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NEW APPROACHES TO MEDITERRANEAN FLUVIAL COMMUNITIES

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SUMMARY

The organization of fluvial benthic communities in the Iberian Mediterranean system shows a series of factors which differ in part from present models suggested in the current literature. The effects of disturbances can be observed in models including the gradient of organization (WARD & STANFORD, 1983; VANNOTE *et al.*, 1980; SABATER *et al*,. in press) in the major and permanent northwest basins, but not in temporary systems.

Temporality does usually not represent a handicap as far as the organization of the algae communities and the macroinvertebrates communities is concerned,: equivalent diversities have been observed in temporary and permanent systems. But a latitudinal gradient is observed among the temporary systems, with an increment to the south of the diversity. Mediterranean fluvial systems have integrated floods as periodical perturbations in the dynamics of benthic communities, which have a high resistance to flood-related disturbance and a high subsequent resilience.

KEY WORDS: Mediterranean rivers, fluvial communities, algae, invertebrates.

INTRODUCTION

The study of fluvial systems in the Iberian peninsula goes back to the work of MARGALEF (1960). Following his path, one approach to the ecology of Catalan fluvial basins has been developed at the Department of Ecology at the University of Barcelona. This approach has involved different perspectives, such as physico-chemical dynamics (PRAT *et al.*, 1982, 1984; SABATER, 1987; PUIG *et al.*, 1987; SABATER *et al.*, 1989, 1991) and the composition and dynamics of benthic fluvial communities (PEÑUELAS & SABATER, 1987; SABATER & SABATER, 1988; PRAT *et al.*, 1984; PUIG, 1984; GONZÁLEZ, 1990). Nowadays, a broader knowledge of the Iberian fluvial systems has been possible thanks to this group and its influence throughout other universities. as well as its collaboration with several universities, and research centers.

This report attempts to elucidate some aspects associated with the structure and organization of the benthic communities of fluvial streams based on previous taxonomic knowledge, especially of algae and macroinvertebrates. A discussion of the longitudinal organization of the fluvial benthos and the use of diversity as a possible parameter for testing the theoretical proposal of SABATER *et al.* (1989, 1991), in relation to disturbance distances (WARD & STANFORD, 1983), is presented. In this model alternative statistical techniques have been used. The role of fluctuations in the complexity of communities has also been considered. Differences between the degrees of temporality, whether the river dries each year or over a longer timespan, have been elucidated as basic with regard to the effects of floods. For the first case, possibly catastrophic flood-related phenomena can be absorbed into the annual cycle and assimilated by the communities dynamics; thus catastrophe or disruption are avoided.

STUDY AREA

The basins of the rivers Ter, Tordera, Matarraña (Ebro basin), Vinalopó, Segura and Yeguas (Guadalquivir basin) were studied. In some cases the work was conducted in the principal course of the basin and in others in smaller sub-basins. All of them are included in figure 1; minimal data of their structural references are shown in Table I.

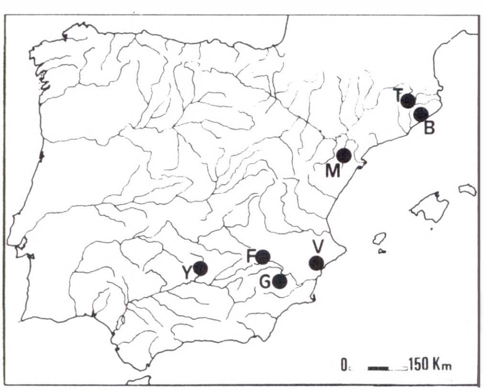

FIGURE 1. Location of study areas in Eastern Spain. Letters refer to rivers and are identified in Table I.

TABLE I. Location and temporal characteristics of the sampling stations (P = permanent stretch; T = temporary stretch; T/P = temporary river with summer pools).

Loc.	River	Basin	Alt. m(a.s.l.)	Dist. to the spring(km)	Type
T7	Ter	Ter	1400	7.0	P
T10	Ter	Ter	915	20.2	P
T12	Ter	Ter	720	38.7	P
T15	Ter	Ter	680	44.9	P
T18	Ter	Ter	540	62.1	P
T21	Ter	Ter	490	71.1	P
T22	Ter	Ter	460	88.1	P
T30	Ter	Ter	160	135.35	P
T38	Ter	Ter	98	148.15	P
T45	Ter	Ter	60	158.15	P
T46	Ter	Ter	30	173.35	P
T47	Ter	Ter	20	186.35	P
T3	Rigart	Ter	1100	14	T
T5	Freser	Ter	740	24.7	T
T9	Tort	Ter	1000	11.3	P
T27	Major	Ter	470	14.0	P
B1	Buscons	Tordera	420	1..5	T
B2	Buscons	Tordera	240	7.0	T/P
B3	Buscons	Tordera	100	11.0	T/P
M1	Matarraña	Ebro	650	8.0	P
M2	Matarraña	Ebro	500	18.0	P
M3	Matarraña	Ebro	170	76.0	T/P
M4	Matarraña	Ebro	95	98.0	T/P
V	Vinalopó	Vinalopó	820	7.0	T/P
F1	Mundo	Segura	1100	20.0	P
F2	Mundo	Segura	1000	40.0	P
F3	Mundo	Segura	997	44.0	P
F4	Mundo	Segura	850	54.0	P
G	Argos	Segura	1050	3.2	T
Y1	Cereceda	Yeguas	700	8.0	P
Y2	Pradillo	Yeguas	660	8.4	P
Y3	Yeguas	Guadalquivir	0	12.5	P
Y4	Términos	Yeguas	570	7.9	T
Y5	Yeguas	Guadalquivir	550	18.0	T
Y6	Yeguas	Guadalquivir	300	51.5	T/P
Y7	Fresnedoso	Yeguas	220	19.0	T
Y8	Yeguas	Guadalquivir	200	4.7	T/P

MATERIALS AND METHODS

Diversity was estimated by Shannon's index (STATZNER, 1981), but working at three different levels: diversity estimated from stationary sampling, accumulated diversity in the treatment of part of the data of the fluvial axes, and annual diversity, studied by monthly sampling.

For the statistical analysis processing, principal component analysis (PCA; BMDP, 1984) was used.

RESULTS AND DISCUSSION

LONGITUDINAL ORGANIZATION OF THE COMMUNITIES

Comparing the values of diversity in the stationary data for the different basins, from the heads of the rivers up to the mouths (Table II) we do not find greater values of diversity in the middle watercourse than in the headwaters.

These results contradict the theories of the "River Continuum Concept" (VANNOTE *et al*., 1980) and the "Serial Discontinuity Concept" (WARD & STANFORD, 1983). In both theories it is presupposed that from a certain value of initial diversity at the head of the river there is an increase up to a maximum inside the mean course of the fluvial axis. This area will, theoretically, show the maximum spatial heterogeneity. This heterogeneity is generated by the effect of natural disturbance in this zone, because of the fact that the inputs are in part absorbed due to the inertia attained by the watercourse.

The data obtained for the basin of the Ter, Matarraña, Yeguas (Table II) or Llobregat (PRAT *et al*., 1983) are clear examples of the high diversity of the heads of the rivers and have practically the same values as the mean sections for the communities of macroinvertebrates.

There are two principal causes for this situation. The first is that the permanent rivers (Ter and Llobregat) lie in a displacement of the diversity curve toward the heads. These are systems with a maximal climatic and structural gradient for the first twenty kilometers while in the rest of the fluvial courses it is similar. In fact, they are rivers in which only one head zone is clearly appreciated and all the rest is an undefined structure, as happens in all Iberian Mediterranean rivers. The mouth *senso stricto* practically constitutes a small independent entity.

The second cause is the regime of temporality of some rivers, in which the

TABLE II. Diversity values in the study stretches. A, algae community; I, invertebrate community.

Locality	Div. (H')	Acc. div.	Comm.	Time
F-1	3.51	3.51	A	
F-2	3.75	4.37	A	
F-3	3.62	4.43	A	
F-4	3.68	4.50	A	
M-1	3.31			winter
M-2	3.25			spring
M-3	3.37			summer
M-4	3.28			fall
Y-1	4.18	4.18	I	
Y-3	4.37	5.25	I	
Y-5	2.68	5.43	I	
Y-6	4.25	5.56	I	
Y-8	3.87	5.75	I	
Y-2	3.62		I	
Y-4	3.87		I	
Y-7	4.12		I	
B-1	2.43	2.43	I	
B-2	3.12	3.37	I	
B-3	2.75	3.56	I	
V	2.93	2.93	I	Aug.
V	2.87	3.10	I	Sept.
V	4.0	4.06	I	Oct.
V	3.40	4.27	I	Dec.
V	3.37	4.40	I	Jan.
V	3.56	4.50	I	Feb.
V	3.60	4.56	I	Apr.
V	3.60	4.56	I	May
T-7	3.09	3.09	I	Oct.
T-10	3.035	3.76	I	Oct.
T-12	3.079	3.97	I	Oct.
T-15	2.175	3.94	I	Oct.
T-18	2.097	3.36	I	Oct.
T-21	2.36	3.49	I	Oct.
T-22	0	3.50	I	Oct.
T-30	3.082	3.73	I	Oct.
T-38	3.248	3.88	I	Oct.
T-45	2.478	3.87	I	Oct.
T-46	2.958	3.94	I	Oct.
T-47	2.380	4.01	I	Oct.
T-3	2.97		I	Oct.
T-3	2.87		I	Nov.
T-3	2.66		I	Jan.
T-3	2.45		I	Apr.
T-3	dry		I	July
T-5	3.5		I	Oct.
T-5	1.37		I	Nov.
T-5	1.93		I	Jan.
T-5	1.93		I	Apr.
T-5	dry		I	July
T-9	4.27		I	Oct
T-9	3.87		I	Nov.
T-9	3.81		I	Jan.
T-9	3.68		I	Apr.
T-9	3.12		I	July
T-27	3.81		I	Oct.
T-27	3.06		I	Nov.
T-27	1.75		I	Jan..
T-27	3.40		I	Apr.
T-27	3.47		I	July

first portion is permanent and the rest, up to the confluence or mouth, is temporal. In this case great structural heterogeneity is produced in the permanent portion with which the highest diversity is also associated.

For the algae communities, the results support the trend of showing the maximal diversity in the middle section of the fluvial system. The results obtained in the Matarraña river are the exception. Due to the calcareous characteristics of the system, with precipitation of travertine in the middle section of the watercourse, this river maintains the same tendency of similar diversity in the heads and successive sections. Here, it is necessary to consider the homogenization of the substratum that the precipitation of calcium carbonate produces; for the communities of epilithic algae, the variation of the stream speed affects neither the general composition nor their diversities (Fig. 2; ABOAL & PUIG, in press).

LONGITUDINAL ORGANIZATION AND DISCONTINUITY DISTANCES ASSOCIATED WITH THE MACROINVERTEBRATE COMMUNITY IN THE TER RIVER

If the accumulated diversity along the fluvial axis is used for a particular stage of the year, as far as changes in the communities of the fluvial zoobenthos are concerned, an increment from the heads up to the mouths of the rivers is observed, with moments of inversion due to different effects of human action, and also a clear absorption of the diversity increment in the final sections of the basin (Fig. 3).

Comparing the curve obtained with the ones proposed for the Ter by SABATER *et al.* (1991), similar trends of variation are appreciated from the chemical distances. We can define the intersite distances for the diversity (H') along the x_i to x_j stretch by $dH'_{ij} = (H_i - H_j) / (H_{max} - H_{min})$. This distance was used to reveal discontinuities along the Ter river, when this synthetic parameter is related to the geographic distance (X), also calculated using the preceding equation (Fig. 3). But in this case it is impossible to summarize it by an empirical equation.

If a methodology like that used by these authors is applied, due to the scores of stations corresponding to the axis of PCA defining the longitudinal gradient of the fluvial course for the basin (Axis 1, PC I), a similar tendency of the curves can be seen. Hence it is possible to propose an alternative model for the changes in the communities, similar to that proposed by SABATER *et al.* (1991) for the physico-chemical behaviour of the Ter river basin (Fig. 4). Variation in the catchment area along the river can be described by the equation:

$$PC\ I' = 9{,}7\ (X)^{0.20} \quad r^2 = 0{,}76 \quad p > 0{,}001$$

The tendency of the curves of accumulated diversity for other basins does not always show the initial absorption effect produced in the lower section of the Ter. This may be due to the shorter length, smaller drainage courses, or the fact that they are temporal basins with a clearly different dynamic. In this last case, because

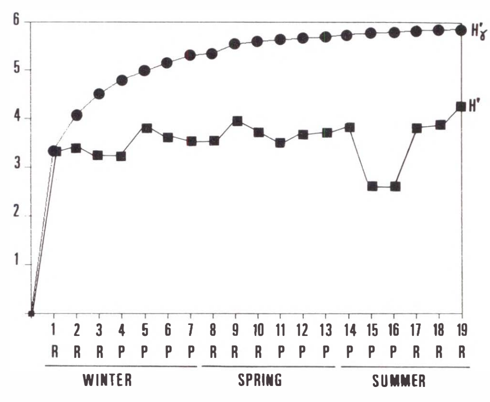

FIGURE 2. Patterns of diversity (H') and accumulated diversity (H'γ) for algae communities at the riffle (R) and pool (P) areas of Matarraña river (M2, travertine precipitation stretch).

they are normally constituted in the Mediterranean slope for permanent karstic heads, temporal lower sections and very variable transitional zones, the communities found in the temporal zones are almost completely different from those of the permanent zone, and due to this high values of accumulated diversity are associated with them. This tendency is noted for the algae communities (Segura river, Matarraña river), and also for the macrobenthos communities (Table II).

DIVERSITY AND TEMPORALITY

We will initially consider the set of clear temporal fluvial systems, with a part of their course dried out every year for variable periods of time. These periods are normally from three to five months, according to the geographic area and the annual rainfall. These rivers are: the Matarraña, the Tordera, the Yeguas and different sub- basins of the Segura river.

In these temporal systems, the results obtained are different if the area completely dries out or if broad ponds of water remain through the summer period. In all cases, maximum diversity is observed during the winter period, with lower values in summer associated with the communities developed in the ponds (Table II).

There are no differences observed among the values obtained for the strict temporal areas and for those with ponds if the global diversity during the flooding period of each station is considered.

We will now consider the results for the permanent station, or the permanent sub-basins studied in relation to the temporal ones. For the algae communities, no differences in diversity are found between the permanent systems and the temporal systems with ponds. Considering diversity in a complete annual cycle, a tendency for lower values of diversity is observed in the strict temporal courses, but it is not the same in the temporal systems with ponds in relation to the permanent ones (Fig. 5).

The communities of macrobenthos in the permanent systems considered in this work also maintain a maximum of winter diversity or spring-winter diversity,

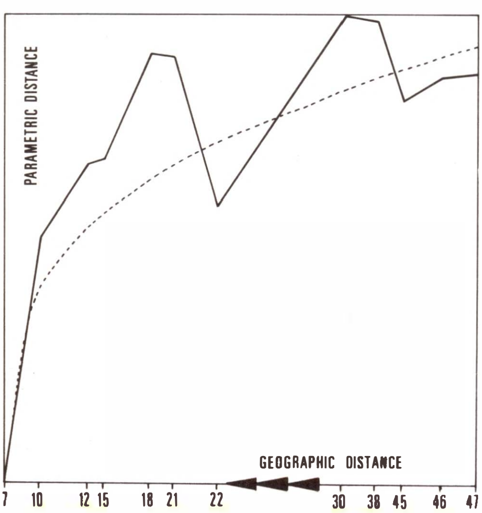

FIGURE 3. Plot of geographical against parametrical distances of accumulated diversity in the Ter river (see text for explanation).

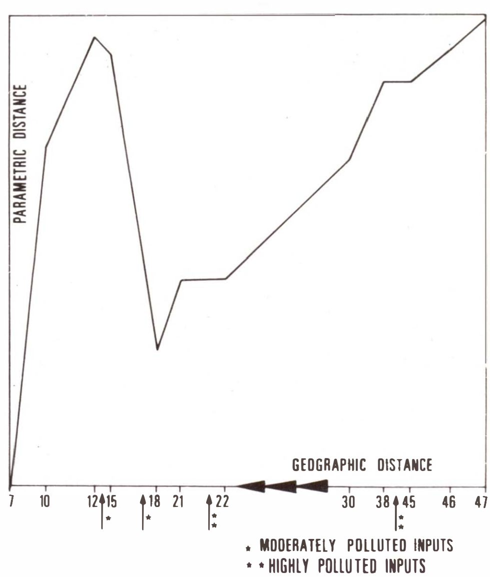

FIGURE 4. Plot of the PC I scores of PCA of each site against the geographical ones in the Ter river, using the benthic invertebrate community data.

depending on the individual case. The summer diversity values are considered for the total set of invertebrates and a wide range is appreciated, inside which the temporal and permanent rivers cannot be clearly separated. Besides, a latitudinal gradient is observed among the temporal systems and this gradient focusses the increment of the diversity of the communities in the temporal Mediterranean system to the south (Fig. 5).

RIVER FLOODS AND DIVERSITY

In the previous section the possible effect of the seasonal cyclic fluctuations on the organization of the communities was discussed. But this type of fluctuation may not only occur during the dry period; for a great number of sections, sub-basins and Mediterranean basins the effects of the annual floods have been considered the principal kind of fluctuations, though of variable intensity over the years.

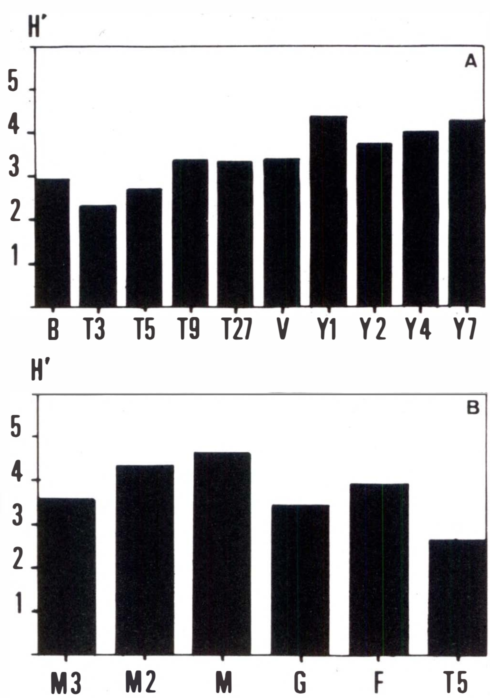

FIGURE 5. Different values of diversity during the annual cycle observed in part of the river basins. A, benthic invertebrate communities; B, algae communities. (B= Tordera river basin; T= Ter river basin; V= Vinalopó river; Y= Yeguas river basin; M= Matarraña river; G and F= Segura river basin).

The basin of the Matarraña river can be considered a typical example of this kind of system. Autumn is the season presenting the lowest values of diversity in the zones permanently under flood effects without any subsequent decrease; indeed, a fast increase in diversity is observed. Detailed study of the benthic communities of this river for more than an annual cycle has allowed us to show that the cycle of the majority of the species is related to the floods. The floods start the initiation of almost all the winter species, while those present all through the year have certain mechanisms which allow them to compensate for the destructive or dispersive effect of this catastrophe (e.g. living in the precipitations of the travertines, burying in the bed river, etc.) (RECASENS & PUIG, 1987; PUIG *et al*., 1990).

Data from this basin are totally different from those of permanent Mediterranean basins where floods of no cyclical periodicity occur. In these other systems (PUIG *et al*., 1987) the effects of floods are more or less disruptive, in part demolishing the communities, and the periods of recuperation can be long (six to eight months, depending on the communities and the zones).

In fact, the fluvial Mediterranean systems are a clear example of the integration of periodical disturbances in the dynamics of the communities.

The temporal sub-basins are as adapted to the autumn maximal rainfalls as the permanent ones. For both systems a flood is only a maximum greater than the common one during an annual cycle. It must be pointed out that associated with the seasonal concentration slope of rainfalls, maximum in the south of the Mediterranean area and less notable in the northern basins, a reduction in the response time for the reorganization of communities after a flood is also registered. In these systems the stream communities appear to have a high resistance to flood-related disturbance and high resilience after disturbances, contrary to the data obtained in Australia by LAKE & BARMUTA (1986).

In fact, we prefer to follow MARGALEF (1960), "... to see the river systems as a mosaic of series that reflected or were constrained by local and regional terrestrial and aquatic ecosystems", but in the Iberian Mediterranean fluvial systems we do not see "an orderly progression from simple, immature head waters to complex, mature downstream reaches" (MARGALEF, 1963), "with a corresponding increase in species diversities as the system became more mature" (MARGALEF, 1968). The headwaters and the downstream reaches exhibited the same degree of immature or mature pattern.

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