Implications of anthropogenic disturbance factors on the Odonata assemblage in a Mediterranean fluvial system

Manuel Ferreras-Romero[1], Joaquín Márquez-Rodríguez & Antonio Ruiz-García

Departamento de Sistemas Físicos, Químicos y Naturales (Zoología).
Universidad Pablo de Olavide, A-376 km 1, 41013 Sevilla, Spain.
[1] Corresponding author. <mferrom@upo.es>

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Abstract

During a period of nine years, from 2000 to 2008, two consecutive studies – one focusing on observations of adult Odonata, the other on collection of larvae - were carried out in the basin of the Guadiamar River in the southwestern Iberian Peninsula. In addition to monitoring Odonata, several environmental variables were assessed, including an index based on macroinvertebrate communities (IBMWP). In April 1998, this river system suffered from an accidental release of a large mass of toxic mining waste, which exterminated macroinvertebrates in the middle and lower parts and floodplain. Several years later, dragonfly communities in these areas were similar to those of unaffected upper reaches. Communities of sites less affected by general human impact were dominated by semivoltine anisopterans. In contrast, headwaters and river reaches where riparian forest had been destroyed many years ago and seasonality of river discharge was boosted by landscape management harboured chiefly uni- or bivoltine species, regardless whether a site had been affected by mining waste or not. Species assemblage was especially poor in lower river reaches that experienced permanent, diffuse urban and agricultural pollution. A few partivoltine species were recorded, but only in habitats with a high IBMWP index. It seems that over the long term, Odonata respond more to land use and catchment management than other groups included in the IBMWP index.

Introduction

Dragonfly species abundance and assemblage composition at any locality can change over time (Moore 1991, 2001). The latter may change as a result of anthropogenic impacts, which can be severe and rapid (Samways 2006), and among these impacts the loss of habitat is recognized as the largest threat to biodiversity. A particular hazard to odonates is habitat fragmentation. Species-specific habitat requirements, pollution, and mismanagement of water bodies result in the alteration of aquatic environment, which may be become largely unusable for some species. Conflicting views have been expressed regarding the usefulness of Odonata as biological indicators of environmental quality (e.g. Schmidt 1995; Corbet 1999: 204). Aquatic pollution and habitat disturbance can reduce odonate numbers and species diversity (e.g. Ormerod et al. 1990; Clark & Samways 1996). However, although studies of temperate lotic freshwaters suggest that Odonata are generally rather tolerant of pollution and few species are useful as biological indicators (Roback 1974; Ward 1992: 128), studies on lowland rivers suggest that odonates are frequently affected by urban and industrial pollution and are good bio-indicators of environmental quality (Carchini & Rota 1985).

In the Mediterranean region, Odonata constitute a primary component of the fluvial benthos used to assess ecological status of basins (Pinto et al. 2004) and can be recognised as key organisms to understand the functioning of running water communities. Consequently, there are several studies that focus on the fluvial dragonfly communities in the Mediterranean region (Aguesse 1960; Jarry & Vidal 1960; Carchini & Rota 1982; Ferreras-Romero 1984, 1999; Suárez et al. 1986; Castella 1987; Schridde & Suhling 1994; Ferreras-Romero & Corbet 1995; Ferreras-Romero & García-Rojas 1995). Moreover, several studies exist that focus on some of the species occurring in the Guadiamar River catchment (e.g. Ferreras-Romero 1991, 1997; Agüero-Pelegrín et al. 1999; Leipelt & Suhling 2001). Extensive investigations on several aspects of the ecology of some typical Mediterranean running water species have been carried out, namely *Onychogomphus uncatus* (Suhling 1996, 1999, 2001; Schütte et al. 1998; Ferreras-Romero et al. 1999), *Cordulegaster boltonii* (Schütte 1997; Ferreras-Romero & Corbet 1999; Leipelt 2005), and *Macromia splendens* (Cordero Rivera 2000; Leipelt & Suhling 2005; Chelmick 2006).

Our study area, the basin of the Guadiamar River, is located in the south-west of the Iberian Peninsula in an area affected by urban and agricultural sewage pollution and a long tradition of intensive mining activity (Prat et al. 1999). Previous studies on the Odonata of this catchment are rather scarce (Dufour 1978; Ferreras-Romero & Gallardo Mayenco 1985). More recent studies were carried out in relation to a mining spill, which occurred in April 1998 and caused the dumping of 5×10^6 m^3 of mud and acid waters with high concentrations of heavy metals, which totally eliminated the ecosystems of the middle and lower Guadiamar River and its floodplain (Prat et al. 1999; Ferreras-Romero et al. 2003).

The main aim of this study was to evaluate the usefulness of Odonata as indicators of general habitat quality in flatland fluvial systems of the Mediterranean area, and furthermore, to assess the different impacts of various anthropogenic disturbance factors.

Study area and methods

Study location

The Guadiamar River basin in Andalusia, SW Spain, covers an area of 1,880 km^2 and extends in north-south direction (Fig. 1). The system drains an important sector of the southern slope of the Sierra Morena mountain range, where the headwaters are situated at 410 m a.s.l., and after 119 km it joins the Guadalquivir River near its mouth (Borja et al. 2001). The study area was originally covered by native perennial Mediterranean forest, in which *Quercus ilex* dominated. Other formerly common tree species were *Quercus suber* and *Olea europaea*. On the banks of the watercourses natural riparian forest consisted of *Alnus glutinosa*, *Fraxinus angusti-*

folia, *Salix* sp., and *Populus alba*, but in the last decades of the 20th century that linear plant cover has become very fragmented or has vanished completely. Conservation status of riparian forest in the region has been evaluated as very poor (Arribas et al. 2002).

In the upper parts of the basin, land is mostly used for forest exploitation (*Pinus pinaster*, *P. pinea*), and ranching of cattle, fight-bulls, and Iberian pigs. Main causes for landscape changes were forestry fires, excessive deforestation of the 'dehesa' – the traditionally managed forest – for ranching, artificial ditches, and fragmentation of riparian forest. In the middle part of the basin, the native forest was destroyed during the second half of the 20th century to introduce extensive agriculture, especially wheat, sunflower, and fruit trees. However, even into the 1950s, *Canis lupus* was not uncommon in this part of the catchment; the last wolf was hunted between Aznalcóllar and Sanlúcar la Mayor in December 1974 (Gutiérrez Alba 2006) (Fig. 1).

The Agrio River contributes runoff from the iron pyrite mining area of Aznalcóllar to the middle and lower reaches of the Guadiamar River. Mine pollution caused an important and well-documented decline in both aquatic insect diversity (Gallardo & Toja 1984; Gallardo Mayenco 1990) and biological water quality in this region, according to the IBMWP index based on the assessment of macroinvertebrate communities (Armitage et al. 1983; Alba-Tercedor et al. 2002; Ferreras-Romero et al. 2008). Main causes of alteration are currently deforestation and agriculture.

Marshes in the lower parts of this basin have been devoted to intensive agriculture since the first half of the 20th century. Urban and industrial pollution, and the excessive use of agricultural fertilizers and pesticides, are the main environmental problems. In addition, parts of the lower reaches suffer from seasonal inorganic pollutants caused by traditional Spanish-style green olive fermentation in the small towns of the Aljarafe region (Fig. 1). As a result of green olive brining procedures, the sewage is loaded with NaOH, brine treated with NaCl, and lactic acid bacteria.

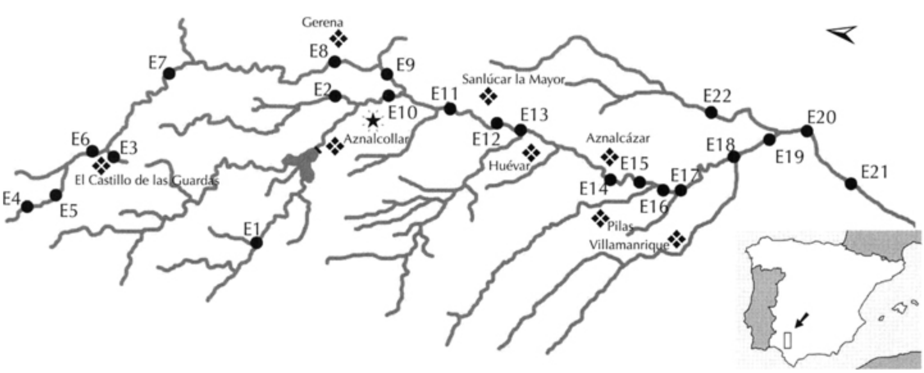

Figure 1: Fluvial system of Guadiamar River, Andalusia — map of study sites. (★) situation of the mining raft which caused the mining spill disaster in April 1998. Study sites: E1: Cañaveroso stream; E2: Los Frailes stream; E3: Aciago stream; E4: Guadiamar River (GR) Las Cortecillas; E5: GR Valdeflores; E6: GR El Castillo de las Guardas; E7: GR El Garrobo; E8: GR Gerena; E9: GR Cortijo La Alegría; E10: Agrio River; E11: GR Aforador CHG; E12: GR Sanlúcar la Mayor; E13: GR Benacazón; E14: GR Aznalcázar; E15: GR before Alcarayón stream; E16: GR after Alcarayón stream; E17: GR Vado de Quemas; E18: R.G. before La Cigüeña stream; E19: GR Vado de Don Simón; E20: GR Vado de Los Vaqueros; E21: GR Casa de Bombas; E22: Majaberraque stream.

Acronyms

All scientific names of Odonata mentioned in the Figures and Tables were transferred into the following code:

Cha	*Calopteryx haemorrhoidalis* (Vander Linden)
Lvn	*Lestes virens* (Charpentier)
Lvi	*Lestes viridis* (Vander Linden)
Sfu	*Sympecma fusca* (Vander Linden)
Cme	*Coenagrion mercuriale* (Charpentier)
Ecy	*Enallagma cyathigerum* (Charpentier)
Eli	*Erythromma lindenii* (Selys)
Evi	*Erythromma viridulum* (Charpentier)
Igr	*Ischnura graellsii* (Rambur)
Pny	*Pyrrhosoma nymphula* (Sulzer)
Plat	*Platycnemis* larvae, either *P. acutipennis* Selys or *P. latipes* Rambur
Pac	*Platycnemis acutipennis* Selys
Pla	*P. latipes* Rambur
Ami	*Aeshna mixta* Latreille
Aim	*Anax imperator* Leach
Apa	*Anax parthenope* Selys
Bir	*Boyeria irene* (Fonscolombe)
Ggr	*Gomphus graslinii* Rambur
Gpu	*Gomphus pulchellus* Selys
Oco	*Onychogomphus costae* Selys
Ofo	*Onychogomphus forcipatus unguiculatus* (Vander Linden)
Oun	*Onychogomphus uncatus* (Charpentier)
Pge	*Paragomphus genei* (Selys)
Cbo	*Cordulegaster boltonii* (Donovan)
Msp	*Macromia splendens* (Pictet)
Ocu	*Oxygastra curtisii* (Dale)
Ble	*Brachythemis leucosticta* (Burmeister)
Cer	*Crocothemis erythraea* (Brullé)
Dle	*Diplacodes lefebvrii* (Rambur)
Oca	*Orthetrum cancellatum* (Linnaeus)
Och	*Orthetrum chrysostigma* (Burmeister)
Oco	*Orthetrum coerulescens* (Fabricius)
Otr	*Orthetrum trinacria* (Selys)
Sfo	*Sympetrum fonscolombii* (Selys)
Sst	*Sympetrum striolatum* (Charpentier)
Tan	*Trithemis annulata* (Palisot de Beauvois)

Sampling methods

Presence and reproductive behaviour of adult Odonata were recorded monthly from April to September in 2000, 2001, and 2004 at one locality not affected by the 1998 mining spill (at E8), and at three localities that had been affected (E12, E14, E17). All localities were situated along the main axis of the basin and were visited during 45 min in the midday hours. The three affected localities were also visited in 2005. There was a total of 90 censuses of adult Odonata.

Table 1. Presence of adults at two study sites (E8, E12) — recorded monthly at the Guadiamar River, Andalusia, from April to September in different years. In contrast to E8, E12 was affected by the mining spill disaster in April 1998 (shaded). T: tenerals; A: mature adults; R: reproductive activities. U: Unspecified data from 1977 taken from Dufour (1978). Species code: see page 416.

Species sites:	**E8**			**E12**				
	2000	2001	2004	1977	2000	2001	2004	2005
Lvn			A					
Lvi	T	A				A		
Sfu								A
Eli	A	AR	AR	U	A	A	A	
Evi		A						
Igr	TAR	TAR	AR	U	TA	TAR	AR	TA
Pac	TA	A	TAR	U	A	TA	TAR	TAR
Pla	AR	TAR	TAR			A	TA	A
Ami			A					
Aim		A				A	A	A
Apa	R	AR	A	U	A	A	A	A
Ofo		A						
Ble	TA				TA	TA	A	TA
Cer	A	AR	AR	U	A	TAR	AR	A
Dle		A	A				A	
Oca	TA	A	A	U	AR	A	A	A
Och	TA	AR	TAR		AR	TAR	AR	TAR
Oco	A	A						
Otr					A		R	
Sfo	AR	AR	AR	U	TAR	TAR	TAR	TAR
Sst	TA							
Tan	A	AR	TAR		A	A	A	A

As a second approach, 14 sites in the catchment of the Guadiamar River (Fig. 1) were sampled for larvae 12 times in autumn, winter, and spring from 2004 to 2008. In eight other localities nine samples were collected from autumn, winter, and spring 2004 to 2007. A total of 240 samples were taken. Larvae were collected with a kick net with an opening of 25 x 25 cm and 250 µm mesh. Samples at each site were taken from all microhabitats, such as pool, riffle, stream bed, submerged and emerged vegetation. Sampled larvae were transferred to ethanol (70%) and later identified in the laboratory.

Environmental variables

Three sets of environmental variables were measured: physico-chemical properties, ecological quality, and land-use. Water temperature, dissolved oxygen (D.O.), pH, and conductivity were measured in situ from headwaters to lower reaches with a Crison Oxi 330 and Crison MM 40 in winter, spring, and autumn 2007, and in winter and spring 2008. Turbidity was estimated by categorizing the water as (1) clear; (2) turbid with bottom visible; and (3) turbid with bottom not visible. Ecological quality was assessed by the IBMWP index (Jáimez-Cuéllar et al. 2002). Land-use categories were obtained from the map of use and vegetation cover of Andalusia

Table 2. Presence of adults at two study sites (E14, E17) — recorded monthly at the Guadiamar River, Andalusia, from April to September in different years. Both sites were affected by the mining spill disaster in April 1998 (shaded) and also by permanent, diffuse urban and agricultural pollution. T: tenerals; A: mature adults; R: reproductive activities. Species code: see page 416.

Species	sites	E14				E17			
		2000	2001	2004	2005	2000	2001	2004	2005
Lvi			A						
Sfu					R				A
Ecy						AR			
Eli					A				
Igr		TAR	TAR	AR	TA	AR	AR	A	TA
Pac				TAR	AR				
Pla				TA	TAR				A
Apa		AR	AR	A	A	AR	A		A
Oco								A	
Ble		A	TA	TA	A	A	A	A	TA
Cer		A	A	AR	TAR	A	TA	A	TA
Oca		A	AR	A	A	AR	A	AR	A
Och		T	A	A	A			A	A
Otr		A				A			
Sfo		TAR	TAR	AR	TA	TAR	A	TAR	TA
Sst						A			
Tan		A	A	A	TA	A		A	A

(2003) at a scale of 1:25,000, which is an adaptation of the methodology CORINE (EU-CORINE Land Cover program). At each sampling site a circle with a radius of 250 m was drawn, and the percentage of four land-use categories within the circle was calculated: forested area, pasture, agriculture, and urban and industrial area. The presence or absence of riparian forest was also recorded.

Data analysis

Dragonfly assemblages breeding along the basin were described by Detrended Correspondence Analysis (DCA) from summarized larval data. A Principal Component Analysis (PCA) was performed to describe similarities and differences among sites with respect to the environmental variables. Variables were examined for normality and log $(x + 1)$ transformed. A PCA was performed on 10 environmental variables representing various catchment characteristics and land use. Significance of PCA axes was obtained by a Monte Carlo permutation test (9,999 runs). Ordination techniques were performed to analyze spatial variations of community composition and to correlate environmental variables with biological data. The ordination method used was selected based on the length of the gradient calculated by DCA (Leps & Smilauer 2003). Since the first DCA axis had a gradient length equal to 3.56 standard deviation units, the use of a unimodal ordination technique was justified. Canonical Correspondence Analysis (CCA) was used to investigate which environmental variables explain the variations of abundance observed in the species matrix. Prior to all ordination analyses, larval dragonfly abundance and environmental data were log $(x + 1)$ transformed to achieve normality. The significance of the CCA axis was tested by a Monte Carlo permutation test (999 unrestricted permutations, $p < 0.05$). All analyses were performed using PCORD 5.0.

Results

Adults

There was a stable dragonfly assemblage at the site unaffected by the mining spill (E8). From 2000 to 2004, four zygopteran and six anisopteran species were recorded. Three additional species were observed for only two years (Table 1).

In the upper study site that had been affected by the mining spill (E12), two Zygoptera (*Ischnura graellsii* and *Platycnemis acutipennis)* and seven Anisoptera (*Anax parthenope* and six libellulid species) were observed during all four years. *Platycnemis latipes* and *Anax imperator* were observed from 2001 onwards (Table 1).

At the other two sites that had been affected by both the mining spill and a permanent, diffuse pollution from sewage outfalls and seasonal inorganic pollutants, the communities were different. Near E14, *I. graellsii* was always present as the only zygopteran from 2000 onwards, and during 2004 and 2005 both *Platycnemis* species were also present (Table 2). In addition, *A. parthenope* and six libellulids were recorded each year. At E17, *I. graellsii* was also always present, but only three individuals of *P. latipes* were recorded during 2005. Four libellulid species were always observed, and *A. parthenope* and *Trithemis annulata* were seen for three years (Table 2). These lower parts were dominated by libellulid species with a wide distribution in the African continent: *Brachythemis leucosticta*, *Crocothemis erythraea*, *Orthetrum chrysostigma*, *Sympetrum fonscolombii*, and *T. annulata.*

Larvae

A total of 29 Odonata species were recorded as larvae across the 22 sites of this study (Table 3). The list includes four species protected by Spanish and European legislation: *Coenagrion mercuriale*, *Gomphus graslinii*, *Macromia splendens*, and *Oxygastra curtisii.* The three Anisoptera were recorded only in headwaters. A near-natural diversity of semivoltine species – *Boyeria irene*, *G. graslinii*, *Onychogomphus uncatus*, *M. splendens*, and *O. curtisii* – was recorded only in the headwaters

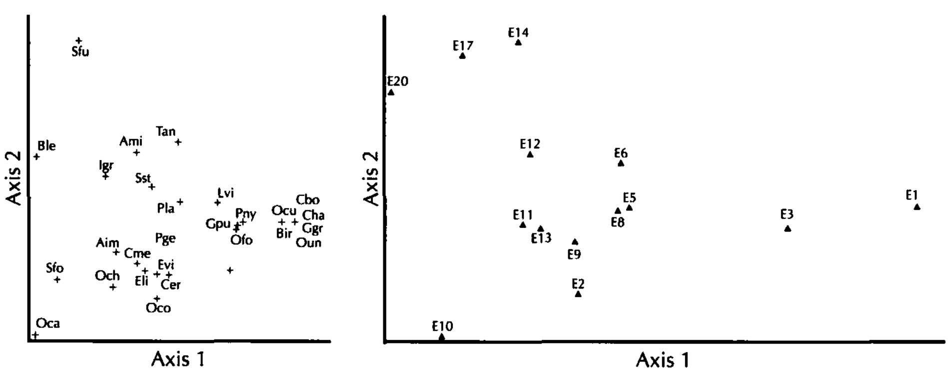

Figure 2: Assemblages of breeding dragonfly species along the Guadiamar basin described by Detrended Correspondence Analysis (DCA) — (a) species assemblages; (b) grouping of study sites. DCA is based on cumulative larval data recorded at 22 sites from autumn 2004 to spring 2008. Species code: see page 416.

Table 3. Presence of larvae — recorded throughout the entire study in the fluvial system of the Guadiamar River, Andalusia, where Odonata were monitored at 22 sites from autumn 2004 to spring 2008. E10-21 were affected by mining spill (shaded). Species code: see page 416.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Cha		■																				
Lvi	■		■	■	■	■	■	■	■						■							■
Sfu														■								
Cme					■				■		■											
Eli		■			■		■	■	■		■	■	■									
Evi		■					■	■	■		■											
Igr		■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Pny			■																			
Plat	■	■				■		■	■	■	■	■	■	■	■	■						
Ami			■	■	■	■					■	■		■	■	■	■	■		■		■
Aim		■				■			■	■	■	■	■	■								
Bir	■		■																			
Ggr	■																					
Gpu	■	■				■		■	■			■										
Ofo	■	■	■	■	■	■		■														
Oun	■																					
Pge		■			■	■		■			■											
Cbo	■																					
Msp	■	■																				
Ocu	■																					
Ble												■						■	■	■		
Cer		■	■		■	■				■	■	■	■									
Oca										■	■					■						
Och		■			■					■	■	■	■									
Oco			■	■					■	■												
Sfo		■								■										■		
Sst				■	■	■					■	■					■					■
Tan	■											■		■	■					■		

of Guadiamar River, and *Gomphus pulchellus* and *Onychogomphus forcipatus unguiculatus* only in upper reaches. The lower reaches were dominated by *B. leucosticta*, *S. fonscolombii*, and *T. annulata*. *I. graellsii*, and *Aeshna mixta* were also present; they are very tolerant species with short life-cycles (Table 4).

The headwaters (E1, E3) were distinctly different in species composition from those lower sites (E17, E20) strongly altered by human impact (DCA, Fig. 2). The majority of sites, including both sites affected (E11-E13) and unaffected (E6, E8, E9) by the mining spill, did not differ from one another (Fig. 2). According to DCA, the odonate assemblages in the middle reaches recovered from the mining spill. Permanently polluted sites in the lower reaches (E14, E17, E20) harboured poorer dragonfly assemblages than those affected by the mining spill only.

Physical characteristics of water

Middle (E8-E13) and lower reaches (E14-E20) were similar in temperature and D.O.; water temperature was always above 10°C and D.O. was always above 5 mg/l at all sites in both regions (Table 5). On the other hand, pH measurements showed that the acidic waters of the Agrio River were diluted in the neutral waters of the Guadiamar River just below their junction. Conductivity values higher than 450 µS/l were recorded sometimes at all sites downstream of the confluence with Agrio River; but in sites E14, E17, and E20, reaches with high anthropogenic incidence, no value lower than 300 µS/l was measured.

Environmental variables analysis

The results obtained by PCA are shown in Table 6. The three axes in Figure 3 explained 73.5% of the variance. Axis 1 explained 42.7% and was positively correlated to the IBMWP index and the forested area, and negatively related to turbidity, water temperature, and conductivity (Fig. 3). Axis 2 explained 16.9% and was positively related to agricultural land use and pH, and negatively related to pasture land. Finally, axis 3 explained 13.8% and was positively related to riparian forest, and negatively related to urban-industrial land use.

The differences in environmental quality correlated with odonate community structure. Composition of forested sites with high biological quality (IBMWP score) was different from that of sites with elevated conductivity and turbidity indicative of polluted areas (Fig. 4, Table 7). The low pH levels of the Agrio River were only tolerated by libellulid species. It was evident in sites where the values obtained by IBMWP were always high (E1, E3), and the Odonata species assemblages consisted of ecologically sophisticated, partivoltine species. On the other hand, assemblages that were rich in uni- and multivoltine species existed in river reaches with very variable values for this index ranging from high to low values (e.g. E6 and E8 vs E11 and E12).

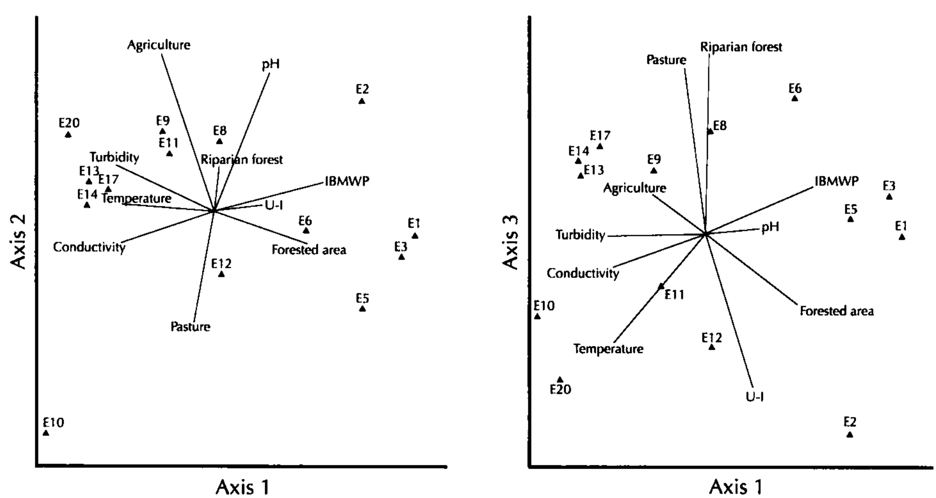

Figure 3: Environmental variability among Guadiamar River sites described by Principal Component Analysis (PCA). PCA is based on 10 environmental variables measured at 14 sites from autumn 2004 to spring 2008. IBMWP: biological index based on macroinvertebrate communities; U-I: urban industrial land.

Discussion

The odonate community in the Guadiamar River fluvial system has been strongly affected by human activities. The fragmentation or loss of riparian forest resulted in an altered species assemblage, where generalists benefit from large open areas and achieve dominance in the odonate community. This effect has also been shown after modification of other forest types (e.g. Samways & Steytler 1996; Stewart & Samways 1998; Clausnitzer 2003; Oppel 2006). The upper and middle reaches of the Guadiamar River harbour similar, species-rich assemblages. Species depending on a closed canopy or on a permanent, superficial flow of water are most susceptible to forest modification (Clausnitzer 2003), and it is generally accepted that the most immediate danger to the Odonata is the threat of destruction and impairment of their larval habitats (Wildermuth 1994). In 1979, the upper reaches of the Guadiamar River provided a breeding habitat of *Oxygastra curtisii* (Ferreras-Romero & Gallardo-Mayenco 1985). The absence of *Calopteryx* and corduliid species along the main axes of this basin suggests that the river is ecologically degraded. Reduced shading of the water course may lead to an upstream shift of certain species in disturbed landscapes (Oppel 2006); open sunny areas and artificial ditches favour the development of libellulids and large aeshnids, as well as disturbance-tolerant species like *Aeshna mixta* and *Ischnura graellsii* (Ferreras-Romero 1988).

The presence of a vigorous and diverse odonate fauna will always be a reliable indicator of the stability, health, and integrity of a wetland ecosystem (Corbet 1999: 204). In Mediterranean river systems with high structural diversity, the abundance and species richness of gomphids is a particularly good indicator of a healthy fluvial system. For example, *Gomphus pulchellus* ranged throughout the river basin in 1979, and *Onychogomphus forcipatus unguiculatus* was also found in the upper reaches (Ferreras-Romero & Gallardo-Mayenco 1985). The low frequencies and

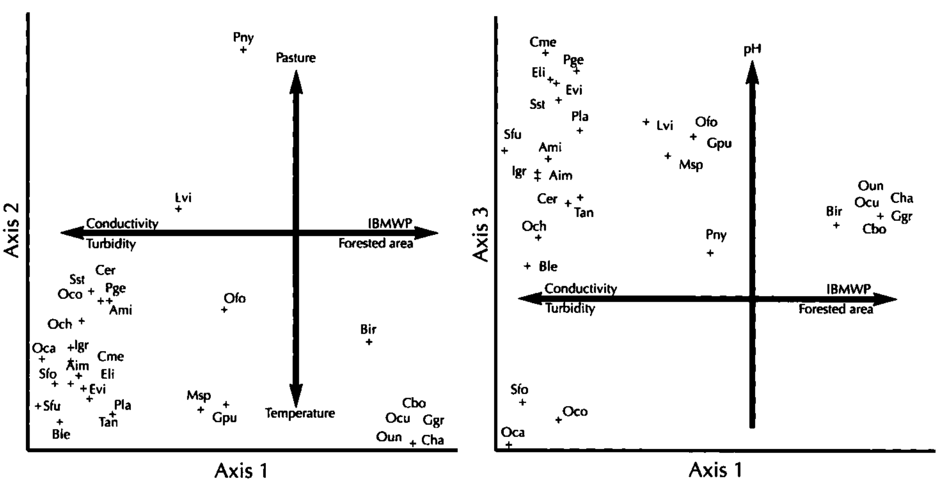

Figure 4: Correlations among environmental variables and abundance of dragonfly species described by Canonical Correspondence Analysis (CCA). CCA is based on data from the fluvial system of the Guadiamar River, Andalusia, at 22 sites from autumn 2004 to spring 2008. IBMWP: biological index based on macroinvertebrate communities. Species code: see page 416.

Table 4. Number of larvae — collected at 14 sites in the fluvial system of Guadiamar River, Andalusia, where twelve samples were taken out from autumn 2004 to spring 2008; cumulative totals. E10-14, 17, 20 were affected by mining spill (shaded). Species code: see page 416.

Species	E1	E2	E3	E5	E6	E8	E9	E10	E11	E12	E13	E14	E17	E20
Cha	4													
Lvi	2		47	180	6	1	1							
Sfu												2		
Plat	23	1			4	9	36	2	46	72	14	21		
Pny			7											
Evi		12				1	2		1					
Eli		20		1		10	18		11	2	6			
Cme				1			5		2					
Igr		27		24	20	21	20	63	109	141	38	54	44	124
Bir	106		4											
Ami			1	1	1				3	4		2	2	1
Aim		4			1		1	2	2	2	1	1		
Ggr	1													
Gpu	16	3			1	1	1			1				
Ofo	48	6	5	10	2	4								
Oun	154													
Pge		2		5	2	1			1					
Cbo	3													
Ocu	4													
Msp	1	3												
Och		5		8				26	5	15	1			
Oca								5	1					
Oco			2				1	18						
Ble										2				3
Cer		1	3	2	1			3	1	1	7			
Sfo		3						13						3
Sst				8	2				2	3			1	
Tan	1									6		2		1

Table 5. Ranges of physical water and biological quality parameters — measured at 14 sites of the Guadiamar River fluvial system, Andalusia, during five samplings carried out from winter 2007 to spring 2008. T: temperature; DO, dissolved oxygene; Cd: conductivity; IBMWP: biological index based on macroinvertebrate communities.

Sites		DO [mg/l]	pH	Cd [µS/l]	IBMWP
E1	9.1-18.6	6.8-11.1	7.49-7.79	67- 95	135-188
E2	9.5-19.6	6.2-14.3	8.34-9.32	117-184	71-157
E3	9.6-16.5	8.4-10.7	8.05-8.57	204-321	96-124
E5	8.8-17.4	8.6-10.6	7.89-8.33	172-216	96-122
E6	9.9-19.2	7.6-9.8	7.61-8.04	154-238	73-109
E8	11.4-20.6	7.1-11.8	7.81-8.77	128-192	88-106
E9	10.7-19.4	5.5-7.6	7.61-8.66	126-246	61-88
E10	13.2-20.5	8.4-12.7	5.62-7.66	126-667	20-32
E11	10.3-20.0	6.6-8.8	7.39-7.69	167-493	39-61
E12	10.3-19.7	7.0-9.2	7.67-7.93	174-474	36-58
E13	11.9-21.6	6.7-11.7	7.34-8.70	270-565	35-41
E14	12.7-18.9	5.7-11.3	7.30-8.18	333-555	25-36
E17	11.4-18.7	5.9-9.9	7.76-8.38	329-712	28-57
E20	13.0-18.1	5.3-12.3	7.56-8.68	354-750	24-28

Table 6. Environmental variables representing various catchment characteristics and land use at 14 sites of the Guadiamar River, Andalusia — average values according to Principal Component Analysis. Data were recorded during five samplings from winter 2007 to spring 2008. T: temperature; Cd: conductivity; Tb: turbidity – 1: clear water; 2: turbid water but visible bottom; 3: bottom not visible; BMWP: biological index based on macroinvertebrate communities; For: forested area; Pas: pasture; Agr: agriculture; UI: urban industry; Rip: riparian forest – 1: existing.

Sites	T [°C]	pH	Cd [µS/l]	Tb	IBMWP	For [%]	Pas [%]	Agr [%]	UI [%]	Rip
E1	14.4	7.6	76.5	1	165.0	100	0	0	0	1
E2	15.1	8.6	152.7	1	112.3	15	0	55	30	0
E3	12.9	8.3	269.2	1	113.3	50	40	0	10	1
E5	13.6	8.0	150.8	1	106.7	25	75	0	0	0
E6	13.5	7.8	198.8	1	89.3	10	65	25	0	1
E8	15.5	8.1	155.4	2	98.0	0	30	70	0	1
E9	15.7	7.9	185.2	3	68.0	0	10	90	0	1
E10	17.2	6.6	539.2	2	25.0	0	100	0	0	0
E11	15.8	7.6	350.0	3	50.3	40	0	60	0	1
E12	16.0	7.7	336.4	3	46.3	45	20	0	35	1
E13	16.3	7.9	415.0	3	38.0	0	45	55	0	1
E14	15.5	7.7	452.0	3	32.0	0	50	50	0	1
E17	15.0	7.9	525.6	3	40.0	0	50	50	0	1
E20	16.3	8.0	553.8	3	26.0	0	0	100	0	0

poor species diversity of gomphids found in the present study both in the middle and lower reaches of the river suggest that there has been significant ecological degradation over the last 30 years.

Wildermuth (1994) suggests that there is a critical need for more studies on odonate recolonization of restored waterways. Fortunately, big mining spills similar to the incident that totally eliminated the aquatic insect communities of the middle and lower reaches of the Guadiamar River and its floodplain (Prat et al. 1999), are rare in European rivers. Regional and national government agencies have made significant investments to minimize the effects of the spill and restore the ecological integrity of the river, but ecological recovery has been slow.

Many odonate species have returned in the years after the spill. Indeed, in 2000, only two years after the spill, seven species recorded as adults in 1977 by Dufour (1978) had returned to the same site (Table 1). In addition, four new libellulids with a wide African distribution were found there for the first time: *Brachythemis leucosticta*, *Orthetrum chrysostigma*, *O. trinacria*, and *Trithemis annulata*. However, the assemblages recorded were dominated by anisopterans, chiefly libellulids, and it is well-known that breeding and foraging areas can differ in many Anisoptera (e.g. Orr 2006). As such, appearance and foraging at a site may not indicate true recolonization of a breeding population (Wildermuth 1994). In the most severely-affected sites, adults of tolerant species like *I. graellsii*, *Anax parthenope*, *Orthetrum cancellatum*, and the 'African' libellulids were recorded in early censuses and consistently thereafter. These populations may have been favored by the degraded state of the riparian forest and canopy, high water temperatures, exaggerated seasonality with drastic flow changes through the year, and the absence of pollution-sensitive species.

Table 7. Results of the Canonical Correspondence Analysis showing Pearson correlation coefficients of environmental variables with the three axes of the analysis ordinating the odonate community in the fluvial system of Guadiamar River, Andalusia, Spain. Correlations: Conductivity -0.79; Turbidity -0.64; IBMWP 0.77; Forested area 0.61; Water temperature -0.65; Pasture: 0.53; pH 0.70.

Axes	**1**	**2**	**3**	**Total inertia**
Eigenvalues	0.607	0.351	0.277	2.129
Explain % variance	28.5	16.5	13.0	
Cumulative % variance	28.5	45.0	58.0	

On the other hand, colonization of the affected sites by *Platycnemis* spp. and *Erythromma lindenii* was lower, especially in Aznalcázar (E14) and Vado de Quemas (E17). Both sites suffered from diffuse pollution from surrounding small towns.

According to the results obtained by DCA after four consecutive years of sampling larvae, several stretches of the Guadiamar River that had been affected by the accidental release of toxic mining waste had recovered in 10 years and were again populated by a dragonfly assemblage similar to that of unaffected upper stretches. It was a poor assemblage of semivoltine species. *E. lindenii*, *I. graellsii*, and the two *Platycnemis* species, as well as widespread anisopterans like *Anax imperator*, *Crocothemis erythraea*, *O. chrysostigma*, and *Sympetrum striolatum* were most abundant and frequent.

The lower reaches of the Guadiamar River, which were affected by the mining spill disaster in April 1998 and suffered from many years of permanent, diffuse, urban and agricultural pollution, showed the poorest dragonfly assemblages of all investigated sites. These sites only harboured very tolerant species like *I. graellsii*, *A. mixta*, and the wide-ranging African libellulids *B. leucosticta* and *T. annulata*.

Odonata assemblages with highest diversity of families were found in sites with the highest IBMWP scores. Indices like the IBMWP, which is based on the ecological needs of Ephemeroptera, Plecoptera, and Trichoptera (EPT taxa), will not always indicate suitable habitat for dragonflies (Corbet 1999: 204). Whereas the EPT taxa are more sensitive to chemicals and dissolved oxygen, Odonata may be affected more by land use changes that affect riparian forest cover, the constancy of water flow, and the permanence of superficial waters.

This study shows that the odonate community can recover quickly from a catastrophic incident like a mining spill, even if there is complete extinction in a stretch of running water. However, human alteration of the fluvial system by continuous pollution or forest degradation can be much worse for odonate community in the long run, even if changes are gradual and do not drive populations to extinction.

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