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ASSESSING IMPACTS OF A HYDROPOWER PLANT: EBRO RIVER, SPAIN

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Ebro River is one of the largest river in the Iberian Peninsula. A small hydropower plant, Viana III, was built in Navarra province (North Spain), so a small dam was constructed to divert flow from the mainstream to the plant channel.
In the reach ("by-pass") affected by the flow reduction (around 263.550 m^2 of aquatic habitat) we studied the impact on the benthic and fish assemblages. Before (autumn 1995) and after (autumn 1996) the plant started to operate, different habitat types (fast and slow waters) were sampled by electrofishing and trammel nets to estimate fish populations. Invertebrates were sampled by Neil cylinder in lotic habitats. Densities and biomasses were estimated for invertebrates and fish populations. Besides, growth, condition coefficients and mortalities were estimated for fish.
Having compared the flow regime before and after the station began to work, we estimated there was a considerable loss of aquatic habitat (40%). In consequence, in fast and shallow waters we noticed a dramatic decrease for the biomass (61%) of the fish assemblage, although we observed an important increase for density (28%). In different types of habitat (fast and slow waters) where we sampled by nets, we also detected notable decreases in the catch ratio (40%) and average weight (59%). We also estimated a remarkable reduction in the density (56%) and biomass (35%) of the benthic fauna.
Results suggest the need of developing latest methods for the impact assessment, studying the natural regime of flow by a set of parameters based on historical data [1] and estimating habitat loss for fish and benthonic assemblages by the Instream Flow Incremental Methodology [2].

Introduction

Ebro River has the highest mean annual flow among the rivers flowing in the Iberian Peninsula. In the mainstream a small dam was constructed in order to divert flow to a channel from the mainstream to the new hydropower plant "Viana III". This channel connects to the Ebro River downstream the study reach again.

We studied the by-pass reach of the river affected by the flow reduction. The study site (around 3360 m long) is located 10 km downstream Logroño city. We surveyed benthos and fish fauna before the plant started to operate, and after 1 year of work. The questions we were wondering were:

- What changes occurred in the flow regime? How could they affect the available habitat for benthic and fish fauna?
- How were the benthic and fish populations going to change in terms of biomass, density and structure?

Study Reach

The by-pass reach affected is part of the mainstream of the Ebro River, 10 km downstream Logroño city. It represents the boundaries between Navarra and La Rioja provinces, entering the last one in the lowest part of the reach. Since the reach is 3360 m long and the mean width is 78.4 m, we estimated the aquatic habitat to be 263,550 m^2 after the dam, 1.2 m height, was constructed and before the plant started to operate.

The thalweg gradient is estimated to be 0.126% and the mean altitude 341 m asl. We found the main part of the reach was slow waters (56.2%) but not much more than the fast water areas (43.8%), the ratio fast/slow lengths was 0.93.

The flow regime was studied in Mendavia gauge station, based on the data from October 1966 to September 1995. The results are included in *Fig.1*. The mean annual flow is 123.4 $m^3 s^{-1}$ and the river has a pluvial discharge regime. We found a low flow period

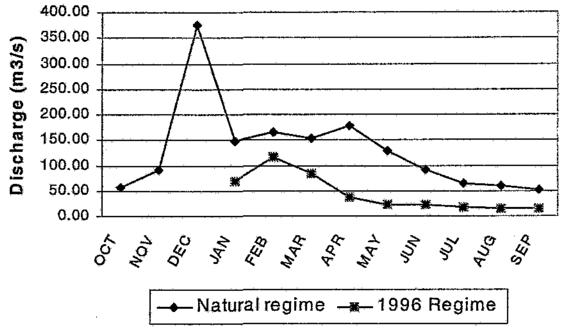
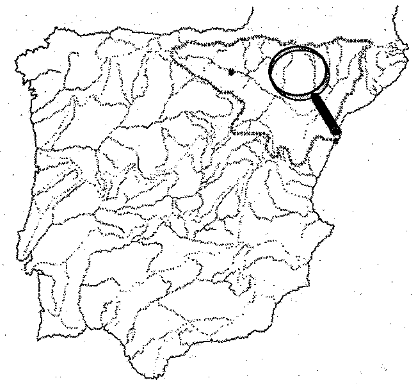


Fig.1 Historical data: Mendavia (Navarra)



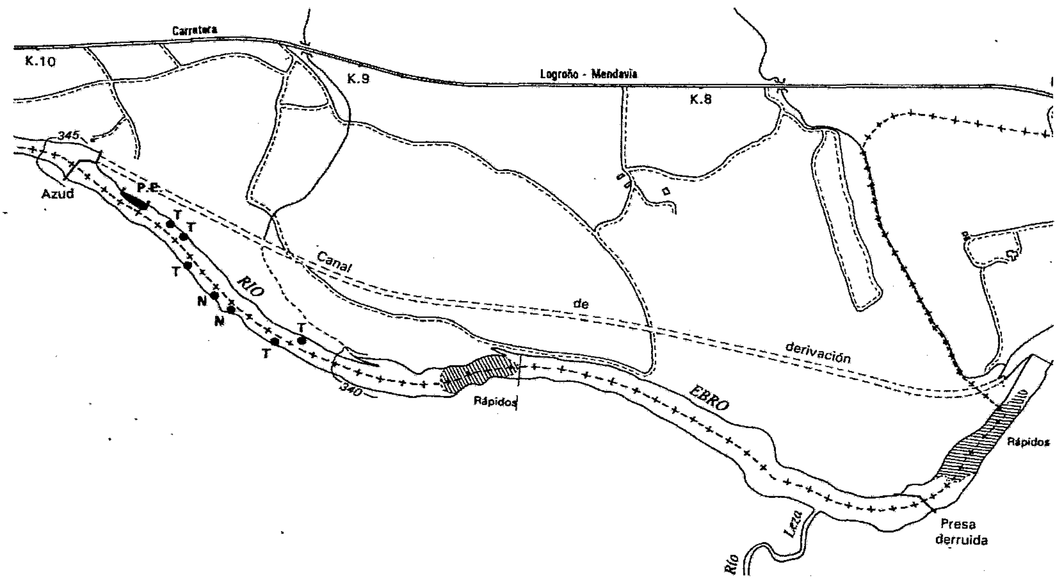


Fig.2 Map of the study

between July and October, the minimum flow occurs in September and the maximum in February.

The riparian habitat was strongly affected by human activities (mainly agriculture). However, we found little areas where the shrubs and trees provided a well structured riparian habitat: Basically Populus, Salix, Tamarix, Ulmus and Alnus. A map of the study reach and the sampling sites can be seen in *Fig.2*.

Method

Based on the gaugings controlled by the Confederación Hidrográfica del Ebro the flow regime was studied. Mendavia was the gauge station selected because only Leza Creek (with very little flow compared with the mainstream) joins Ebro River between the study reach and the gauge station.

We calculated the mean annual flow for every month using the historical data from 1966 to 1995. After the plant started to operate, a new study was done. Based on the turbinated flow by the plant (data given by the company in charge), the new gauge in the Ebro River was estimated, obtaining the mean flow for every month in the period January-September 1996.

Both methods, electrofishing and nets, were used to survey the fish assemblage in different sites of the reach. Every fish was weighed (1-2 gr. error) and its fork length measured. Hydroacoustic techniques were not suitable in the study reach, where the depths (less than 2-3 m) do not get to the necessary values to apply this technique successfully.

Thanks to the low flow in September-October, a wadeable unit (1491 m^2 in 1995 and 1161 m^2 in 1996) was found. We netted off the unit and applied electrofishing in order to obtain quantitative results. The unit was a glide in a side channel with an estimated mean depth of 50 cm.

Electrofishing technique was applied with removal method (we did 3 passes). The rectificator device was custom-made in our laboratory and the power was supplied by a 1200 W generator. With 220 V, we obtained 2.5 A, avoiding danger for the fish [3] and the sampling team.

The first step to study the fish populations was the calculation of length frequency [4], assimilating normal distribution to every age class. Mean length and weight was calculated for every age class with a 95% confidence interval. Weight/length relationship was calculated according to RICKER [5,6] and condition coefficients were calculated for every age class.

Table 1 Historical Data (Q natural regime avg.: 129.9; Q 1996 regime avg.: 44.1)

Hydrological year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1966	44.0	76.8	251.2	167.3	241.7	232.4	133.0	105.3	158.3	77.4	62.8	64.1
66-67	105.2	357.2	210.2	122.7	95.2	98.1	101.0	104.0	57.0	43.4	50.7	43.2
67-68	38.1	120.2	257.7	327.7	220.0	200.3	217.9	112.6	68.6	44.2	48.1	83.9
68-69	48.3	25.8	38.6	66.4	75.7	128.4	154.7	119.1	76.7	41.8	42.1	74.9
69-70	33.3	28.1	272.0	319.7	231.6	251.2	88.7	84.8	43.1	21.1	23.6	26.9
70-71	39.7	37.7	43.7	47.1	54.7	116.0	128.7	248.8	164.0	63.8	42.9	40.4
71-72	33.8	150.3	191.4	180.8	380.1	217.0	169.0	258.6	126.6	70.8	58.2	71.9
72-73	78.2	57.4	7524.0	110.8	312.9	125.0	147.0	76.0	183.2	61.9	58.2	53.1
73-74	62.4	54.1	96.9	103.1	199.9	282.7	184.3	74.8	58.6	63.6	55.6	54.6
74-76	116.4	187.7	101.0	100.3	90.7	145.8	350.1	152.7	110.3	64.0	59.6	60.9
76-76	55.0	148.0	145.1	74.3	235.4	99.6	201.9	92.9	57.3	57.3	52.3	54.2
76-77	51.7	74.9	78.3	105.5	132.1	78.4	134.8	199.8	277.9	104.4	85.1	61.2
77-78	58.3	58.3	103.9	287.8	515.4	283.3	322.5	307.0	131.2	94.3	85.3	77.2
78-79	77.2	69.9	122.1	307.7	430.9	222.6	347.0	157.8	92.1	85.9	78.2	84.3
79-80	103.5	276.7	114.1	225.1	92.4	199.9	210.5	230.4	126.5	78.4	67.6	63.6
80-81	72.8	67.2	255.3	345.7	132.4	114.7	183.7	130.1	62.9	50.7	51.8	54.7
81-82	49.0	33.2	95.5	115.2	103.5	137.5	57.3	39.7	52.6	65.4	58.3	43.9
82-83	51.8	101.3	328.9	108.5	185.0	161.4	250.4	116.3	56.6	64.2	139.0	75.6
83-84	50.8	41.4	75.6	137.5	182.6	197.3	157.4	202.5	132.6	61.4	64.4	66.3
84-85	70.9	145.4	88.8	166.3	128.7	126.5	124.9	142.9	65.9	65.4	51.0	47.4
85-86	28.4	41.4	36.2	101.8	201.1	119.4	116.2	91.5	52.8	58.9	58.6	42.2
86-87	33.2	31.8	61.4	116.1	174.8	109.2	160.0	52.9	52.0	60.2	58.9	53.2
87-88	41.9	83.8	116.2	122.3	156.7	208.4	396.9	156.2	107.4	86.6	57.5	44.9
88-89	34.8	26.3	38.3	32.6	26.0	45.8	120.6	53.4	48.0	56.6	45.0	32.6
89-90	19.9	28.8	43.2	45.0	43.6	26.4	148.4	35.7	22.7			13.3
90-91	12.5	22.3	82.3	66.2	51.0	143.1	215.6	229.5	49.2	42.3	40.0	26.9
91-92	29.8	119.1	57.1	32.3	26.4	67.3	275.7	77.7	116.6	74.3	52.7	33.0
92-93	185.7	159.3	188.3	54.9	33.0	154.4	93.6	112.5	65.2	65.2	50.9	25.8
93-94	60.1	41.6	170.8	209.4	102.0	84.4	103.5	56.9	50.8	55.7	45.9	27.1
94-95	20.6	37.8	35.4	252.1	102.4	218.8	55.1	44.4	46.1	62.4	52.0	28.5
Natural regime ($m^3 s^{-1}$) →	56.9	90.1	374.1	148.4	165.3	153.2	178.3	128.9	90.4	63.5	58.5	51.0
1996 regime				69.2	116.1	84.7	36.3	21.5	23.2	17.6	14.9	13.7

Length/age relationship was calculated adjusting a Von-Bertalanffy curve [7]. Using the same asymptotic value permitted the comparison between 95 and 96 population growth.

In the unit surveyed, the mathematical method to estimate the total number of fish was the maximum weighted likelihood [8], the most robust method recommended by COWX [9]. In order to minimize the error due to the different catch probability in every species and age class, we calculated the 95% confidence interval independently for every species and, when necessary, for every age class. Biomass was calculated by assigning a mean weight to the fish in every species and age class. Finally, relative density (number of fish per m^2) and biomass ($g\ m^{-2}$) was calculated for the unit surveyed.

We studied the changes in the fish assemblage comparing the total number of fish, total biomass and composition between 1995 and 1996. Indexes of diversity and evenness were also calculated.

Besides, we made electrofishing from a raft in deeper sites. As we could not net off a piece of water, no quantitative results could been obtained. These data completed our data base to study the fish assemblage composition and the age, length and weight relationships for every species.

We got more data about the fish assemblage by sampling different habitats with trammel nets. These nets consist of three parallel panels of netting, the two outer panels are of large-mesh netting and the inner panel is of a small mesh. The three panels are suspended from a float line and attached to a lead line. Our trammel nets were 1.5 m tall and 12 m long. They were sited in different habitats and stayed floating one night.

Based on all the data obtained by trammel nets, we calculated catch per unit effort (CPUE) and the mean weight for every species. We grouped the results obtained from nets sited in fast water and slow water habitats. Then we compared the situation in every group before and after the plant was in operation. This way of sampling gave us more data about the assemblage composition and its variation in different types of habitats in the study reach.

The benthonic fauna plays a crucial role as a bio-indicator for the quality of the aquatic habitat. To study the benthos assemblage we used the Neil cylinder, taking 4 replicates of 0.1 m^2 each. The sample was done in lotic habitats, close to the same glide where we did electrofishing. In every replicate, we removed the cobbles to sample the complete assemblage living upon the river bed. We estimated the density and biomass for every population and the assemblage in 1995 and 1996. Diversity and water quality indexes were calculated as well.

Results

The natural flow regime based on the monthly data from 1966 to 1995 was compared with the flow regime registered after the plant started to operate. The natural flow had a winter peak in December (374,12 $m^3 s^{-1}$) and a low period between July and October, with the minimum in September (51 $m^3 s^{-1}$).

Table 2 Data obtained by sampling with trammel nets in 1995 and 1996

TRAMMEL NETS	Year 1995				Year 1996			
	FAST WATER HABITATS		SLOW WATER HABITATS		FAST WATER HABITATS		SLOW WATER HABITATS	
	CPUE	Mean weight	CPUE	Mean weight	CPUE	Mean weight	CPUE	Mean weight
Barbus graellsii	5.75	307.9	7.00	559.2	4.25	31.7	5.25	64.7
Carassius auratus	0.75	278.3	3.00	746.7	-	-	-	-
Cyprinus carpio	2.75	283.8	1.00	410.0	2.25	340.1	3.25	312.3
Chondrostoma toxostoma	9.50	34.5	6.25	33.3	2.25	42.33	4.50	29.8
Gobio gobio	0.25	10.0	-	-	-	-	-	-
TOTAL (MEAN)	19.00	(162.6)	17.25	(392.6)	8.75	(113.75)	13	(114.54)

The flow regime based on the data from 1996 showed strong changes in the drought period. From April to September we observed a mean flow of 21,18 $m^3 s^{-1}$ (17% of the natural mean annual flow –MAF-) and a reduction of 27% in the minimum (13,66 m3/s) that still occurs in September.

Using the month averages, the maximum/MAF ratio was studied. It reveals strong changes in the torrential regime: the ratio was 3 for the natural regime and 0.94 for the available data of 1996. As we expected, the flow regime line started to become flatter in 1996.

The mean reduction in flow was calculated and a 66% of the MAF was obtained. The available series of data is considered time enough to evaluate the changes in the habitat available for benthos and fish fauna. The IFIM, Instream Flow Incremental Methodology (2), permitted us to estimate the potential usable habitat (m^2 m^{-1} of available habitat) for fish based on a very simple survey. At least ten cross-sections (measuring mean velocity, depth, substrate and cover for fish) enable us to run a hydraulic model and predict changes in the habitat caused by changes in flow. Therefore, a 66% reduction in the MAF can be evaluated in terms of suitable habitat for fish, based on the suitability curves that were calculated for cyprinids in Spain [10]. Processing data by the RHYHABSIM program [11], the weighted usable area (WUA) was related to the discharge and a 40% of potential loss of habitat was obtained for the cyprinids.

The structure of the fish assemblage suffered patent changes after the plant started to operate. The data obtained by electrofishing and trammel nets are showed in *Tables 2* and *3*. In the unit where we made electrofishing, a notable increase of relative density was detected (+28%), mainly due to the increase of the young of the year. Relative density was 1.14 ind. m^{-2} in 1995 and 1.46 ind. m^{-2} in 1996. Dominant species in number were *Barbus graellsii* and *Chondrostoma toxostoma*. The first increased its importance from 5% to 17%, whereas the second decreased from 89% to 77% in the assemblage. The changes in the importance for the rest of species were not representative, except for *Rutilus arcasii* and *Phoxinus phoxinus* that were not found in 1996.

In terms of biomass, the relative values of the unit surveyed fell a 61% related to 1995, due to the reduction in the number of fish belonging to the older classes. Biomass changed from 41.4 g m^{-2} (1995) to 15.9 g m^{-2} (1996). Relative importance of the principal

Table 3 Results obtained for the benthic assemblage

BENTHIC ASSEMBLAGE	Year 1995		Year 1996	
	Average	Standard deviation	Average	Standard deviation
Mean density of samples (ind m^{-2})	1856	765.9	808	452
Mean biomass of samples (g m^{-2})	1.15	0.50	0.74	0.62

species stayed the same in 1995 and 1996. *Barbus graellsii* (70%), *Cyprinus carpio* (20%) and *Chondrostoma toxostoma* (9%) were the most important, and the rest of species maintained each one under 1% of the assemblage biomass.

The results obtained by trammel nets also reveal great differences between the 1995 and 1996 situation. In the slow water areas, the mean decrease of the capture per unit effort (CPUE) for all the species was 25% related to 1995 and the decrease of the mean weight was 71%. In fast water areas, the results were a 54% of reduction in the average of CPUE and a 30% of the mean weight. *Carassius auratus* was captured only in the first survey, in 1995.

Based on the two methods, every fish population was studied. In the electrofishing area, *Barbus graellsii* increased its stock of youngest classes (0-2+), which number were multiplied by 10. Oldest classes (5-7+) suffered an important reduction: 50% for relative density and a 65% in terms of relative biomass. Results by trammel nets were in concordance with the results obtained by electrofishing. No data could be obtained for the young classes by nets, because the smallest fish captured was 115 mm long (age 1+) for this species. Both types of results showed that the population was getting younger; results represent a change in the mean weight from the typical barbel 6-8 years old to a 2 years old barbel.

Chondrostoma toxostoma suffered an increase in the stock of young of the year -YOY- (10%) but a decrease in the rest of the classes. In general, it supposed a 62% reduction in the total biomass in the electrofishing area. The results obtained by nets also revealed big reductions in the stocks and a movement of the adults to the faster waters from the lentic areas. The minimum size of the fish captured was 120 mm (age 1+).

In the area shocked, *Cyprinus carpio* suffered a general reduction in the stocks (47%), which supposed a 63% reduction in the biomass. By trammel nets we captured 3 times more carps in the slow water habitats and the number decreased in the nets sited in the fast water habitats. The minimum size of the fish captured was 78 mm (age 0+). *Gobio gobio* was the only species that clearly increased its stocks. In the electrofishing area, its number was multiplied by 4.5 and the biomass by 2.5. We only captured a fish in 1995 by nets, due to their small size. *Noemacheilus barbatulus* stayed in the same patterns in both surveys. We only fished 2 individuals of *Rutilus arcasii* and none of *Phoxinus phoxinus* by electrofishing in 1996. *Carassius auratus* was only fished in 1995 by nets and none was observed in the 1996 survey.

Length/weight and length/age relationships were calculated only for *Barbus g.*, *Cyprinus c.* and *Chondrostoma t.* Length/weight relationship didn't show relevant changes between 1995 and 1996. The Von-Bertalanffy curves showed the same pattern as well. Condition coefficients K (100 g cm^{-3}) did not reveal clear changes in any species. Mortalities could not be calculated due to the lack of fish in different age classes of the principal species.

The benthic fauna is crucial to study how the physical changes affect the aquatic habitat. Most of the fish species living in the study reach feed on the benthic fauna, therefore its density and biomass are considered fundamental elements to explain the changes that we observe in the fish assemblage.

The index of TUFFÉRY-VERNEAUX [12], Extended Biotic Index [13] and BMWP' [14] were calculated in 1995 and 96, showing no representative changes in the water quality. In both years, the water was polluted and diversity was very low. The survey team found that silt particles were abundant in the site where the samples were taken. The flow was between 20 and 25 m^3 s^{-1} in both surveys.

Strong reduction in terms of density and biomass was observed. Density fell 56% and biomass 36% related to the 1995 survey, so we noticed an important loss in the available quantity of food for cyprinids in the lotic areas.

Discussion

The instream flow regime after the plant started to operate was characterized by a notable reduction in the minimum month average. Besides, the drought period became longer and more intense (the flow was lower than before in the summer). Based on the available data from 1996, we calculated an important decrease in the mean annual flow. Applying the Instream Flow Incremental Methodology to the cyprinid populations, we calculated that a reduction of 66% in the mean annual flow potentially represented a 40% of loss for the aquatic habitat. The changes in the aquatic habitat affected the fish assemblage in different manners: the assemblage composition, the populations' structure and the relative density and biomass of each species.

The percentages of relative importance for the principal species mantained the same in the assemblage, in terms of biomass. However, in terms of density, we observed higher importance of barbels and lower of *Chondrostoma toxostoma* related to 1995. We think that these changes are due to the physiological conditions of each species, as barbel is considered a genus that tolerates a very wide range of conditions while *Chondrostoma* is a genus very adapted to the fast water habitats that decreased in the study reach.

The population structure also changed for the principal species. In the area where we could sample the young classes, a general increment of the recruitment was noticed for *Chondrostoma toxostoma* and specially for *Barbus graellsii*. We think that the reason was the reduction in the mean velocity and depth in the area, because this reduction created better conditions for the survival of the young of the year.

The relative biomass obtained by electrofishing survey for *Barbus graellsii, Chondrostoma toxostoma* and *Cyprinus carpio* suffered great reductions (the average loss was about 60%). In general, the results obtained by trammel nets were in accordance with these results, showing great reductions in the CPUE and the mean weights of the fishes captured. Only the carp was a different case, because it multiplied its number by 3 in the slow water habitats; the explanation is that the carp is considered as a species completely adapted to the slow waters.

Gobio gobio, species that was introduced in Spain, was the only one that increased its stocks greatly in the area of electrofishing. The wide range of conditions that it tolerates in terms of velocity and depth permits it to spread widely in the Spanish rivers today. The same as the carp, *Carassius auratus* prefers slow water habitats, and it was captured by nets only in 1995. We think that they have not disappeared of the study reach. The rest of species: *Rutilus arcasii*, *Phoxinus phoxinus* and *Noemacheilus barbatulus*, are benthic and ephibenthic species. They vary in their capture efficiency because they are very small, mobile and cryptic, and they hide on the river bed. The population density and structure of the environment strongly modify the size of error, so it is difficult to get reliable results by electrofishing [15].

We did not notice changes in the water quality based on the study of macroinvertebrates. However, their relative density suffered a 56% reduction and a 36% in their relative biomass after 1995. Another study in Austrian rivers also found important reductions in the benthic biomass with no changes in the diversity [16]. The declination of the benthos assemblage was due to the fine particles deposition because of the flow reduction that caused the increasing filling of the interstitial habitat. The great reduction of fish biomass is explained by the loss of the basic food for the principal species. *Chondrostoma toxostoma* and *Barbus graellsii* feed on the benthos fauna in different stages of growth. However, the carp feeds on the abundant silt of the river bed and does not depend on the benthos populations.

Therefore, the increase of lentic habitats largely benefits the carp populations.

Conclusion

The impacts of Viana III hydropower plant in River Ebro ecosystems can be synthesised as follows. An increasing bed-filling in the study reach was due to the abundance of fine particles and a notable decrease of the mean flow. This loss of suitable habitat for macroinvertebrates caused a great reduction of their biomass. In different manners, every fish population was affected by the changes in the available habitat and by the food reduction in the reach. While a slow waters species (the carp) found greater areas of available habitat, the rest of the species suffered important decrement in the stock of adults. We remark that a better comprehension of the habitat selection by fish, and the application of new methods to study the aquatic habitat [1,2,10,11,17] are hot points to take into account for this kind of studies.

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