

# 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

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**ABSTRACT.** – We assessed the observed effects of land-use alterations and global warming by analyzing changes in the Odonata community of a Mediterranean stream in northeastern Algeria, sampled at a 25-year interval. Results indicate that species richness has increased from 13 to 21 species. However, the apparent increase in species richness seemed to mirror recent physical and chemical changes brought upon the stream. In particular, these anthropogenic environmental changes seemed to have been driving a large-scale shift in the composition of the Odonata community of Wadi Bouaroug with an influx of widespread, thermophilic species (*Paragomphus genei*, *Crocothemis erythraea*, *Sympetrum fonscolombii*, *Trithemis* spp.) at the expense of rare, stenotypic species (*Coenagrion puella*, *Gomphus lucasii*). In the light of impending and challenging climatic scenarios, we urge that steps should be taken to set up more long-term monitoring schemes and research of North African streams that may provide insights into causal mechanisms of global changes.

## INTRODUCTION

There is compelling evidence that our planet is facing a global biodiversity crisis driven by human demography, massive land conversion and climate warming (Hansen *et al.* 2001). Worldwide, biodiversity depletion is being achieved through extinction, alteration of ecological communities and homogenization. Considerable attention has been given to how changes in land use are adversely affecting biodiversity (Frishkoff *et al.* 2016). Likewise, climate warming, although global in its impact, is expected to have stronger effects in different parts of the world like in North Africa (Vizy & Cook 2012, Russo *et al.* 2016), a region considered as a hotspot for biodiversity (Médail & Quézel 1999). However, North African countries are also projected to become global hotspots for drought in the coming decades, thus testing the resilience and adaptive capacity of their inhabitants (World Bank 2017).

Global changes are particularly impacting freshwater ecosystems (Heino *et al.* 2009, Fenoglio *et al.* 2010). If the ecological degradation of streams and rivers is worldwide (Paul & Meyer 2001), these pressures are exacerbated in arid North Africa where human encroachment, water abstraction, reservoir construction, flow regulation and pollution have altered considerably the riverine landscape and modified its function (Hafiane *et al.* 2016). Just like temporary ponds, Mediterranean streams and North African wadis might be ideally suited for monitoring

the effects of habitat conversion and climate change on aquatic communities (Lawrence *et al.* 2010).

Most research focusing on climate-change impact on Mediterranean-climate streams and rivers have been conducted in California (Bêche & Resh 2007), Australia (Chessman 2009) and southern Europe (Bonada *et al.* 2007, Feio *et al.* 2010). North Africa's wadis provide harsher conditions to aquatic macroinvertebrates and thus there is a real need to investigate species' and communities' response under increasingly acute conditions. Previous studies have indicated that macroinvertebrate communities are sensitive to both extreme climatic events (Mouthon & Daufresne 2006, Thomson *et al.* 2012) and climatic oscillations (Bêche & Resh 2007, Bradley & Ormerod 2001). Long-term studies have also demonstrated directional changes in community composition and structure associated with increase in temperature and low-flow stream conditions (Chessman 2009, Daufresne *et al.* 2009, Ormerod & Durance 2009).

Although there are still some large gaps in our knowledge of the aquatic macroinvertebrates of Algeria and the rest of North Africa, Odonata stand out as a major exception considering that they have been the focus of intensive research for many decades (Samraoui & Menai 1999, Boudot *et al.* 2009). In addition, the status of most species is also relatively well established (Samraoui *et al.* 2010) making Odonata suitable indicators to monitor both lotic and lentic freshwater habitats. Indeed, the focus of recent research has been the use of this charismatic group as a low-cost monitoring tool to evaluate river integ-

rity (Simaika & Samways 2009) and to provide reliable assessments of hydrology and habitat alterations of fluvial systems (Ferrerias-Romero *et al.* 2009).

In the face of mounting anthropogenic stressors ranging from habitat loss to recreational activities, dragonflies and freshwater biodiversity as a whole are increasingly threatened (Clausnitzer *et al.* 2012). Generally, individual species may respond differentially to changes (Pearson *et al.* 2014). Thus, in an ever changing landscape, it is crucial to reassess the conservation status of species (Rovelli *et al.* 2016). In addition, to mitigate the impacts of global and local alterations and develop sustainable management strategies, there is a need to assess and understand the consequences of ecosystem changes (Hooper *et al.* 2012). Bio-assessments provide such cost-effective and sensitive tools to monitor the consequences of human activities (Rovelli *et al.* 2016).

Odonatological surveys of Wadi Bouaroug started in 1989 with a systematic study being carried out in 1993–1994 (Benchalel & Samraoui 2012). Recently, a parallel survey to our own study was carried out at the same locality (Benchalel *et al.* 2018). The main objectives of our study were to record the impact of environmental changes, principally land use changes and climate warming on the Odonate assemblage of a North African stream and to underscore the value of long-term ecological studies of Mediterranean streams by comparing past and present data.

## MATERIALS AND METHODS

*Study area:* The study area is located in North-eastern Algeria (Numidia) (Fig. 1) which experiences a typically Mediter-

anean climate characterized by a hot, dry season (May to October) and a mild, wet season (November to April). The annual rainfall varies from 700 mm to 950 mm. A large part of the wadi crosses the Natural Reserve of Brabtia before reaching Lake Mellah, a brackish lagoon linked to the Mediterranean Sea by a wide channel.

The Brabtia compound was turned gradually from a natural reserve in the early 1990s to a zoo and an amusement park attracting a large audience in the past ten years. This expansion brought with it logistic problems on how to feed a growing populations of captive lions and dispose of increasing amount of refuse (carcasses of confiscated donkeys destined to feed captive carnivores, plastic bottles left behind by visitors, etc.), which quickly accumulated in an area south of the park and adjacent to Wadi Bouaroug. The transformation of Brabtia park has also involved the creation of an artificial pond at the Brabtia Reserve, the clearing of the riparian forest and the widening of wadi's bed further north, creating in essence another adjacent pond.

The two upstream stations G1 and G2 are both located on the southern area of the Brabtia Reserve which has so far been shielded most from visitors and major alterations while G3 and its surroundings are used as recreational areas by visitors. The downstream stations G4 and G5 are the most impacted stations with considerable changes of their physical characteristics (bed width, water depth, clearing of riparian vegetation and organic pollution) (Benchalel & Samraoui 2012).

*Sampling and methodology:* A total of five stations along the watercourse were sampled monthly from March 2015 to November 2015, in agreement with the emergence and flight period exhibited by Mediterranean Odonates (Ferrerias-Romero & Corbet 1995, Samraoui & Corbet 2000b). At each location, adult Odonates were collected by walking slowly and repeatedly along a transect (50 m). Flying adults were often identified on sight, but some were caught using a butterfly net and these voucher specimens were carried to the laboratory to be identified and stored. We strove to adopt the same sampling methods used by Benchalel & Samraoui (2012). Additionally, the watercourse was also kick-sampled for Odonate larvae on both October 2015 and January 2016. Samples were placed in plastic boxes and identified in laboratory. Nine abiotic descriptors were measured quarterly in each station: water temperature (T: °C), pH, conductivity (µS/cm), dissolved oxygen (O<sub>2</sub>: %), salinity (mg/l), current velocity (m/s), bed width (m), and water depth (m).

*Statistical analysis:* Analysis of the relationship between Odonate species and habitat characteristics was carried out using a Co-inertia analysis (CIA) (Dolédéc & Chessel 1994). These analyses were made using the software R (R Development Core Team 2017), and the package ade4 (Dray & Dufour 2007).

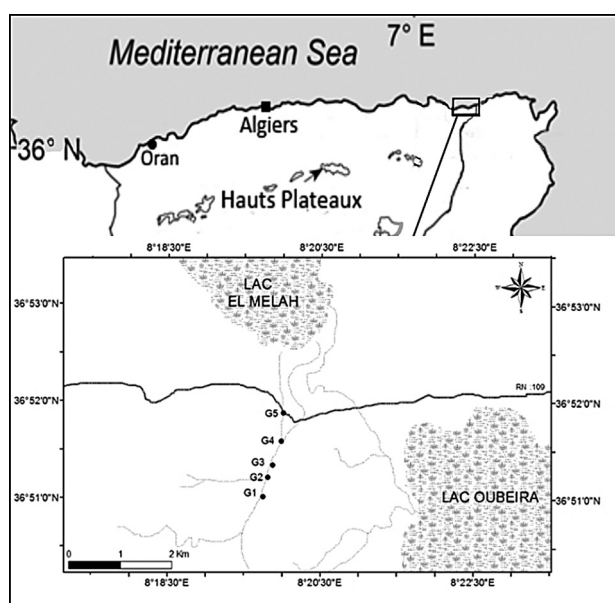


Fig. 1. – Map of Algeria with location of Sampling stations (G1–G5) at Wadi Bouaroug.

## RESULTS

Despite the relatively short distance (< 2 km) separating the sampling stations, a strong upstream-downstream gradient of water characteristics is evident. Water temperature, water conductivity and dissolved oxygen exhibited a clear spatiotemporal variation along the upstream-downstream gradient (Fig. 2). Similarly, there are considerable differences in current velocity, bed width and water depth between opposing ends of the station gradient (Fig. 3).

If we only compare the mean annual temperature of G1 (the least impacted station) with that of 1993/94, there is an increase of 1 °C between the two periods. This is of course a conservative value, well below the 4 °C that would result from considering all five stations. The maximum temperature record has also increased, soaring from

21.3 °C in 1993-1994 (Benchalel & Samraoui 2012) to 32.4 °C in 2015. Similarly, the mean annual value of pH has increased from 6.8 in 1993-1994 to 7.7 in 2015 and water depth rose from a mean value of 18.0 cm in 1993-1994 (Benchalel & Samraoui 2012) to 38 cm in 2015. The higher values of conductivity (and salinity) in downstream stations could be explained by the anthropogenic activities surrounding the wadi or by intrusion from Lake Mellah, a lagoon which saw the channel linking it to the sea widened in the early 1990s thereby increasing its water salinity.

In total, 21 Odonate species were recorded (Table I, Fig. 4): 18 of them as adults and three others as larvae (*Boyeria irene*, *Onychogomphus uncatus* and *Gomphus lucasii*). Compared to the 1993-1994 survey, newly recorded species were *Erythromma lindenii*, *Anax parthenope*, *Paragomphus genei*, *Brachythemis*

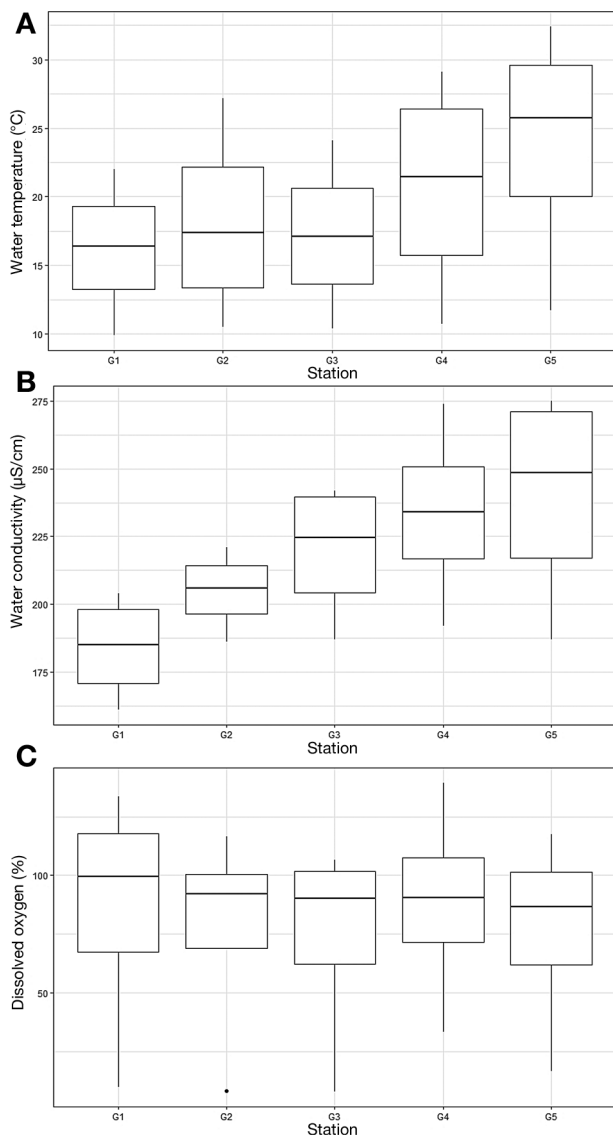


Fig. 2. – Extent of variation of water temperature (A), water conductivity (B), and dissolved oxygen (C), of sampled stations.

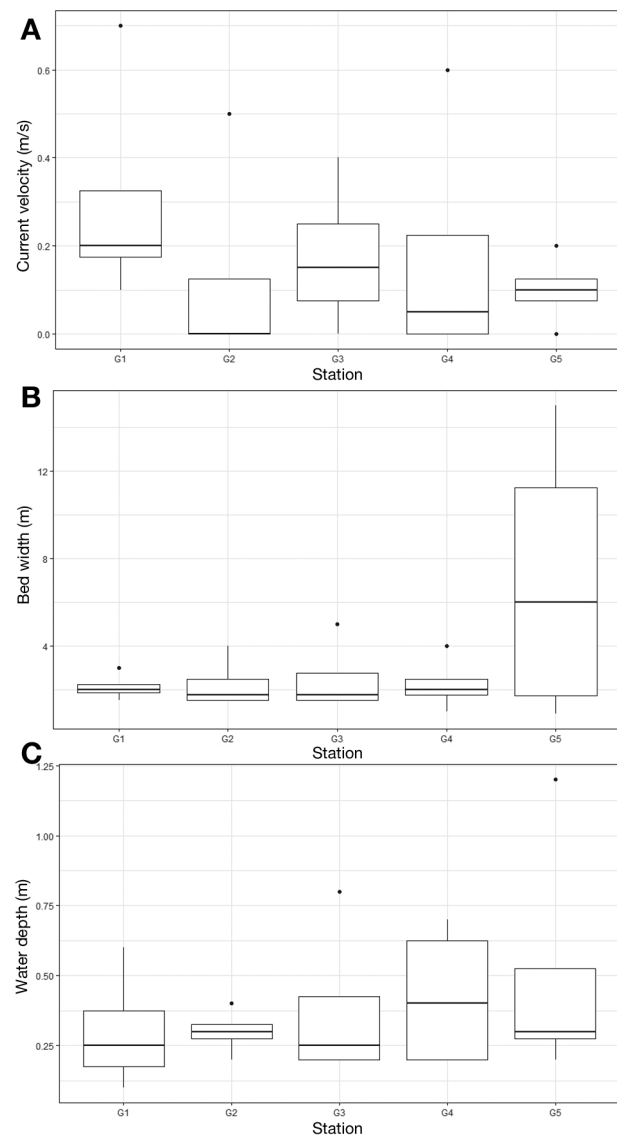
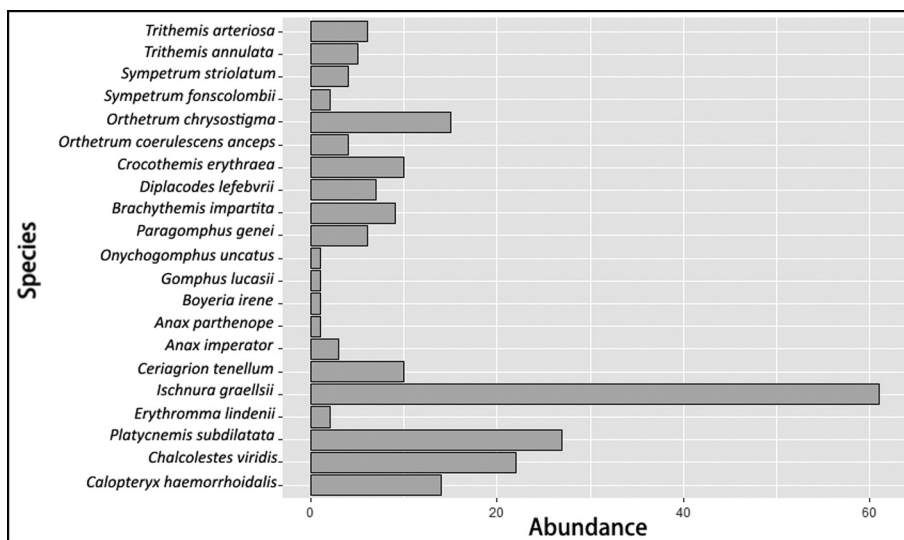


Fig. 3. – Extent of variation of current velocity (A), bed width (B), and water depth (C) of sampled stations.

Fig. 4. – Cumulated abundance of adults at Wadi Bouaroug in 2015. *Gomphus lucasii*, *Boyeria irene* and *Onychogomphus uncatus* were recorded as larvae and set arbitrarily to 1.



*impartita*, *Diplacodes lefebvrii*, *Orthetrum chrysostigma*, *Sympetrum fonscolombii*, *Trithemis annulata* and *T. arteriosa*. The only species missing was *C. puella*. There was no consistent trend of species richness which varied between 8 and 12 along the upstream-downstream gradient (Table II). However, both the abundance and species richness dipped in the middle of the study area (G3) while the downstream stations (G4 and G5) hosted a greater abundance of flying adults (Table II).

Results of the CIA of Wadi Bouaroug indicated that the first two factorial axes accounted for 96.5 % of the total variation (Fig. 5). The coefficient of vectorial correlation (RV) of CIA reflects the relationship between the species and the sampled environmental descriptors. Despite the reduced number of stations, the RV was significant ( $RV = 0.84$ ,  $p = 0.03$ ), thus suggesting the existence of a significant co-structure between the environmental setting and the odonotological community of Wadi Bouaroug. The first axis represented the upstream-downstream gradient with upstream stations, characterized by collinear variables

like current velocity, and low values of temperature, water level and conductivity, opposed to downstream stations that harbor high values of conductivity, salinity, bed width and water temperature. The first axis of the CIA also highlighted the presence of two distinct assemblages (Fig. 2).

Table I. – Species and subspecies occurrence at Wadi Bouaroug (March-November 2015). “L” indicates larval record only. Records of 1993-1994 are from Benchalel and Samraoui (2012) whereas those of 2015 pertain to this study.

| Num   | Species                                                 | Benchalel & Samraoui: 1993-1994 | This study: 2015 |
|-------|---------------------------------------------------------|---------------------------------|------------------|
| 1     | <i>Calopteryx haemorrhoidalis</i> (Vander Linden, 1825) | 1                               | 1                |
| 2     | <i>Chalcolestes viridis</i> (Vander Linden, 1825)       | 1                               | 1                |
| 3     | <i>Platycnemis subdilata</i> Selys, 1849                | 1                               | 1                |
| 4     | <i>Erythromma lindenii</i> (Selys, 1840)                | 0                               | 1                |
| 5     | <i>Coenagrion puella</i> (Linnaeus, 1758)               | 1                               | 0                |
| 6     | <i>Ischnura graellsii</i> (Rambur, 1842)                | 1                               | 1                |
| 7     | <i>Ceriagrion tenellum</i> (de Villiers, 1789)          | 1                               | 1                |
| 8     | <i>Anax imperator</i> Leach, 1815                       | 1                               | 1                |
| 9     | <i>Anax parthenope</i> (Selys, 1839)                    | 0                               | 1                |
| 10    | <i>Boyeria irene</i> (Fonscolombe, 1838)                | L                               | L                |
| 11    | <i>Gomphus lucasii</i> Selys, 1849                      | 1                               | L                |
| 12    | <i>Onychogomphus uncatus</i> (Charpentier, 1840)        | L                               | L                |
| 13    | <i>Paragomphus genei</i> (Selys, 1841)                  | 0                               | 1                |
| 14    | <i>Brachythemis impartita</i> (Karsch, 1890)            | 0                               | 1                |
| 15    | <i>Diplacodes lefebvrii</i> (Rambur, 1842)              | 0                               | 1                |
| 16    | <i>Crocothemis erythraea</i> (Brullé, 1832)             | 1                               | 1                |
| 17    | <i>Orthetrum coerulescens anceps</i> (Schneider, 1845)  | 1                               | 1                |
| 18    | <i>Orthetrum chrysostigma</i> (Burmeister, 1839)        | 0                               | 1                |
| 19    | <i>Sympetrum fonscolombii</i> (Selys, 1840)             | 0                               | 1                |
| 20    | <i>Sympetrum striolatum</i> (Charpentier, 1840)         | 1                               | 1                |
| 21    | <i>Trithemis annulata</i> (Palisot de Beauvois, 1807)   | 0                               | 1                |
| 22    | <i>Trithemis arteriosa</i> (Burmeister, 1839)           | 0                               | 1                |
| Total |                                                         | 13                              | 21               |

Table II. – Species richness and abundance of Odonata at 5 stations of Wadi Bouaroug.

| Site | Abundance | Species richness |
|------|-----------|------------------|
| G1   | 40        | 11               |
| G2   | 33        | 12               |
| G3   | 30        | 8                |
| G4   | 49        | 12               |
| G5   | 50        | 10               |

A group led by *Ischnura graellsii* and *Crocothemis erythraea* located in downstream stations characterized by high values of temperature and conductivity. This assemblage is opposed to another group which includes *Ceriagrion tenellum*, *Orthetrum coerulescens* and to a lesser extent *Calopteryx haemorrhoidalis*, which occupy the relatively well shaded upstream stations, also characterized by high current velocity. The second axis (8.9 % of total inertia) separates G4 from the other downstream station G5 on the basis of pH and dissolved oxygen and the presence of *Erythromma lindenii* and *Anax parthenope*.

## DISCUSSION

Over the last 25 years, Wadi Bouaroug has undergone a considerable alteration of its physical characteristics

(bed width, water depth, riparian vegetation and canopy) which have undoubtedly affected its hydrology. Such modifications are known to shape the distribution and abundance of Odonates (Buchwald 1992, Remsburg *et al.* 2008, Kietzka *et al.* 2014). Indeed, previous research has shown that flow velocity may have a substantial impact on aquatic macroinvertebrates (Poff *et al.* 1997, Walters & Post 2011).

Likewise, Odonata larval assemblages are known to be influenced by flow regimes (Hoffmann & Mason 2005). Equally important are the changes in water chemistry with an increase in pH and the apparent rise in salinity, at least in lower reaches of the wadi, possibly triggered by land clearing and urbanization (Kay *et al.* 2001). Such rise in water salinity is known to facilitate colonization by invasive species (Schröder *et al.* 2015).

Over the same time span, the mean water temperature of Wadi Bouaroug has substantially increased (1–4 °C), with notable higher maximum values. This increase is congruent with numerous studies which have documented a sustained rise of temperatures in Algeria over the past four decades (Achite & Ouillon 2016; Zeroual *et al.* 2017). In addition, the frequency of heat extremes in North Africa is projected to increase (Lelieveld *et al.* 2016). Temperature may influence directly species distribution and abundance by regulating growth and development (Suhling *et al.* 2015) or indirectly through dissolved

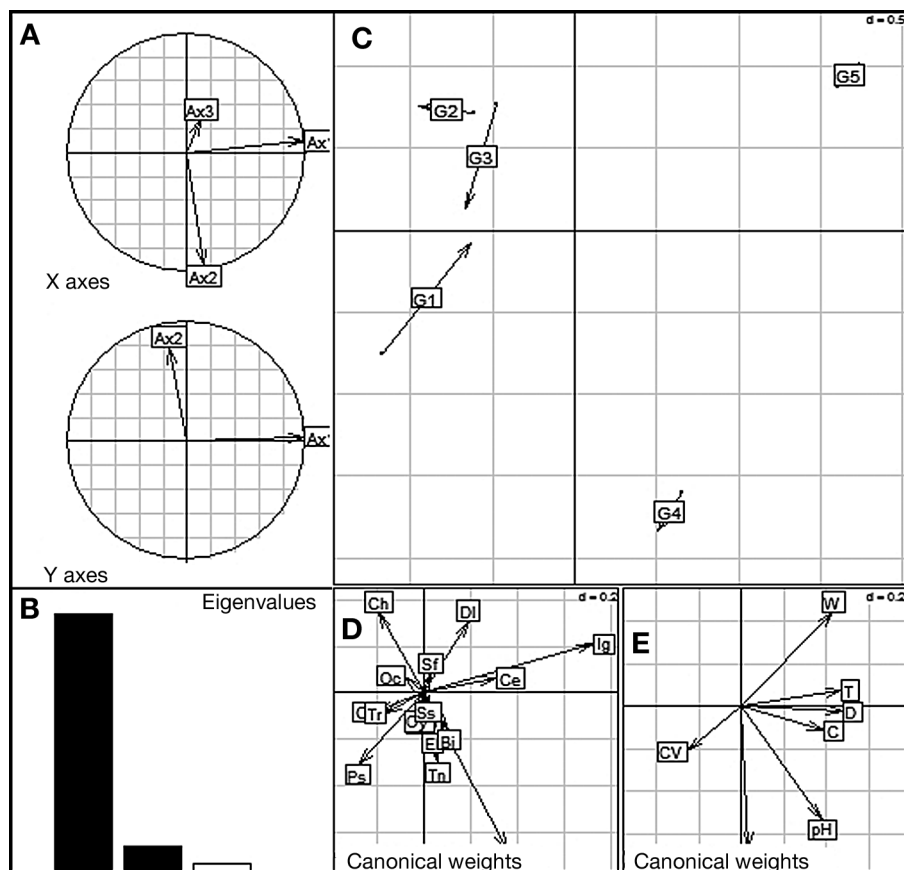


Fig. 5. – Results of the Co-Inertia Analysis (CIA) using 21 Odonates (coded as presence/absence) and 9 environmental descriptors. A: Components of the standardized principal component analysis of the environmental data set projected onto the co-inertia axes (top) and components of the centred principal component analysis of the odonatological data set projected onto the co-inertia axes (bottom). B: Distribution of eigenvalues of the CIA. C: F1 x F2 factorial plane of the CIA with arrows linking localities according to physico-chemical descriptors (base of arrows) and Odonata (end of arrows). D: Distribution of species on the F1 x F2 factorial plane of the CIA. E: Distribution of environmental descriptors on the F1 x F2 factorial plane of the CIA.

oxygen (Rajwa-Kuligiewicz *et al.* 2015) or primary production (Lamberti & Steinman 1997).

Using Earth Observation tools, Benslimane *et al.* (2019) have shown that, over the last 25 years, agriculture has been expanding in a marked way across the dune system north of the study site. The rise of speculative crops (water melons and peanuts) has taken advantage of the unregulated use of ground water. In parallel, the natural vegetation in the same area has shrunk substantially, giving way to cultivated plots or rangelands (Benslimane *et al.* 2019).

Although species richness may have increased significantly, a closer examination of the ecology and origin of the new species paint a different picture of the apparent gain. Newly recorded species are *Erythromma lindenii*, *Anax parthenope*, *Paragomphus genei*, *Brachythemis impartita*, *Diplacodes lefebvreii*, *Orthetrum chrysostigma*, *Sympetrum fonscolombii*, *Trithemis annulata* and *T. arteriosa*. Many of these new arrivals are lentic species with wide dispersal capacities that are indicative of the anthropogenic changes that have occurred within the relatively small watershed of Wadi Bouaroug,

The only species missing is *C. puella* which, as a rare species (Samraoui & Corbet 2000a), can easily be overlooked. However, the species is now considered as extinct in Tunisia (Boudot *et al.* 2009) and its status in Algeria and Morocco is of a great concern (Ferreira *et al.* 2016). A recent study based on molecular data has indicated that the North African *C. puella* could represent a distinct phylogenetic lineage from its European counterpart fueling questions on its conservation status (Ferreira *et al.* 2016). Many of the North African cryptic taxa (*Coenagrion puella*, *C. scitulum*, *Pyrrhosoma nymphula*, *Aeshna cyanea*, and *Cordulegaster boltoni*) that exhibit considerable genetic (Ferreira *et al.* 2016) and/or behavioral differentiation have gone extinct in Algeria or are faring badly (Samraoui *et al.* 2010).

We are thus witnessing a high prevalence of invasive species and probably a displacement of lotic species by widespread and competitive species taking advantage of new habitat opportunities (Pearson *et al.* 2014, Frishkoff *et al.* 2016). The presence of these exotic/opportunistic species has increased species richness with unpredictable impacts on the wadi's community structure and function. A number of studies have shown that intermediate human interference may benefit common species thereby increasing species richness at the expense of stenotopic species (Hoffmann & Mason 2005). This was the case at Wadi Isser where species richness peaked under intermediate level of habitat alteration (Bouchelouche *et al.* 2015)

The species composition of Wadi Bouaroug has shown a marked shift towards including opportunistic species with traits that are associated with desert species (Suhling *et al.* 2003): *Paragomphus genei*, *Crocothemis erythraea*, *Trithemis arteriosa*, *T. kirbyi*, *Sympetrum fonscolombii*, *Orthetrum chrysostigma*, *Anax imperator*, *A. parthenope*,

*Brachythemis impartita*, and *Diplacodes lefebvreii*. Most, if not all, of these invasive species are highly mobile and have long been known for their tolerance to arid conditions (Suhling *et al.* 2003). This pattern fits with the observation of two desert species (*Trithemis kirbyi* and *Selysiothemis nigra*) expanding their range northward in Algeria (Yalles-Satha & Samraoui 2017, B.S. unpubl), and, for the former, reaching Europe over the last decade (Boudot & Kalkman 2015).

Elsewhere, the same pattern has been reported with thermophilic invertebrate taxa and fish replacing cold-water invertebrate taxa and fish, respectively (Daufresne *et al.* 2004). The downstream part of Wadi El Harrach characterized by poor water quality and no canopy cover, was dominated by widespread, salt-tolerant and thermophilic species (*Anax imperator*, *Crocothemis erythraea*, *Onychogomphus costae*, *Sympetrum fonscolombii*, *Trithemis annulata* and *T. kirbyi*) (Hafiane *et al.* 2016).

### *The influence of climatic events*

There is a striking similarity between our recorded pattern and the influence of severe droughts on perennial or intermittent streams. Indeed, the shift in species composition and structure in our study is reminiscent of changes that occur in riverine residual pools following drought and flow disruption when flowing water invertebrates are replaced by lentic taxa (Boulton & Lake 2008, Bond *et al.* 2008). Similarly, severe droughts do not seem to systematically lower species richness or total abundance while it does provoke a marked shift in community structure (Dewson *et al.* 2007, Bêche *et al.* 2009).

Extreme climatic events may encompass various forms of climatic phenomena (prolonged unseasonal droughts, El Niño-North Atlantic (ENSO) oscillations and unidirectional global warming) and their effects may be difficult to disentangle without the benefit of long-term studies (Mouthon & Daufresne 2006, Bêche & Resh 2007). It is known that stream communities undergo fluctuations due to ENSO oscillations (Bradley & Ormerod 2001). However, this relatively periodic event has to be dissociated with the unidirectional shift produced by climate warming which may alter species composition and abundance of stream ecosystems (Durance & Ormerod 2007).

### *The status of Algerian streams and wadis*

The rich and wide array of wetlands hosted by north-eastern Algeria (Samraoui & Samraoui 2008) has been threatened by the irrational land-use of industrial, agricultural and recreational activities. These human-driven changes are amplified by climate change with adverse and irreversible consequences that are compromising vital ecosystem services. Although less impacted than the wadis in the environs of Algiers, where human footprint is at its greatest, Wadi Bouaroug clearly exhibits a

typical “urban stream syndrome” (Walsh *et al.* 2005) due to the massive inflow of visitors peaking in summer. An alarming trend has emerged over the last decade with recreational activities across the country expanding and encroaching on protected or sensitive habitats, thus creating new conflicts (Touati *et al.* 2017).

Although their importance is unquestioned, a dearth of long-term ecological studies and monitoring of freshwater macroinvertebrates has been stressed (Jackson and Funder 2006). For neglected North African streams, which face multiple anthropogenic stressors (Hafiane *et al.* 2016), such long-term ecological research projects could offer unprecedented insights into the functioning and dynamics of stream populations, communities and ecosystems with implications for global change scenarios. In a period of unparalleled rapid alterations and biodiversity loss currently affecting natural communities and ecosystems (Hooper *et al.* 2012), it is essential to assess whether current modifications are indicative of change in the medium-to-long term, and North African streams may be ideally suited for providing models to monitor the influence of human activities at different scales. Without high-quality baseline data from the recent past, predicting future responses will be fraught with uncertainties.

## CONCLUSIONS

Investigating the impact of land conversion and climate change on freshwater biodiversity is a continuing concern among limnologists and ecologists. However, research on Mediterranean streams has been restricted to Europe, with no previous study investigation of North African wadis where global changes appear to be more acute. An analysis of the Odonate community of Wadi Bouaroug at a 25-y interval indicates a marked shift in species composition towards including more widespread, thermophilic species whereas stenotopic species appear to be on the decline. This trend matches patterns recorded elsewhere in Algeria and abroad.

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