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ANTHROPOGENIC IMPACTS AND THEIR INFLUENCE ON THE SPATIAL DISTRIBUTION OF THE ODONATA OF WADI EL HARRACH (NORTH-CENTRAL ALGERIA)

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RESUME.— *Impacts des facteurs anthropiques et leur influence sur la distribution spatiale des Odonates de l'oued El Harrach (Centre-Nord de l'Algérie)*.— Malgré une connaissance relativement bonne de l'odonatofaune de l'Algérie et du Maghreb, de vastes régions comme le centre de l'Algérie demeurent peu explorées. Ces régions ont connu une explosion démographique et leur développement agro-industriel, au cours du siècle passé, a impacté défavorablement la plupart des écosystèmes naturels. L'oued El Harrach, un cours d'eau saisonnier qui traverse la plaine de la Mitidja, près d'Alger, est notoirement connu pour sa pollution et il représente ainsi un cas intéressant pour évaluer les impacts anthropiques sur les peuplements de macro-invertébrés dulçaquicoles. L'utilisation de plus en plus fréquente des méthodes d'évaluation mises au point pour le suivi et l'évaluation de l'intégrité écologique des cours d'eau, nous a encouragés à échantillonner les Odonates de l'oued El Harrach et mesurer divers paramètres physico-chimiques représentatifs de la qualité de l'eau du milieu. Les deux jeux de données ont été analysés conjointement pour établir une correspondance entre les deux évaluations. Les résultats indiquent une congruence entre les deux approches et soulignent le potentiel des Odonates comme bio-indicateurs utiles des conditions écologiques des écosystèmes lotiques.

SUMMARY.— In spite of a relatively good knowledge of the odonatofauna of the Maghreb, some large areas like the centre of Algeria have remained little explored. These areas have witnessed a demographic explosion and an agro-industrial development over the last century which have adversely impacted most natural ecosystems. Wadi El Harrach, an intermittent river that cuts through the Mitidja plain, near Algiers, is notorious for its pollution and represents a good model to investigate anthropogenic impacts on freshwater communities. In line with the increasing use of assessment methods developed to monitor and evaluate the ecological integrity of running waters, we sampled Odonata of Wadi El Harrach and measured various abiotic parameters representative of the water quality of the habitat. Both data sets were jointly used to analyse the correspondence between the two assessments. Results indicated congruence between both approaches and highlighted the potential of Odonata as reliable bioindicators of ecological conditions of lotic ecosystems.

In the light of global and local habitat alterations, there is a real need to assess the consequences of ecosystem change for human well-being and develop management strategies to conserve and enhance the sustainable use of ecosystems (Millenium Ecosystem Assessment, 2005). Freshwater ecosystems are under severe pressure worldwide (Abell, 2002) and, in North Africa, they will probably face increasing alterations, demands and depletions. Human encroachment on northern African wadis, as happened with rivers, worldwide (Dynesius & Nilsson, 1994), has been unsparing. Water extraction, pollution, dam construction, and channelization have profoundly modified the riverine landscape and altered its function.

One important step in the management of ecosystems is a good knowledge of patterns in species diversity and their driving processes. Insects are a successful group of living organisms that are essential to the functioning of many terrestrial and freshwater ecosystems (Schminke, 2007). Odonata, perceived as charismatic insects, have been deemed to provide direct benefit to humans (Simaika & Samways, 2008) through their contribution to ecosystem services to humans in four distinct categories: provisioning, cultural, supporting, and regulating services, recognized by the authoritative document known as the Millenium Ecosystem Assessment (2005).

Benthic macroinvertebrates have been widely used for monitoring aquatic habitats, but Odonata, both as adults and larvae, have proven excellent surrogates and may outperform macroinvertebrates as bioindicators of freshwater health and ecological integrity (Oertli, 2008; Monteiro-Junior *et al*., 2015; Willigalla & Fartmann, 2012) and by providing reliable assessments of the hydrology and habitat alterations of fluvial systems (Ferreras-Romero *et al*., 2009).

Despite its geographical position near Algiers, and notoriety as one of the most polluted watercourse in North Africa, Wadi El Harrach has so far received little attention from researchers. Likewise, the benthic macrofauna, increasingly used to monitor freshwater health, of the Algerian watercourses is still relatively poorly known, but recent progress has been made (Thomas & Lounaci, 1989; Lounaci *et al*., 2000a, b; Arab *et al*., 2004; Chaib *et al*., 2013a, b). Recent research has mainly focused on the larval stages (Cherairia *et al*., 2014) with few studies focused on the adult stages (Annani *et al*., 2012). Odonatology is an exception with work spanning over a century and a half (Samraoui & Menai, 1999; Boudot *et al*., 2009). In recent work, more emphasis was put on using lotic Odonata as indicators of ecosystem integrity (Bouchelouche *et al*., 2015; Hamzaoui *et al*., 2015).

Knowledge of the status, distribution and life history of riverine Odonata, acting as umbrella species (Betrus *et al*., 2005), as well as the identification of threats to their habitats are urgently needed to set up conservation and restoration strategies in view of the fast degradation of watercourses within the Mediterranean landscape (Olson & Dinerstein, 1998). Thus, there is a real need to survey North African riparian biodiversity and monitor changes through the use of rapid, low-cost methods (Chovanec & Waringer, 2001; Simaika & Samways, 2009). The identification of the physical habitat factors that influence Odonata abundance and distribution can facilitate the development of such tools. In this context, we set up to survey the Odonata of Wadi El Harrach and attempt to identify environmental determinants of their distribution.

MATERIALS AND METHODS

STUDY AREA

Wadi (or Oued) El Harrach is located in the northern center of Algeria. It springs in the Blidian Atlas, crosses the plain of Mitidja, and reaches the bay of Algiers. The length of the study area spans 40 km from the village Magtaa Lazreg to Baba Ali. The local climate is Mediterranean with hot, dry summers and wet, mild winters.

Upstream of the confluence of Wadi Magtaa and Wadi Lakhra (Fig. 1), the region has been deserted over the last twenty years due to security reasons. The upper part reaches of the wadi, between the two villages of Magtaa and Hammam Melouane is often used as a holiday resort in summer and the area is managed (clearance of vegetation) to that effect. The middle course is mainly impacted by agriculture (use of pesticides) whereas the lower course is the receptacle of industrial effluents. In this part of the wadi, the bed is channelled and the banks are heavily planted with *Eucalyptus* trees.

SAMPLING AND METHODOLOGY

Monthly sampling was carried out from March 2013 to February 2014. Records of adult Odonata were noted at 8 stations (S1-S8) selected along the main watercourse, and distributed between altitudes 25-220 m (Fig. 1, Tab. I). The two upstream stations S1 and S2 are both located on the two tributaries whose confluence gives birth to Wadi El Harrach. The most notable difference between S1 and S2 is the size of the boulders (larger in S1) that litter the watercourse. The surrounding vegetation of both stations is dominated by plantations of *Pinus halepensis* and more often than not the native *Nerium oleander* gives way to the invasive *Arundo donax*. S3 and its surroundings are used as recreational areas by holidaymakers during the summer months. These parts of the wadi are managed as swimming pools. The water quality of all the stations located downstream of S3 decreases markedly due to the increase of human encroachment (presence of villages). At S4, the wadi is the receptacle of discharges from Hammam Melouane, a thermal resort. The middle and downstream parts of the wadi are characterized by the straightening of their banks and the loss of their native riverine vegetation replaced by *Eucalyptus* trees. The next two stations, S5 and S6, are sandwiched between Hammam Melouane and Bougara, where the Mitidja plain starts. This is the most fertile agricultural land in Algeria and intensive agriculture is the hallmark of the surroundings of S7 and S8. At Baba Ali and neighbourhood, the wadi is the receptacle of residues of chemical fertilizers and pesticides that wash off from the adjacent fields. In these two stations, household waste becomes more frequent and conspicuous.

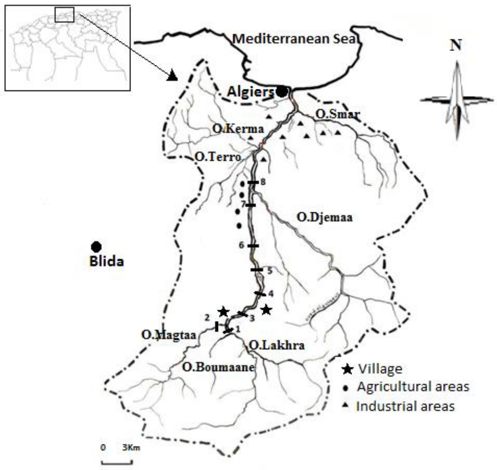

Figure 1.— Localization of sampled stations along Wadi El Harrach.

TABLE I

List of surveyed stations

Stations code	Stations (locality)	Altitude (m)	Latitude	Longitude
S1	MagtaaLazreg	220	36°27'53.30"N	3°0'54.82"E
S2	Lakhra and Boumaane	219	36°28'15.99"N	3°0'24.97"E
S3	Hammam Melouene 1	170	36°28'59.75"N	3°2'31.57"E
S4	Hammam Melouene 2	158	36°29'22.32"N	3°3'06.91"E
S5	Bougara 1	119	36°30'41.05"N	3°4'05.57"E
S6	Bougara 2	92	36°32'6.34"N	3°3'44.83"E
S7	Baba Ali 1	29	36°37'22.02"N	3°3'48.35"E
S8	Baba Ali 2	25	36°37'32.75"N	3°3'44.75"E

Sampling of Odonata was performed by walking slowly and repeatedly along a transect (100 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 (Dijkstra & Lewington, 2006; Grand & Boudot, 2007) and stored.

Field data collection was also carried out using a WTW 340i multiparameter to monitor physical and chemical variables: temperature (°C), pH, electric conductivity (µS/cm), salinity (‰), dissolved oxygen (mg/l). Other environmental parameters were also measured, such as current velocity (cm/s), bed's width, water depth, abundance of submerged and shore vegetation and shading/sun exposure.

STATISTICAL ANALYSIS

Analysis of the relationship between odonate species and habitat characteristics was carried out using an Ascending Hierarchical Classification (ACH) and a Canonical Correspondence Analysis (CCA). These analyses were made using the program R (R Development Core Team, 2014).

RESULTS

As might be expected, the results exhibited a strong upstream-downstream gradient of water characteristics. Dissolved oxygen exhibited a spatio-temporal variation with lower oxygen content in the downstream part (Tab. II), mainly during summer. The level of oxygen is known to decrease with rising temperature and dissolved mineral salts reduce the oxygen solubility. Very low values of dissolved oxygen (1.52 mg/l and 0.69 mg/l) were recorded during the summer at S7 and S8, respectively. The high values of salinity and conductivity recorded at S4 are explained by the discharges of the thermal resort of Hammam Melouene which is located upstream of this station whereas those of S7 and S8 are due to agricultural and industrial effluents combined to increased domestic sewage (Tab. II).

TABLE II

Environmental variables measured at Wadi El Harrach

Stations		T° air	T° wat.	O_2d.	pH	Cond.	Sal.	V.C.	Aqua.v.	Riv.v.	Wid.	Dep.	Chg.edg.
Station1	Mean	27.7	24.9	6.5	8.7	1105.7	0.3	56.4	0	2.0	9.5	54.7	2
	S.D.	7.5	5.7	2.0	0.5	254.0	0.2	10.3	0	0	0.7	9.2	0
Station 2	Mean	27.0	23.6	6.2	8.6	594.3	0.0	42.6	0	3.0	17.4	39.3	2
	S.D.	6.6	5.6	1.5	0.3	104.9	0.1	6.7	0	0	1.6	8.9	0
Station 3	Mean	27.4	22.6	6.8	8.5	880.5	0.2	51.0	0	2.0	14.2	46.7	3
	S.D.	6.3	3.7	1.2	0.3	153.5	0.1	17.4	0	0	0.5	1.5	0
Station 4	Mean	31.5	23.5	6.9	8.6	2351.5	1.1	51.0	0	3.0	9.5	20.7	2
	S.D.	6.4	3.5	1.2	0.4	1042.8	0.7	5.8	0	0	0.5	4.7	0
Station 5	Mean	34.0	23.6	6.4	8.7	1590.0	0.6	33.3	2.0	2.0	15.0	41.7	1
	S.D.	6.2	3.8	1.4	0.5	577.7	0.4	4.7	1.3	1.3	0	2.6	0
Station 6	Mean	31.0	23.7	7.0	8.9	1241.8	0.4	40.9	1.0	1.0	8.0	25.7	1
	S.D.	5.5	2.6	1.0	0.2	447.5	0.2	14.7	0	0	0.3	8.9	0
Station 7	Mean	29.3	22.5	4.7	8.6	1266.2	0.4	49.9	0	0	4.0	37.8	1
	S.D.	5.4	3.6	1.8	0.6	434.9	0.2	10.4	0	0	0	4.9	0
Station 8	Mean	26.0	21.1	2.6	8.3	1338.7	0.5	40.4	0.5	2.0	4.0	40.3	1
	S.D.	5.4	2.8	2.8	0.7	431.4	0.3	13.1	0.5	0	0.2	0.8	0

T° air: air temperature (°C), T° water: water temperature (°C), O2d: Dissolved oxygen (mg/l), Cond.: Electric conductivity (µS/cm), Sal.: salinity (‰), V.C.: current velocity (cm/s), Aqua.v.: index of aquatic vegetation, Riv.v.: index of riverine vegetation, wid.: width (m), dep.: depth (cm), Chg.edg: index of changes of wadi banks. S.D.: Standard Deviation. 0: Absence; 1: Low; 2: Medium; 3: Dense/Important; Number of observations: N= 12.

In total, thirteen Odonata species were recorded. Four species were Zygopterans and nine were Anisopterans, including six Libellulids (Tab. III). No species was recorded along the watercourse during November-February.

TABLE III

Check-list of the Odonata of Wadi El Harrach

Suborder	Family	Species
Zygoptera	Calopterygidae	*Calopteryx haemorrhoidalis* (Vander Linden, 1825)
	Platycnemidae	*Platycnemis subdilatata* Selys, 1849
	Coenagrionidae	*Erythromma lindenii* (Selys, 1840)
		Ischnura graellsii (Rambur, 1842)
Anisoptera	Gomphidae	*Onychogomphus costae* Selys, 1885
		Onychogomphus forcipatus unguiculatus (Vander Linden, 1823)
	Aeshnidae	*Anax imperator* Leach, 1815
	Libellulidae	*Orthetrum coerulescens anceps* (Schneider, 1845)
		Orthetrum chrysostigma (Burmeister, 1839)
		Sympetrum fonscolombii (Selys, 1840)
		Crocothemis erythraea (Brullé, 1832)
		Trithemis annulata (Palisot de Beauvois, 1807)
		Trithemis kirbyi Selys, 1891

Species richness was uneven along the watercourse, varying between 2 and 9. S5 was the richest with 9 species whereas S3 hosted only 2 species. The upstream part, which had a greater vegetation cover, was noticeably poorer than the downstream part. However, this was the part where the Zygopterans were most abundant and where *Erythromma lindenii* was confined (S2). The other three species of Zygopterans were found in both upstream and downstream parts: *Calopteryx haemorrhoidalis* was observed at all stations except S7 where there was no vegetation.

The endemic but common *Platycnemis subdilatata* was observed at S1, S2 and S5. *Ischnura graellsii* was associated with stations where low vegetation was present. Likewise, three species of Anisoptera (*Onychogomphus forcipatus, Orthetrum coerulescens anceps* and *Orthetrum chrysostigma*), were also present both upstream and downstream.

From S4, where the habitat starts to worsen (poor water quality, low vegetation cover and almost no shading), Zygopterans were gradually replaced by Anisopterans which settled in numbers. Six Anisopterans species (*Anax imperator*, *Crocothemis erythraea*, *Onychogomphus costae*, *Sympetrum fonscolombii*, *Trithemis annulata* and *T. kirbyi*) were confined to the downstream part (from S5 downwards).

VARIATION OF THE ODONATA ASSEMBLAGES WITH ENVIRONMENTAL FACTORS

Ascending Hierarchical Classification (AHC) and the Canonical Correspondence Analysis (CCA) of the environmental and physico-chemical parameters of water suggested an association between habitat quality and the distribution of Odonata along the watercourse.

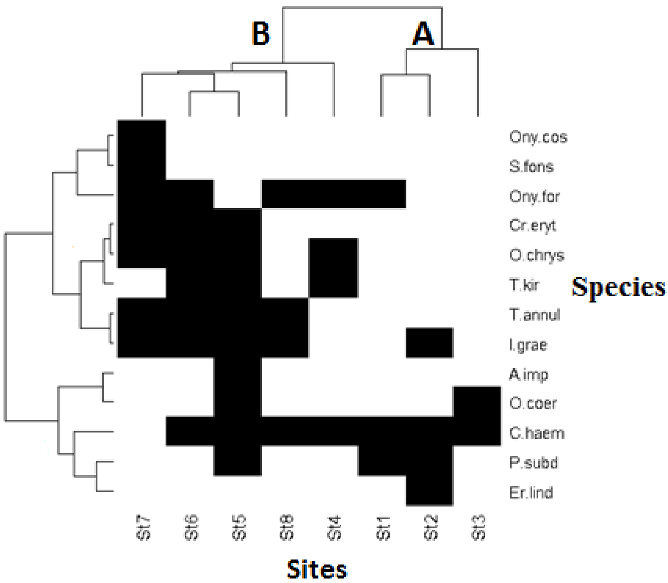

Figure 2.— Clusters based on ACH, representing the sampled stations of Wadi El Harrach: **A**: stations located upstream, and **B**: stations located downstream.

AHC indicated the presence of two distinct groups (Fig. 2). Group A included the first three upstream stations which sheltered a low number of species dominated by Zygopterans. The second group B was composed of the rest of the stations located downstream and which sheltered a higher number of species dominated by Anisopterans. Both groups may further be divided with S3 and S4 being distinct from their respective subgroups.

Results of the CCA indicated that the first two factorial axes accounted for 81.0 % of the total variation (Fig. 3). The first axis represented the altitudinal gradient with upstream stations, characterized by collinear variables like altitude, riverine vegetation, dissolved oxygen and bed width, opposed to downstream stations that harbour high values of conductivity, salinity, sunshine exposure and air temperature. The second axis spread out the upstream stations along a gradient of current velocity and conductivity/salinity. This axis separates the middle course of the wadi (S3-S6) from both the upstream part (S1 and S2) and the downstream one (S7 and S8). As was found for the AHC, the CCA organized the Odonata community along the same altitudinal gradient (first axis) by opposing a community dominated by Zygopterans in the upstream part of the wadi to another one dominated by Anisopterans.

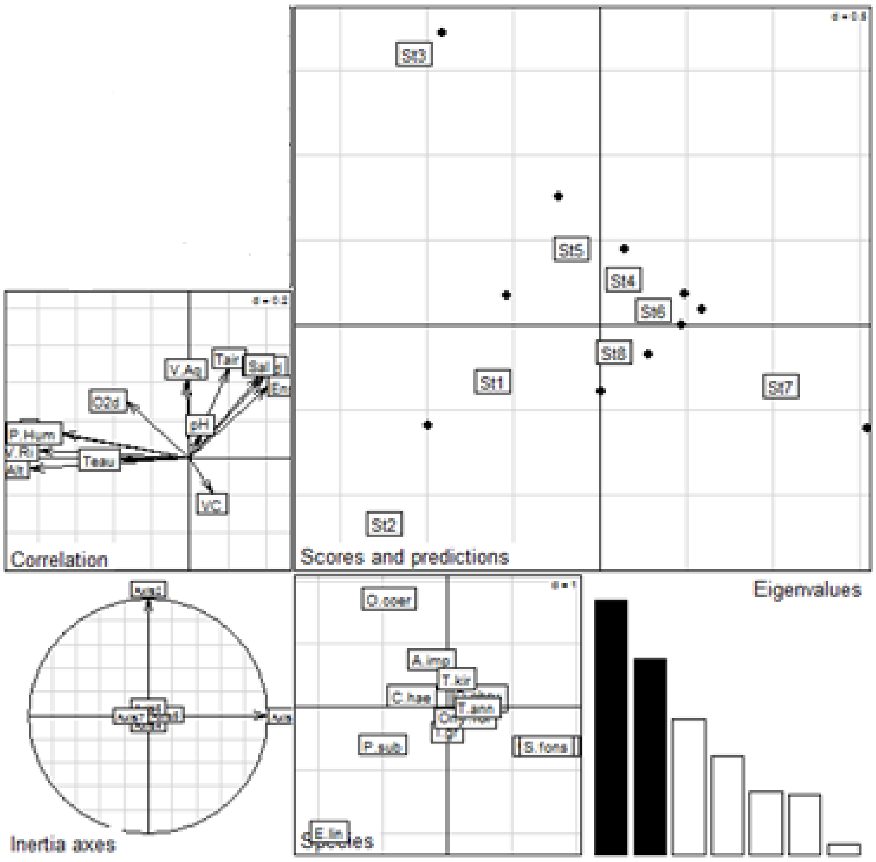

Figure 3.— Results of the Canonical Correspondence Analysis performed using recorded Odonata (presence/absence) and measured environmental parameters. The F1xF2 factorial plane represents 81.0% of the total inertia.

DISCUSSION

In Algeria, like in the rest of the Maghreb, the last decades have witnessed a sizeable demographic increase (Tabutin *et al.*, 2002) but the anarchic occupation of space by both industrial and agricultural activities has had adverse consequences on the rich but vulnerable spectrum of wetlands hosted by this arid North African country (Samraoui & Samraoui, 2008; Toubal *et al.*, 2014). Thus, aquatic communities, particularly in northern Algeria, are facing up increasing pressures affecting the overall Maghrebian biodiversity and disrupting valuable ecosystem functions (Constanza, 1997; De Groot *et al.*, 2002; Wallace, 2007). Continental aquatic ecosystems, particularly watercourses, are the receptacle of urban, industrial and agricultural wastes which threaten their biota and prevent local communities from access to vital and increasingly rare freshwater. Biodiversity erosion is one of many factors that may work synergistically to compromise ecosystem services and impact human health (Chivian & Bernstein, 2008).

It comes as no surprise that the survey of the Odonata of Wadi El Harrach recovered a reduced list of species. Although sampling efforts were limited to one flight season and did not include the higher reaches of the wadi, it is possible to suggest that the overall species richness of Wadi El Harrach, amounting to 13 Odonates, is relatively poor. In other Algerian wadis like Wadi Bouarroug, that witnessed similar sampling effort, 11 species were recorded at a single station (Benchalel & Samraoui, 2012). Likewise, in a single station, 13 species were recorded at Wadi Kébir Est (Benchalel & Samraoui, 2012). A two-year survey of the watershed at Wadi Seybouse totaled 35 species (Khelifa *et al*., 2011) whereas, with comparable sampling effort and a total of six stations, Wadi Isser provided 19 species (Bouchelouche *et al*., 2015). However, a thorough comparison between these wadis needs to take into account their hydrology and habitat heterogeneity which may influence aquatic biodiversity (Hardersen, 2008). Sampling of exuviae and larvae would undoubtedly provide a more thorough survey of the community structures of these wadis.

Both anthropogenic and natural factors seemed to affect the Odonata assemblages of Wadi El Harrach. Physical habitat conditions like altitude (Samways, 1989; Corbet, 1999), bed width (Kietzka *et al*., 2014), riverine vegetation (Buchwald, 1992) and shade (Remsburg *et al*., 2008) are known to drive the distribution and abundance of Odonata riparian site selection. There is thus a need to maintain a structurally complex and heterogeneous landscape and a network of wadis exhibiting a great diversity of physical conditions (Kietzka *et al*., 2014).

No species were recorded between November and February. Although this result agrees relatively well with the known flight period of most Mediterranean Odonates (Ferreras-Romero & Corbet, 1995; Samraoui & Corbet, 2000), it is worth noting that a few species (*Calopteryx haemorrhoidalis*, *Lestes barbarus* and *L. numidicus*) may be seen flying in November whereas others like *Chalcolestes viridis*, *Aeshna mixta* and *Sympetrum striolatum* may extend their flight period till winter (Samraoui & Corbet, 2000; Samraoui, 2009).

The anthropogenic impact is reflected in the recreational use of the upstream parts of the wadi, the remodelling of the watercourse by channel straightening (Elosegi *et al*., 2010), native tree logging, pine plantations (Bellot *et al*., 2004) and invasion of alien plants like *Eucalyptus* trees (Tererai *et al*., 2013) and Giant Reed (Boose & Holt, 1999; Quinn & Holt, 2008; Coffman *et al*., 2010), and changes in water chemistry (Vörösmarty *et al*., 2010) (Fig. 4).

Plant invaders and plantations have been associated with biodiversity erosion through increase of fire risks, modified hydrology, a decrease in resource levels in litter and soil processes and competition with native plant species (Richardson *et al.* 1994; Le Maitre *et al.* 2000; Brockerhoff *et al.* 2008). It is known that land clearing for agriculture or urbanization can cause substantial increase in stream and river salinities (Williams, 1987; Kay *et al*., 2001). Although many studies have pointed to the high tolerance of macroinvertebrates to natural salinity, there is unanimity about the lack of data on the sensitivity of freshwater invertebrates to salinity increases (Hart *et al*., 1991). Likewise, we know little about interactions of salinity with temperature (Nelson & Palmer, 2007) or any other environmental stressors. It is known however that increased salinity may facilitate colonization of freshwater communities by invasive species (Schröder *et al*., 2015).

All these combined anthropogenic stressors (invasive plant species, pine and *Eucalyptus* plantation, land clearing and urbanization, recreational activities, thermal pollution, increased salinity, agriculture) and their potential interactions have led to the virtual extirpation of insect life in the lowest part of Wadi El Harrach (unpublished). As was found for Wadi Isser (Bouchelouche *et al.,* 2015), the number of recorded species was highest in the middle course of the wadi. Species richness is known to peak under intermediate levels of disturbance (Connell, 1978; Wilkinson, 1999). Further down, habitat degradation was acute and, downstream of S8, the aquatic habitat was unfit for larval survival (unpublished).

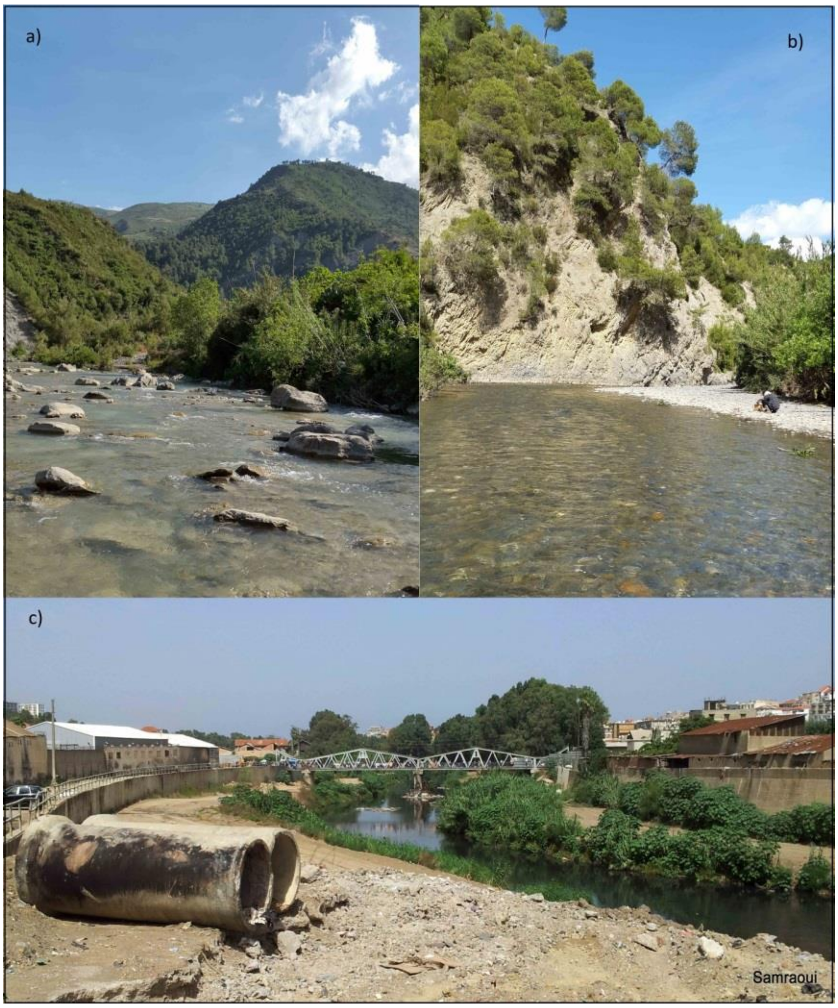

Figure 4.— A view of three stations of Wadi El Harrach: a) S1 at Lakhra and Boumaane, b) S2 at Magtaa Lazreg, c) at El Harrach (downstream of S8), a suburb of Algiers.

A further indication of the degraded state of Wadi El Harrach might be found in the IUCN North African Red List (Samraoui *et al.*, 2010): No threatened species was recorded at Wadi El Harrach during the study period. Noteworthy is the absence of two threatened endemics: *Calopteryx exul* and *Gomphus lucasi* (Riservato *et al*., 2009). This is unsurprising as specialist species are often the most prone to extinction when their habitats are altered (Colles *et al*., 2009). Likewise, noteworthy is the absence of other gomphids like *Onychogomphus coastae* and *Paragomphus genei*. The dominance of common species, mainly Anisopterans, was associated with the degradation of habitats in the downstream part of the wadi. Adult Anisopterans are large-bodied, accomplished insects which disperse widely (Corbet, 1999) and, in particular, recorded species like *Anax imperator*, *Crocothemis erythraea*, *Sympetrum fonscolombii*, and *Trithemis annulata* are widespread taxa, relatively tolerant of altered habitats. The presence of *Trithemis kirbyi* at Wadi El Harrach, a salt-tolerant species, previously confined to the Sahara (Samraoui & Menai, 1999), reflects the northward expansion of this dragonfly over the last decades (Boudot & Kalkman 2015).

CONCLUSION

Wadi El Harrach's poor odonatological diversity reflects the intense anthropogenic pressures it has been bearing for decades. Global changes and a concomitant loss of ecosystem services is a major source of concern as it represents a major obstacle to the Millenium objectives goals: poverty, hunger and disease reduction (Millenium Ecosystem Assessment, 2005; Patz *et al*., 2005). In North Africa, habitat loss and degradation, water pollution, water extraction, dam construction, exotic fish introduction and human disturbance as the result of tourism and outdoor recreational activities have been identified as major threats to dragonflies and to freshwater biodiversity as a whole (Samraoui *et al*., 2010).

Results of the physical and chemical studies are congruent with those based on the presence of Odonata and they indicate two, possibly three distinct areas: an upstream part dominated by Zygopterans associated to riverine vegetation and relatively good water quality. A downstream part dominated by salt-tolerant and ubiquitous Anisopterans, subdivided into a middle course with the highest species richness and a lower course of the wadi characterized by poor water quality and a lower species richness.

Implementing monitoring schemes and assessing regularly freshwater biodiversity are essential to resource management, thus paving the way to maintaining biological diversity and ensuring sustainable development. Such steps may include a Freshwater Action Plan for the Maghreb or frameworks like the Integrated River Basin Management (IRBM) implemented in Europe and the South African Working for Water Program. If nothing is done to avert the rapid degradation of North African freshwater ecosystems, the consequences will ultimately direly affect local people.

ACKNOWLEDGEMENTS

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