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Effect of forest fires on a Mediterranean Odonata assemblage

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Abstract. Large-scale forest fires have shaped the Mediterranean landscape for millennia, causing a recurrent disturbance that constitutes a serious environmental issue. Following a devastating forest fire, changes in the Odonata larvae assemblage of a headwater stream were analysed during six consecutive years. Five dragonflies survived the fire as larvae: *Boyeria irene*, *Gomphus pulchellus*, *Onychogomphus forcipatus*, *O. uncatus*, and *Cordulegaster boltonii*. Mediterranean semivoltine odonates, in contrast to species with short life cycles, exhibited resilience to forest fires, suggesting that species with long life cycles were adapted to fire disturbances that periodically sweep through their habitats.

Key words. Dragonflies, larvae, Mediterranean streams, semivoltine species, wildfires.

Research Article

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All relevant data are within the paper.

Introduction

The Mediterranean basin is one of the world's biologically richest regions with remarkable levels of plant diversity and endemism (Médail & Quezel, 1999; Mittermeier et al., 1998). However, the region is facing a large array of anthropogenic pressures with habitat loss, pollution, climate change, and poor governance threatening the singular but vulnerable ecology of this biodiversity hotspot (Taylor et al., 2021).

One issue of conservation concern for the Mediterranean region is the frequency of forest fires and their impact on biodiversity (Pausas, 2004). Wildfires destroy forests and shrublands but also decrease soil fertility, cause flooding, erosion, and silting of dams and reservoirs (Bento-Gonçalves et al., 2012; Certini, 2005). While fire is an important natural process determining the evolution, structure, and function of the Mediterranean biome and a tool in ecosystem management and restoration ecology (Bond & Keeley, 2005; Keeley et al., 2012; Pausas et al., 2008), the added pressure of human-caused recurrent fires in the context of climate change and population growth have made it of global conservation significance (Caldararo, 2002; Syphard et al., 2009).

Disturbances as droughts, fires, and floods play a major role in determining the structure of benthic communities (Resh et al., 1988). Acting as pulse disturbances of the terrestrial environment of streams and rivers, forest fires may have short- and long-term influences on stream temperature, sediment, and nutrient levels (Gresswell, 1999). Thus, understanding the long-lasting impact of wildfires on Mediterranean stream communities may inform freshwater conservation efforts.

Odonates are a key component of stream communities with complex habitat requirements (May, 2019; Remsburg et al., 2008). They are predators in both larval and adult stages, a rare occurrence in other insect orders that lend them to occupy a critical place in both terrestrial and aquatic food webs (Corbet, 1999; Remsburg, 2011). The diversity of their life cycle has made them a key indicator group of the quality of the environment and the management of aquatic and terrestrial ecosystems (Bried & Samways, 2015; Clark & Samways, 1996; Samways et al., 2010). Knowledge of the ecological requirements of Odonata has been turned into a useful tool for the evaluation of the overall conservation status of aquatic environments and the bio-monitoring of wetlands (Miguel et al., 2017; Steward & Downing, 2008; Tennessen, 2019). Because of all their attributes, dragonflies and damselflies are viewed by many conservationists as "guardians of the watershed" (Clausnitzer & Jödicke, 2004).

Fourteen percent of the Odonata occurring in the Mediterranean basin are endemic (Riservato et al., 2009). While species richness is not always negatively correlated with pollution (Bouchelouche et al., 2015; Korbaa et al., 2018), many Mediterranean endemic odonates are threatened by water pollution and habitat degradation (Samraoui et al., 2010). The odonate diversity of Mediterranean watercourses is also positively associated with the density of the riverine vegetation and it is generally accepted that the most immediate danger to Odonata is the threat of destruction and impairment of their larval habitats (Riservato et al., 2009; Wildermuth, 1994). Although the impact of bushfires on vertebrates is well-documented, the corresponding effects on insect taxa are rarely examined (Goodman et al., 2022). The aim of the present study is show how the ever-increasing forest fires in some parts of the world, particularly regions with Mediterranean type climate, affect dragonflies and damselflies, a neglected topic so far.

Materials and methods

Study area

The Cañaveroso Stream is located in Monte Madroñalejo just at the upper part of the Guadiamar River basin, Seville province, SW Spain (Fig. 1). This basin occupies a surface of 1,880 km² and extends in North-South direction (Ferreras-Romero et al., 2009). The Guadiamar River originates in the western Sierra Morena Mountains at an altitude that varies from 400 to 450 m a.s.l. After 119 km, it joins the Guadalquivir River near its mouth (Borja et al., 2001). The freshwaters of the Cañaveroso Stream flow to the reservoir of the Agrio Stream, the main tributary of the Guadiamar River (Fig. 1).

Since 2015, Monte Madroñalejo (a natural area of undulating mountains with more than 7,400 ha) has become part of the Special Area of Conservation 'Corredor Ecológico del Río Guadiamar (ES6180005)' of the European Ecological Net Natura 2000 (Consejería de Medio Ambiente y Ordenación del Territorio, 2015; Council of the European Communities, 1992). The Guadiamar River connects the marshes of the Doñana National Park with the Dehesas de Sierra Morena Biosphere Reserve (Junta de Andalucía, 2010).

The study area houses a small heliport for firefighting (Aeródromo de Madroñalejo, CEDEFO). This infrastructure contributes to the maintenance and restoration of the conservation status of the natural values for which the Natura 2000 Network space (ZEC) was designated (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2014).

The climate is typically Mediterranean, divided into a rainy season from October to May and a dry season from June to September. Annual precipitation recorded

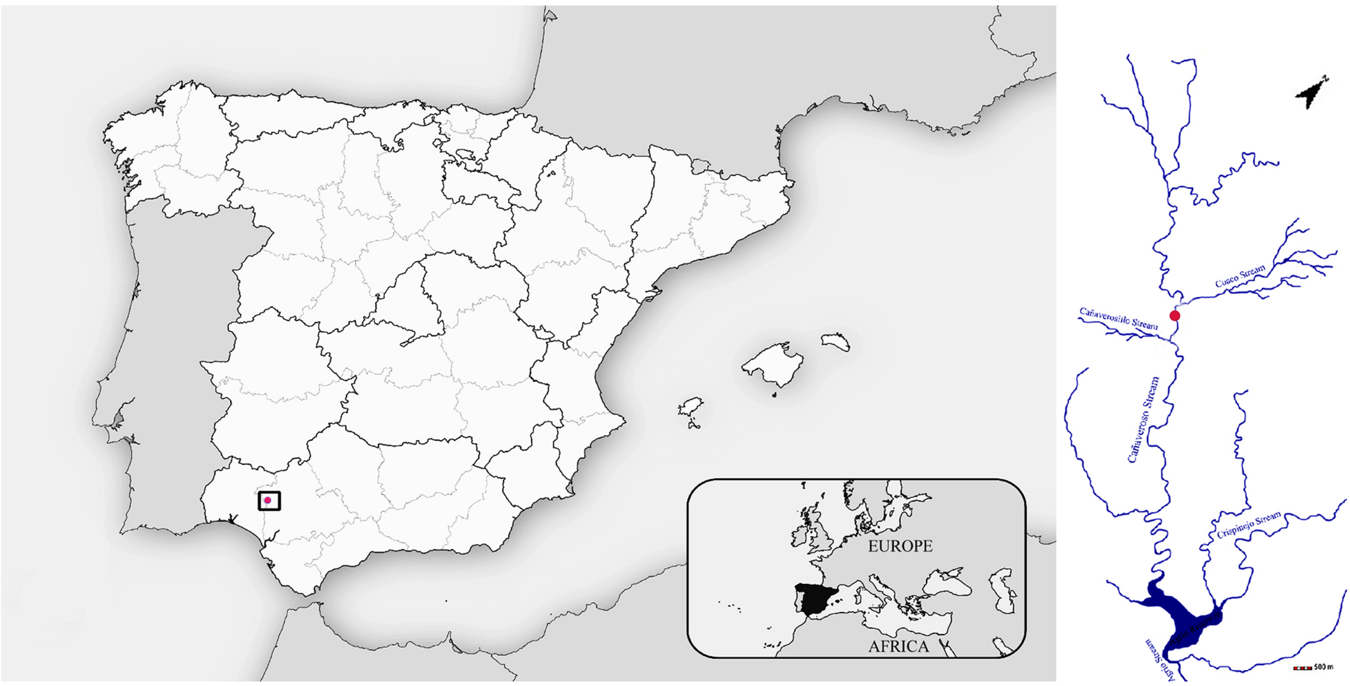

Figure 1. Sampling point at the Cañaveroso Stream basin and location of the Agrio reservoir, in Aznalcóllar (Seville), southwestern Spain.

Table 1. Physical parameters measured in the Cañaveroso stream: Tª (°C), water temperature; pH; DO, dissolved oxygen (mg/l); % O_2, oxygen saturation; Cond., conductivity (µS/cm); TDS (mg/l), total dissolved solids. In summer 2009 this stretch of stream lacked surface water.

	Winter 2005	Spring 2005	Autumn 2005	Winter 2006	Spring 2006	Autumn 2006	Winter 2007	Spring 2007	Autumn 2007	Winter 2008	Spring 2008	Summer 2008	Autumn 2008	Winter 2009	Spring 2009	Summer 2009	Autumn 2009	Winter 2010	Spring 2010	Autumn 2010
Tª	13.1	17.4	9.5	8.2	19.3	13.9	13.0	18.6	9.1	14.2	17.3	20.4	5.5	12.4	18.8	–	10.8	14.2	20.9	10.6
pH	–	–	–	–	–	–	7.58	7.70	7.49	7.70	7.53	7.28	7.70	7.93	7.38	–	7.72	7.24	7.05	7.56
Cond.	–	–	–	–	–	–	77.7	67.3	66.7	76.4	94.6	87.7	67.6	61.1	72.4	–	81.5	56.0	70.1	63.1
DO	8.98	6.88	10.28	9.02	7.11	9.97	11.09	8.73	9.32	6.80	7.22	8.04	6.55	10.05	7.35	–	12.74	10.04	7.67	11.90
% O_2	86.6	73.1	89.6	76.5	78.3	97.1	105.9	93.0	81.2	65.9	72.5	94.6	49.1	94.9	80.5	–	115.5	98.2	86.1	109.9
TDS	–	–	–	–	–	–	49.4	43.1	42.7	48.8	60.2	56.1	43.3	39.1	46.3	–	52.2	35.8	44.9	40.8

at Seville Airport from 1995 to 2010 was highly variable. It ranged from 254.5 mm (2005) to 908.6 mm (2010). The second lowest recorded annual precipitation coincided with the 2004 fire: 364.2 mm. The following two hydrological years after the fire, 2004/05 and 2005/06, were relatively dry years. There was no rapid recovery of the watercourses, but they were preserved from the accumulation of abundant amounts of ash could have submerged them. The average annual temperature recorded at the Seville Airport was very constant, ranging between 19.0ºC (1995) and 20.4ºC (2009) (AEMET 5783-Sevilla Aeropuerto).

The study area was originally covered by native perennial vegetation as found in a typical Mediterranean forest in which *Quercus ilex* and *Q. suber* were the dominant species. In recent decades, this native vegetation was, for the most part, replaced by re-stocked forest species (*Pinus pinaster*, *P. pinea*, *Eucalytus* spp.). On the banks of the watercourses there are still natural riparian forest formed by *Alnus glutinosa*, *Fraxinus angustifolia*, *Salix* spp., and *Populus alba*. The bed of these watercourses is composed mainly of schists in the riffles and sand in pools. Among the main causes of landscape changes are forest fires, deforestation for ranching and fragmentation of riparian forest.

The freshwater biodiversity of the study area is noteworthy with breeding populations of three Odonata species (*Macromia splendens* Pictet, 1843, *Oxygastra curtisii* (Dale, 1834), and *Gomphus graslinii* Rambur, 1842), considered threatened on the Mediterranean IUCN Red List (Riservato et al., 2009), found in the Cañaveroso Stream (Márquez-Rodríguez & Ferreras-Romero, 2008; Ferreras-Romero et al., 2009). These species are currently protected by Spanish legislation (Weihrauch & Weihrauch, 2006; Ministerio de Medio Ambiente, y Medio Rural y Marino, 2011).

The study area witnessed recently two large-scale fires, in spring 1995 and summer 2004. The latest affected 36.259 ha (27.822 ha were forest) and the entire length of the watercourse studied (iMA, 1996; iMA, 2005). Due to the burned wood management tasks, sampling of the watercourses studied here was not allowed in the months immediately after the fire but the forestry authorities allowed seasonal sampling to obtain reliable data on the dynamics of the aquatic macroinvertebrate community six months after the fire.

Sampling

From the first winter after the fire to the late autumn 2010, seasonal samplings were carried out in winter, spring, and autumn at a shallow riffle stretch (37.564483 N, 6.364695 W), with a canopy of *Alnus glutinosa*, in the Cañaveroso Stream (Fig. 2). Over a six-year period, from 18 March 2005 to 15 December 2010, a total of 18 samples were collected. Moreover, in the summer 2008 an additional sample was taken. In the summer 2009, this stretch of stream was also visited but lacked surface water.

Environmental variables

Physical characteristics of water were measured in situ. Since winter 2005, at each sampling water temperature and dissolved oxygen (DO) were measured with a Crison Oxi 330 whereas conductivity, total dissolved solids (TDS), and pH were recorded with a Crison MM 40 since autumn 2006.

Water temperature records ranged from 5.5 to 20.9°C in autumn 2008 and spring 2010, respectively (Table 1). Dissolved oxygen concentration ranged from 6.5 mg/l (saturation 49.1%) to 12.7 mg/l (115.5%) in autumns 2008 and 2009, respectively. Conductivity records were very low. Values ranged from 56.0 µS/cm in winter 2010 to 94.6 µS/cm in spring 2008. Total dissolved solids (TDS) ranged from 35.8 to 60.2 mg/l in winter 2010 and spring 2008, respectively. The pH values oscillated from 7.05 to 7.93 in spring 2010 and winter 2009, respectively.

Odonata larvae sampling

Collection of Odonata exuviae and larvae is probably the best method to define the breeding assemblage of a given site in regions where the species can be reliably identified (Golfieri et al., 2016). At each sampling, Odonata larvae were collected with a kick net with an opening of 25 × 25 cm and 250 µm mesh, taken in 100 m transect across the watercourse. Samples were taken from all microhabitats, including submerged and emerged vegetation. Hand-net sampling, limited to 0.75 m in depth, was used, as it is well adapted to old riverbeds with dense aquatic vegetation. Sampled odonates were transferred to ethanol (70%) and later identified in the laboratory to species level using a Nikon SMZ800 binocular microscope, according to Aguesse (1968), Askew (2004), Carchini (1983), Heideman & Seidenbusch (2002). Dominance index of McNaughton & Wolf (1970) and Shannon-Wiener index of Diversity ($H' = -\sum p_i \cdot \ln p_i$) were used to show changes in Odonata assemblages over time.

Biometric methods

In the laboratory, those Odonata larvae collected during the first sampling year postfire (2005) were measured. Head width (HW) and metathoracic wing sheath length (WSL) of each larva were measured to the nearest 0.05 mm using a Nikon SMZ800 binocular microscope with an eyepiece micrometer. The number of abdominal segments covered by the wing pads, if present, was also recorded. The criteria for instar assignment were head width (HW), metathoracic wing sheath length (WSL), and the ratio WSL/HW (Ferreras-Romero, 1997; Ferreras-Romero et al., 1999; Tennessen, 2017). On the basis of these data, each larva was assigned to one of the last three stadia (F-0, F-1, F-2) or designated “smaller” (F-S). According to the instar assigned, the age of each larva was estimated.

Figure 2. Stream Cañaveroso: (a) General view of the canyoned stream; (b) aspect of the stream with the presence of a canopy in winter 2007; (c) firewall built in spring of the year 2009, close to the Cañaveroso Stream. It is 12 m wide and no vegetation is appreciable because it is eliminated with mechanical works.

Table 2. Odonate larvae collected in the Cañaveroso Stream, southwestern Spain. Semi-/partivoltine species in bold. The two years after the fire shaded in grey.

	Winter 2005	Spring 2005	Autumn 2005	Winter 2006	Spring 2006	Autumn 2006	Winter 2007	Spring 2007	Autumn 2007	Winter 2008	Spring 2008	Summer 2008	Autumn 2008	Winter 2009	Spring 2009	Autumn 2009	Winter 2010	Spring 2010	Autumn 2010
Calopteryx haemorrhoidalis							1	1	2			2	1	1					
Chalcolestes viridis					1														
Platycnemis latipes								3											
Boyeria irene	14	6	2	4	28	2	4	6	5	12	3	13	3	8	7		2	1	3
Gomphus pulchellus	2				1			1		1									
Onychogomphus forciptaus		4	4	3	1		12	6	3	5	1	1	1	3	4			1	6
Onychogomphus uncatus	75	37	3	2	2	2	7	10	9	10		6	5	25	1		9	8	1
Cordulegaster boltonii	2	1																	
Orthetrum chrysostigma											1	1							

Results

Species composition

A total of 405 larvae belonging to nine species were collected (Table 2). Other four species were only observed as adults: *Ischnura graellsii* (Rambur, 1842), *Orthetrum brunneum* (Fonscolombe, 1837), *Crocothemis erythraea* (Brullé, 1832), and *Sympetrum fonscolombii* (Selys, 1840). Two specimens in teneral stage belonging to two last species were recorded in August 2008 and June 2010, respectively.

Two anisopterans, *Boyeria irene* (Fonscolombe, 1838) and *Onychogomphus uncatus* (Charpentier, 1840), were the most abundant species, amounting to 30.4% and 50.6% of the total odonates, respectively. Annual Dominance index was always high, ranging between 91.3 (2005) and 67.1 (2007) (Table 3). The highest values of the Diversity index (> 1.2) were reached in 2007 (1.41) and 2008 (1.29) (Table 3).

Indication of larval survival during the fire

In the first sampling year, only larvae belonging to five species were found: *B. irene*, *Gomphus pulchellus* Selys, 1840, *Onychogomphus forcipatus* (Linnaeus, 1758), *O. uncatus*, and *Cordulegaster boltonii* (Donovan, 1807). Samples in 2005 included final instar larvae of these five species.

Table 3. Annual values of Dominance index (McNaughton & Wolf, 1970) and Shannon index of Diversity (H').

	2005	2006	2007	2008	2009	2010
Dominance index	91.3	86.9	67.1	76.7	83.7	80.6
H'	0.78	0.87	1.41	1.29	1.05	0.97

The summer of oviposition is considered the starting point of the life cycle. In this way, final instar larvae (F-0) of *C. boltonii* collected in 2005 were estimated 30–33 months old (winter sample) and 33–36 months old (spring sample) (Fig. 3). Ages of final and penultimate instar larvae collected of the rest four species were estimated 18–21 months old (winter sample) or 21–24 months old (spring sample). Only *B. irene* has egg diapause along the summer-autumn-winter period (nine months). Clearly, the larvae of these five species collected in March (winter sample) and May 2005 (spring sample) had survived, in

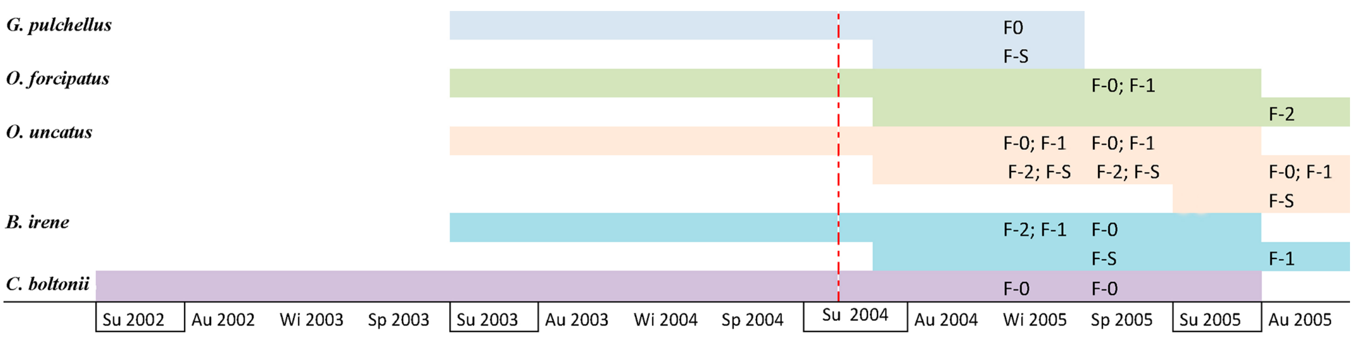

Figure 3. Dragonfly species (larvae) collected in the Cañaveroso Stream after the 2004 fire. The last three instars (F-0, F-1, F-2) are indicated. The summer of oviposition estimated is considered the starting point of the life cycle. Broken red line represents the fire that occurred in the summer of 2004.

the bed of the Cañaveroso Stream, the forest fire that occurred at the end of July 2004, only eight and ten months, respectively, before taking these two samples.

Discussion

Thousands of hectares in the study area have burnt in two large forest fires that occurred in 1995 and 2004. The latter is considered one of the largest that has taken place in Andalusia in the 21st century, with more than 36,000 ha burnt during one whole week (iMA 1996; Costa, 2005). Recurring fires with lesser magnitude are frequent in the studied area, such as those that occurred in 2017, 2020, and 2022. However, the fire of 2004 that swept across the study area was exceptional due to its magnitude. Any surviving odonate larvae must have been able to withstand extreme conditions of high temperatures generated over several days. According to Dehedin et al. (2013), after the fire, autumn precipitations might have produced ash washing and input of sediments to the streams with probable adverse impacts on the surviving aquatic fauna. It is unknown whether or not there was an input of ashes and sediments in the stream here studied. Fortunately, rainfall was relatively scarce in the autumn following the fire.

The distribution and abundance of aquatic insects such as Odonata are very much dependent on their sensitivity to habitat alteration or pollution (Scheffer et al., 1984; Vinson & Hawkins, 1998). Likewise, consequence of the Mediterranean seasonality there is a greater flow of surface water during winter and spring, and a much lower flow in summer and early autumn. The maintenance of surface water in permanent streams allows for a high capacity of self-purification if the water quality is altered (Bonada et al., 2000). Abiotic variables (water temperature, substrate, water flow, altitude, hydroperiod) and vegetation cover could explain habitat preference and species composition (Menezes et al., 2010) whereas biotic interactions (predation, competition) may also play an important role in shaping community structure (Vinson & Hawkins, 1998).

Moderate pollution as an anthropogenic stressor might increase Odonata species richness at intermediate levels (Connell, 1978; Wilkinson, 1999). A similar effect can occur in seasonal courses where water becomes scarce or in agricultural areas (Ferreras-Romero & Márquez-Rodríguez, 2014; Ferreras-Romero et al., 2009). Often, degraded sites are colonized by opportunistic thermophilic species (Bouhala et al., 2019; Morghad et al, 2019). Therefore, Odonata might be useful group to analyse the recovery of a river after a severe alteration with effects that can be long-lasting as a severe wildfire in Mediterranean region.

Odonata occurrence

Throughout the present study, the Cañaveroso Stream hosted abundant *B. irene* and *O. uncatus* populations. Other three species with long-life cycles were also collected within the first two postfire years: *G. pulchellus*, *O. forcipatus*, and *C. boltonii* (Table 2). Likewise, during the years 2007 and 2008 took place the natural recovery of the alder forest, and this coincided with reaching maximum richness of the odonate assemblage. Our results reinforce the idea of a recovery of the optimal natural conditions from 2007.

Life histories and fire resilience

It is known that responses of insects to floods or droughts are directly related to their life cycles, dispersal abilities, and the availability of refugia (Bixby et al., 2015; Rouault et al., 2006; Samraoui et al., 1998). Short-lived and fast-colonizing aquatic insects often dominate after fires, floods, or droughts (Bogan et al., 2015; Malison & Baxter, 2010; Minshall, 2003; Miyake et al., 2003).

However, the five odonates collected in Cañaveroso Stream within the first two postfire years have semivoltine or partivoltine life cycle (Ferreras-Romero, 1997; Ferreras-Romero & Corbet, 1999; Ferreras-Romero & García-Rojas, 1995; Ferreras-Romero et al., 1999). The biometry of the collected larvae indicated that many of them were aged over one year, originating from ovipositions that happened previous to the fire. Our results suggest that Mediterranean semivoltine odonates may be very resilient to forest fires, indicating that species with long life cycles may be adapted to this type of disturbance that periodically occurs in the Mediterranean forests. Other species, whose egg or larval stages probably are more vulnerable to wildfires, must rely on recolonization and dispersal to reoccupy a site.

Firewalls and environmental disturbances

Fire prevention generates considerable expenses in Spain. Only in Andalusia, 222 million of euros were spent in 2005 (iMA, 2005). In the study area, one of the most important forest management actions was the construction of large firewalls (12 m wide) (iMA, 2010). One of them that directly affected the stretch of Cañaveroso Stream studied here was built in winter 2009. It runs along the slopes that drain water to the third-order course here studied through the Cuaco Stream (Fig. 2). The directionality of these structures is perpendicular to the layout of the stream courses themselves. The rains that fell after construction of this firewall mobilized large amounts of schists and sands that ended up in the bed of the course studied. The year 2010 was especially rainy (more than 900 mm at Seville Airport), surpassing the annual records of the previous fifteen years. The accumulation of sediments was of such magnitude that the water column of a pool nearby to stretch sampled barely reached 70 cm of maximum depth in late spring 2010 (June), while it was close to 200 cm in the spring 2007 (May).

On the other hand, the forest management (silviculture) that was carried out in these streams, consisting of the cleaning of riparian vegetation, might have increased the adverse impact of the forest fire itself. The summer of 2009 was dry. To remove the build-up of dry scrub, the forest management agency carried out a cleaning of the riparian forest during the summer and early autumn (iMA, 2010). They also proceeded to cut and remove green branches in the alder riparian forest.

Ash acidification and sediment accumulation in streams may affect the survival of aquatic insects (Westveer et al., 2017). Furthermore, forest fires may also cause a significant disappearance or decrease in the volume of litter that reaches riverbeds in the first two years after the fire disturbance (Rodríguez-Lozano et al., 2015). Because of these recurrent disturbances, studies carried out in low-order courses have shown that most species occur in low numbers and very few species are favoured for a long enough period to establish dominance to the extent that their congeners are excluded (Anderson, 1992).

The interstitial zones of aquatic environments as well as the hyporheic layer (Mugnai et al., 2015) are known to act as a refuge for many benthic macroinvertebrates (Sánchez-Ortega & Alba-Tercedor, 1990; Stanford & Gaufin, 1974; Stanford & Ward, 1988; Williams, 1984), especially during floods and dry periods (Jacobi & Cary, 1996; Kazanci et al., 2009), and confirmation is building up in the case of Odonata larvae (Reygrobellet & Castella, 1987; Suhling & Müller 1996; Wildermuth 2005). The clogging of ponds can significantly alter the development of the larval stage of species with long life cycle (Dehedin et al., 2013; Descloux et al., 2013). This clogging might also be consequence of firewall inappropriate designs. Nevertheless, more data are required to strengthen this hypothesis. Clearly, some Anisopteran species appear to be well adapted (by larval survival) to recurring forest fires. However, they probably need deep ponds in the beds or others shelters to overcome those extremely dry summers, quite frequent in the Mediterranean area, such as the one that occurred in 2009. In the autumn sample of that year, no odonate larvae were found in the stretch of rapids studied.

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References

Aguesse, P. (1968). *Les Odonates de l'Europe Occidentale, du Nord de l'Afrique et des lies Atlantiques.* Paris: Masson et Cíe Ed.

Anderson, N. H. (1992). Influence of disturbance on insect communities in Pacific Northwest streams. *Hydrobiologia*, *248*, 71–92. doi:10.1007/BF00008887

Askew, R. R. (2004). *The dragonflies of Europe*. Colchester: Harley Books. doi:10.1163/9789004474383

Bento-Gonçalves, A., Vieira, A., Úbeda, X. & Martin, D. (2012). Fire and soils: Key concepts and recent advances. *Geoderma*, *191*, 3–13. doi:10.1016/j.geoderma.2012.01.004

Bixby, R. J., Cooper, S. D., Gresswell, R. E., Brown, L. E., Dahm, C. N. & Dwire, K. A. (2015). Fire effects on aquatic ecosystems: an assessment of the current state of the science. *Freshwater Science*, *34*, 1340–1350. doi:10.1086/684073

Bogan, M. T., Boersma, K. S. & Lytle, D. A. (2015). Resistance and resilience of invertebrate communities to seasonal and supraseasonal drought in arid-land headwater streams. *Freshwater Biology*, *60*, 2547–2558. doi:10.1111/fwb.12522

Bonada, N., Rieradevall, M. & Prat, N. (2000). Temporalidad y contaminación como claves para interpretar la biodiversidad de macroinvertebrados en un arroyo mediterraneo (Riera de Sant Cugat, Barcelona). *Limnetica*, *18*, 81–90. doi:10.23818/limn.18.07

Bond, W. & Keeley, J. (2005). Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution*, *20*, 387–394. doi:10.1016/j.tree.2005.04. 025

Borja, F., López Geta, J. A., Martín Machuca, M., Mantecón, R., Mediavilla, C., del Olmo, P., Palancar, M. & Vives, R. (2001). Marco geográfico, geológico e hidrológico regional de la cuenca del Guadiamar. *Boletín Geológico y Minero*, Vol. Especial, 13–34.

Bouchelouche, D., Kherbouche-Abrous, O., Mebarki, M., Arab, A. & Samraoui, B. (2015). The Odonata of Wadi Isser (Kabylia, Algeria): Status and environmental determinants of their distribution. *Revue d'Ecologie (La Terre et la Vie)*, *70*, 248–260. doi:10.3406/revec.2015.1787

Bouhala, Z., Chakri K. C., Márquez-Rodríguez, J., Ferreras-Romero, M., Samraoui F. & Samraoui, B. (2019). Ecological correlates of odonate assemblages of a Mediterranean stream, Wadi Cherf, northeastern Algeria: implications for conservation. *International Journal of Odonatology*, *22*, 181–197. doi:10.1080/13887890.2019.1688199

Bried, J. T. & Samways, M. J. (2015). A review of odonatology in freshwater applied ecology and conservation science. *Freshwater Science*, *34*, 1023–1031. doi:10.1086/682174

Caldararo, N. (2002). Human ecological intervention and the role of forest fires in human ecology. *The Science of the Total Environment*, 292, 141–165. doi:10.1016/S0048-9697(01) 01067-1

Carchini, G. (1983). *A key to the Italian odonate larvae*. *Societas Internationalis Odonatologica Rapid Communications (Supplements)*, *1*, 1–101.

Certini, G. (2005). Effects of fire on properties of forest soils: A review. *Oecologia*, *143*, 1–10. doi:10.1007/s00442-004-1788-8

Clark, T. E. & Samways, M. J. (1996). Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *Journal of Applied Ecology*, *33*, 1001–1012. doi:10.2307/2404681

Clausnitzer, V. & Jödicke, R. (2004). Guardians of the watershed (Editorial). *International Journal of Odonatology*, *7*, 111. doi:10.1080/13887890.2004.9748202

Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, *199*, 1302–1310. doi:10.1126/science.199.4335.1302

Consejería de Medio Ambiente y Ordenación del Territorio (2015). Decreto 1/2015, de 13 de enero, por el que se declaran las Zonas Especiales de Conservación de la Red Ecológica Europea Natura 2000 Acebuchales de la Campiña Sur de Cádiz (ES6120015), Cola del Embalse de Bornos (ES6120002), Cola del Embalse de Arcos (ES6120001), Río Guadalmez (ES6130004), Sierra de Santa Eufemia (ES6130003) y Corredor Ecológico del Río Guadiamar (ES6180005). *BOJA,* 51, 22–108.

Corbet, P. S. (1999). *Dragonflies: Behaviour and ecology of Odonata*. Colchester: Harley Books.

Costa, J. C. (2005). Restauración de zonas incendiadas. *MA medioambiente*, *49*, 28–31.

Council of the European Communities (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities*, *L206*, 7–50.

Dehedin, A., Dole-Olivier, M-J., Piscart, C., Mimoun, D., Bornette, G. & Marmonier, P. (2013). Long-term changes and drying modality affect interstitial assemblages of alluvial wetlands. *Wetlands*, *33*, 537–550. doi:10.1007/s13157-013-0411-3

Descloux, S., Datry, T. & Marmonier, P. (2013). Benthic and hyporheic invertebrate assemblages along a gradient of increasing streambed colmation by fine sediment. *Aquatic Sciences*, *65*, 1532–1544. doi:10.1007/s00027-013-0295-6

Ferreras-Romero, M. (1997). The life history of *Boyeria irene* (Fonscolombe, 1838) (Odonata: Aeshnidae) in the Sierra Morena Mountains (southern Spain), *Hydrobiologia*, *345*, 109–116.

Ferreras-Romero, M., Atienzar, M. D. & Corbet, P. S. (1999). The life cycle of *Onychogomphus uncatus* (Charpentier, 1840) (Odonata: Gomphidae) in the Sierra Morena Mountains (southern Spain): an example of protracted larval development in the Mediterranean basin. *Archiv für Hydrobiologie*, *144*, 215–228. doi:10.1127/archiv-hydrobiol/144/1999/215

Ferreras-Romero, M. &. Corbet, P. S. (1999). The life cycle of *Cordulegaster boltonii* (Donovan, 1807) (Odonata: Cordulegastridae) in the Sierra Morena Mountains (southern Spain). *Hydrobiologia*, *405*, 39–48. doi:10.1023/A:1003763819991

Ferreras-Romero, M. & García-Rojas, A. M. (1995). Life-history patterns and spatial separation exhibited by the odonates from a Mediterranean inland catchment in southern Spain. *Vie et Milieu*, *45*, 157–166.

Ferreras-Romero, M. & Márquez-Rodríguez, J. (2014)**.** Odonatos asociados a cursos estacionales de Sierra Morena (sur de España). *Boletín de la Asociación española de Entomología*, *38*, 173–184.

Ferreras-Romero, M., Márquez-Rodríguez, J. & Ruiz-García, A. (2009). Implications of anthropogenic disturbance factors on the Odonata assemblage in a Mediterranean fluvial system. *International Journal of Odonatology, 12*, 413–428. doi:10.1080/13887890.2009.9748354

Golfieri, B., Hardersen, S., Maiolini, B. & Surian, N. (2016). Odonates as indicators of the ecological integrity of the river corridor: development and application of the Odonate River Index (ORI) in northern Italy. *Ecological Indicators*, *61*, 234–247. doi:10.1016/j.ecolind.2015.09.022

Goodman, A. M., Kass, J. M. & Ware, J. (2022). Dynamic distribution modelling of the swamp tigertail dragonfly *Synthemis eustalacta* (Odonata: Anisoptera: Synthemistidae) over a 20-year bushfire regime. *Ecological Entomology*, 1–17. doi:10.1016/j.ecolind.2015.09.022

Gresswell, R. E. (1999). Fire and aquatic ecosystems in forested biomes of North America. *Transactions of the American Fisheries Society*, *128*, 193–214. doi:10.1577/1548-8659(1999)128<0193:FAAEIF>2.0.CO;2

Heidemann, H. & Seidenbusch, R. (2002). *Larves et exuvies des libellules de France et d'Allemagne (sauf de Corse)*. Bois-d'Arcy: Société Française d'Odonotologie.

iMA, 1996. *Medio Ambiente en Andalucía. Informe 1996*. Consejería de Medio Ambiente, Junta de Andalucía.

iMA, 2005. *Medio Ambiente en Andalucía. Informe 2005*. Consejería de Medio Ambiente, Junta de Andalucía.

iMA, 2010. *Medio Ambiente en Andalucía. Informe 2010*. Consejería de Medio Ambiente, Junta de Andalucía.

Jacobi, G. S. & Cary, J. (1996). Winter stoneflies (Plecoptera) in seasonal habitats in New Mexico, USA. *Journal of the North American benthological Society*, *15*, 690–699. doi:10.2307/1467816

Junta de Andalucía (2010). Ley 7/2010, de 14 de julio, para la Dehesa. *BOJA*, *144*, 6–11.

Kazanci, N., Öz, B., Dügel, M., Ertunc, O. & Türkmen, G. (2009). First faunistic survey and canonical correspondence analysis of interstitial aquatic insect assemblages of running waters in Turkey. *Review of Hydrobiology*, *1*, 1–10.

Keeley, J. E., Bond, W. J., Bradstock, R. A., Pausas, J. G. & Rundel, P. W. (2012). *Fire in Mediterranean ecosystems: ecology, evolution and management*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139033091

Korbaa, M., Ferreras-Romero, M., Ruiz-García, A. & Boumaiza, M. (2018). TSOI – a new index based on Odonata populations to assess the conservation relevance of watercourses in Tunisia. *Odonatologica*, *47*, 43–72.

Malison, R. W. & Baxter, C. V. (2010). Effects of wildfire of varying severity on benthic stream insect assemblages and emergence. *Journal of the North American benthological Society*, *29*, 1324–1338. doi:10.1899/09-022.1

Márquez-Rodríguez, J. & Ferreras-Romero, M. (2008). Contribución al conocimiento de la distribución ibérica de *Macromia splendens* (Pictet, 1843) (Odonata: Corduliidae). *Boletín de la Asociación española de Entomología*, *32*, 371–374.

May, M. L. (2019). Odonata: Who they are and what they have done for us lately: Classification and ecosystem services of dragonflies. *Insects*, *10*, 62. doi:10.3390/insects10030062

McNaughton, S. J. & Wolf, L. L. (1970). Dominance and the niche in ecological systems. *Science*, *167*, 131–139. doi:10.1126/science.167.3915.131

Médail, F. & Quézel, P. (1999). Biodiversity hotspots in the Mediterranean basin: setting global conservation priorities. *Conservation Biology*, *13*, 1510–1513. doi:10.1046/j.1523-1739.1999.98467.x

Menezes, S., Baird, D. J. & Soares, A. M. V. M. (2010). Beyond taxonomy: a review of macroinvertebrate trait-based community descriptors as tools for freshwater biomonitoring. *Journal of applied Ecology*, *47*, 711–719. doi:10.1111/j.1365-2664.2010.01819.x

Miguel, T. B., Oliveira-Junior, J. M. B., Ligeiro, R. & Juen, L. (2017). Odonata (Insecta) as a tool for the biomonitoring of environmental quality. *Ecological Indicators*, *81*, 555–566. doi:10.1016/j.ecolind.2017.06.010

Ministerio de Agricultura, Alimentación y Medio Ambiente (2014). Resolución de 30 de diciembre de 2013, de la Secretaría de Estado de Medio Ambiente, sobre la evaluación de impacto ambiental del proyecto Aeródromo de Madroñalejo (Sevilla). Base contra incendios de Andalucía. *BOE*, *32*, 9927–9935.

Ministerio de Medio Ambiente, y Medio Rural y Marino (2011). Real Decreto 139/2011, de 4 de febrero, para el desarrollo del Listado de Especies Silvestres en Régimen de Protección Especial y del Catálogo Español de Especies Amenazadas. *BOE*, *46*, 20912–20951.

Minshall, G. W. (2003). Responses of stream benthic macroinvertebrates to fire. *Forest Ecology and Management*, *178*, 155–161. doi:10.1016/S0378-1127(03)00059-8

Mittermeier, R. A., Myers, N., Thomsen, J. B., da Fonseca, G. A. B. & Olivieri, S. (1998). Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. *Conservation Biology*, *12*, 516–520. doi:10.1046/j.1523-1739.1998.012003516.x

Miyake, Y., Hiura, T., Kuhara, N. & Nakano, S. (2003). Succession in a stream invertebrate community: a transition in species dominance through colonization. *Ecological Research*, *18*, 493–501. doi:10.1046/j.1440-1703.2003.00573.x

Morghad, F., Samraoui, F., Touati, L. & Samraoui, B. (2019). The times they are a changin': impact of land-use shift and climate warming on the odonate community of a Mediterranean stream over a 25-year period. *Vie et Milieu*, *69*, 25–33.

Mugnai, R., Messana, G. & Di Lorenzo, T. (2015). The hyporheic zone and its functions: revision and research status in Neotropical regions. *Brazilian Journal* of *Biology*, *75*, 524–534. doi:10.1590/1519-6984.15413

Pausas, J. G. (2004). Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). *Climatic Change*, *63*, 337–350. doi:10.1023/B:CLIM.0000018508.94901.9c

Pausas, J. G., Llovet, J., Rodrigo, A. & Vallejo, R. (2008). Are wildfires a disaster in the Mediterranean basin? – A review. *International Journal of Wildland Fire*, *17*, 713–723. doi:10.1071/WF07151

Remsburg, A. (2011). Relative influence of prior life stages and habitat variables on dragonfly (Odonata: Gomphidae) densities among lake sites. *Diversity*, *3*, 200–216. doi:10.3390/d3020200

Remsburg, A. J., Olson, A. C. & Samways, M. J. (2008). Shade alone reduces adult dragonfly (Odonata: Libellulidae) abundance. *Journal of Insect Behavior*, *21*, 460–468. doi:10.1007/s10905-008-9138-z

Resh, V. H., Brown, A. V., Covich, A. P., Gurtz, M. E., Li, H. W., Minshall, ... Wissmar, R. C. (1988). The role of disturbance in stream ecology. *Journal of the North American Benthological Society*, *7*, 433–455. doi:10.2307/1467300

Reygrobellet, J. L. & Castella, E. (1987). Some observations on the utilization of groundwater habitats by Odonata larvae in an astatic pool of the Rhône alluvial plain (France). *Advances in Odonatology*, *3*, 127–134.

Riservato, E., Boudot, J. P., Ferreira, S., Jović, M., Kalkman, V. J., Schneider, W., Samraoui, B. & Cuttelod, A. (2009). *The status and distribution of dragonflies of the Mediterranean Basin.* Gland: IUCN. doi:10.2305/IUCN.CH.2009.18.en

Rodríguez-Lozano, P. Rieradevall, M., Rau, M. A. & Prat, N. (2015). Long-term consequences of a wildfire for leaf-litter breakdown in a Mediterranean stream. *Freshwater Science*, *34*, 1482–1493. doi:10.1086/683432

Rouault, G., Candau, J. N., Lieutier, F., Nageleisen, L. M., Martin, J. C. & Warzée, N. (2006). Effects of drought and heat on forest insect populations in relation to the 2003 drought in Western Europe. *Annals of Forest Science*, *63*, 613–624. doi:10.1051/forest:2006044

Samraoui, B., Boudot, J.-P., Ferreira, S., Riservato, E., Jovic, M., Kalkman, V. J. & Schneider, W. (2010). The status and distribution of dragonflies. In: N. Garcia, A. Cuttelod & D. Abdul Malak (Eds), *The status and distribution of freshwater biodiversity in Northern Africa*. pp. 51–70. Gland: IUCN.

Samraoui, B., Bouzid, S., Boulahbal, R. & Corbet, P. S. (1998). Postponed reproductive maturation in upland refuges maintains life-cycle continuity during the hot, dry season in Algerian dragonflies (Anisoptera). *International Journal of Odonatology*, *1*, 118–135. doi:10.1080/13887890.1998.9748100

Samways, M.J., McGeoch, M.A. & New, T.R. (2010). *Insect conservation: a handbook of approaches and methods*. Oxford: Oxford University Press.

Sánchez-Ortega, A. & Alba-Tercedor, J. (1990). Life cycle of some species of Plecoptera in Sierra Nevada (South of Spain). In: I. C. Campbell (Ed.), *Mayflies and Stoneflies Life Histories and Biology.* pp. 43–52. Dordrecht: Kluwer Academic Publishers. doi:10.1007/978-94-009-2397-3_6

Scheffer, M., Achterberg, A. A. & Beltman, S. (1984). Distribution of macroinvertebrates in a ditch in relation to the vegetation. *Freshwater Biology*, 14, 367–370. doi:10.1111/j.1365- 2427.1984.tb00160.x

Stanford, J. A. & Gaufin, A. R. (1974). Hyporheic communities of two Montana Rivers. *Science*, *185*, 700–702. doi:10.1126/science.185.4152.700

Stanford, J. A. & Ward, J. V. (1988). The hyphoreic habitat of river ecosystems. *Nature*, *335*, 64–66. doi:10.1038/335064a0

Steward, T. W. & Dowing, J. A. (2008). Macroinvertebrate communities and environmental conditions in recently constructed wetlands. *Wetlands, 28*, 141–150. doi:10.1672/06-130.1

Suhling, F. & Müller, O. (1996). *Die Flußjungfern Europas (Gomphidae)*. Die Neue Brehm-Bücherei, Band 628. – Magdeburg: Westarp-Wissenschaften.

Syphard, A. D., Radeloff, V. C., Hawbaker, T. J. & Stewart, S. I. (2009). Conservation threats due to human-caused increases in fire frequency in Mediterranean-climate ecosystems. *Conservation Biology*, *23*, 758-769. doi:10.1111/j.1523-1739.2009.01223.x

Taylor, N. G., Grillas, P., Al Hreisha, H., Balkız, Ö., Borie, M., Boutron, O., ... Sutherland, W. J. (2021). The future for Mediterranean wetlands: 50 key issues and 50 important conservation research questions. *Regional Environmental Change, 21*, 33. doi:10.1007/s10113-020-01743-1

Tennessen, K. (2017). A method for determining stadium number of late stage dragonfly nymphs (Odonata: Anisoptera). *Entomological News*, *126*, 299–306. doi:10.3157/021.126.0407

Tennessen, K. J. (2019). *Dragonfly nymphs of North America: An Identification Guide*. Cham: Springer. doi:10.1007/978-3-319-97776-8

Vinson, M. R. & Hawkins, C. P. (1998). Biodiversity of stream insects: Variation at local, basin and regional scales. Annual Review of Entomology, *43*, 271–293. doi:10.1146/annurev.ento.43.1.271

Weihrauch, F. & Weihrauch, S. (2006). Records of protected dragonflies from Rio Tera, Zamora province, Spain (Odonata). *Boletín de la Sociedad Entomológica Aragonesa*, *38*, 337–338.

Westveer, J. J., Verdonschot, P. F. M. & Verdonschot, R. C. M. (2017). Substrate homogenization affects survival and fitness in the lowland stream caddisflies *Micropterna sequax* and *Potamophylax rotundipennis*: a mesocosm experiment. *Freshwater Science*, *36*, 585–594. doi:10.1086/692940

Wildermuth, H. (1994). Habitatselektion bei Libellen. *Advances in Odonatology*, *6*, 223–257.

Wildermuth, H. (2005). Beitrag zur Larvalbiologie von *Boyeria irene* (Odonata: Aeshnidae). *Libellula*, *24*, 1–30.

Williams, D. D. (1984). The hyporheic zone as a habitat for aquatic insects and associated arthropods. In: V. H. Resh & D. R. Rosenberg (Eds.), *The ecology of aquatic insects*. pp. 430–455. New York: Praeger Publishers.

Wilkinson, D. M. (1999). The disturbing history of intermediate disturbance. *Oikos*, *84*, 145–147. doi:10.2307/3546874