Water quality in the Mondego river basin: pollution and habitat heterogeneity

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ABSTRACT

The "IMAR- Departamento de Zoologia, Universidade de Coimbra" and "Direcção Regional de Ambiente e Ordenamento do Território" started a partnership with the objective of establishing bases for the assessment of water quality in the Mondego river basin. Here we present the preliminary results of the study. We sampled 75 sites covering the Mondego river basin. At each site we took 18 physical and chemical measurements and sampled macroinvertebrates with a hand net. Site quality was assessed by the application of a biotic index (BMWP'), water chemistry and habitat heterogeneity. Fifty two percent of the sites had good biological water quality (based on BMWP' index). The strongly polluted sites were concentrated in the Lower Mondego region. Thirty three percent of sites had bad chemical water quality and 45% of the sites had low habitat complexity. Only 40% of the sites with low biological quality also had low chemical water quality. We concluded that (1) in general, the waters on the Mondego river basin do not suffer from strong water pollution and (2) low BMWP' values can be explained by low water quality or low habitat heterogeneity (natural or man-made).

Key words: biological water quality, chemical water quality, habitat heterogeneity, BMWP'.

RESUMEN

El "IMAR- Departamento de Zoologia, Universidade de Coimbra" y la "Direcção Regional de Ambiente e Ordenamento do Território" iniciaron una colaboración con el objetivo de establecer las bases para la evaluación de la calidad del agua en la cuenca hidrográfica del Río Mondego. En esta publicación presentamos los datos preliminares de ese estudio. Se muestrearon 75 localidades, repartidas por toda la cuenca del Mondego. En cada localidad se midieron 18 parámetros químicos y físicos y se muestreó la comunidad de macroinvertebrados acuáticos con una red de mano. La calidad ambiental fue calculada mediante la aplicación del índice biótico BMWP', por las características químicas del agua y por la heterogeneidad del hábitat. Un 51% de las localidades muestreadas tenían una buena calidad ambiental, de acuerdo con el índice BMWP'. Los sitios fuertemente contaminados estaban concentrados en la zona del Bajo Mondego. Un 33% de los locales tenían una calidad química mala, mientras que el 45% tenían una baja heterogeneidad del hábitat. Solamente un 40% de las localidades con baja calidad biológica también tenían baja calidad química. Concluimos que (1) en general, las aguas de la cuenca del río Mondego no sufre de contaminaciones fuertes, y (2) que los bajos valores de BMWP' pueden ser explicados por la baja calidad del agua o bien por una baja heterogeneidad del hábitat (por causas humanas o naturales).

Palabras clave*: calidad biológica del agua, calidad química del agua, heterogeneidad del hábitat, BMWP'.*

INTRODUCTION

The increase in water necessities for domestic, industrial and agricultural use has led to an increase in water consumption and contributed to the degradation of the water quality. Since water degradation results mainly from chemical changes in water, early standard methods for assessing quality relayed on water chemistry. According to Metcalfe (1989), biological assessments offer important advantages over chemical assessments: (1) they are more sensitive than chemical methods under conditions of toxic, intermittent or organic pollution; (2) they detect the more subtle disruptions as well as non-source pollution; (3) they measure actual effects on

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biota, whereas chemical methods must be interpreted on a biological basis; and (4) organisms integrate environmental conditions over long periods of time, whereas chemical data are instantaneous and therefore require large numbers of measurements for an accurate assessment.

Biotic indices are numeric expressions that classify water quality based on the ecological sensitivity of the taxa present and on the taxa richness. Many biotic indices are based on macroinvertebrates because they occupy a central role in the aquatic ecosystem by participating in the decomposition of organic matter and by constituting the major food source for other aquatic invertebrates, fishes and some birds (Callisto *et al.*, 2001).

An example of a biotic index based on macroinvertebrates is the BMWP index, originally developed in Great Britain (Armitage *et al.*, 1983) and then adapted to the Iberian Peninsula (Alba-Tercedor & Sánchez-Ortega, 1988; Alba-Tercedor, 1996). This index requires only qualitative data and macroinvertebrates are identified only to family level. Although the index is expected to respond negatively with an increase in organic pollution, low values may also reflect low habitat heterogeneity (Armitage *et al.*, 1983; Blijswijk *et al.*, 2005; Oliveira *et al.*, 2001). The goals of this study were (1) to elaborate a map of biological quality of the Mondego river basin, the largest single basin located entirely in Portugal, and (2) to estimate the effect of pollution and habitat heterogeneity on the BMWP' scores values.

METHODS

Study area

The source of the Mondego River is located in the "Serra da Estrela" mountain (Central Portugal), at 1547 m above sea level. The river flows along 227 Km into the Atlantic Ocean, draining a hydrological basin of about 6670 Km^2, the largest single basin located entirely in Portuguese territory (Marques *et al.*, 2002). It is possible to divide the Mondego basin into 3 areas, according with hydro-morphologic characteristics; the Upper Mondego region, which comprises the mountainous region drained by the upper Dão and Alva tributaries and the upper part of the Mondego river, is mainly composed of granite; the Middle Mondego region, which comprises the area between the base of Serra da Estrela Mountain and the city of Coimbra, is mainly schistose. This section contains the final parts of the Dão, Alva and Ceira tributaries; and the Lower Mondego region that spans from the city of Coimbra to the sea (Figueira da Foz), and where the main tributaries are Pranto, Arunca and Ega, is calcareous (Marques *et al.*, 2002). In this basin, land is mostly used for coniferous forest plantations (22%), mix forest plantations (21%), agriculture (25%) and furze-field and pasture (15%) (INAG, 2003). The Lower Mondego region is comprised of 15,000 hectares of good agricultural land where the main crops are rice (60% of the valley), corn, and beans (18% of the valley), which require the use of great amounts of fertilizers and pesticides. Another important economic activity is wood extraction for pulp production for which there are large extensions of *Eucalyptus globulus* plantations in the central part of the basin (Marques *et al.*, 2002; DGF, 2003). The main sources of pollution in this basin are collective sepias ditches (75%), wastewater treatment plants (18%), and direct discharges of urban sewage (7%) (INAG, 2003). We sampled a total of 75 sites distributed all over the basin and covering altitudinal, geological, and stream size gradients. The lowland main channel of the river was avoided due to sampling methodology restrictions and because its artificial configuration.

Sampling, sorting, and identification of macroinvertebrates

Samples were taken between June and September, 2001, by kick sampling with a hand net (0.3 x 0.3 m opening and 0.5 mm mesh size) covering a transept of approximately 6 meters in

3 minutes. The transept was perpendicular to the riverbanks and was set to cover all major microhabitats. In addition, invertebrates were obtained from 10 different stones randomly retrieved from the streambed at each site. The stones were inspected *in situ* and invertebrates removed and placed in plastic bags. This is a modification of the methodology described by Alba-Tercedor & Sánchez-Ortega (1988). The hand- net and "stone" samples were stored individually. Samples were conserved in 4% formalin until they were sorted. In the lab, each sample was washed through a sieve series (0.5- 1.0- 2.0 mm) to increase sorting efficiency. The macroinvertebrates were sorted and stored in 70% ethanol for further identification. Identification was made to family level except for mites (Hydracarina), Oligochaeta, and Hydridae.

Particulate organic matter

After removing the invertebrates, we determined the particulate organic matter of each sample (total area of approximately 6 x 0.3m) and fraction: fine fraction (FPOM: 0.5 - 1mm) and coarse fraction (CPOM: > 1 mm). Each fraction was dried in a stove at 70ºC for 24 h, weighed, placed in a muffle at 550ºC for 4 h and reweighed, to obtain ash free dry mass (AFDM).

Environmental parameters and habitat characterization

Variables measured at sampling sites included river width, mean depth (n=3 or 6/site), mean current velocity (n=3 or 6/site; VALEPORT 15277), dissolved oxygen (% and mg/L; WTW OXI 92), pH (JENWAY 3310), conductivity and total dissolved solids (WTW LF 330), temperature, and mean substrate size (9 or 18 substrate particles from the substratum/site).

Habitat assessment was made based on habitat complexity - heterogeneity: a site with a variety of types (logs, branches, boulders and aquatic vegetation) and sizes of material was considered an optimal site; a site where structural types or sizes of material were less than optimum but where adequate cover was still provided was considered a sub optimal site; a site dominated by only one or two structural components was considered a marginal site; and a site with homogeneous, simple habitats (where silt and sand dominate) was considered a poor site. Pool quality was also assessed into 4 classes: optimal (river bed with all 4 possible combinations of depth (shallow / deep) and current velocity (low / high)), sub-optimal (river bed with 3 of the 4 possible combinations), marginal (two combinations) and poor (homogeneous pool) (EPA, 1999).

Water chemistry

At each site 600 mL of water were collected into acid washed plastic bottles. Water samples were transported to the laboratory in an ice chest. Water was analyzed for ammonia, nitrate, nitrite, sulfate, phosphate and chloride, using an ion analyzer (Dionex DX-120). We also measured alkalinity by titration to an end pH of 4.5 (A.P.H.A., 1995).

The chemical water quality index was determined based on concentrations of the 6 ions. We considered a site to have bad chemical water quality if at least one ion was in excess, according with the Decree-law nº 236/98 of August 1^{st} (Rocha & Vieira, 1998), which gives the threshold values for the different ions in water for human consumption.

BMWP' index

For the application of the BMWP' index, we considered a family as present, when more than one individual was counted. The family Calamoceratidae (Trichoptera) is not considered in the original or adapted version of the index. However, in this study we found the Calamoceratidae family in 9 sites (> 1 individual), 3 of which with very high abundances. In consequence we included this family in the table and gave it a score of 6. This score is arbitrary and was achieved by looking at the most polluted site where the Calamoceratidae family appeared (Louriçal) and giving it the same

Table 1. Presence of macroinvertebrate "families" in the Mondego River basin. *Presencia de "familias" de macroinvertebrados en la cuenca del río Mondego.*

Taxa	Nº of sites	Taxa	Nº of sites	Taxa	Nº of sites
Hydridae	2	Heptageniidae	42	Ecnomidae	13
Dugesiidae	26	Leptophlebiidae	55	Glossosomatidae	19
Planariidae	16	Oligoneuridae	3	Goeridae	15
Nemathelmintha	12	Leuctridae	60	Helichopsychidae	1
Ancylidae	47	Nemouridae	16	Hydropsychidae	55
Hydrobiidae	38	Perlidae	7	Hydroptilidae	13
Lymnaeidae	5	Aeshnidae	22	Lepidostomatidae	23
Physidae	16	Calopterygidae	17	Leptoceridae	41
Planorbidae	8	Cordulegasteridae	24	Limnephilidae	22
Valvatidae	2	Gomphidae	41	Philopotamidae	19
Corbiculidae	2	Lestidae	2	Phryganeidae	13
Sphaeriidae	11	Platycnemidae	11	Polycentropodidae	44
Unionidae	1	Aphelocheiridae	3	Psychomyiidae	39
Echytraeidae	11	Corixidae	20	Rhyacophilidae	35
Haplotaxidae	5	Gerridae	27	Sericostomatidae	35
Lumbricidae	31	Hydrometridae	9	Uenoidae	3
Lumbriculidae	56	Nepidae	6	Athericidae	38
Naididae	39	Notonectidae	6	Anthomyiidae	7
Tubificidae	26	Vellidae	3	Blephariceridae	2
Erpobdellidae	30	Dryopidae	15	Ceratopogonidae	22
Glossophoniidae	12	Dytiscidae	6	Chironomidae	75
Acari	63	Elmidae	64	Dixidae	8
Ostracoda	5	Gyrinidae	8	Dolichopodidae	1
Copepoda	6	Haliplidae	8	Ephydridae	4
Asellidae	5	Hydraenidae	23	Empididae	29
Cambaridae	6	Hydrochidae	11	Limoniidae	17
Atyidae	11	Hydrophilidae	27	Psychodidae	10
Gammaridae	1	Hydroscaphidae	2	Rhagionidae	5
Colembolla	1	Scirtidae	3	Sciomyzidae	1
Baetidae	71	Sialidae	16	Simuliidae	50
Caenidae	51	Beraidae	4	Tabanidae	10
Ephemerellidae	39	Brachycentridae	2	Tipulidae	12
Ephemeridae	10	Calamoceratidae	14		

value as the most intolerant family present (Ancylidae), knowing that this can be over scoring this family. Based on BMWP` score we used the 5 biological water quality classes: I (BMWP'> 100), pollution free waters or high quality; II (BMWP': 61-100), good quality; III (BMWP': 36-60), moderate quality; IV (BMWP': 16-35), poor quality and V (BMWP'< 15), strongly polluted or bad quality. The ASPT' value for each site was computed by dividing the BMWP' value of each site by the total number of BMWP' families present at the considered site (Alba-Tercedor, 1996).

RESULTS

Ninety-eight "families" of macroinvertebrates were identified. Fifty six percent of the total individuals were members of the families Chironomidae, Hydrobiidae and Baetidae. Forty-one families were very rare, together contributing with less than 1000 individuals (<1%) for a total of 137,000. Ten families were present at almost all sites, whereas 20 families were rare, having appeared in less than 5 sites (Table 1). The sites with higher number of individuals (> 4000) were Tentúgal (17711), Anobra (6807), Vimieiro (5240), Porto da Carne (5161), Miranda do Corvo (5084), Ribamondego (4777), Carqueijal (4711), S. Miguel de Vila Boa (4612), and Louriçal (4454). The sites with lower number of individuals (< 200) were Liceia (35), Vila Moinhos (48), Nascente do Catarredor (83), Campizes (97), Casal Ermio (101), Vila Nova do Ceira (120), and Tondela (158) (see table 2). Six sites presented more than 50 different taxa: Ribamondego (61), S. Miguel de Vila Boa (59), Nespereira (59), Casal Mundão (58), Carqueijal (57), and Sabugueiro (53), and 10 sites presented less than 20 different taxa: Soure (8), Vila Moinhos (10), Liceia (13), Campizes (14), Nascente do Catarredor (15), S. Paio do Mondego (16), Casal Ermio (18), Foz do Alva (19), Tondela (19), and Casal da Rola (19). The sites with the lower number of individuals were also the ones presenting lower number of taxa, however the opposite didn't happen for sites with higher number of individuals. This may be explained by the fact that in some sites there's a high number of individuals, but most of them belonging to the same family.

Table 2. Stream name, total number of individuals, number of BMWP' taxa, number of intolerant taxa (sum of BMWP' taxa with a score of 7, 8 and 10), BMWP' value and ASPT' value for the 75 sites sampled in the Mondego river basin, in summer 2001. *Nombre del río, número total de individuos, número de familias para BMWP', número de taxa intolerantes (suma de taxa con valores de 7, 8 y 10 para BMWP'), valores de BMWP' y ASPT' para las 75 localidades muestreadas en la cuenca del río, en verano de 2001.*

Number	Site	Stream name	No. individuals	No. BMWP' taxa	No.Intolerant taxa	BMWP'	ASPT
1	Botão	Ribeira do Botão	1393	15	7	92	6.13
2	Lorvão	Ribeira do Lorvão	2929	20	2	87	4.35
3	Rebordosa	Ribeira do Lorvão	1293	26	8	150	5.77
4	Tábuas	Ribeira da Nossa Sra. da Piedade	931	14	7	100	7.14
5	Ponte do Espinhal	Rio Dueça	551	19	8	119	6.26
6	Miranda do Corvo	Rio Dueça	5084	13	3	67	5.15
7	Tourigo	Ribeira de Marruge	423	19	10	128	6.74
8	Vila Moinhos	Ribeira da Fraga	48	5	1	20	4.00
9	Vila Gozendo	Ribeira da Fraga	493	18	5	99	5.50
10	Póvoa	Ribeira de Mortágua	493	13	4	69	5.31
11	Vendas de Ceira 1	Rio Ceira	730	16	6	87	5.44
12	Vendas de Ceira 2	Rio Dueça	385	12	4	65	5.42
13	Foz de Arouce	Rio Ceira	879	20	7	113	5.65
14	Casal de Ermio	Rio Ceira	101	7	2	45	6.43
15	Múceres	Rio de Múceres	981	25	14	168	6.72
16	Carqueijal	Ribeira do Farreco	4711	32	12	172	5.38
17	Vila Nova de Ceira	Rio Ceira	120	9	3	36	4.00
18	Góis	Rio Ceira	407	15	4	81	5.40
19	Cabreira	Rio Ceira	780	25	10	148	5.92
20	Candosa	Ribeira do Carvalhal Sapo	1186	23	8	129	5.61
21	Lousã	Ribeira de S.João	1604	21	10	140	6.67
22	Candal	Ribeira do Candal	865	16	7	102	6.38
23	Nascente do Catarredor	Ribeira do Catarredor	83	6	3	36	6.00
24	Golpilhares	Ribeira Barroca da Tijosa	353	16	9	109	6.81
25	Santa Eulália	Ribeira do Esporão	3018	17	2	72	4.24
26	Arrifana	Ribeira do Vodra	1668	13	5	69	5.00
27	S.João da Boa Vista	Ribeira da Tábua	841	27	13	166	6.15
28	Ançã	Ribeira de Ançã	1468	16	3	69	4.31
29	Tentúgal	Ribeira de Moinhos	17711	21	6	105	5.00
30	Liceia	Rio do Fojo	33	7	1	25	3.57
31	Ferreira-a-Nova	Ribeira das Barreiras	460	12	2	53	4.42
32	Fornos de Algodres	Rio Mondego	646	13	6	80	6.15

Table 2. (Continuation.)

33	Vila Franca de Serra	Ribeira de Linhares	786	20	8	119	5.95
34	Ribamondego	Ribeira do Freixo	4777	34	16	206	6.06
35	Vila Cortêz da Serra	Ribeira do Paço	1056	26	10	153	5.88
36	Nespereira	Ribeira de Gouveia	3748	27	6	126	4.67
37	Sandomil	Rio Alva	741	19	8	114	6.00
38	Caldas de S.Paulo	Rio Alva	1172	22	14	155	7.05
39	Alvoco das Várzeas	Ribeira do Alvoco	409	16	7	100	6.25
40	Avô 1	Rio Alva	2263	20	8	113	5.65
41	Avô 2	Ribeira da Moura	1189	20	9	117	5.85
42	Foz do Alva	Rio Alva	412	10	3	50	5.00
43	Vimeiro	Rio Alva	5240	16	7	92	5.75
44	S. Paio do Mondego	Ribeira de S.Paulo	825	8	2	40	5.00
45	Folques	Ribeira de Folques	2615	29	13	177	6.10
46	Côja 1	Rio Alva	3743	18	9	114	6.33
47	Côja 2	Ribeira da Mata	2421	26	9	150	5.77
48	Vinhó	Ribeira do Casal	2186	23	13	156	6.78
49	Porto da Balsa	Ribeira da Castanheira	2026	21	10	134	6.38
50	Pombal	Rio Arunca	1446	20	6	110	5.50
51	Ponte de Assamaça	Ribeira de Valmar	1285	16	3	65	4.06
52	Louriçal	Ribeira das Castelhanas	4454	12	0	45	3.75
53	Casal da Rola	Ribeira de Carnide	462	10	1	41	4.10
54	Soure	Rio de Anços	705	3	0	10	3.33
55	Vale dos Azares	Ribeira da Cabeça Alta	2602	26	11	159	6.12
56	Trinta	Rio Mondego	1289	19	12	131	6.89
57	Porto da Carne	Rio Mondego	5161	20	6	102	5.10
58	Minhocal	Ribeira dos Tamanhos	2199	21	8	119	5.67
59	Cardal	Ribeira Quinta das Seixas	808	26	11	157	6.04
60	Muxagata	Ribeira de Muxagata	1134	15	2	71	4.73
61	Póvoa da Rainha	Rio Mondego	374	16	7	99	6.19
62	Sabugueiro	Ribeira de Fervença	3954	27	12	162	6.00
63	Campizes	Ribeiro do Gaio	97	4	0	9	2.25
64	Anobra	Ribeira de Arzila	6807	15	3	77	5.13
65	Vila da Barba	Ribeiro do Poto	472	24	11	146	6.08
66	Várzea	Ribeira da Mata	1277	11	4	61	5.55
67	Travanca de S.Tomé	Ribeira de Cabanas	809	20	9	120	6.00
68	Tondela	Rio Dinha	158	8	2	43	5.38
69	Casal de Mundão	Ribeira da Fraga	1686	31	10	171	5.52
70	Alcafache	Rio Dão	572	16	6	90	5.63
71	Fail	Rio Paiva	3999	11	1	46	4.18
72	Antas	Ribeira do Carrapito	2255	19	8	115	6.05
73	Penalva do Castelo	Rio Dão	332	16	9	105	6.56
74	S.Miguel da Vila Boa	Ribeira de Satão	4612	31	14	183	5.90
75	Senhorim	Rio do Saldo	412	14	2	61	4.36

The BMWP' index classified 14 sites (19%) as being moderately to highly polluted (classes III-V), 22 sites (29%) as being of good quality (class II) and 39 sites (52%) as lightly or not polluted (class I) (Table 2 and Fig. 1). The BMWP' values are explained by both the type and number of taxa present in each site; so, a site with a high number of intolerant taxa (score: 7-10) will present a high BMWP' value (for example, Caldas de S. Paulo with 64% of intolerant taxa has an index value of 155); on the other hand, a site with a low number of intolerant taxa will present a low BMWP' value (for example, Soure and Campizes with 0% of intolerant taxa have an index value of 10 and 9, respectively). However, a site with a low number of intolerant taxa, but with a high total number of taxa may present a high BMWP' value (for example, Nespereira with only 22% of intolerant taxa, but with 27 BMWP' taxa, has an index value of 126); on the other hand, a site with a high percentage of intolerant taxa, but with a low total number of taxa can present a low BMWP' value (for example, Nascente do Catarredor with 50% of intolerant taxa, but with only 6 BMWP' taxa, has an index value of 36). However, it seems like the BMWP' values are more related to the total number of BMWP' taxa considered in the index calculation (R^2= 0.9255) than to the type of taxa (number of intolerant taxa, R^2= 0.8982). There was no relationship between the BMWP' values and the ASPT' values (R^2= 0.4565). Also, there was no relationship between the number of individuals and the BMWP' values (R^2= 0.0371). This could be explained by the fact that in some sites there was a large number of individuals (>4000) but most of them belonging to the same family; for example, in Tentúgal, Anobra and Louriçal, 98, 84 and 58 % of the individuals belong to the Hydrobiidae family; in Vimieiro, 81% of the individuals belong to the families Leuctridae, Hydropsychidae, Philopotamidae, Chironomidae; in Miranda do Corvo and Fail, 81 and 51% of the individuals belong to the Chironomidae family and in Porto da Carne 72% of individuals belong to the Simullidae family. The ASPT' values are more independent from the number of taxa than the BMWP' values, but depend more on the type of taxa (% of intolerant taxa). Because the ASPT' values reflect the percentage of intolerant taxa (in general, increasing with the increase in the % of these taxa), it makes it possible to compare sites with similar BMWP' values, but that differ in the percentage of intolerant taxa (which could reflect differences in ambient conditions). For example, Nascente do Catarredor and Vila Nova de Ceira have the same BMWP' value (36) and the same number of intolerant taxa (3), but the 1st one has 6 BMWP' taxa and the 2nd one has 9 BMWP' taxa. This leads to a higher % of intolerant taxa in Nascente do Catarredor (50%) than in Vila Nova de Ceira (33%), which explains the

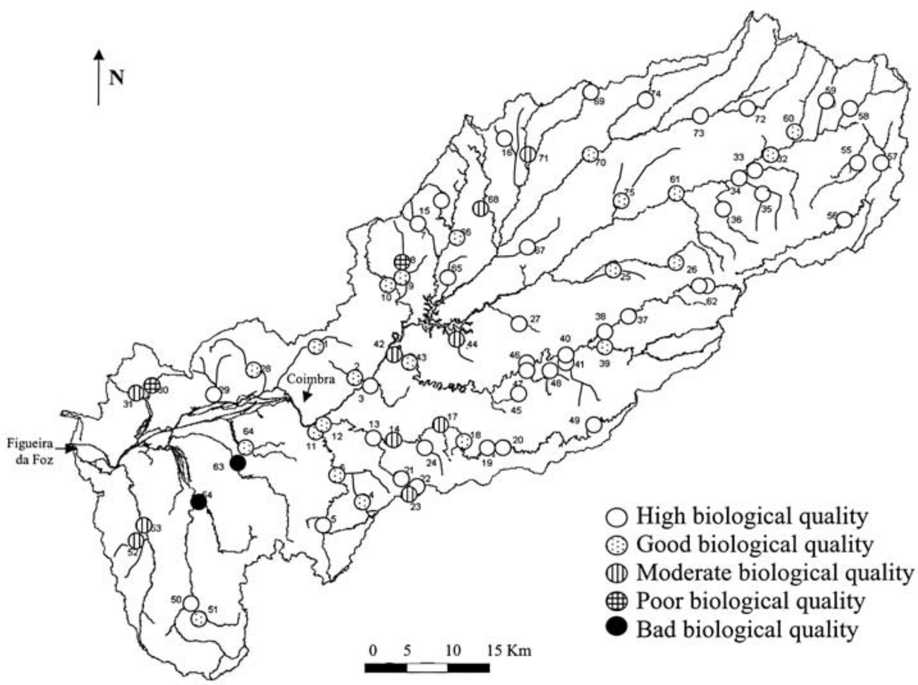

Figure 1: Biological water quality based on BMWP` index in the Mondego river basin. *Calidad Biológica del agua en la cuenca hidrográfica del río Mondego, de acuerdo con el índice BMWP'.*

different ASPT' values (6 in the 1st one and 4 in the 2nd one), and is in agreement with the chemical water characteristics. Another example, is the case of Minhocal, Vila Franca da Serra, and Ponte do Espinhal, all with the same BMWP' value (119) and the same number of intolerant taxa (8), but differing in the total number of BMWP' taxa (21, 20 and 19, respectively), which leads to a higher % of intolerant taxa in Ponte do Espinhal, followed by Vila Franca da Serra and Minhocal, which explains the different ASPT' values (6.26, 5.95 and 5.67 respectively). This tendency to find higher ASPT' values in sites with the same BMWP' value but that only differ in the % of intolerant taxa, can be observed in all the cases were the sites have the same BMWP' value (see table 2).

Polluted sites were located mainly in the Lower Mondego region, at low altitudinal sites (< 100m asl; just 29% of sites in class I), at > 50 Km from the source (just 21% of sites in class I), in river sections with a width superior to 10 m (just 42% of sites in class I) and lower amounts of CPOM (< 5g AFDM/kick sample; 50 % of sites in class I). Conversely, sites with high quality were located in altitudes superior to 400 m asl (87% of sites in class I), at < 10 Km from the source (64% of sites in class I), in river sections with a width inferior to 3 m (64% of sites in class I) and higher amounts of CPOM (>10g AFDM/kick sample; 67% of sites in class I).

Biological water quality was also low at sites with fine sediment (sand; 0% of sites in class I), low pool quality (just 29% of sites in class I), and low habitat heterogeneity (33% of sites in class I). The Lower Mondego region is characterized by fine sediment, low pool quality, and low habitat heterogeneity. Globally, 44% of sites had low habitat heterogeneity and were distributed through the whole area.

In terms of water chemistry (Table 3), polluted sites, according to the BMWP', were the ones that had an alkaline pH (just 39% of sites in class I) and alkalinity superior to 20 mg/L (just

Table 3. Geographic (altitude and distance to the source), structural (mean substrate size and CPOM) and chemical (pH, alkalinity, conductivity, ammonia, nitrate, nitrite, chloride, phosphate and sulfate) parameters for the 75 sites sampled in the Mondego river basin, in summer 2001. *The critical threshold (Decreto-Lei 236/98) for the 6 ions is: NH_4^+: 0.05mg/L; NO_3^-: 25mg/L; NO_2^-: 0.01mg/L; Cl^-: 25mg/L; PO_4^{2-}: 0.4mg/L; SO_4^{2-}: 5mg/L. *Parámetros geográficos (altitud y distancia al nacimiento del río), estructurales (tamaño medio del sustrato y CPOM) y químicos (pH, alcalinidad, conductividad, amonio, nitratos, nitritos, cloro, fosfatos y sulfatos) para las 75 localidades muestreadas en la cuenca del río Mondego, en verano de 2001. *El límite máximo (Decreto-Lei 236/98) para los 6 iones es:* NH_4^+*: 0.05mg/L;* NO_3^-*: 25mg/L;* NO_2^-*: 0.01mg/L;* Cl^-*: 25mg/L;* PO_4^{2-}*: 0.4mg/L;* SO_4^{2-}*: 5mg/L.*

Number	Site	Altitude (m)	Distance to the source (Km)	Width (m)	Mean substrate size (mm)	CPOM (>1mm, g/ kick sample)	pH	Alkalinity (mg $CaCO_3$/L)	Conductivity (mS/cm)	NH_4^+* (mg/l)	NO_2^-* (mg/l)	NO_3^-* (mg/l)	Cl^-* (mg/l)	PO_4^{2-}* (mg/l)	SO_4^{2-}* (mg/l)
1	Botão	80	85.442	4.20	109.2	4.99	7.70	40	190.2	6.9	0	3.59	14.88	0	5.61
2	Lorvão	183	4.701	3.25	93.3	5.45	6.82	21	123.2	36.6	0.05	6.02	13.53	0	2.37
3	Rebordosa	82	8.819	2.00	94.8	3.44	6.60	18	140.7	18.8	0	6.50	16.76	0	2.58
4	Tábuas	310	3.433	2.50	105.6	5.56	7.35	11	52.4	0.9	0	0.82	8.96	0	1.01
5	Ponte do Espinhal	181	15.174	6.90	171.7	3.98	7.97	82	498.0	0	0	0.00	14.34	0	30.24
6	Miranda do Corvo	118	33.271	10.50	90.6	2.87	7.76	87	407.0	1626.4	0.01	0.96	16.62	0.19	14.25
7	Tourigo	300	5.792	2.60	128.3	2.20	6.53	3	42.7	33.6	0	2.05	6.40	0	1.10
8	Vila Moinhos	107	12.346	3.90	134.2	6.36	7.05	23	81.9	11.8	0	1.36	9.01	0	1.58
9	Vila Gozendo	111	16.865	6.00	92.8	7.25	7.02	7	87.2	45.9	0	1.73	9.08	0	2.61
10	Póvoa	115	19.785	6.00	99.2	4.44	7.12	15	87.8	12.2	0	3.01	9.75	0	3.44
11	Vendas de Ceira 1	115	102.970	12.10	53.9	2.94	7.57	27	123.1	32.6	0	3.40	10.62	0	3.18
12	Vendas de Ceira 2	115	63.635	6.50	28.1	1.00	8.06	99	410.0	5.4	0	4.21	18.12	0	18.76
13	Foz de Arouce	84	86.560	26.80	77.2	2.96	7.90	14	102.9	5.1	0	4.35	8.73	0	2.87
14	Casal de Ermio	71	81.975	13.00	79.2	4.04	8.31	9	90.6	10.9	0	3.75	10.20	0	2.48
15	Múceres	71	0.834	5.70	74.7	5.21	6.71	7	60.8	0	0	3.29	8.01	0.09	1.44
16	Carqueijal	166	4.244	5.00	129.2	7.14	6.27	7	73.5	0	0.04	7.69	11.11	0.07	1.48
17	Vila Nova de Ceira	138	69.472	12.60	144.2	2.00	7.23	11	76.3	8.1	0	4.01	7.42	0	2.49
18	Góis	201	63.170	6.50	164.3	6.83	7.41	15	63.6	18.2	0	1.67	6.00	0	1.88

Table 3. (Continuation.)

19	Cabreira	290	31.407	6.50	118.1	1.50	7.32	11	55.5	0	0	1.77	5.75	0	1.79
20	Candosa	330	6.500	2.70	91.1	16.05	8.24	12	43.5	0	0	0.51	5.59	0	0.90
21	Lousã	260	5.806	3.95	96.0	5.54	7.07	8	53.3	0	0.05	1.09	9.43	0	1.12
22	Candal	620	1.502	2.00	98.9	3.32	7.09	5	31.0	0	0	0.44	4.75	0	0.76
23	Nascente do Catarredor	730	0.546	2.60	83.3	4.69	6.82	6	34.9	0	0	1.01	5.45	0	0.69
24	Golpilhares	219	0.809	2.10	91.1	1.16	7.76	17	70.2	0	0	0.58	8.96	0	1.48
25	Santa Eulália	392	7.627	1.85	94.4	6.71	7.07	24	134.7	724.2	0.09	4.03	15.75	0	0.247
26	Arrifana	437	5.179	1.80	105.6	2.68	6.89	14	115.0	33.0	0	7.67	10.86	0	4.71
27	S.João da Boavista	309	3.268	1.55	76.7	1.70	7.27	12	98.2	0	0	4.19	16.20	0	2.08
28	Ançã	30	16.902	4.10	16.0	10.22	7.79	164	813.0	16.9	0	12.96	19.94	0	4.47
29	Tentúgal	36	6.415	2.30	18.9	2.83	8.04	141	559.0	0	0	13.69	22.46	0	5.26
30	Liceia	22	7.380	2.25	sand	1.46	7.92	43	421.0	38.3	0	4.82	28.02	0	6.24
31	Ferreira-a-Nova	27	6.601	3.95	25.6	3.74	7.25	31	223.0	16.8	0	6.90	25.76	0	9.17
32	Fornos de Algodres	345	78.993	5.70	138.9	2.37	8.03	21	83.0	0	0	0.09	7.85	0	1.38
33	Vila Franca de Serra	350	19.090	3.67	35.0	9.44	6.84	14	86.4	229.4	0.01	3.90	9.20	0.20	1.91
34	Ribamondego	337	16.763	6.40	115.3	10.15	7.01	16	77.9	15.1	0	2.66	9.55	0.54	1.83
35	Vila Cortêz da Serra	446	4.018	3.20	100.0	6.35	6.89	11	77.2	0	0	2.50	9.98	0	1.66
36	Nespereira	488	10.188	2.60	9.6	5.61	7.21	31	161.8	6.6	0.05	18.60	20.20	0.67	4.22
37	Sandomil	318	25.873	27.00	136.9	3.19	7.31	9	24.1	7.2	0	0.99	3.38	0	0.40
38	Caldas de S.Paulo	287	32.741	16.00	165	4.51	7.15	5	31.9	4.4	0	1.55	4.31	0	0.65
39	Alvoco das Várzeas	279	30.409	8.00	144.2	2.78	7.22	13	47.0	14.7	0	2.20	5.31	0	0.99
40	Avô 1	237	42.097	6.37	167.2	1.53	7.86	9	45.1	13.4	0	2.15	7.19	0	0.85
41	Avô 2	237	11.374	7.90	133.3	3.79	7.62	13	63.2	7.4	0	2.64	6.39	0	1.52
42	Foz do Alva	232	115.447	8.40	81.9	2.08	7.41	10	50.1	21.7	0	0.93	4.28	0	0.82
43	Vimeiro	97	108.625	30.00	135.6	2.18	7.32	10	49.0	11.9	0	1.46	5.44	0	1.04
44	S. Paio do Mondego	129	5.936	3.20	118.4	5.17	7.07	12	88.0	0	0	0	15.30	0	1.82
45	Folques	180	7.239	3.60	126.5	1.41	7.47	21	96.8	21.6	0	0.67	9.51	0	3.42
46	Côja 1	178	56.291	29.00	95.6	2.78	7.33	9	49.2	0	0	2.75	6.01	0	1.10
47	Côja 2	191	15.896	3.85	106.7	3.31	6.97	13	77.6	0	0	2.56	8.59	0	2.12
48	Vinhó	306	4.282	1.75	38.3	1.57	7.05	15	75.5	0	0	1.05	9.76	0	2.00
49	Porto da Balsa	634	5.573	2.50	83.3	0.73	7.61	5	38.2	0	0	0.64	5.81	0	0.83
50	Pombal	68	21.592	8.60	81.4	2.49	7.98	94	405.0	42.9	0.13	3.83	23.49	0	4.38
51	Ponte de Assamaça	97	11.708	3.00	101.7	3.50	7.63	170	542.0	49.5	0	0.22	13.58	0	2.59
52	Louriçal	17	6.562	3.00	47.6	1.01	7.87	56	362.0	15.7	0.06	20.56	40.80	0.41	10.48
53	Casal da Rola	19	23.900	5.70	sand	1.20	7.5	61	306.0	29.2	0.14	11.72	43.60	0	4.64
54	Soure	27	24.391	14.00	sand	0.07	7.88	126	598.0	36.0	0.08	9.77	39.40	0	5.80
55	Vale dos Azares	473	14.718	2.80	65.0	7.37	6.57	15	55.5	0	0	0.55	6.46	0	1.37
56	Trinta	800	33.609	5.00	150.6	1.10	7.10	7	25.7	48.2	0	0.35	2.94	0	0.36
57	Porto da Carne	455	51.188	14.90	121.7	4.51	6.76	8	51.4	23.5	0	1.07	3.97	0	1.17
58	Minhocal	460	15.044	3.50	58.9	5.35	6.61	26	101.1	0	0	0.71	63.71	0.37	19.00
59	Cardal	437	7.503	3.00	100.0	3.12	6.87	13	58.8	51.3	0	2.62	5.80	0	1.26
60	Muxagata	380	14.738	6.50	97.8	2.21	6.45	20	83.1	0	0	0.13	8.86	0	1.12
61	Póvoa da Rainha	260	99.152	10.20	173.3	2.12	7.41	22	87.2	0	0	0	8.22	0	1.14
62	Sabugueiro	1040	5.277	2.70	111.1	1.57	6.90	5	19.2	43.5	0	0.59	2.62	0	0.26
63	Campizes	30	5.924	4.70	sand	2.19	7.50	119	682.0	0	0.02	5.06	30.28	0	12.45
64	Anobra	25	13.318	1.80	53.3	11.17	8.05	16	762.0	36.8	0.12	15.54	21.94	0	42.71
65	Vila da Barba	229	6.748	2.85	16.1	7.91	5.96	15	185.7	0	0	19.35	21.37	0	4.14
66	Várzea	136	23.969	2.75	122.2	3.54	6.53	12	111.2	15.7	0	8.22	15.34	0	2.58
67	Travanca de S.Tomé	247	11.000	2.20	128.9	9.22	6.01	17	156.0	18.7	0.03	0	17.05	0	5.69
68	Tondela	250	22.072	7.30	51.9	6.32	6.49	9	81.3	36.6	0	5.32	10.58	0	1.31
69	Casal de Mundão	547	2.445	1.90	63.3	9.76	6.61	21	104.4	3.0	0	1.64	6.02	0	0.87
70	Alcafache	238	50.579	7.00	221.4	1.38	7.04	19	114.5	10.1	0	0.58	6.59	0	1.50
71	Fail	325	19.548	3.00	60.6	4.26	7.27	68	593.0	5631.3	0.21	10.36	81.00	5.31	10.78
72	Antas	538	18.337	4.50	112.8	0.04	6.89	15	66.7	0.2	0	0.76	9.96	0	0.72
73	Penalva do Castelo	388	27.474	2.00	105.5	4.32	6.76	8	78.6	4.4	0	0	10.05	0	0.46
74	S.Miguel da Vila Boa	405	15.114	3.00	74.4	110.40	7.07	22	136.6	0	0	5.28	15.19	0	2.02
75	Senhorim	369	19.533	3.30	126.4	3.51	6.19	25	136.6	19.4	0	0.50	21.11	0	11.24

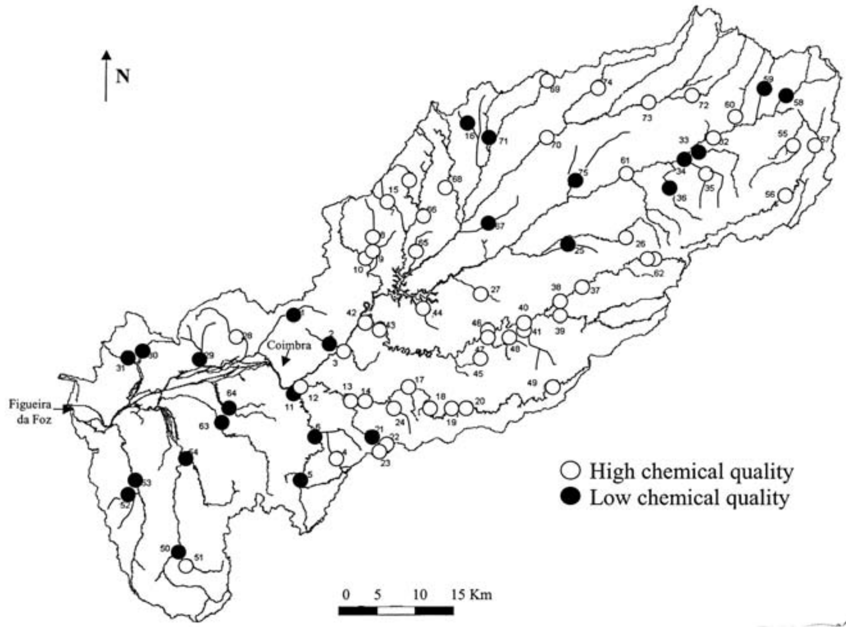

Figure 2. Chemical water quality (at least one ion to excess; see text) index in the Mondego river basin. *Calidad química del agua en la cuenca hidrográfica del río Mondego (al menos 1 ion en exceso; ver texto).*

25% of sites in class I). With respect to ions, ammonia was in excess (>0.05 mg/L) in 5 sites (7%); nitrite was in excess (> 0.01 mg/L) in 15 sites (20%); chloride was in excess (> 25 mg/L) in 8 sites (11%); phosphate was in excess (> 0.4 mg/L) in 4 sites (5%) and sulfate was in excess (>5 mg/L) in 15 sites (20%). Globally, there were 25 sites (33%) with at least one ion in excess, 9 (36%) of them in the Lower Mondego region (Fig. 2). Thus, 33% of sites had bad chemical water quality. In the Lower Mondego region, bad chemical water quality was reflected in conductivity that in this region exceeded 400µS/cm in the majority of sites. Low values of BMWP' can then be explained by low chemical quality and/or habitat heterogeneity (Table 4).

The low BMWP' scores in the Lower Mondego region (Table 2 and Fig. 1) can be explained by the reduced number of individuals belonging to sensitive taxa, which can reflect the lower chemical water quality and the lower habitat heterogeneity in this area. For example, Soure, Campizes and Liceia presented none (Campizes) or only a few (max. of 5, Soure and Liceia) individuals from the orders Trichoptera, Ephemeroptera and Plecoptera. Casal da Rola (BMWP' = 41) presented no Plecoptera, and the Ephemeroptera (all Baetidae) and Trichoptera (all Hydropsychidae) accounted for only 0.6% and 0.4%, respectively, of the total number of individuals; dipterans represented 90% of the total number of individuals in this site. Louriçal (BMWP'= 45) presented only 6.8 % of Ephemeroptera individuals (all Baetidae) and 8% of Trichoptera (all Hydropsychidae) individuals. Ferreira-a-Nova (BMWP'= 53) presented 34% of Ephemeroptera (most of them Baetidae) and Trichoptera (most of them Hydropsychidae) individuals. For these sites it seems that the BMWP' index reflected the poor chemical water quality. However, for Casal Ermio, Vila Nova de Ceira, Foz do Alva, S.Paio do Mondego and Nascente do Catarredor (located in the medium part of the basin), the BMWP' values (between 36 and 50), can only be explained by the low quality of structural parameters; reduced mean size of the substrate and/or poor pool quality, which results in a low habitat heterogeneity, since all the chemical parameters were

Table 4. Relationship between biological water quality classes and combinations of chemical quality and habitat complexity for sites in the Mondego river basin. *Relación entre clases de calidad biológica y combinaciones de calidad química y complejidad de hábitat para las localidades de la cuenca del río Mondego.*

Biological quality		Bad chemical quality +Low habitat complexity	Bad chemical quality	Low habitat complexity	Good chemical quality +High habitat complexity
Classes	Nº of sites	% of sites	% of sites	% of sites	% of sites
I	39	8	18	18	56
II	22	35	0	22	43
III	10	30	10	40	20
IV	2	50	0	50	0
V	2	100	0	0	0

within acceptable intervals. For Tondela, and extra explanation can be the high nitrate concentration in the water. In Ribamondego the highest BMWP' value (206) was achieved due to the presence of a high number of individuals belonging to 34 taxa. However, upstream of this site there was a domestic effluent, but because this was not reflected in an increase of the ions concentrations in the water, beyond threshold values the aquatic community was not negatively affected.

DISCUSSION

In general, in the Mondego basin area, the lower section had lower water quality than the upper section. This information was generally consistent with the chemical water quality. However, some inconsistencies were observed, mainly in some upper sections where low biological water quality was obtained for zones with high chemical quality. The lower sections were also the ones naturally having fine substrate particle sizes, high ion concentrations (nitrite, chloride, and sulfate), and high conductivity, and proportionally high amounts of fine particulate organic matter.

The lower value of BMWP' in the lower sections of the Mondego basin has two not mutually excluding explanations. Firstly, the lower sections are the ones receiving more pollutants due to (a) transport from upstream, (b) high population density through domestic sewage, (c) high industrial activities through industrial sewage and (d) high agricultural activities through the use of large amounts of fertilizers and pesticides. Therefore, the BMWP' seems to be responding, as desired, to environmental degradation.

Secondly, BMWP' values could be biased by the ecology of indicator taxa. In general, low order rivers had higher amounts of CPOM whereas high order rivers had high amounts of FPOM. Shredders, invertebrates feeding on CPOM, have generally "high scores" in the BMWP' table (indicators of high water quality), whereas invertebrates feeding on FPOM (filterers and gatherers) have lower scores (Armitage *et al*., 1983; Alba-Tercedor & Sánchez-Ortega, 1988; Alba-Tercedor, 1996; Tachet *et al*., 2000). Low order rivers are also characterized by intolerant taxa to low oxygen and flow conditions, these taxa being recorded as intolerant in the BMWP' family list. Conversely, taxa inhabiting lowland streams and rivers are naturally more tolerant to low oxygen conditions since in the depositional areas the decomposition of organic matter under low flow conditions could cause natural decreases in dissolved oxygen. Another feature that can influence the distribution of shredders is the size of the substrate, because shredders prefer stony substrate rather than sandy ones; for example, the Trichoptera families that shred (Sericostomatidae, Leptoceridae, Lepidostomatidae, Phryganidae and Calamoceratidae) were found mostly in the middle and upper part of the basin, while in the lower part of the basin we only found Sericostomatidae

(Anobra), Lepidostomatidae (Pombal), Leptoceridae (Pombal and Ponte de Assamaça) and Calamoceratidae (Tentúgal and Louriçal). Therefore, the BMWP' index seems to be influenced by habitat heterogeneity. Stream with sandy substrates are simpler and provide less niches capable of being colonized by invertebrates (Graça *et al.*, 1989). This dependence may be desirable if decreases in habitat heterogeneity are related to human activities, but undesirable if habitats with low complexity are natural. Low habitat complexity explained low BMWP' scores in a greater number of sites than bad chemical water quality. Therefore, the BMWP` index was sensitive to structural parameters (low habitat heterogeneity), classifying clean sites as polluted.

Besides the problems of possible mismatching sites, biotic indices are useful tools since they integrate the biological information when evaluating water quality.

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