CHEMICAL AND BIOLOGICAL CHANGES IN THE TER RIVER INDUCED BY A SERIES OF RESERVOIRS

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INTRODUCTION

The climatological and topographical characteristics of the Iberian peninsula have made the construction of reservoirs a necessity. Thus, more than 700 reservoirs have been constructed since the beginning of the century, one hundred of which have been the object of intensive study (Margalef et al. 1976). Nevertheless, the effect of these reservoirs on rivers is practically unknown. Garcia de Jalon (1984) reached a similar conclusion in a survey of existing literature on this topic. In this study we attempt to quantify the biological and chemical effects of three reservoirs located in the middle section of the River Ter. An earlier study suggested that these reservoirs had affected the macroinvertebrate communities residing below the reservoirs (Prat 1981). Because a flood occurred during our study we were also able to monitor the regulatory efficiency of these reservoirs.

STUDY AREA

The River Ter originates in the eastern Pyrenees at an altitude of 2500m (a.s.l.) and flows into the Mediterranean Sea. It is 206 km in length with a drainage basin of 3010 km^2. The dominant geologic strata are calcareous, however the headwaters and portions of the Prelitoral mountains are siliceous.

The hydrological characteristics of the Ter are Mediterranean although the headwaters exhibit a Pyrenean influence (Sabater & Armengol 1985). Water levels are lowest in summer and increase in autumn due to an increase in rainfall. Rainstorms also cause occasional flooding. During the past 10 years flows average 29 m^3 s^{-1}. Rainfall in the drainage ranges from 1000 mm in the upper streches to 600 mm at the mouth.

The reservoir system examined in our study, the Sau system, stabilizes flows in the middle and lower portions of the river. Hydrographic and morphometric characteristics of these reservoirs are presented in Table 1.

Table 1. Hydrographic and morphometric characteristics of the Sau system reservoirs.

	SAU	SUSQUEDA	EL PASTERAL
Altitude (m a.s.l.)	410	300	185
Distance to the mouth (km)	91.8	76.8	68.6
Storage capacity (Hm^3)	177	233	2
Area (Ha)	760	463	35
Maximum depth (m)	73	110	33
Mean depth (m)	23.3	50.3	5.7
Residence time (day)	117	146	1.3

MATERIALS AND METHODS

Fifty-two stations were established throughout the length of the drainage. Of these 30 were sampled monthly (October 1982 - October 1983) whereas the remainder were sampled partly. During each sampling period we obtained detailed measurements on: 1. physico-chemical composition of surface and hyporreic water (Sabater & Armengol 1985); 2. periphyton; 3. macrophytes; 4. macroinvertebrates (Puig et al. 1985); and 5. hyporreic fauna.

In this study we present monthly data from three stations above the reservoirs and two stations below the reserviors (Figure 1).

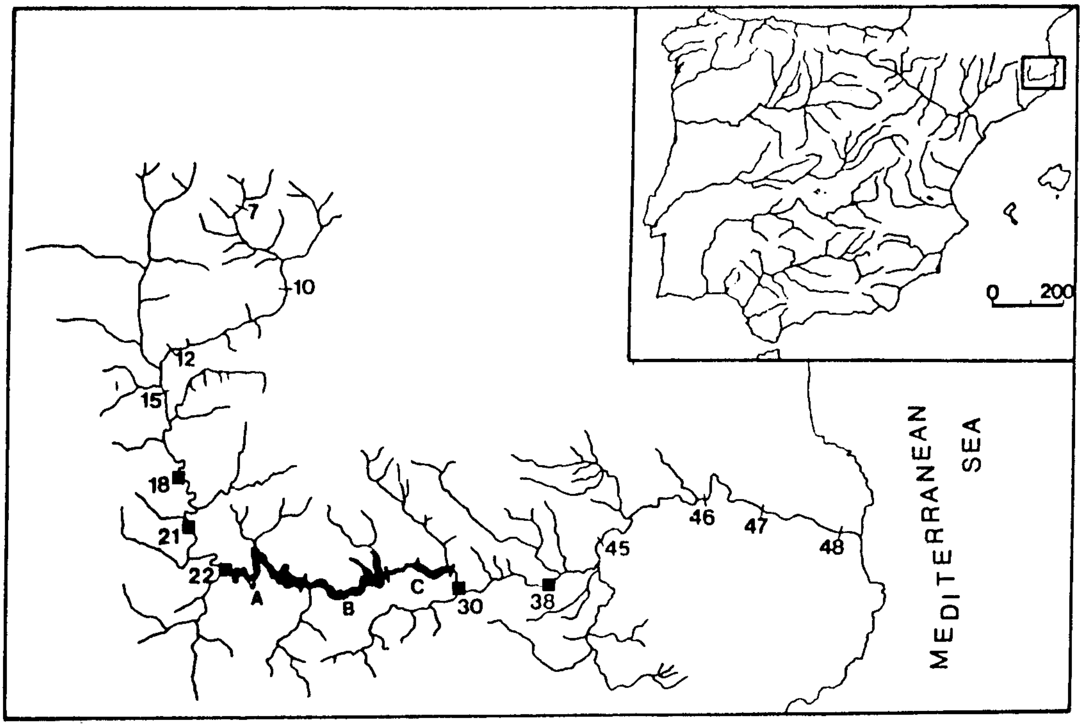
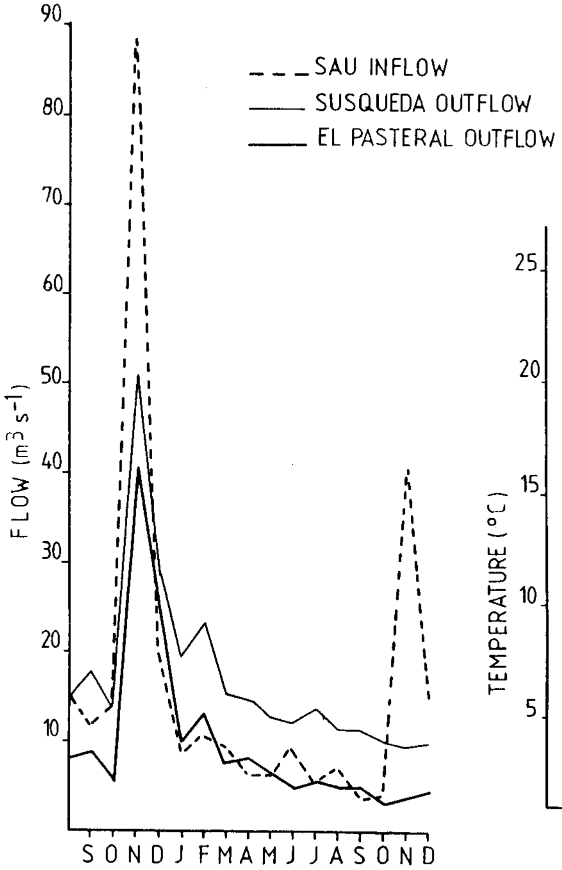


Figure 1. Location of the sampling sites on the Ter River basin. A) Sau Reservoir; B) Susqueda Reservoir and C) El Pasteral.

In addition 6 m^3 s^{-1} are diverted from the downstream reservoir, El Pasteral, for domestic consumption in cities located outside this hydrographic region. This represents a reduction of 30% in average annual flows.

Due to the regulations of flow we expected to observe related changes in water temperatures. Annual temperature profiles for station 22 (located just above the reservoirs) and 30 (located just below the reservoirs) are presented in Figure 3. Water temperatures in the river are affected by water diversions because water is diverted from different depths during the year. In contrast to maximum and minimum temperatures observed in station 22 (Figure 3) water temperatures in station 30 were >8°C in winter and <24°C in summer. These temperatures were identical to hypolimnetic temperatures during winter and thermocline temperatures in summer. These similarities exist because downstream releases are made from the hypolimnion in winter and thermocline in summer. Hence the effect of the reservoirs is to reduce the temperature range present in the river although seasonal patterns remain the same (Figure 3).



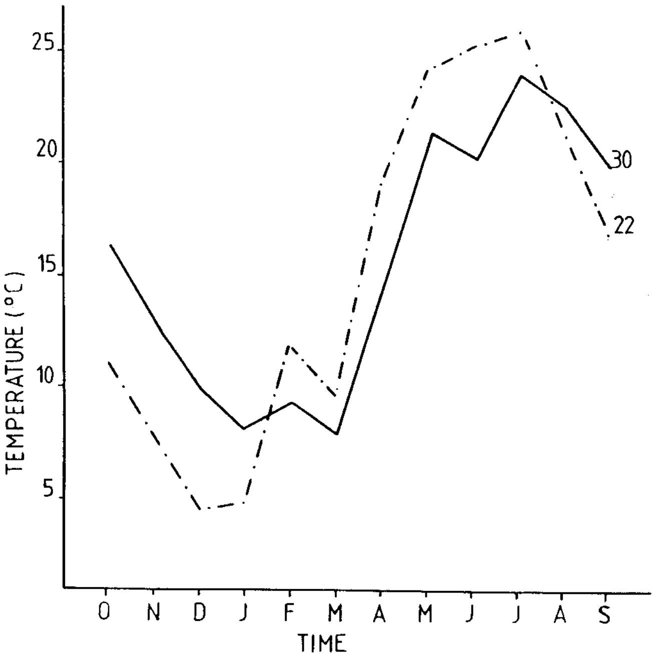


Figure 2. Annual variations of the Sau infow, the Susqueda outflow and the El Pasteral outflow during out study.

Figure 3. Annual temperature changes above the reservoirs (station 22) and below the reservoirs (station 30).

Changes in Major Ion Concentrations

Dissolved salts (Cl^-, HCO_3, SO_4) increase in concentrations from the headwaters to the mouth of the Ter (Sabater & Armengol 1985). The Gurri River enters the Ter just upstream of station 22. It appears that this contributes considerable amounts of dissolved salts which also is expressed in an increase in conductivity (Table 2). These changes were not substantial in comparison to these observed in other compounds (e.g. nutrients). In general, sulfates and chlorides decreased in concentration whereas bicarbonates increased slightly.

Table 2. Changes in major ion concentrations and conductivity (the mean annual concentrations are indicated only.)

	CONDUCTIVITY	Cl^-	HCO_3	$SO_4^=$
STATION	(S.cm^{-1})	(mg.l^{-1})	(mg.l^{-1})	(mg.l^{-1})
21	284.60	9.92	140.30	46.10
22	556.98	75.65	186.70	59.04
30	459.25	26.80	196.42	52.32

Nutrients

Increases in nutrients in the Ter can be attributed to anthropogenic sources. In general, however, increase in nutrients from anthropogenic sources are localized probably due to their rapid mobilization by bacteria and plants.

We observed substantial differences in nitrogen and phosphorus concentrations between stations (Figure 4 & 5). In station 22 (just

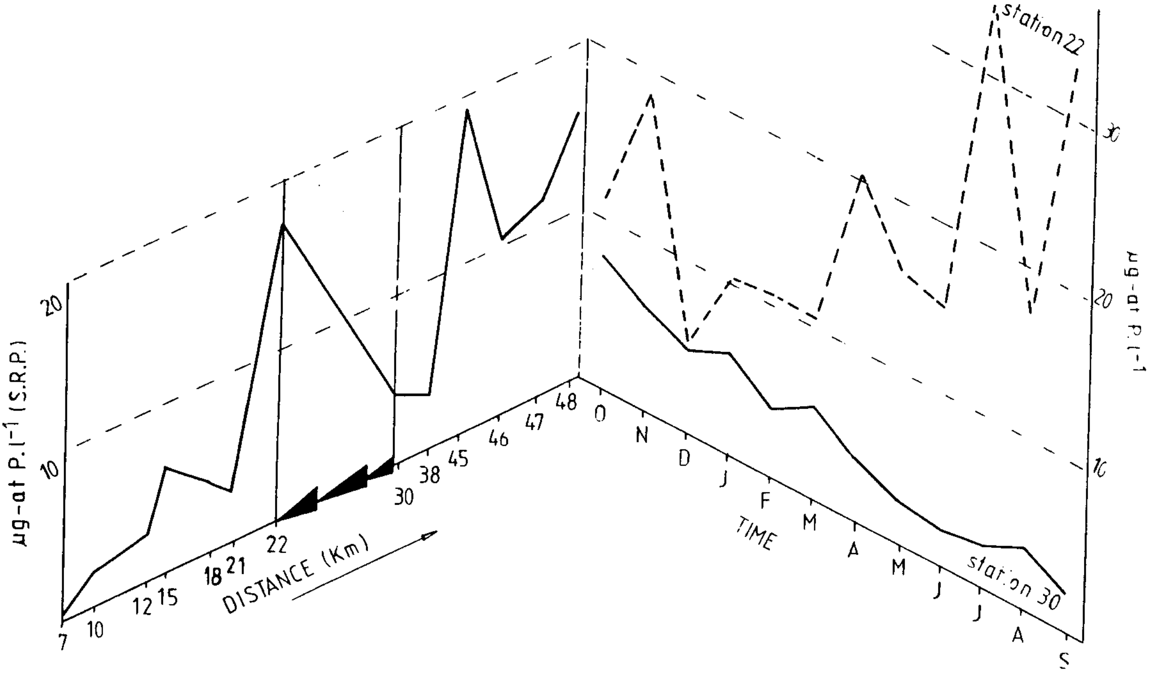


Figure 4. Annual fluctuations and spatial changes of the phosphate concentrations. The annual fluctuations are given for two stations only (station 22, above the reservoirs and station 30,

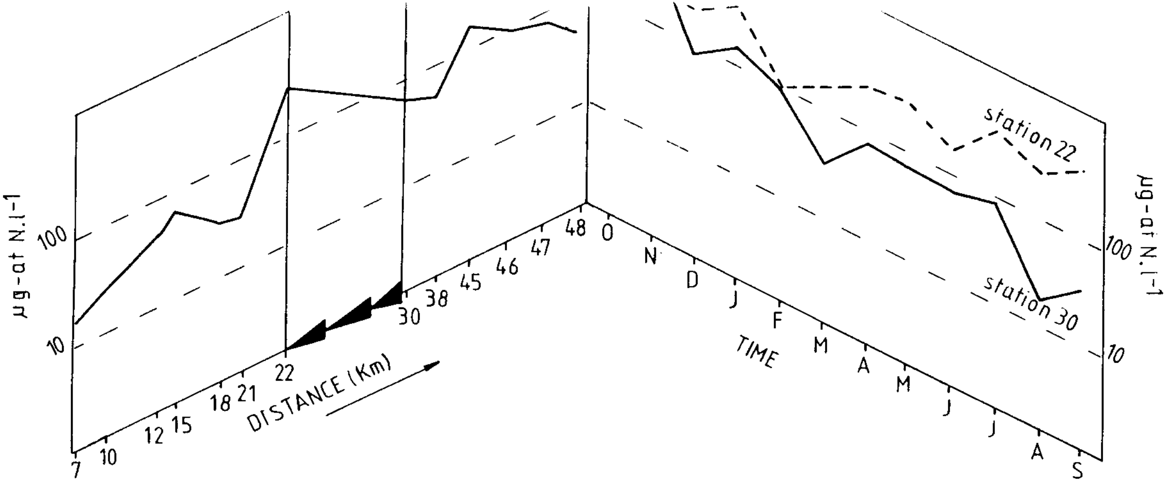


Figure 5. Annual fluctuations and spatial changes of the total nitrogen concentrations. The annual fluctuations are given for two stations only (station 22, above the reservoirs and station 30, below the reservoirs).

upstream from the reservoirs) the river was subjected to intense pollution. The nutrient inputs raised nitrogen and phosphorus concentrations to levels higher than those observed elsewhere in the drainage. Eighty-one percent of the dissolved P and N entering the reservoirs is retained, accumulating phosphorus in the sediment (Table 3) and substantial amounts of nitrogen also are released to the atmosphere via denitrification. Downstream from the reservoirs concentrations of dissolved phosphorus and nitrogen decrease. Annual fluctuations of these two compounds also are lower below the reservoirs than above them (i.e. at station 22). There was one exception, however in the flood of 1982 the concentration of total nitrogen was higher below the reservoir than at station 22 (Figure 5).

Besides the decrease in total dissolved nitrogen content occurring within the reservoirs, oxidative processes transform the majority of dissolved nitrogen leaving the reservoirs to nitrates. In station 22 practically all of the detectable nitrogen was in the form of ammonia (ratio of nitrates to ammonia was 10:1 (Figure 6).

Table 3. Input, output, and percent retained of P and N for Sau system reservoirs.

	NITROGEN TOTAL	PHOSPHORUS (S.R.P.)
INPUT (up.at.l^{-1})	271.02	17.68
(ANNUAL MEAN) (Tm.$year^{-1}$)	1918.10	277.00
OUTPUT (ug.at.l^{-1})	63.43	4.20
(ANNUAL MEAN) (Tm.$year^{-1}$)	356.20	52.23
% RETAINED BY RESERVOIRS	81.50	81.00

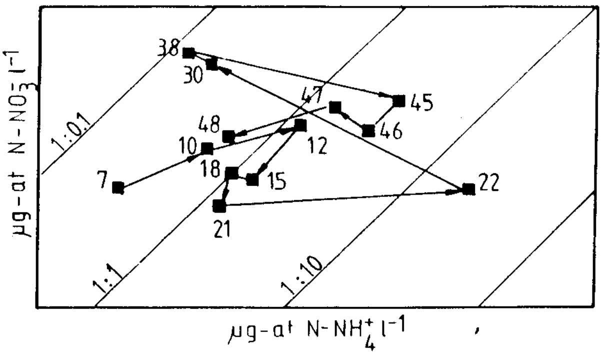


Figure 6. Ratio of nitrates to ammonia along the River Ter.

In conclusion, nutrient concentrations present in station 30 were similar to those observed in station 21, located upstream of the confluence of the River Gurri. The reservoirs act as a nutrient sink that stabilizes nutrient concentrations in the lower portion of the river.

Periphyton

The response of periphyton to various perturbations, and especially the diatom community, manifests the effects of the environmental changes (Patrick 1973). In the stations above the reservoirs (18, 21) the diatom community corresponds to a community typical of the middle reaches of the river, which is composed primarily of species of *Navicula* and *Nitzschia* (Figure 7). The contamination present in station 22, however, reduces the diversity of the community and two species (*Nitzschia palea* and *N. gandersheimiensis*) become dominant. Below the reservoirs we encountered a completely different diatom community from that present above the reservoirs. This community was dominated by species of the genus *Fragilaria* (Table 4).

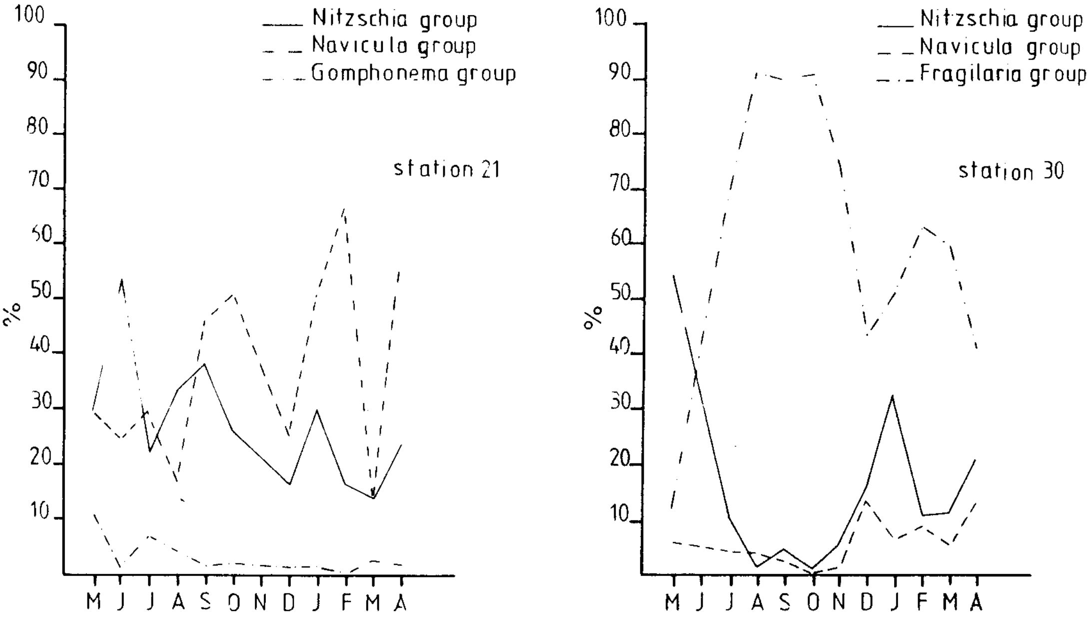


Figure 7. Changes in relative abundance for the dominant species of diatoms in station 21 (above the reservoirs) and station 30 (below the reservoirs).

Table 4. Biological communities observed above and below of the reservoirs in the River Ter.

COMMUNITIES	ABOVE RESERVOIRS 18 & 21	POLLUTED REACH 22	BELOW RESERVOIRS 30 & 38
DIATOM COMMUNITY	*Diatoma elongatum* *Navicula gregaria* *N. tripunctata* *Nitzschia frustulum* *N. romana*	*Nitzschia palea* *N. gandersheimiensis*	*Fragilaria construens* *F. construens venter* *F. pinnata* *F. brevistriata*
MACROPHYTES COMMUNITY	*Leptodictyum riparium* *Rhynchostegium riparioides* *Eurhynchium speciosum* *Dialytrichia mucronatus* *Fissidens crasipes*		*Cinclidotus fontinaloides* *Fontinalis antipyretica* *Fontinalis hypnoides* *Fissidens crassipes* *Leptodictyum riparium* *Rhynchosteguim riparioides* *Potamogeton nodosus* *Potamogeton crispus* *Myriophyllum verticillatum* *Calitriche* sp.
MACROINVERTEBRATES COMMUNITY	*Baetis vardarensis* *Ecdyonurus lateralis* *Ephemerella ignita* *Rhyacophila evoluta* *Rhyacophila dorsalis* *Simulium ornatum*	*Chironomus* sp. *Tubificidae*	*Baetis fuscatus* *Ephemerella mesoleuca* *Caenis luctuosa* *Hydropsyche exocellata* *Hydropsyche siltalai* *Cheumatopsyche lepida* *Psychomyia pusilla* *Simulium erythrocephalum*

Chlorophyll *a* values for stations 18 and 21 approximated 130 mg m^{-2} whereas values were much higher, 314 mg m^{-2} in the lower station (30). The cause of this increase could have been due to the higher concentrations of nitrates liberated by the reservoirs (McConnell & Sigler 1959).

The effects of physical barriers (i.e. dams) on the dispersion of benthic diatoms is well known (Holmes & Whitton 1981). This effect is easily observed in the River Ter (Table 4). The autumn flood had a strong impact on the diatom communities of the upper stations which were completely destroyed. Below the reservoirs, the flood caused a restructuring of the community resulting in the loss of *Fragilaria* as the dominant genus and a diversity increase. In both cases, however, the diatom communities returned to their initial composition one month after the flood.

Macrophytes

Responses of the macrophytes to environmental changes attributable to the reservoirs were similar to those observed in the periphyton. The stations above and below reservoirs could be separated by the absence in the upper stations of higher plants (Table 4). Substrate diversity was greater below the reservoirs and resulted in a wide diversity of macrophytes at the stations. Areas with sand and silt substrates were dominated by *Potamogeton nodosus, P. crispus* and *Myriophyllum verticilatum* whereas habitats with stony substrates were dominated by bryophytes (*Cinclidotus fontinaloides, Fissidens crassipes, Fontinalis hypnoides, F. antipyretica, Leptodictyum riparium* and *Rhynchostegium riparioides*). Some differences were present, however, among the upper stations. For example, station 22, in contrast to stations 18 and 21 did not contain any macrophytes which could tolerate the intense pollution present there.

Macroinvertebrates

Ward & Stanford (1983 a; b) has noted that the maximum diversities observed in a river should be in areas experiencing intermediate disturbance. The impacts produced by reservoirs, however, cause a decrease in downstream diversity, which is a result of decreased environmental variability.

In the River Ter we did not observe these patterns. Macroinvertebrate diversity was similar in uncontaminated stations above and below the reservoirs. However the impact of the flood was apparent. We observed a decrease in diversity immediately after the flood which was probably caused by the massive downstream transport of macroinvertebrates from the upper stations. This impact was less pronounced below the reservoirs due to the attenuation of flood effects. Diversity values below the reservoirs returned to levels comparable to initial conditions within seven months; a shorter recovery period than that observed above the reservoirs (Figure 8).

As with periphyton and macrophyte communities, distinct macroinvertebrate communities were observed above and below the reservoirs (Table 4). Ephemeroptera (*Baetis vardarensis, Ecdyonurus lateralis, Ephemerella ignita*) were dominant above the reservoirs, whereas below the reservoirs the dominant species were generally Trichoptera (*Hydropsyche exocellata, H. siltalai, Cheumatopsyche lepida* and *Psychomyia pusilla*).

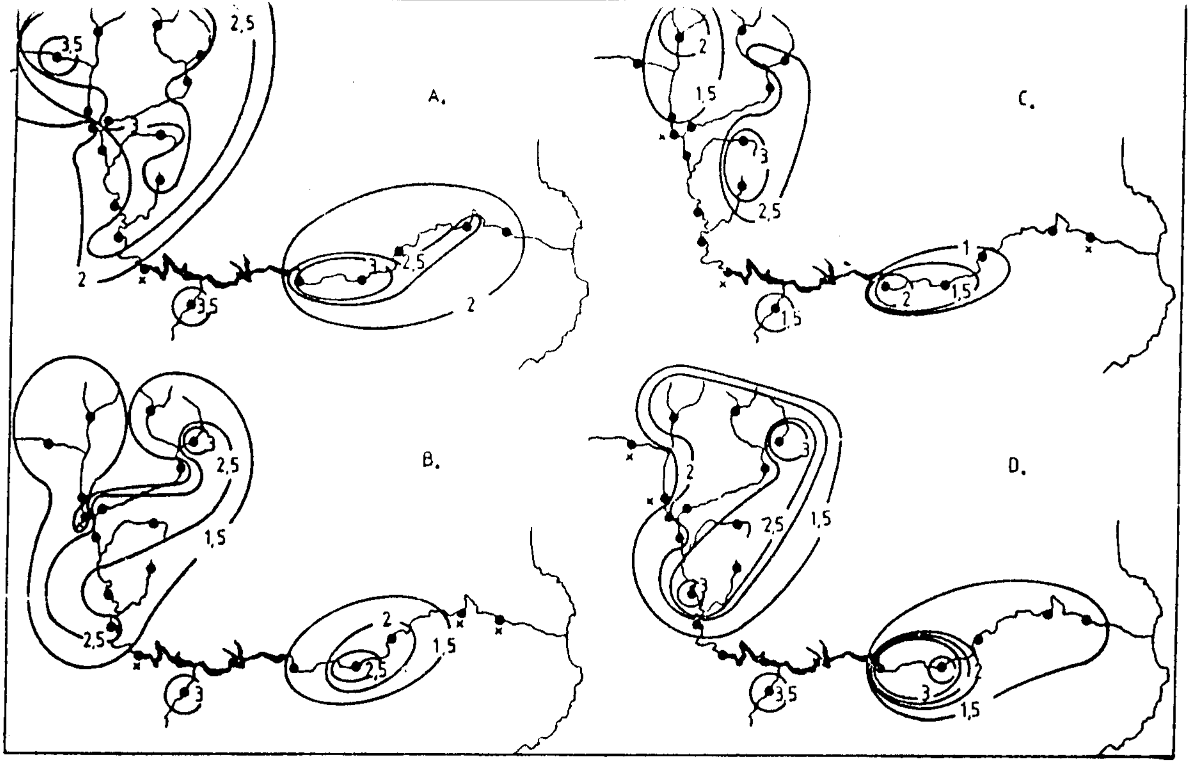


Figure 8. Longitudinal and temporal variation of specific macroinvertebrate diversity: A) October, 1982; B) November, 1982, after the flood; C) December, 1982; and D) June, 1983.

CONCLUSIONS

The interaction between the effects produced by the pollution above the reservoirs (station 22) and the ecological discontinuities caused by the reservoirs themselves resulted in effects which balanced one another. This compensation was very clear in the case of nutrients, where more than 81% of the phosphorus and nitrogen entering the reservoirs was retained. This resulted in the occurence of similar nutrient concentrations in both stations below the reservoirs and in unpolluted stations above the reservoirs.

Distinct biological communities were observed above and below the reservoirs. This situation was facilitated by the presence of a dispersion barrier (i.e. the dams). In the River Ter we did not observe a decrease in macroinvertebrate diversity below the reservoirs. We believe that this was a result of the lack of thermal stress as well as the presence of high substrate diversity below the reservoirs.

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