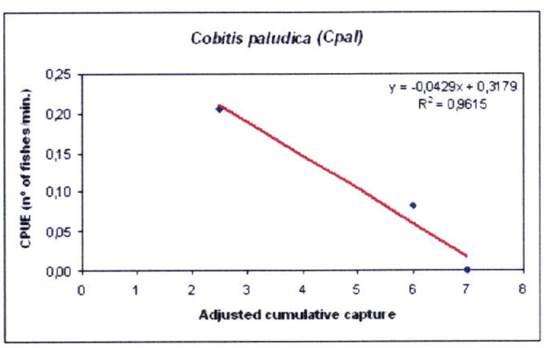
RIVER ERRA (REFERENCE STREAM) – R12



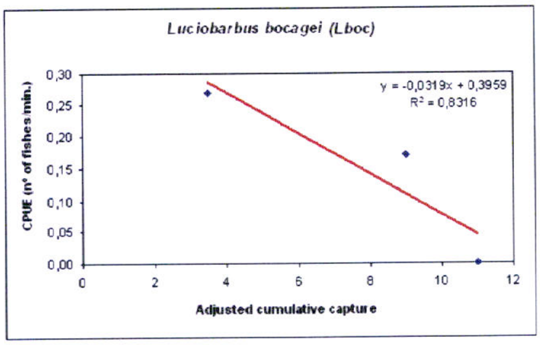


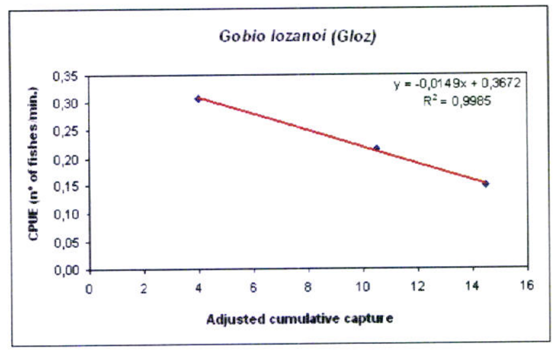


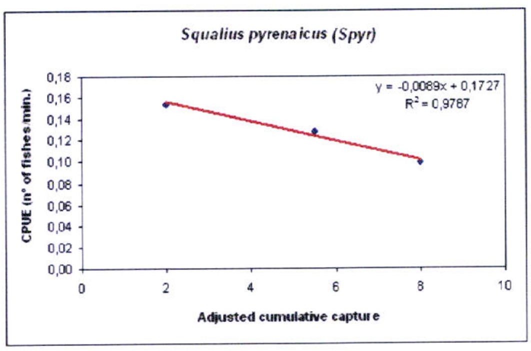


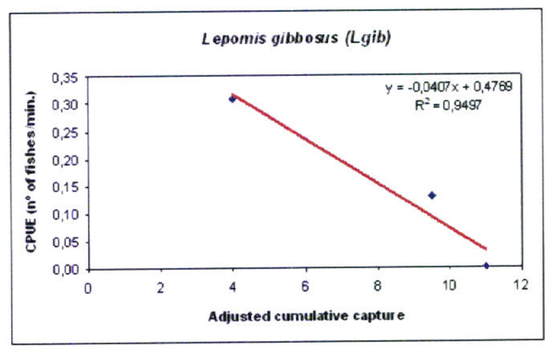


RIVER ERRA (REFERENCE STREAM) – R13

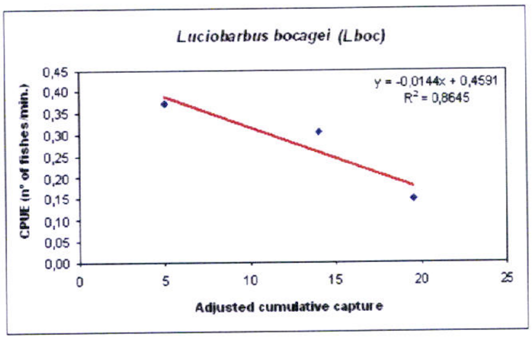


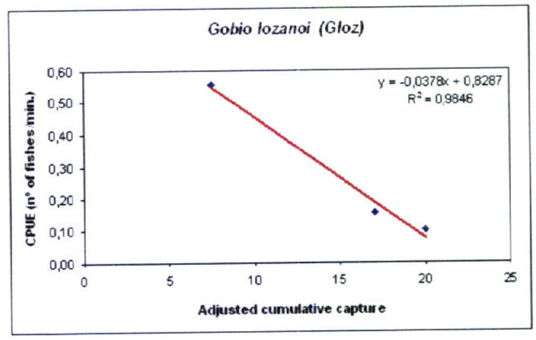


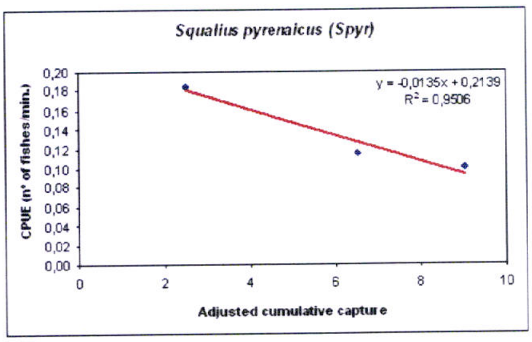


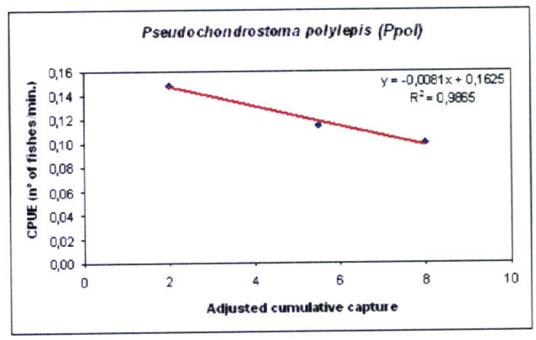


River Erra (Reference stream) – R14

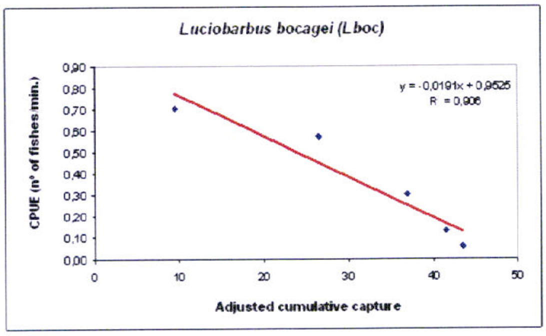


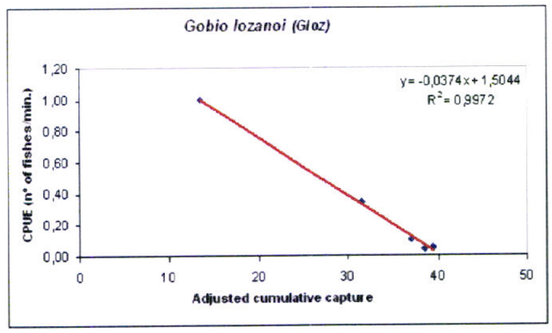


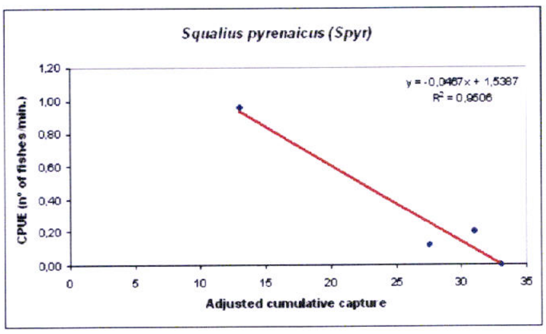


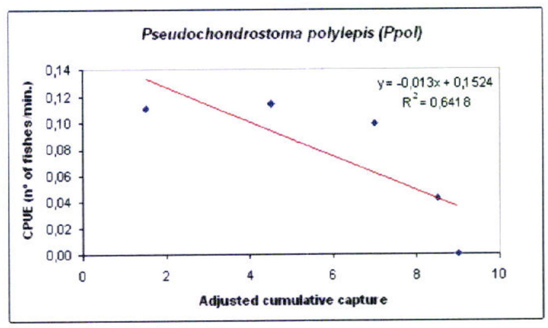


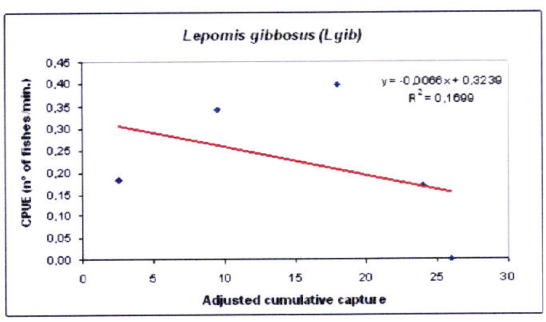
RIVER MUGE (OBSTACLES STREAM) – DO1

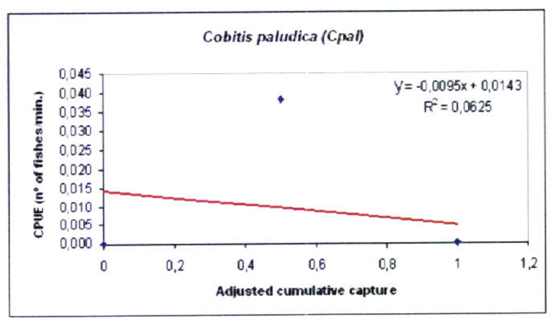


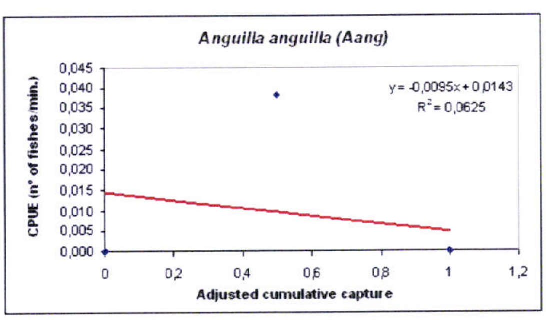


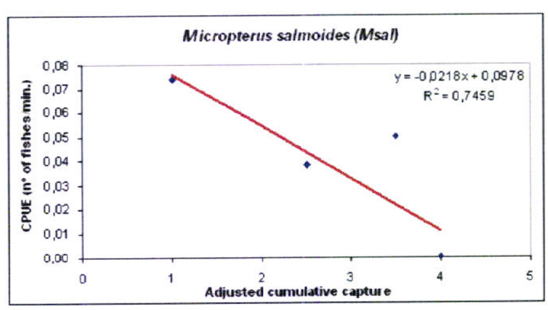




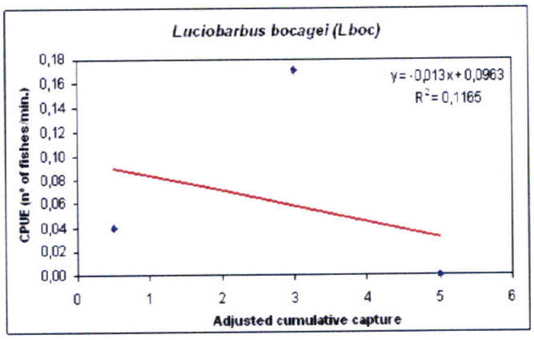


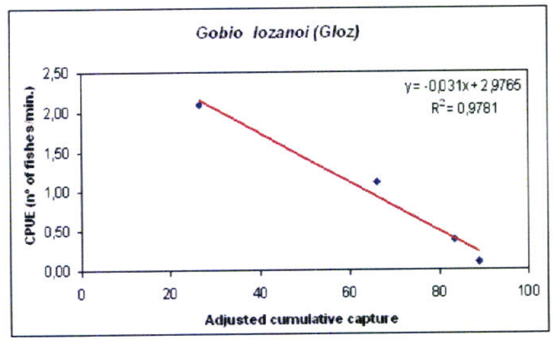


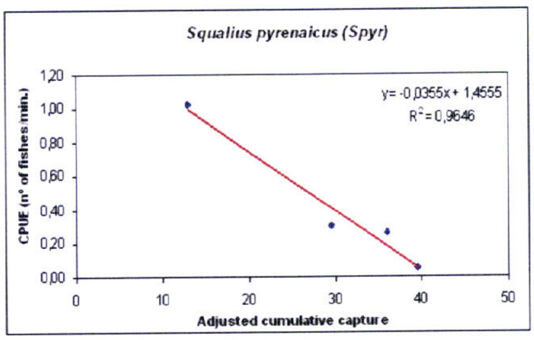


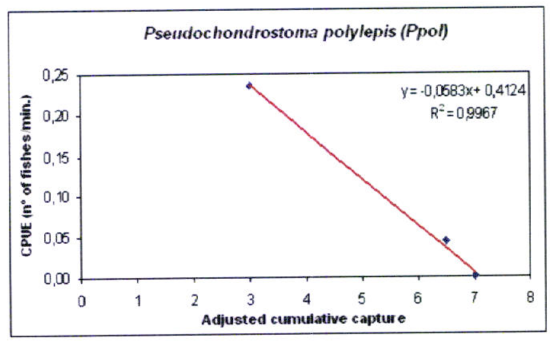


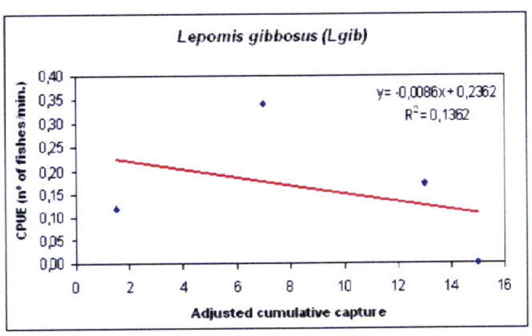
RIVER MUGE (OBSTACLES STREAM) – UO1

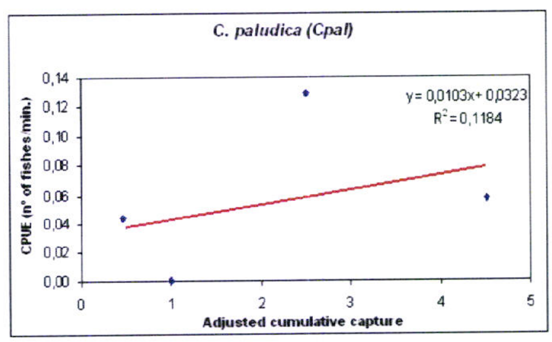

Luciobarbus bocagei (Lboc)
y = -0,013x + 0,0963
R² = 0,1165
CPUE (n° of fishes min.)
Adjusted cumulative capture

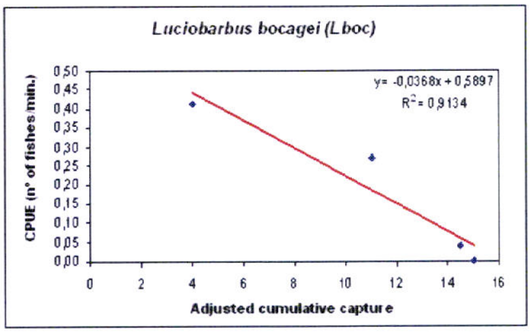

Gobio lozanoi (Gloz)
y = -0,031x + 2,9765
R² = 0,9781
CPUE (n° of fishes min.)
Adjusted cumulative capture

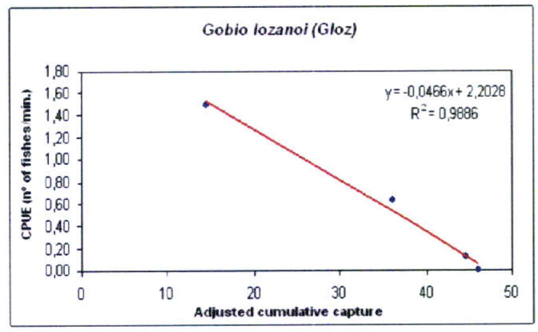

Squalius pyrenaicus (Spyr)
y = -0,0355x + 1,4555
R² = 0,9646
CPUE (n° of fishes min.)
Adjusted cumulative capture

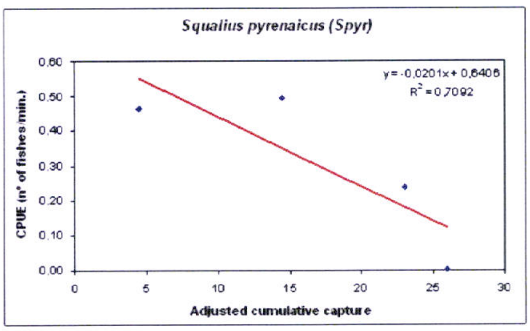

Pseudochondrostoma polylepis (Ppol)
y = -0,0583x + 0,4124
R² = 0,9967
CPUE (n° of fishes min.)
Adjusted cumulative capture

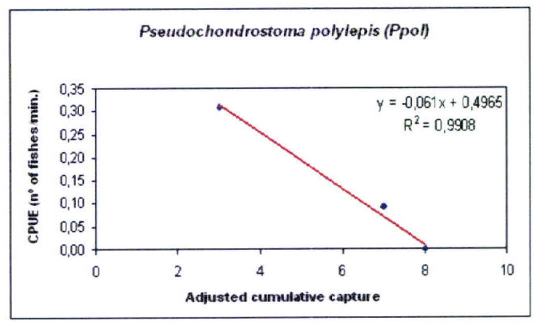

Lepomis gibbosus (Lgib)
y = -0,0086x + 0,2362
R² = 0,1362
CPUE (n° of fishes min.)
Adjusted cumulative capture

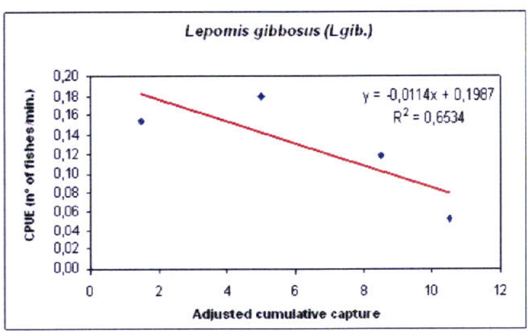

C. paludica (Cpal)
y = 0,0103x + 0,0323
R² = 0,1184
CPUE (n° of fishes min.)
Adjusted cumulative capture

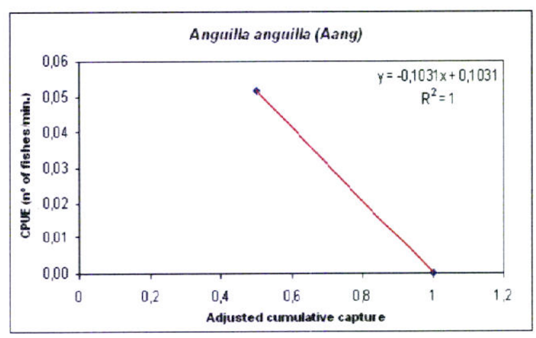

Luciobarbus bocagei (Lboc)
y= -0,0368x + 0,5897
R²= 0,9134
CPUE (n° of fishes/min.)
Adjusted cumulative capture

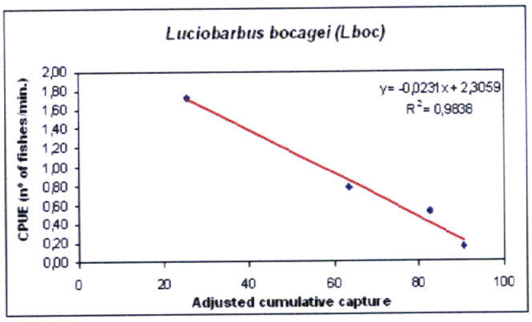

Gobio lozanoi (Gloz)
y= -0,0466x+ 2,2028
R²= 0,9886
CPUE (n° of fishes/min.)
Adjusted cumulative capture

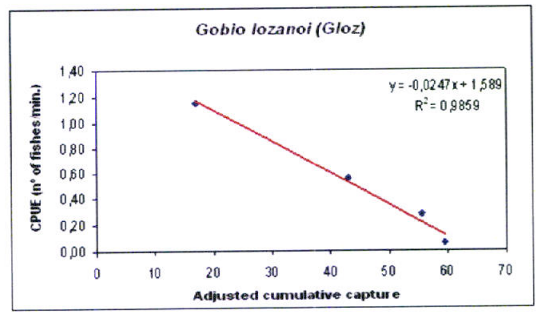

Squalius pyrenaicus (Spyr)
y= -0,0201x+ 0,6406
R²= 0,7092
CPUE (n° of fishes/min.)
Adjusted cumulative capture

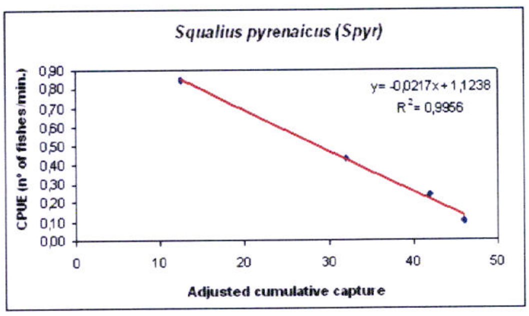

Pseudochondrostoma polylepis (Ppol)
y = -0,061x + 0,4965
R² = 0,9908
CPUE (n° of fishes/min.)
Adjusted cumulative capture

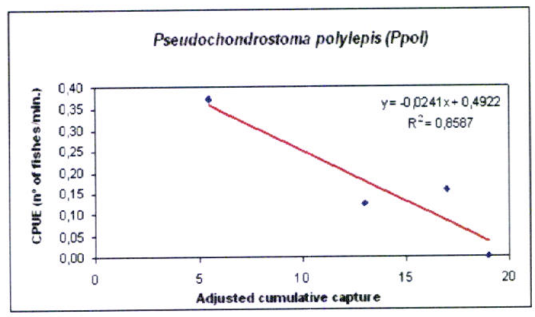

Lepomis gibbosus (Lgib.)
y = -0,0114x + 0,1987
R² = 0,6534
CPUE (n° of fishes/min.)
Adjusted cumulative capture

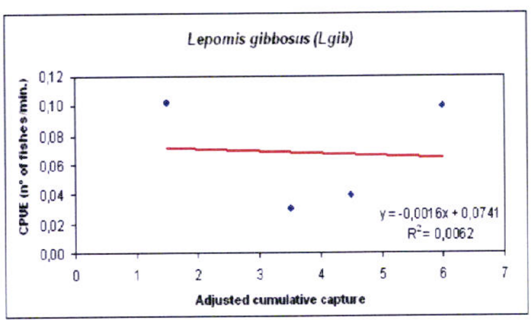

Anguilla anguilla (Aang)
y= -0,1031x+ 0,1031
R²= 1
CPUE (n° of fishes/min.)
Adjusted cumulative capture

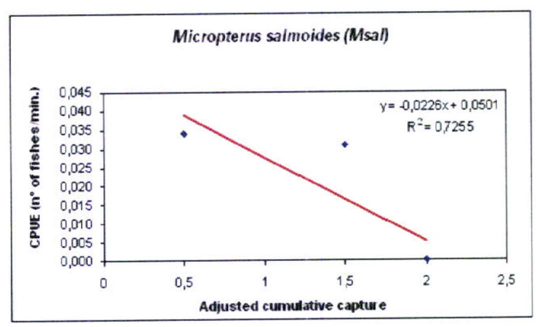

Luciobarbus bocagei (Lboc)
y = -0,0231x + 2,3059
R² = 0,9838
CPUE (n° of fishes min.)
Adjusted cumulative capture

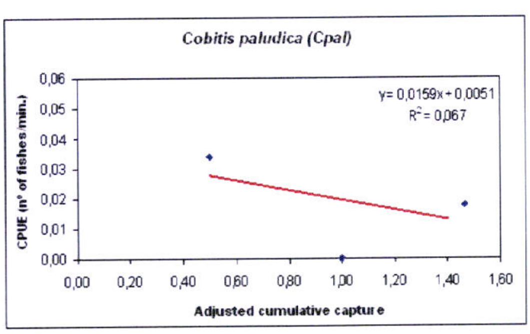

Gobio lozanoi (Gloz)
y = -0,0247x + 1,589
R² = 0,9859
CPUE (n° of fishes min.)
Adjusted cumulative capture

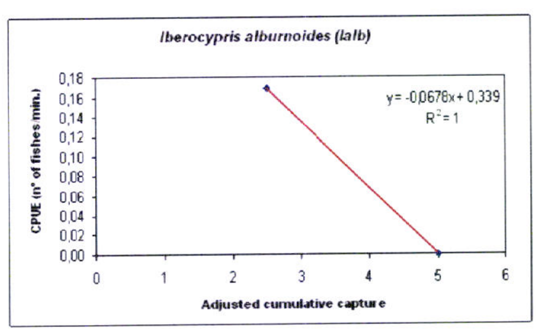

Squalius pyrenaicus (Spyr)
y = -0,0217x + 1,1238
R² = 0,9956
CPUE (n° of fishes min.)
Adjusted cumulative capture

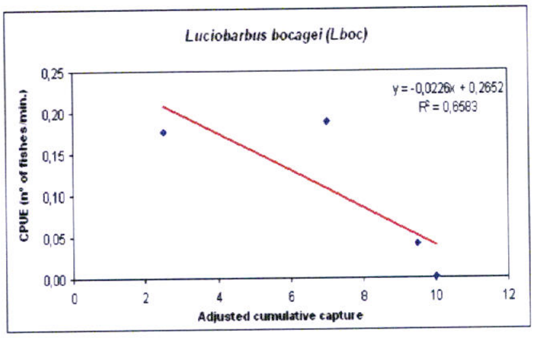

Pseudochondrostoma polylepis (Ppol)
y = -0,0241x + 0,4922
R² = 0,8587
CPUE (n° of fishes min.)
Adjusted cumulative capture

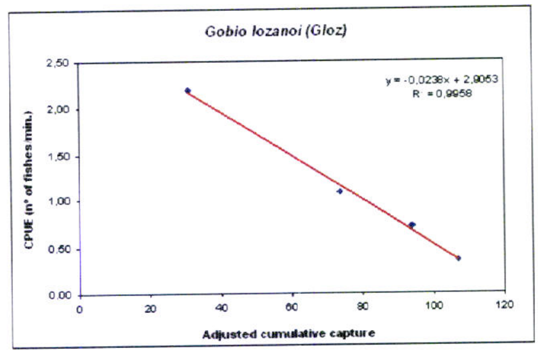

Lepomis gibbosus (Lgib)
y = -0,0016x + 0,0741
R² = 0,0062
CPUE (n° of fishes min.)
Adjusted cumulative capture

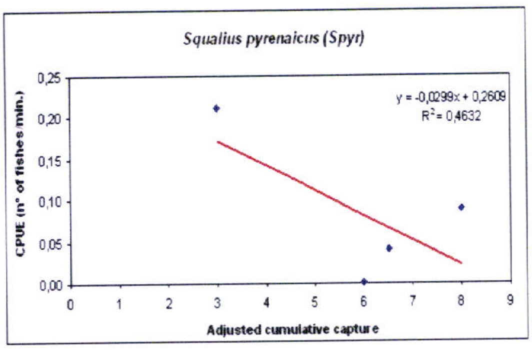

Micropterus salmoides (Msal)
y = -0,0226x + 0,0501
R² = 0,7255
CPUE (n° of fishes min.)
Adjusted cumulative capture

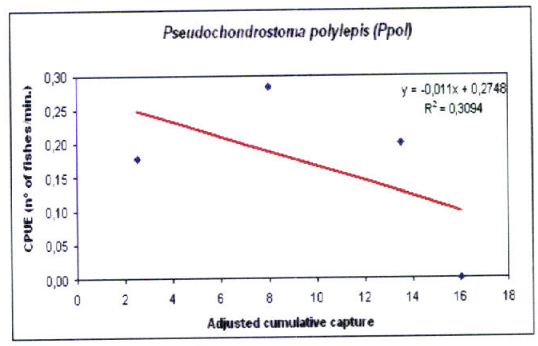

Cobitis paludica (Cpal)
y = 0,0159x + 0,0051
R² = 0,067
CPUE (n° of fishes min.)
Adjusted cumulative capture

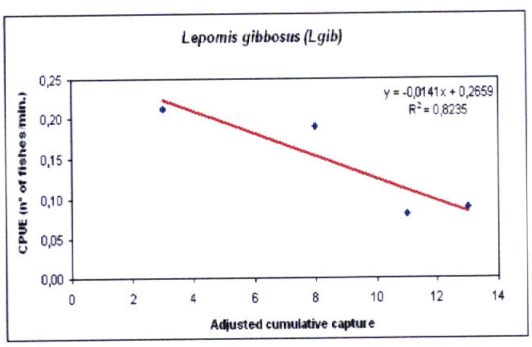

Iberocypris alburnoides (Ialb)
y = -0,0678x + 0,339
R² = 1
CPUE (n° of fishes min.)
Adjusted cumulative capture

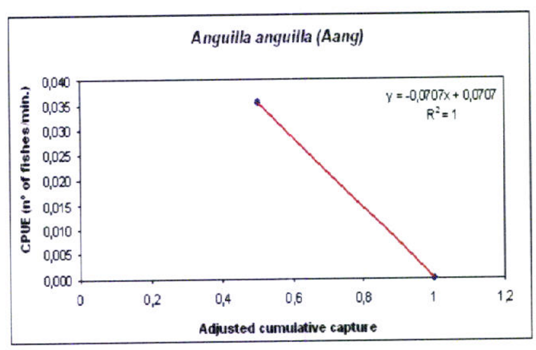

Luciobarbus bocagei (Lboc)
y = -0,0226x + 0,2652
R² = 0,6583
CPUE (n° of fishes/min.)
Adjusted cumulative capture

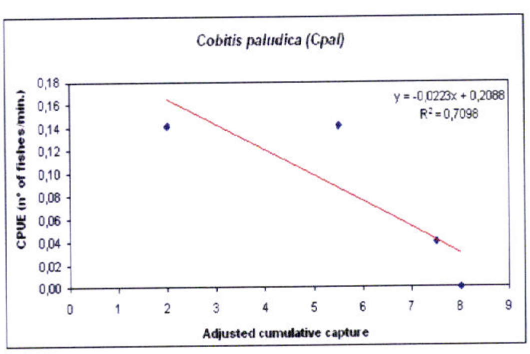

Gobio lozanoi (Gloz)
y = -0,0238x + 2,9053
R = 0,9958
CPUE (n° of fishes/min.)
Adjusted cumulative capture

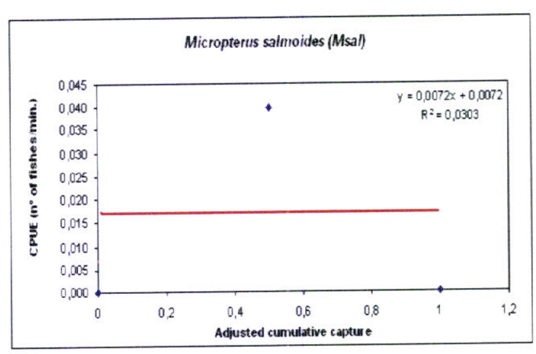

Squalius pyrenaicus (Spyr)
y = -0,0299x + 0,2609
R² = 0,4632
CPUE (n° of fishes/min.)
Adjusted cumulative capture

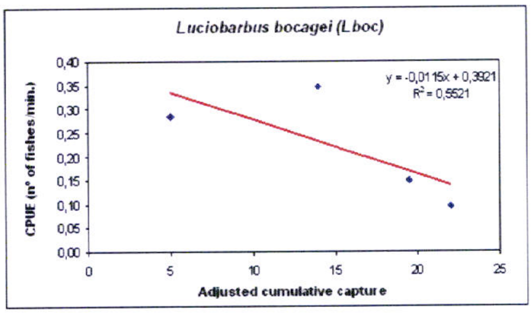

Pseudochondrostoma polylepis (Ppol)
y = -0,011x + 0,2748
R² = 0,3094
CPUE (n° of fishes/min.)
Adjusted cumulative capture

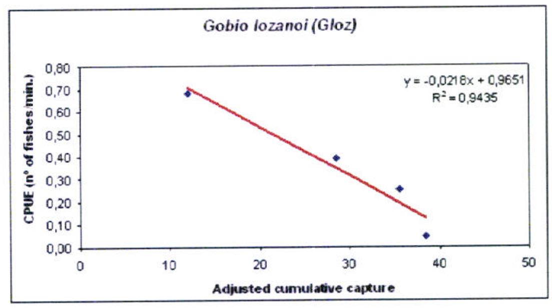

Lepomis gibbosus (Lgib)
y = -0,0141x + 0,2659
R² = 0,8235
CPUE (n° of fishes/min.)
Adjusted cumulative capture

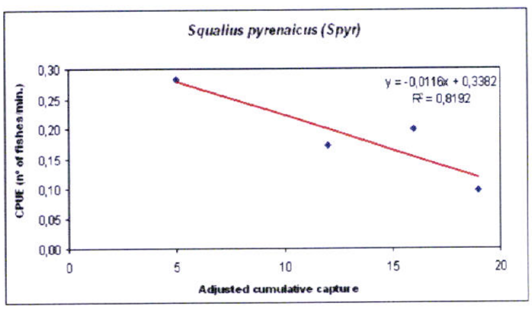

Anguilla anguilla (Aang)
y = -0,0707x + 0,0707
R² = 1
CPUE (n° of fishes/min.)
Adjusted cumulative capture

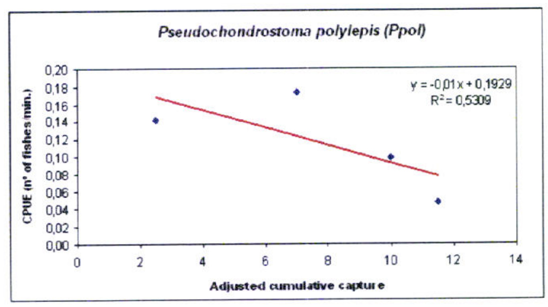

Cobitis paludica (Cpal)
y = -0,0223x + 0,2088
R² = 0,7098
CPUE (n° of fishes/min.)
Adjusted cumulative capture

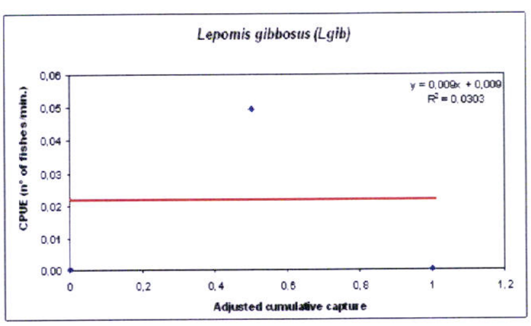

Micropterus salmoides (Msal)
y = 0,0072x + 0,0072
R² = 0,0303
CPUE (n° of fishes/min.)
Adjusted cumulative capture

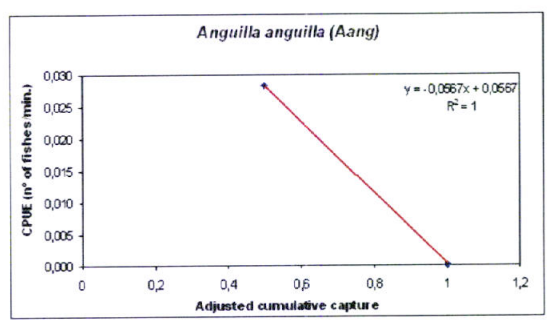

Luciobarbus bocagei (Lboc)
y = -0,0115x + 0,3921
R² = 0,5521
CPUE (n° of fishes min.)
Adjusted cumulative capture

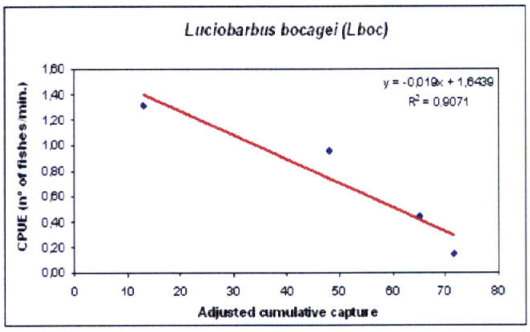

Gobio lozanoi (Gloz)
y = -0,0218x + 0,9651
R² = 0,9435
CPUE (n° of fishes min.)
Adjusted cumulative capture


Squalius pyrenaicus (Spyr)
y = -0,0116x + 0,3382
R² = 0,8192
CPUE (n° of fishes min.)
Adjusted cumulative capture

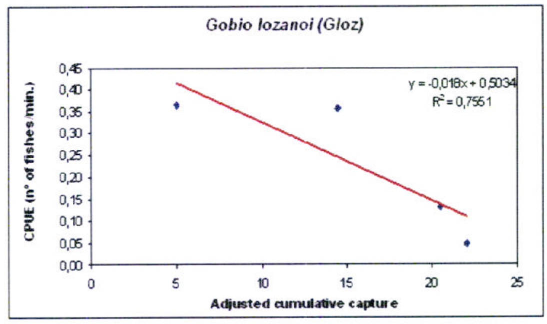

Pseudochondrostoma polylepis (Ppol)
y = -0,01x + 0,1929
R² = 0,5309
CPUE (n° of fishes min.)
Adjusted cumulative capture


Lepomis gibbosus (Lgib)
y = 0,009x + 0,009
R² = 0,0303
CPUE (n° of fishes min.)
Adjusted cumulative capture

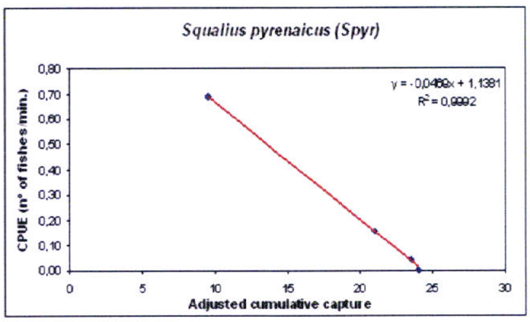

Anguilla anguilla (Aang)
y = -0,0567x + 0,0567
R² = 1
CPUE (n° of fishes min.)
Adjusted cumulative capture



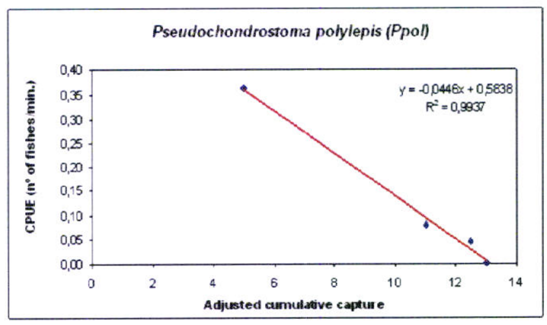
Luciobarbus bocagei (Lboc)
y = -0,019x + 1,6439
R² = 0,9071
CPUE (n° of fishes min.)
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0 10 20 30 40 50 60 70 80
Adjusted cumulative capture



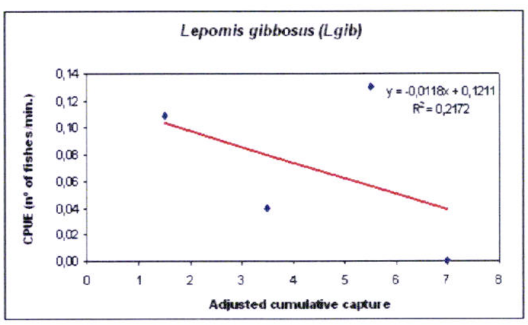
Gobio lozanoi (Gloz)
y = -0,018x + 0,5034
R² = 0,7551
CPUE (n° of fishes min.)
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
0 5 10 15 20 25
Adjusted cumulative capture



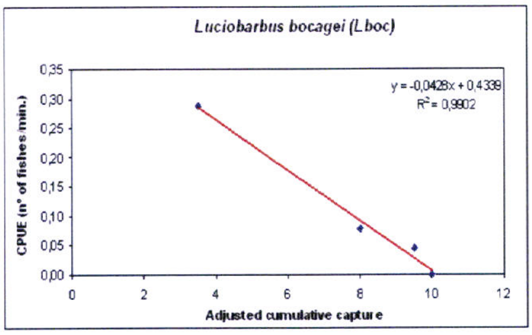
Squalius pyrenaicus (Spyr)
y = -0,0469x + 1,1381
R² = 0,9992
CPUE (n° of fishes min.)
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0 5 10 15 20 25 30
Adjusted cumulative capture



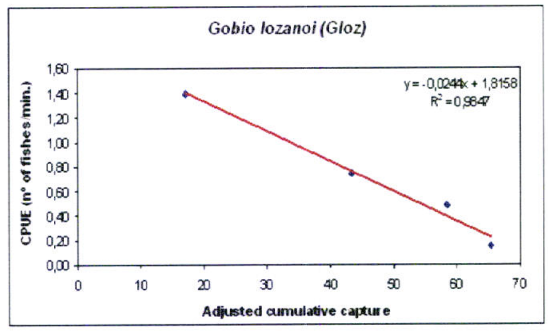
Pseudochondrostoma polylepis (Ppol)
y = -0,0446x + 0,5838
R² = 0,9937
CPUE (n° of fishes min.)
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
0 2 4 6 8 10 12 14
Adjusted cumulative capture



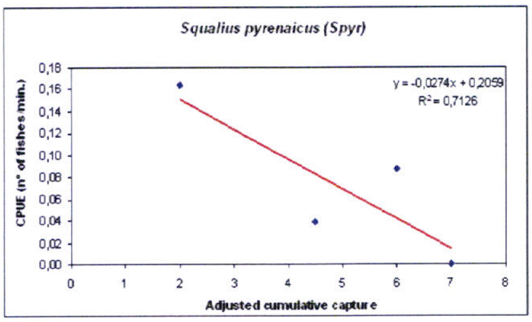
Lepomis gibbosus (Lgib)
y = -0,0118x + 0,1211
R² = 0,2172
CPUE (n° of fishes min.)
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0 1 2 3 4 5 6 7 8
Adjusted cumulative capture



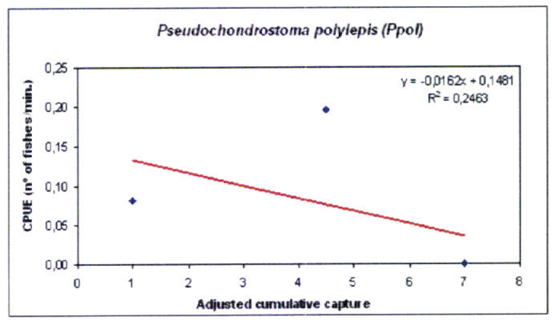
Luciobarbus bocagei (Lboc)
y = -0,0428x + 0,4339
R² = 0,9902
CPUE (n° of fishes min.)
Adjusted cumulative capture



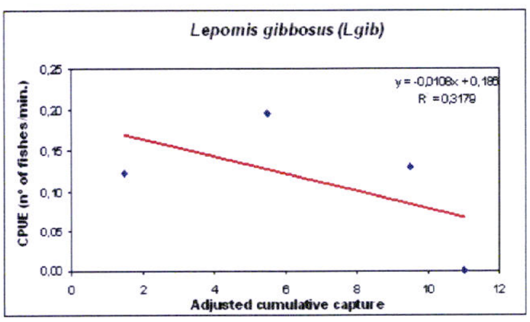
Gobio lozanoi (Gloz)
y = -0,0244x + 1,8158
R² = 0,9847
CPUE (n° of fishes min.)
Adjusted cumulative capture



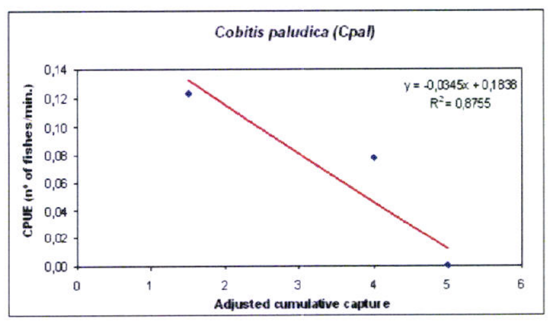
Squalius pyrenaicus (Spyr)
y = -0,0274x + 0,2059
R² = 0,7126
CPUE (n° of fishes min.)
Adjusted cumulative capture



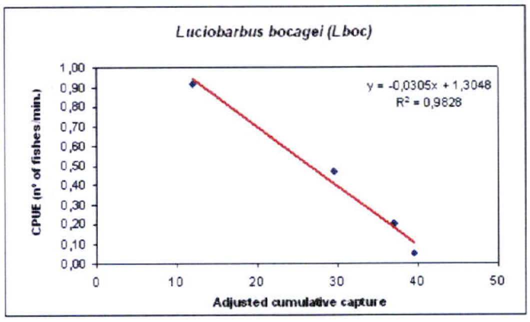
Pseudochondrostoma polylepis (Ppol)
y = -0,0162x + 0,1481
R² = 0,2463
CPUE (n° of fishes min.)
Adjusted cumulative capture

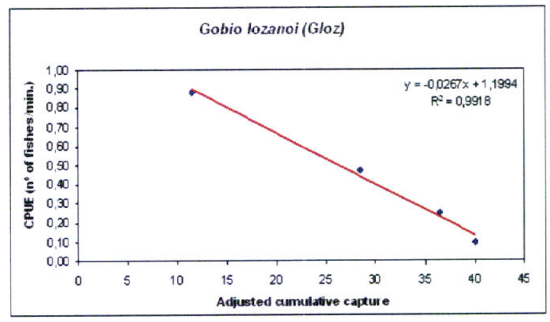


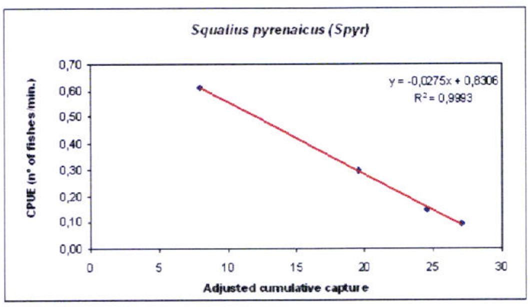
Lepomis gibbosus (Lgib)
y = -0,0108x + 0,186
R = 0,3179
CPUE (n° of fishes min.)
Adjusted cumulative capture

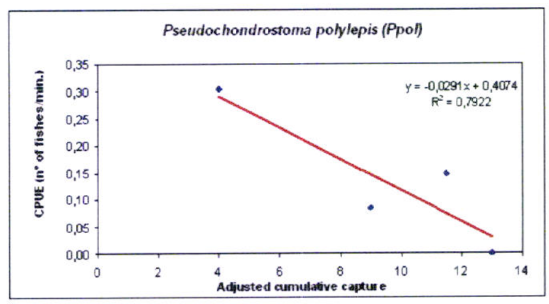


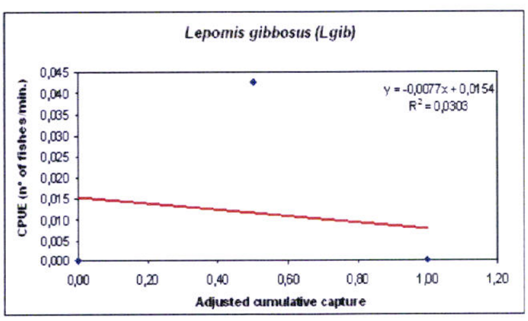
Cobitis paludica (Cpal)
y = -0,0345x + 0,1838
R² = 0,8755
CPUE (n° of fishes min.)
Adjusted cumulative capture

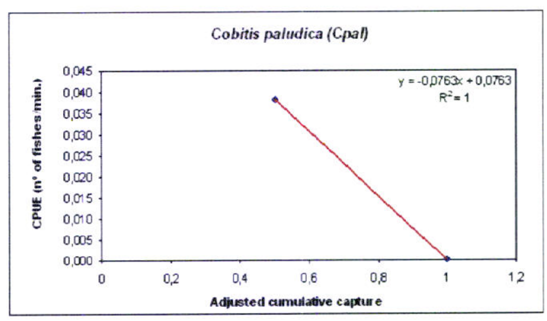

Luciobarbus bocagei (Lboc)
y = -0,0305x + 1,3048
R² = 0,9828
CPUE (n° of fishes min.)
Adjusted cumulative capture

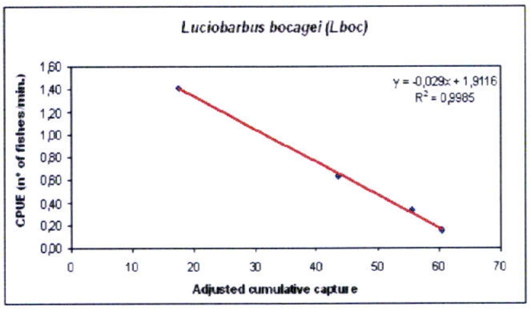

Gobio lozanoi (Gloz)
y = -0,0267x + 1,1994
R² = 0,9918
CPUE (n° of fishes min.)
Adjusted cumulative capture

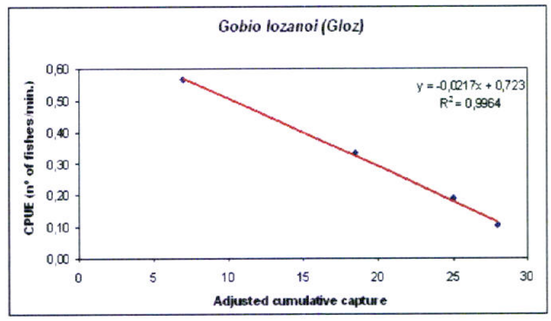

Squalius pyrenaicus (Spyr)
y = -0,0275x + 0,8306
R² = 0,9993
CPUE (n° of fishes min.)
Adjusted cumulative capture

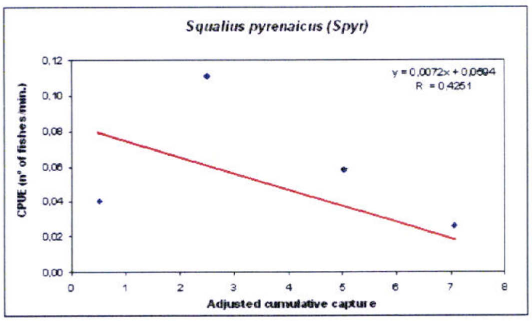

Pseudochondrostoma polylepis (Ppol)
y = -0,0291x + 0,4074
R² = 0,7922
CPUE (n° of fishes min.)
Adjusted cumulative capture

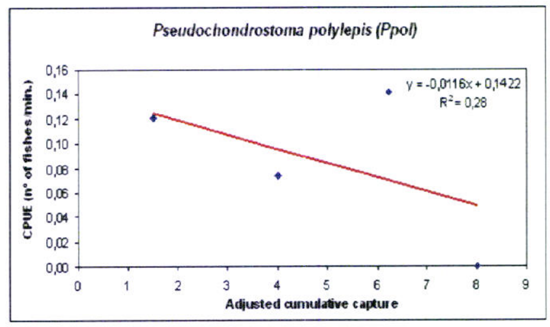

Lepomis gibbosus (Lgib)
y = -0,0077x + 0,0154
R² = 0,0303
CPUE (n° of fishes min.)
Adjusted cumulative capture

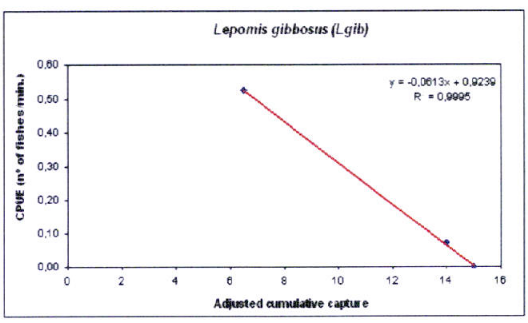

Cobitis paludica (Cpal)
y = -0,0763x + 0,0763
R² = 1
CPUE (n° of fishes min.)
Adjusted cumulative capture

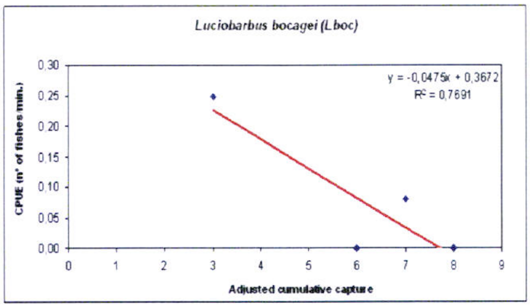

Luciobarbus bocagei (Lboc)
y = -0,029x + 1,9116
R² = 0,9985
CPUE (n° of fishes min.)
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0 10 20 30 40 50 60 70
Adjusted cumulative capture

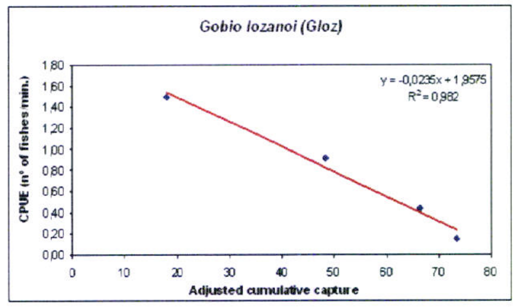

Gobio lozanoi (Gloz)
y = -0,0217x + 0,723
R² = 0,9964
CPUE (n° of fishes min.)
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0 5 10 15 20 25 30
Adjusted cumulative capture

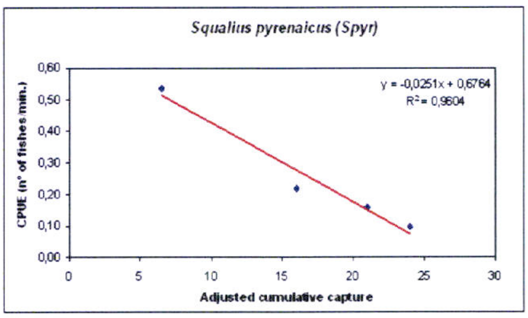

Squalius pyrenaicus (Spyr)
y = 0,0072x + 0,0594
R = 0,4251
CPUE (n° of fishes min.)
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0 1 2 3 4 5 6 7 8
Adjusted cumulative capture

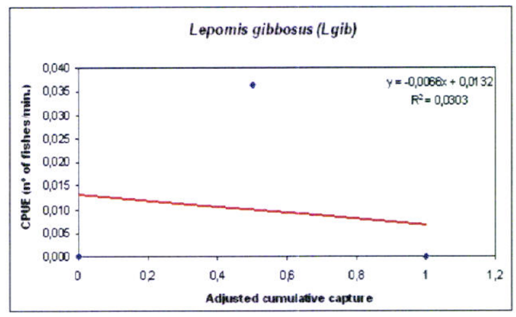

Pseudochondrostoma polylepis (Ppol)
y = -0,0116x + 0,1422
R² = 0,28
CPUE (n° of fishes min.)
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0 1 2 3 4 5 6 7 8 9
Adjusted cumulative capture

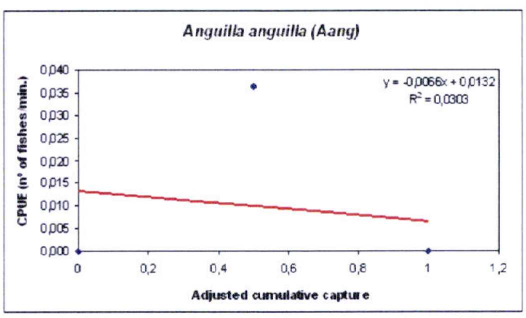

Lepomis gibbosus (Lgib)
y = -0,0613x + 0,9239
R = 0,9995
CPUE (n° of fishes min.)
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0 2 4 6 8 10 12 14 16
Adjusted cumulative capture

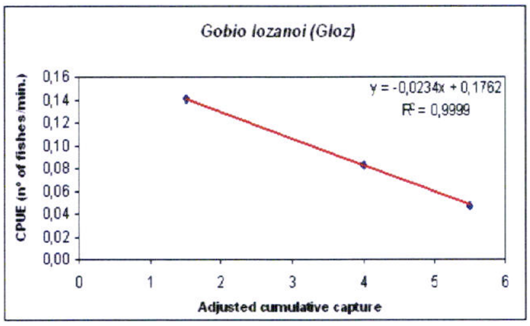

Luciobarbus bocagei (Lboc)
y = -0,0475x + 0,3672
R² = 0,7691
CPUE (n° of fishes min.)
Adjusted cumulative capture

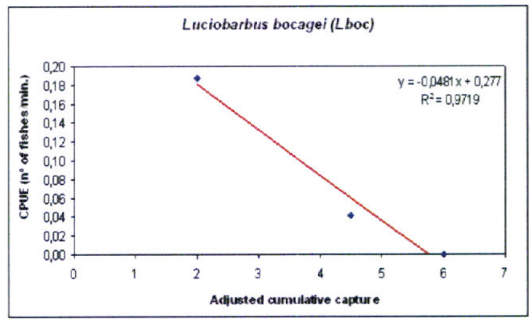

Gobio lozanoi (Gloz)
y = -0,0235x + 1,9575
R² = 0,982
CPUE (n° of fishes min.)
Adjusted cumulative capture

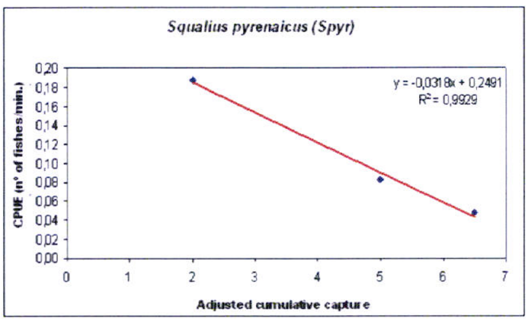

Squalius pyrenaicus (Spyr)
y = -0,0251x + 0,6764
R² = 0,9604
CPUE (n° of fishes min.)
Adjusted cumulative capture

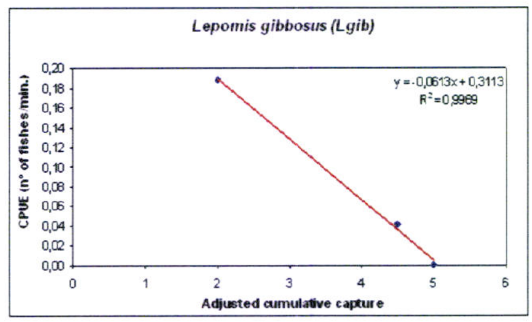

Lepomis gibbosus (Lgib)
y = -0,0066x + 0,0132
R² = 0,0303
CPUE (n° of fishes min.)
Adjusted cumulative capture

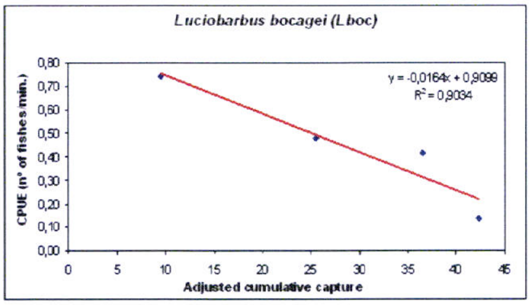

Anguilla anguilla (Aang)
y = -0,0066x + 0,0132
R² = 0,0303
CPUE (n° of fishes min.)
Adjusted cumulative capture


Gobio lozanoi (Gloz)
y = -0,0234x + 0,1762
R² = 0,9999
CPUE (n° of fishes/min.)
Adjusted cumulative capture

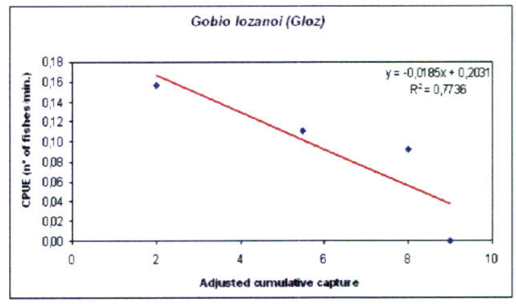

Luciobarbus bocagei (Lboc)
y = -0,0481x + 0,277
R² = 0,9719
CPUE (n° of fishes/min.)
Adjusted cumulative capture


Squalius pyrenaicus (Spyr)
y = -0,0318x + 0,2491
R² = 0,9929
CPUE (n° of fishes/min.)
Adjusted cumulative capture

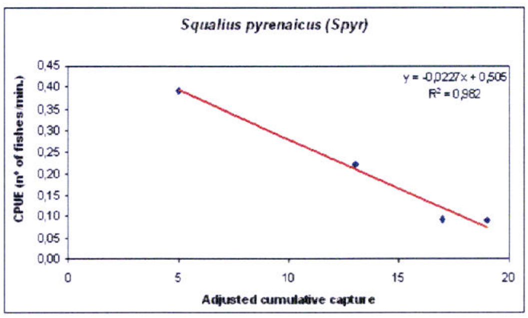

Lepomis gibbosus (Lgib)
y = -0,0613x + 0,3113
R² = 0,9969
CPUE (n° of fishes/min.)
Adjusted cumulative capture



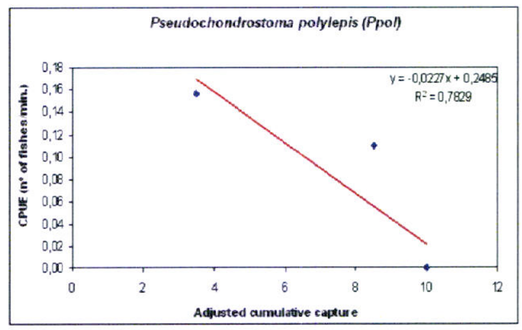
Luciobarbus bocagei (Lboc)



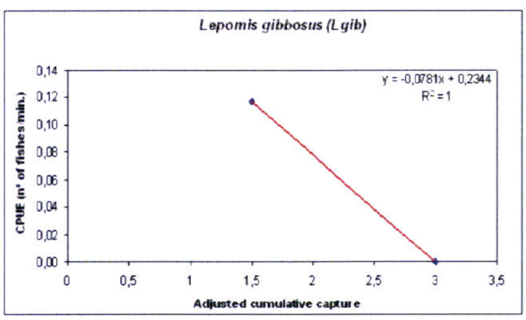
Gobio lozanoi (Gloz)



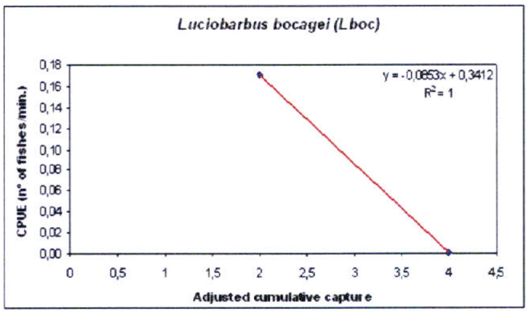
Squalius pyrenaicus (Spyr)

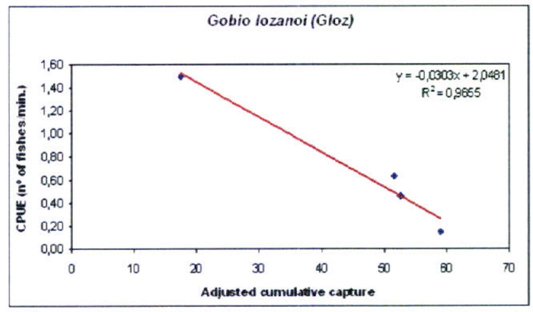


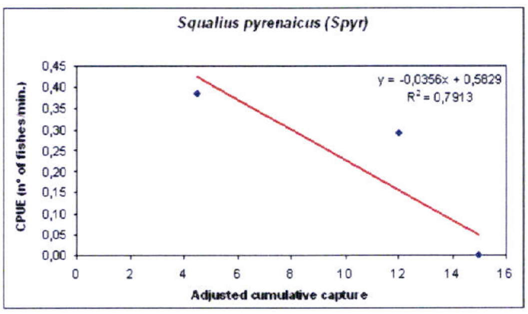
Pseudochondrostoma polylepis (Ppol)

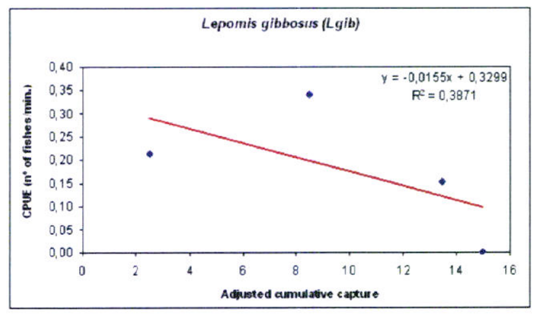


Lepomis gibbosus (Lgib)


Luciobarbus bocagei (Lboc)
y = -0,0853x + 0,3412
R² = 1
CPUE (n° of fishes/min.)
Adjusted cumulative capture


Gobio lozanoi (Gloz)
y = -0,0303x + 2,0481
R² = 0,9655
CPUE (n° of fishes/min.)
Adjusted cumulative capture


Squalius pyrenaicus (Spyr)
y = -0,0356x + 0,5829
R² = 0,7913
CPUE (n° of fishes/min.)
Adjusted cumulative capture


Lepomis gibbosus (Lgib)
y = -0,0155x + 0,3299
R² = 0,3871
CPUE (n° of fishes/min.)
Adjusted cumulative capture