With my best regards, AGM

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Dedicated to the memory of M. Valdayo

Macroinvertebrate associations in two basins of SW Spain

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With 1 figure and 7 tables in the text

Abstract

The aquatic macroinvertebrates that inhabit the headwater of the Guadaíra and Guadalete river basins were sampled during January 1988 and January 1989. In the Guadaíra basin gypsum is quite abundant and makes the water extremely saline, while the Guadalete basin has water with a normal salinity. Most streams of the Guadaíra basin were completely dry during drought (from May until November). In the Guadalete basin however most streams discharge throughout the year.

During the study we have found seven associations of species. That constituted by *Mercuria confusa*, *Bezzia* sp., *Helius* sp. and *Echinogammarus obtusidens* is an index of very saline watercourses (up to 19 mS cm^{-1} of conductivity). Associations formed by *Simulium intermedium*, *S. pseudequinum* and *Atyaephyra desmarestii;* and *S. ruficorne, B. lutheri* and *P. clarkii*, are representative of very degraded trenches.

Introduction

The aquatic macroinvertebrates that inhabit the headwater of the Guadaíra and Guadalete river basins were sampled during January 1988 and January 1989. Among the sampling stations various different environments were found, due mainly to the diverse salinity and current speed existing in the study area.

If these parameters can determine the existence of characteristic populations, other parameters related with them, such as conductivity, chloride, carbonate, sulphate, suspended matter and chlorophyll, can determine as well some association of species. The aim of this work is to determine the species associations existing in the study area which are able to characterize the different environments found.

Study area and methodology

The area chosen was the headwaters of the Guadaíra and Guadalete river basins (Fig. 1). They are close, but differ notably. In the Guadaíra basin gypsum is quite abundant and makes the water extremely saline (up to 19 mS cm^{-1} of conductivity measured in the Spring of 1986 (GALLARDO & TOJA, 1989)), while the Guadalete basin has water

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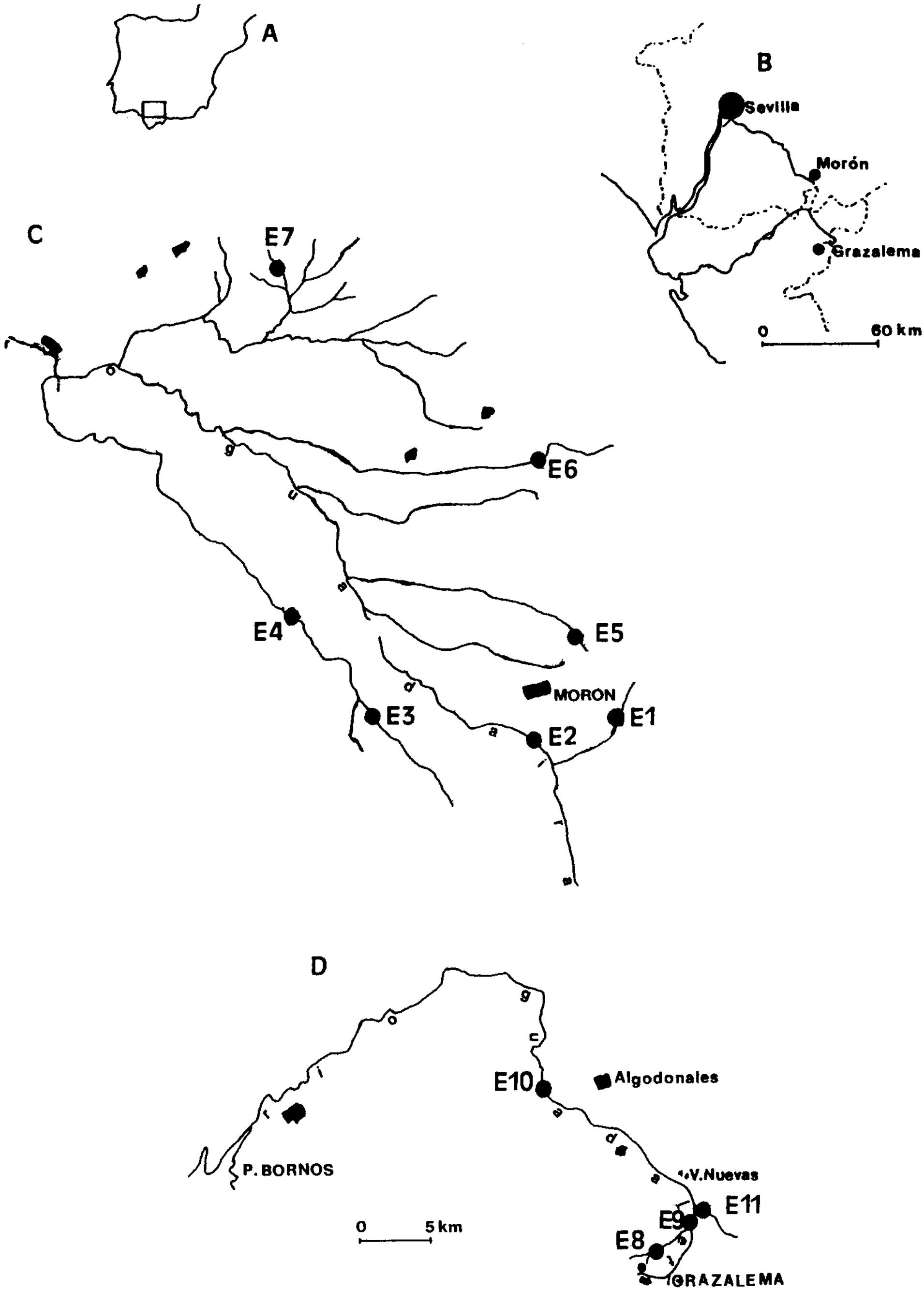

Fig. 1. A and B: Location of the study area. C and D: Situation of the sampling stations in the Guadaíra and Guadalete basins, respectively. Guadalete river basin is drawn in D as far as Bornos Reservoir.

with a normal salinity (up to 1.3 mS cm^{-1}). Likewise both of them are Mediterranean rivers, characterized by strong flow irregularities. Most streams of the Guadaíra basin were completely dry during drought (from May until November). In the same period, the river Guadaíra itself has water, though in many stretches the flow falls to zero. In the Guadalete basin however most streams present flow throughout the year.

The sites were apparently free of pollution. The most important features of both Guadalete and Guadaíra basins are described in Table 1.

In order to perform this study macroinvertebrate samples were taken in two ways: with a triangular net (35 cm of side) by the kicking-method (MACAN, 1958) and with a square box (20 × 20 cm of side) (MONTES et al., 1981). The latter was used only in the zone where current speed was highest (GALLARDO, 1991). At the same time, physical and chemical data were obtained on each site visit and Table 2 presents mean values based on all visits. The analytical methods used are described in APHA (1978) and RODIER (1981).

Macroinvertebrate and physico-chemical data were submitted to BMDP4M Factorial analysis in order to arrange the sampling stations in two ways: 1) by the mean of the physico-chemical values measured throughout the study in each sampling station; and 2) by the mean of the macroinvertebrates caught throughout the study in each sampling station. This second analysis considered only taxa completely identified at species level, although some taxa at higher level were considered because we were sure they belonged to the same species. Likewise, the same analysis considered only macroinvertebrate data belonging to taxa present in at least ten samples from the whole study (20 % presence in the sampling). Taxa not reaching this value but with a population representing 20 % of the total specimens caught at any site in any sample, were also considered.

Results and discussion

Table 3 shows the factor loadings obtained for each of the physical and chemical factors analyzed for the first 5 axes of the BMDP4M Factorial analysis. Table 4 shows the coordenates of each sampling station obtained for the first five axes of the BMDP4M Factorial analysis.

Axis I is determined by conductivity, sulphate, chloride and silicate parameters associated with the salinity. It separates Barros and Salado streams from the rest of the sampling stations. Axis II is determined by chlorophyll and suspended matter against current speed (though this latter has a lower factor loading). This axis suggests that most of the suspended matter is determined by floating algae or debris of macrophytes, which can heap in places where the current speed is lower. It markedly separates the Gavilán stream, where a great growth of *Ranunculus* sp. was found. Alkalinity and current speed (the latter with lower factor loading) determine axis III, which separates the Guadaíra river and Gaidovar stream. Axis IV is determined by phosphate. It could be related with the drainage of fertilizers from farms and/or waste waters. This axis separates the principal sampling stations in the Guadalete basin (Guadalete-Grazalema and Guadalete-Algodonales). These sites receive the domestic sewage from small towns on their banks. Probably as a result of current speed, these nutrients cannot be used in situ by primary producers, as probably happens in the other sampling stations, where current speed is lower. Axis V is de-

Table 1. Most important characteristics of the sampling stations.

Station	Stretch Width (m)	characteristic Depth (cm)	Substratum	Plant cover: Bank	Plant cover: Water	Land use	Remarks
Salado E1	2	35 (with pools of 150–200)	Cobble, gravel, sand and clay	*Tamarix africana* *Phragmites* sp. *Nerium oleander*	*Nerium oleander* *Ranunculus* sp.	Intensive agriculture, watering-place for cattle	Great bloom of *Ranunculus* sp. in Autumn. Plenty of *Rana ridibunda* in Summer.
Guadaíra E2	4	30	Cobble, sand and silt	*Tamarix africana* *Scirpus* sp. *Nerium oleander*	*Typha* sp. Filamentous alge	Intensive agriculture (Olives)	Domestic and industrial rubbish.
Aguade-rilla E3	1–3	40	Cobble, gravel, sand and clay	*Nerium oleander* *Cyperus longus*	*Phragmites* sp. *Typha* sp. Filamentous algae	Intensive agriculture	Presence of *Gambussia affinis* in Summer (in isolated pools). Very great changes in the water level throughout the year.
Guadai-rilla E4	1–3	30	Sand, pebble and clay	No plants	*Phragmites* sp. *Typha* sp.	Intensive agriculture (maize)	Isolated pools in Summer. Watercourse covered by *Phragmites* sp. in May. Very great changes in the water level throughout the year.
Barros E5	2	20	Sand, clay and silt	No plants	*Phragmites* sp.	Intensive agriculture (sorghum)	Brackish water. A section of the sampled stretch produced CH_4 and SH_2.
Gavilan E6	2	25	Cobble, sand clay and silt	*Phragmites* sp. *Rubus* sp. *Tamarix africana* *Typha* sp.	*Phragmites* sp. *Typha* sp. *Ranunculus* sp. Filamentous algae	Intensive agriculture (cereals)	Completely dry at the end of Spring. Great bloom of *Ranunculus* sp. in March.
Alcaudete E7	1	18	Sand with plant debris	*Hordeum* sp. *Tripholium* sp. *Cyperus longus*	*Cyperus longus* *Phragmites* sp.	Intensive agriculture	Completely dry in Summer. It is used for irrigation.
Gaidovar E8	2	25 (with pool of 200–300)	Cobble, gravel and sand	*Salix* sp.	*Elodea* sp. *Nasturtium offici-nalis* Filamentous algae	Small farms and exten-sive agriculture (Olives) and cattle	The zone has been repopulated with the autochthonous crayfish (*Astacus pallipes*).
Guadalete (Grazalema) E9	8	45 (some zones reache 300)	Boulder, cobble, gravel, sand and silt	*Populus niger* *Nerium oleander*	*Nerium oleander* *Cyperus* sp. Filamentous algae	Extensive agriculture and watering-place for cattle	Zones of the bank showed pollution from cattle.
Guadalete (Algodonales) E10	7	51 (Maximum reaches 300–400)	Boulder, gravel and sand	*Tamarix africana* *Typha dominguensis* *Nerium oleander* *Scirpus* sp.	No plants	Reforestation (*Eucalyptus globulus*) and recreation	Upstream there are some saline springs and a dam (recently opened).
Aguila E11	2–3	30	Cobble, sand and silt	*Olea europea* *Rubus* sp. *Nerium oleander* *Tamarix africana*	*Tamarix africana* *Spirogyra* sp.	Extensive agriculture (Olives) and cattle	Completely dry in Summer.

Table 2. Mean values based on all visits in the study area.

	Guadaíra							Guadalete			
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Altitude masl	240	180	120	80	200	140	70	660	380	240	360
Current speed cm/s	24.5	35.7	26.6	8.2	10.2	5	15	33.6	27.5	74	17.3
Conductivity mS/cm	6.8	3.4	3.2	2.6	11.1	2.1	0.4	0.5	0.7	1.2	0.4
Suspend. matter mg/L	98	160	140	144	35	260	93.3	10	2.5	16.7	16.7
Alkaline reserv meq/L	4.9	5.1	4.6	5	4.1	3.9	3.1	5.4	4.3	4.4	5.2
Chloride meq/L	70.2	18.9	16.8	13.4	171	33.6	2	1	0.9	5.1	1
Sulphate meq/L	9.4	6.2	5.6	4.2	9.5	4.1	0	1	4	4.5	0.7
C. O. D. mg/L	5.9	3.5	6	4.1	8.1	6.8	5.5	2.2	2.7	3.7	5
Silicate μg-at/L	182	191	201	151	206	115	93.4	80.6	95.6	138	134
Phosphate μg-at/L	0.4	0.8	0.8	0.7	0.6	1.5	0.1	0.2	5.9	3.3	0
Nitrate μg-at/L	13.1	103	285	274	26.7	8.6	878	28.8	32.7	50.8	22.3
Nitrite μg-at/L	0.6	1.6	1.7	9	0.5	1.3	2.9	0.4	0.3	2.1	0.2
Ammonium μg-at/L	24.6	10.8	4.3	9.4	77	8.9	4.8	12.1	79.8	23.9	3.4
Chlorophyll *a* μg/L	2.6	2.3	3.3	2.7	0.7	8.5	2.1	0.5	1.5	1.3	1.8

termined by nitrite, and separates the Guadairilla stream. The origin of this nitrite is unknown. The physico-chemical parameters of organic pollution indicate low concentrations in this stream, but as the number of inhabiting species is very low, there must be some kind of non organic pollution.

Briefly the results point to the importance of the saline character of the Guadaíra basin and the effect of the water flow variability (characteristic of mediterranean rivers), which is shown in the current speed. This in turn influences soil erosion, amount of suspended matter, concentration of chlorophyll and nutrient consumption speed. At the same time, all those variables affect species composition.

The second analysis attempts to characterize each sampling station according to the macroinvertebrate data. Table 5 shows the factor loading obtained for each taxa analyzed for the first 7 axes of the BMDP4M Factorial analysis, and Table 6 the coordenates of each sampling station obtained for the first 7

Table 3. Factor loadings obtained for each physico-chemical variable analyzed for the first five axes of the Principal component Analysis.

	F1	F2	F3	F4	F5
Current speed	−0.20	−0.39	0.45	0.41	0.10
Conductivity	0.98	−0.06	−0.08	−0.08	−0.11
Suspended matter	0.11	0.91	−0.06	−0.18	0.29
Alkalinity	−0.01	−0.16	0.92	−0.22	−0.02
Chloride	0.91	−0.07	−0.22	−0.07	−0.26
Sulphate	0.92	0.11	0.19	0.22	0.01
C. O. D.	0.65	0.35	−0.48	−0.30	−0.18
Silicate	0.85	0.08	0.23	−0.15	0.22
Phosphate	−0.16	−0.04	0.01	0.97	−0.08
Nitrate	−0.29	−0.11	−0.69	−0.29	0.51
Nitrite	−0.04	0.13	−0.06	−0.08	0.88
Ammonium	0.46	−0.35	−0.22	0.65	−0.33
Chlorophyll concentrat.	−0.06	0.98	−0.12	−0.01	−0.05
% variance	37.0	26.8	15.1	12.3	8.8
Accumulated variance	37.0	63.8	78.9	91.2	100.0

Table 4. Coordinates of each station analyzed, obtained for the first five axes of the Principal Component Analysis performed on the physico-chemical variables.

	F1	F2	F3	F4	F5
Salado	1.087	0.130	0.568	−0.300	−0.301
Guadaíra	0.290	0.267	1.116	−0.109	0.594
Aguaderilla	0.339	0.467	0.192	−0.381	0.501
Guadairilla	0.109	0.253	0.272	−0.209	2.204
Barros	2.279	−0.855	−0.965	−0.082	−0.787
Gavilán	−0.295	2.647	−0.482	0.217	−0.900
Alcaudete	−1.014	−0.495	−2.371	−0.750	0.675
Gaidovar	−1.132	−0.943	0.877	−0.761	−0.863
Guadalete-Grazalema	−0.592	−0.458	−0.342	2.305	−0.616
Guadalete-Algodonales	−0.322	−0.641	0.602	1.300	0.556
Aguila	−0.749	−0.371	0.534	−1.229	−1.063

axes of the BMDP4M Factorial analysis. The results gave 7 species associations:

ASSOCIATION 1 (Fb1): *E. ignita, A. fluviatilis, H. punica, A. marginata* and *B. rhodani.*

ASSOCIATION 2 (Fb2): *O. skhounate, E.* gr. *forcipula, B. fuscatus* and *S. sergenti sergenti.*

ASSOCIATION 3 (Fb3): *Discranota* sp., *O. rivularis, C. luctuosa* and *Laccobius* sp.

ASSOCIATION 4 (Fb4): *Pericoma* sp., *Polycentropus* sp. and *B. muticus.*

ASSOCIATION 5 (Fb5): *M. confusa, Bezzia* sp., *Helius* sp. and *Ech. obtusidens.*

Table 5. Factor loadings obtained for each species analyzed for the first seven axes of the analysis.

	F1	F2	F3	F4	F5	F6	F7
M. confusa	−0.20	−0.12	0.07	−0.10	0.94	0.07	−0.15
A. fluviatilis	0.97	0.03	0.14	0.13	−0.07	−0.08	−0.06
A. desmarestii	−0.06	−0.08	0.58	−0.21	0.15	0.70	0.14
P. clarkii	0.23	−0.06	−0.43	−0.09	−0.17	0.09	0.60
Ech. obtusidens	−0.28	−0.16	0.36	−0.10	0.61	0.58	−0.11
B. fuscatus	−0.12	0.89	−0.14	−0.06	−0.04	−0.08	0.13
B. lutheri	−0.10	0.49	−0.12	−0.25	−0.21	0.35	0.70
B. muticus	0.44	−0.14	0.38	0.68	−0.15	−0.33	−0.12
B. rhodani	0.86	−0.07	0.11	0.42	−0.15	−0.13	−0.11
O. skhounate	−0.07	0.96	0.02	−0.07	−0.01	−0.13	−0.03
E. gr. *forcipula*	0.11	0.96	0.04	−0.13	−0.02	−0.12	−0.03
E. ignita	0.98	−0.08	0.05	0.11	−0.05	0.01	−0.04
C. luctuosa	0.15	0.12	0.74	0.20	−0.14	0.19	−0.01
Laccobius sp.	−0.27	−0.22	0.64	−0.14	0.57	0.11	0.03
Oulimnius rivularis	0.38	0.22	0.85	0.10	0.02	−0.10	−0.13
H. punica	0.93	−0.11	0.19	0.24	−0.09	−0.12	−0.07
Polycentropus sp.	0.46	−0.09	0.09	0.84	−0.09	−0.14	−0.09
Bezzia sp.	0.12	0.01	0.04	0.02	0.81	−0.33	−0.22
Helius sp.	−0.21	−0.06	−0.52	−0.12	0.74	−0.11	−0.01
Dicranota sp.	0.06	−0.20	0.93	0.12	−0.01	0.04	−0.12
A. marginata	0.88	−0.10	0.05	0.43	−0.07	−0.04	−0.06
Pericoma sp.	0.30	−0.10	−0.09	0.91	−0.01	−0.06	−0.06
S. intermedium	−0.01	−0.14	−0.06	−0.19	−0.20	0.88	−0.10
S. velutinum	−0.17	−0.48	−0.29	−0.31	0.22	0.07	−0.68
S. pseudequinum	−0.30	0.59	−0.01	−0.09	−0.16	0.71	−0.06
S. ruficorne	−0.12	−0.18	−0.07	−0.13	−0.08	−0.24	0.81
S. sergenti sergenti	−0.15	0.85	0.01	−0.01	−0.13	0.36	−0.01
% Variance	36.0	19.7	15.6	10.9	7.4	5.7	4.7
Accumulated variance	36.0	55.7	71.3	82.2	89.6	95.3	100.0

Table 6. Coordinates of each station analyzed, obtained for the first seven axes of the Principal Component Analysis performed on the samples of macroinvertebrate.

	F1	F2	F3	F4	F5	F6	F7
Salado	−0.606	−0.540	1.772	−0.412	0.875	1.231	−0.080
Guadaíra	−0.415	0.259	0.014	0.228	−0.506	2.091	0.012
Aguaderilla	−0.360	−0.008	−1.005	0.040	−0.185	0.252	0.999
Guadairilla	−0.367	−0.546	−0.202	−0.392	−0.235	−0.716	2.452
Barros	−0.244	−0.250	−0.884	−0.122	2.625	−0.564	−0.552
Gavilán	−0.653	−0.623	−0.499	−0.741	−1.080	−0.932	−1.285
Alcaudete	−0.314	−0.544	−1.092	−0.477	−0.772	0.436	−0.944
Gaidovar	0.790	−0.251	−0.284	2.734	−0.134	−0.079	−0.183
Guadalete-Gra	2.788	−0.135	0.272	−1.068	−0.083	0.083	−0.019
Guadalete-Alg	−0.206	2.906	0.058	−0.205	−0.045	−0.391	−0.097
Aguila	−0.413	−0.267	1.851	0.416	−0.459	−1.411	−0.303

ASSOCIATION 6 (Fb6): *S. intermedium, S. pseudequinum* and *A. desmarestii.*
ASSOCIATION 7 (Fb7): *S. ruficorne, B. lutheri* and *P. clarkii.*

In order to see if any of these associations is related with any of the discriminative physico-chemical parameters, we did a Simple Regression Analysis between the coordenates of each sampling station in the physico-chemical and macroinvertebrate analysis. Table 7 shows the significant correlation values obtained in this analysis.

We can see that all species associations are related with some of the physico-chemical factor groups. The 5th species association (*Mercuria confusa, Bezzia* sp., *Helius* sp. and *Echinogammarus obtusidens*) has positive correlation with axis I of the physico-chemical analysis, it separates strongly at Barros stream (somewhat less at Salado stream). Therefore, this association is clearly an index of very saline streams, though we cannot affirm that its species are really halophilous or simply euryhalines, which allows them to improve in sites where the salinity can be an obstacle for the development of competitors.

This same association, and the 1st association (*Ephemerella ignita, Ancylus fluviatilis, Hydropsyche punica, Atherix marginata* and *Baetis rhodani*), 2nd association (*Oligoneuriopsis skhounate, Ecdyonurus* gr. *forcipula, Baetis fuscatus* and *Simulium sergenti sergenti*) and 7th association (*Simulium ruficorne, Baetis lutheri* and *Procambarus clarkii*), are negatively correlated with streams with very high levels of suspended matter and chlorophyll, though some species included in these associations, such as *Ancylus fluviatilis, H. punica* and *A. marginata* (Hynes, 1970; Thomas, 1978; Herranz & Garcia de Jalon, 1984) can really respond at current speed. For 1st, 2nd and 5th associations the analysis results are logical, because they separate strongly the Guadalete-Grazalema, Guadalete-Algodonales and Barros respectively (sites arranged on the negative part of axis II). However, the 7th association is probably determined more by chlo-

Table 7. Significant correlations between the coordinates of each sampling station for the axes of the physico-chemical analysis (Fq, independent variables) and for the axes of the biological analysis (Fb, dependent variables).

	Fq1	Fq2	Fq3	Fq4	Fq5
Fb1		m −0.62*		l 0.65*	
Fb2		e −0.68*			
Fb3			m 0.79***		
Fb4				e −0.79***	
Fb5	l 0.77**	e −0.84***			
Fb6				m 0.83***	m 0.82***
Fb7		e −0.70*			l 0.73*

*** $p \leq 0.005$ l: linear regression
** $p \leq 0.01$ m: potential regression
* $p \leq 0.05$ e: exponential regression

rophyll concentration, because the suspended matter values are high and the flow very weak (null during drought). Moreover *S. ruficorne* has been registered in still waters (CROSSKEY, 1967).

Positive correlation between 1st association and phosphate has been found, which could be a consequence of the high levels of this nutrient in Guadalete-Grazalema. This association separates strongly that station, and is an index of the higher altitude stretches with flow throughout the year (GIROD et al., 1980; EDINGTON & HILDREW, 1981; ALBA-TERCEDOR, 1984; GONZALEZ DEL TANAGO, 1984; LODGE, 1985). MUÑOZ et al. (1986) describe *H. exocellata*, *Ancylus* sp. and *B. rhodani* as characteristic of the rheophilous zones in the river Llobregat (NE Spain). The 2nd association separates strongly the sampling station Guadalete-Algodonales and could be an index of a river stretch in medium altitude and very strong current.

The 3rd association (*Dicranota* sp., *Oulimnius rivularis*, *Caenis luctuosa* and *Laccobius* sp.) is positively correlated with alkalinity and current speed. This correlation is difficult to explain, because though alkalinity has greater factor loading, current speed (moderate to null) possibly plays a more important rôle. This association separates strongly the Aguila (temporary stream) and Salado (stream conserving water throughout the year, but without flow in summer), each with a different water chemistry.

The 4th association (*Pericoma* sp., *Polycentropus* sp. and *Baetis muticus*) is negatively correlated with phosphate. It separates the Gaidovar stream.

The 6th association (*Simulium intermedium*, *S. pseudequinum* and *Atyaephyra desmarestii*) is positively correlated with phosphate and nitrite, separating the Guadaíra; and the 7th association (*S. ruficorne*, *B. lutheri* and *P. clarkii*) shows a positive correlation with nitrite, separating the Guadairilla. These associations showed the greatest resistence to the more adverse environments (CROSSKEY, 1967; GUIDICELLI et al., 1985).

Conclusion

During the study we have found seven associations of species. That constituted by *Mercuria confusa*, *Bezzia* sp., *Helius* sp. and *Echinogammarus obtusidens* is an index of very saline watercourses (up to 19 mS cm^{-1} of conductivity). *Ephemerella ignita*, *Ancylus fluviatilis*, *Hydropsyche punica*, *Atherix marginata* and *Baetis rhodani* make up an association that acts as an index of high stretch of rivers with flow throughout the year. *Oligoneuriopsis skhounate*, *Ecdyonurus* gr. *forcipula*, *Baetis fuscatus* and *Simulium sergenti sergenti* act as an index of middle stretch of rivers with very strong current (up to 130 cm s^{-1}). Associations formed by *Simulium intermedium*, *S. pseudequinum* and *Atyaephyra desmarestii*; and *S. ruficorne*, *B. lutheri* and *P. clarkii*, are representative of very degraded trenches.

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