

## Invasion increasing risk of Al Jawahir Wadi lentic habitats by *Pistia stratiotes* L. (North-Central Morocco)

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**Abstract.** Draining of wetlands and their inadequate planning contribute greatly to the decline of hygrophilous vegetation. The arrival of invasive hygrophilous species, as noted recently for *Pistia stratiotes* L. in Al Jawahir Wadi (North Central Morocco) could also aggravate this situation. Surveys carried out in the watershed of this river show that *P. stratiotes* form spontaneous communities over a river-length of 10 km, twice of that reported in 2012, in spite of measures taken to limit its spread. Plants description on the basis of vegetative and reproductive criteria ascertains the permanent presence of this species upstream of the wadi, and reveals a succession of factors causing its intermittent suffocation downstream, including hydrological and planning hazards, and water pollution. The decontamination endeavors of Al Jawahir River and the exceptional propagating power of this species would represent a real threat to local water bodies for long.

**Keywords:** *Pistia stratiotes*; planning; invasion risk; Morocco.

## [es] Aumento del riesgo de invasión por *Pistia stratiotes* L. de los hábitats lenticos del río Al-Jawahir (Centro norte de Marruecos).

**Resumen.** El drenaje de los humedales y su manejo inadecuado contribuyen ampliamente a la degradación de la vegetación higrófila. En particular, la invasión de estos hábitats por especies exóticas, constituye un riesgo añadido para unos ecosistemas tan vulnerables. Un episodio de este tipo es el que ha ocurrido en Marruecos con la especie *Pistia stratiotes* L. en el río Al Jawahir (Fez). Las prospecciones realizadas en la cuenca de dicho río señalan que este hidrófito flotante ha llegado a formar comunidades espontáneas a lo largo de 10 km del cauce, lo que duplica la extensión constatada en 2012, a pesar de las acciones llevadas a cabo para detener su expansión. Hemos comprobado que la presencia de la especie río arriba se ha hecho permanente, produciendo estragos en el ecosistema fluvial, tales como la anoxia intermitente aguas abajo, la alteración del régimen hidrológico del propio río y el deterioro de la calidad del agua. Las medidas contra la contaminación del río Al Jawahir que habría que implementar, así como los daños directos provocados por esta especie, constituyen una amenaza ambiental real a medio plazo.

**Palabras clave:** *Pistia stratiotes*; planificación; riesgo de invasión; Marruecos.

### Introduction

Water lettuce (*Pistia stratiotes* L., *Araceae*) is the only surviving species of the *Pistia* genus (Evans 2013). It is a perennial floating aquatic macrophyte, known by different names: floating aroid, Nile cabbage, pistia, shell-flower, tropical duckweed, water bonnet, water cabbage, water fern, water lettuce, and water lily (Brundu et al. 2012; E.P.P.O. 2017; C.A.B.I. 2019). *P. stratiotes* is used widely, namely in traditional medicine, biogas production, fertilizer production, animal feeding, ornamentation, and phytoremediation (e.g. Abbasi et al.

1991; Koné et al. 2002; Lu et al. 2010; E.P.P.O. 2017).

*P. stratiotes* is a pantropical species with uncertain geographical origin (probably native to South America or Africa), and it could come from the Gondwana origin (E.P.P.O. 2017; Rodríguez-Merino et al. 2017; I.U.C.N. 2019). The distribution of this species currently includes about 100 countries between latitudes 40°S-40°N, or beyond latitude 60°N for the North America. It apparently does not concern the Middle East, Europe and North Africa besides Egypt (I.U.C.N. 2019). Nevertheless, *P. stratiotes* is reported in about 15 European

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countries and in Russia (E.P.P.O. 2017), and it considered as an exotic naturalized species (Domingues de Almeida & Freitas 2006).

The introduced and naturalized hygrophilous species from Morocco do not include submerged or floating taxa: *Modiola caroliniana* (L.) G. Don, *Populus alba* L., *P. nigra* L., *Heliotropium curassavicum* L., *Asclepias curassavica* L., *Gomphocarpus fruticosus* (L.) W.T. Aiton, *Phoenix dactylifera* L., and *Arundo donax* L. (Fennane et al. 1999, 2007, 2014; Valdés et al. 2002; Ennabili & Gharnit 2003b; Libiad 2013). However, the “Service de la Protection des Végétaux, Fès” mentioned in 2012 the first appearance of *Pistia stratiotes* in Fez Wadi (Al Jawahir Wadi) but could not possibly identify any of its introduction circumstances (S.P.V. 2019). Moreover, this species is part of invasive plants –*Eichhornia crassipes*, *Pistia* spp., *Salvinia molesta*, and *Typha australis*–, whose introduction to the country is prohibited by a Ministerial Order (B.O. 2002), given their potential for dysfunction of water bodies.

This study was carried out following the unexpected identification of this species in several locations of Al Jawahir Wadi. It consists of a survey of the Al Jawahir Wadi watershed and surrounding areas in order to morphologically characterize the species growing locally, and comment on its current distribution according to socio-ecological and planning hazards.

## Material and methods

### *Al Jawahir Wadi*

The natural environment of the Fez city had attracted many 12<sup>th</sup>-20<sup>th</sup>-century Moroccan poets by praising and describing its nature, especially Al Jawahir Wadi (Fez Wadi), having been compared to the Nile in Egypt and preferred to the Euphrates in Iraq and the Abi Rerraq River in Morocco. Among these poets, we quote muḥammad al-ūḡdī al-ḡamād, muḥammad ben al-maūla ismā’īl, muḥammad bū’šrīn, muḥammad ḡarwīt, muḥammad al-mihdī al-ḡaḡwiwy (Al-ssaqāt 1993).

As part of the upstream watersheds of Sebou Wadi, the watershed of Al Jawahir Wadi originates in the area of Ras El Ma, where it is fed by very important sources such Aïn Ras El Ma, Atrous, Bergama, Sen-

nad..., and covers an area of approximately 879 km<sup>2</sup>. It is the main collector of intermittent seasonal flow tributaries of the Middle Atlas (wadis of Boufekrane, El Mehraz, El Himmer, and Chkou) or tributaries, fed by permanent flow sources of the Saïs plateau (wadis of Ain Chkef, Ain Smen, Ain Chgag, and Ain Bou Rkaiz), in addition to El Malleh Wadi and other ravines from the pre-Rif. It should also be noted that this river receives most of the wastewater from the Fez urban agglomeration, without receiving sufficient treatment (Reynard et al. 2011). According to 2013 data, the water quality of Al Jawahir Wadi is good upstream, and very bad downstream until its confluence with Sebou Wadi, due to domestic, industrial, and agricultural pollution (A.B.H.S. 2015).

The Al Jawahir Wadi watershed has a Mediterranean climate, influenced by the continental character of the territory -hot and dry summer, and cool and wet winter-, and by irregular intra-annual and inter-annual rainfalls (Reynard et al. 2011). The maximum drought period in Fez tends to increase by around 3.6 days/decade, and thus its climate changed from semi-humid in 1961-1980 to semi-arid in 1981-2008 (Driouech 2010).

### *Surveying and plant description*

The hygrophilous vegetation of the Sebou Wadi watershed is relatively poor in aquatic species, related to steep slopes and erosion of the rivers banks, that in turn prevent the setting-up of aquatic and semi-aquatic plant communities (Hammada 2007).

Considering the site conditions such as water quality, flow velocity, surface water depth, conservation status, and accessibility, 29 locations were selected for prospecting, numbered from the upstream towards downstream: watershed of Al Jawahir Wadi (Site.1-S.19), Sebou Wadi (S.20-S.23, S.26-S.28), Inaouene Wadi (S.24), Lebene Wadi (S.25), and Ourgha Wadi (S.29) (Fig. 1). The surveyed sites on the scale of the Al Jawahir Wadi watershed are located between latitudes N33°59’10.18”-N34°07’0.001”, longitudes W4°55’59.998”-W5°07’16.078”, and altitudes 310-494 m. By comparing the current distribution of *P. stratiotes* to that in 2012 (S.P.V. 2019), the occupation progression of the Al Jawahir Wadi by this plant is assessed using Google Maps (2019).

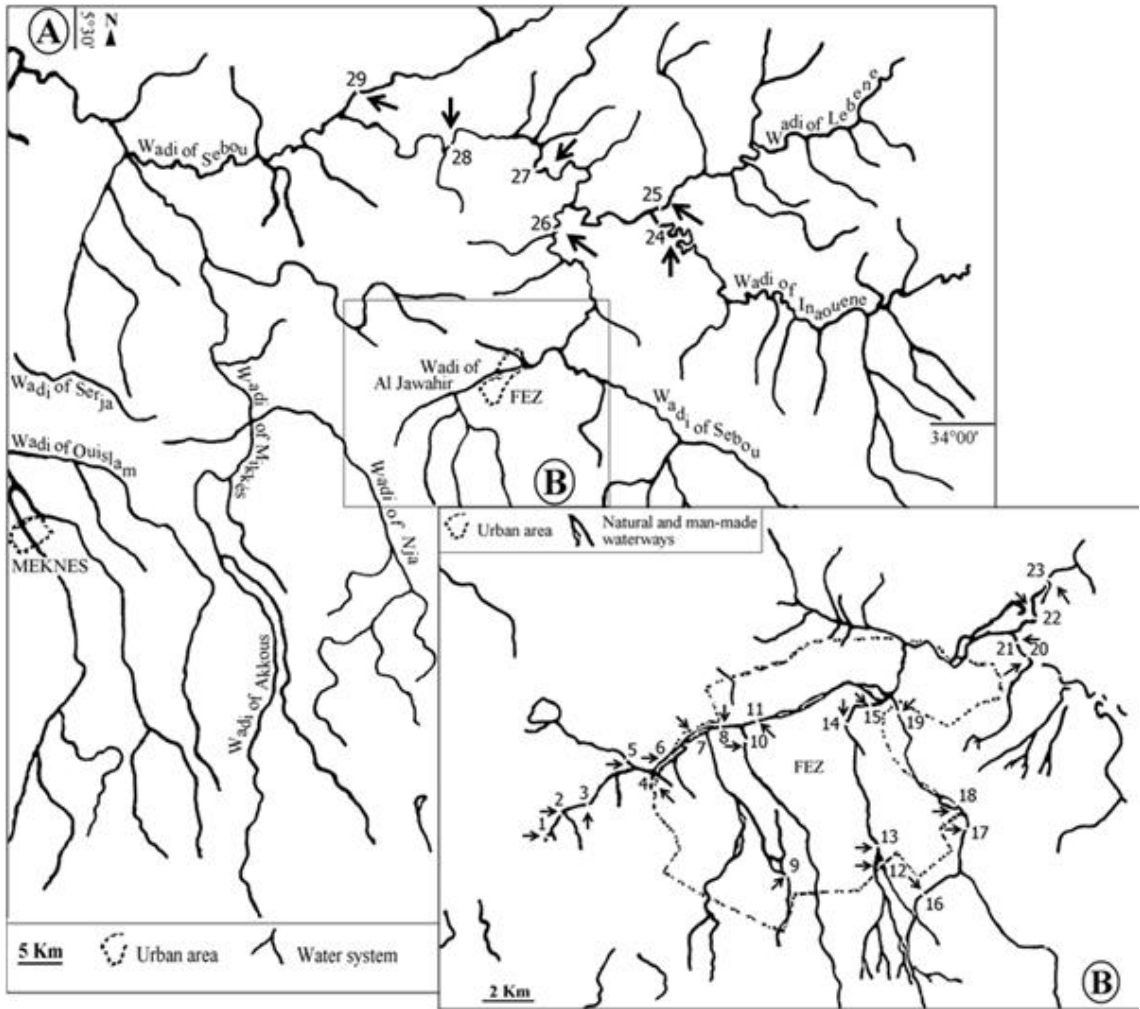


Figure 1. Situation of the surveyed sites in the Sebou Wadi watershed. Modified sources: A.B.S. (1970)- Fig. 1-A; Reynard et al. (2011) and Google Maps (2019)- Fig. 1-B.

Field surveys were carried out during the period “December 2018-April 2019”, across two successive seasons-winter and spring-. Plants of *P. stratiotes* communities were sampled in the main upstream and downstream

sites of Al Jawahir Wadi (S.1, S.8, Tab. 1) for examination, description and comparison. The measured parameters in this plant are shown in Figure 2.

Table 1. Presence sites of *P. stratiotes* in the surveyed area

Site numbers (Fig. 1)	Geographic coordinates	Altitudes (m)
1	N 34°00'12" W 005°07'16"	388
2	N 34°00'33" W 005°07'00"	388
3	N 34°00'51" W 005°06'41"	388
6	N 34°02'42" W 005°03'68"	373
7	N 34°02'48" W 005°03'44"	374
8	N 34°02'63" W 005°02'94"	377
11	N 34°02'72" W 005°02'26"	380

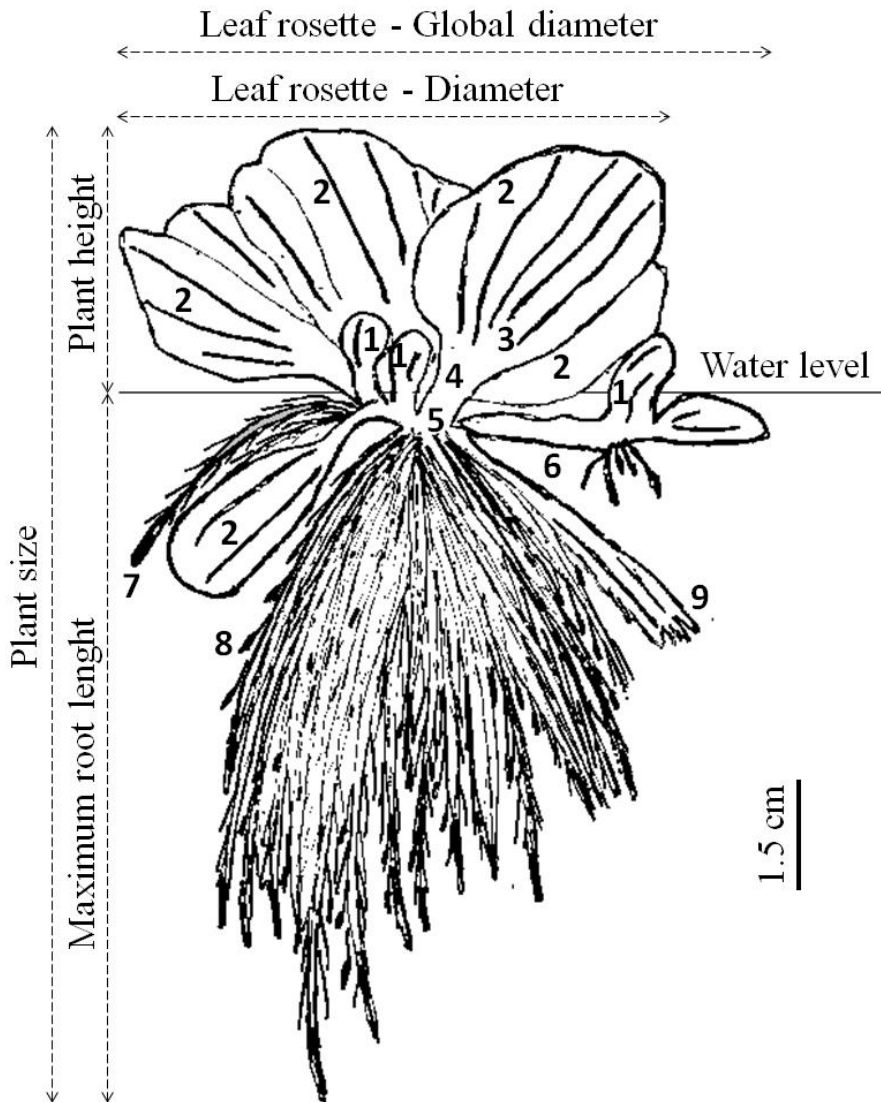


Figure 2. Scheme of *P. stratiotes* plant indicating measured parameters. 1, offspring; 2, outer leaf; 3, ribs; 4, petiole; 5, collar; 6, stolon; 7-8, root cap of primary (7) and secondary (8) roots; 9, senescing leaf.

## Results and discussion

### Habitat and distribution

*P. stratiotes* locally forms spontaneous monospecific communities on calmer water surfaces, mesotrophic or eutrophic, in semi-protected natural areas of the extreme headwaters of Al Jawahir Wadi (Fig. 3), given the presence in its immediate surroundings of indicator genera of moderately or unpolluted sites, such as *Rubus*, *Salix*, *Phragmites*, *Typha*, *Samolus*,

*Potentilla*, *Lythrum*, *Mentha*, *Nasturtium*, *Juncus*, *Ranunculus*... (Ennabili & Ater 1996 ; Ennabili 1999 ; Ennabili et al. 2000 ; Ennabili & Ghamit 2003a ; Libiad et al. 2012; Libiad et al. 2015). With a more pronounced flow of water further downstream, *Pistia* constitutes small floating communities in *Typha* beds (Fig. 4-F) or under *Salix* shrubs (Fig. 5-J), always on quieter and shallower waters. In areas bordering rangelands, *Pistia* is apparently grazed by livestock and is only present in scattered individuals, sometimes rooted in mud as a result of intermittent flooding (Fig. 6).

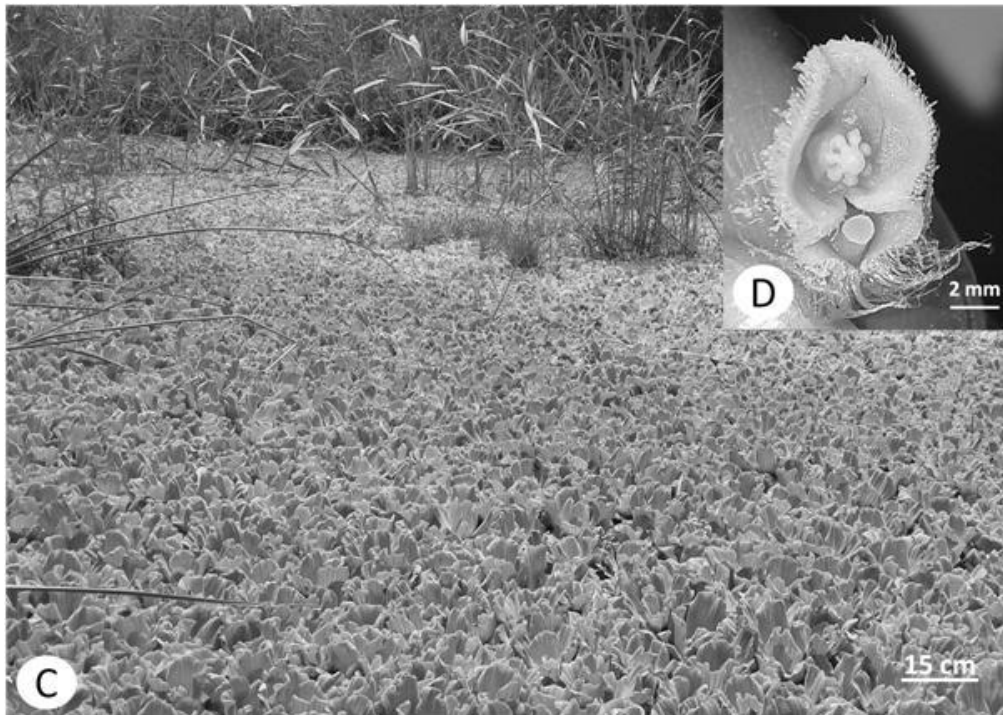


Figure 3. *Pistia stratiotes* community sprinkled with *Phragmites australis* (C), and details of the inflorescence (D) (S.1; Tab. 1- Fig. 1).

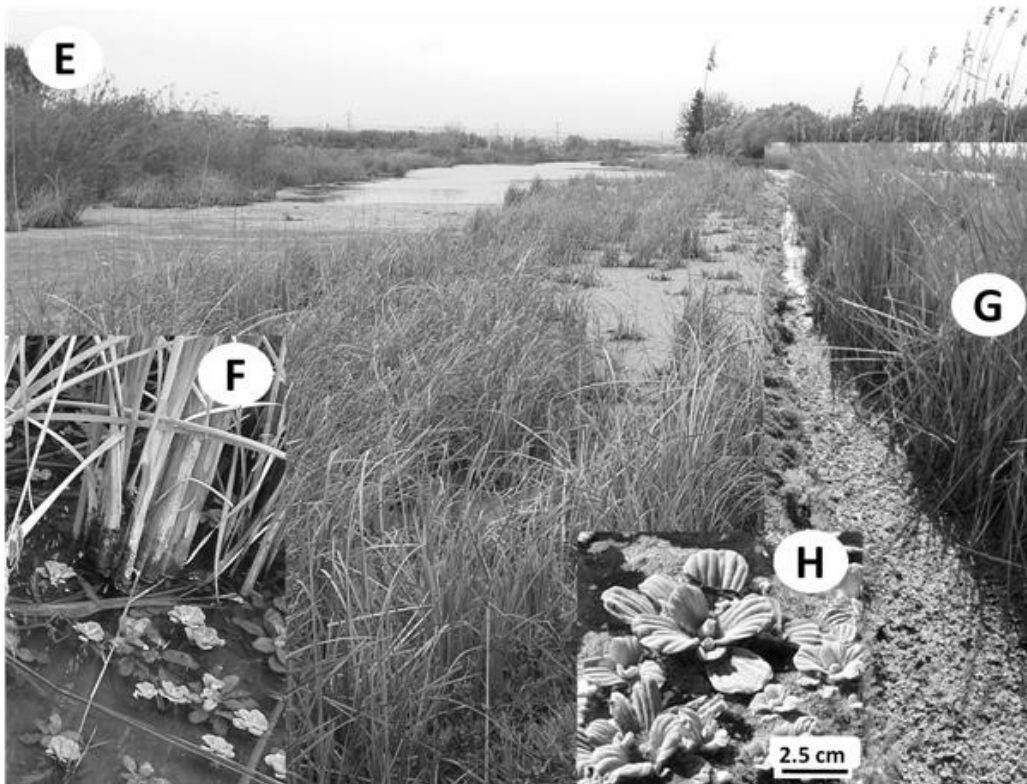


Figure 4. Wetland invaded by *Pistia stratiotes* (E), *Pistia* community in *Typha* bed (F), floating cape of *Pistia* at a *Typha* bed edge (G), and *Pistia* plants in competition with filamentous algae (H) ; S. 2 et 7 (Fig. 1, Tab. 1).

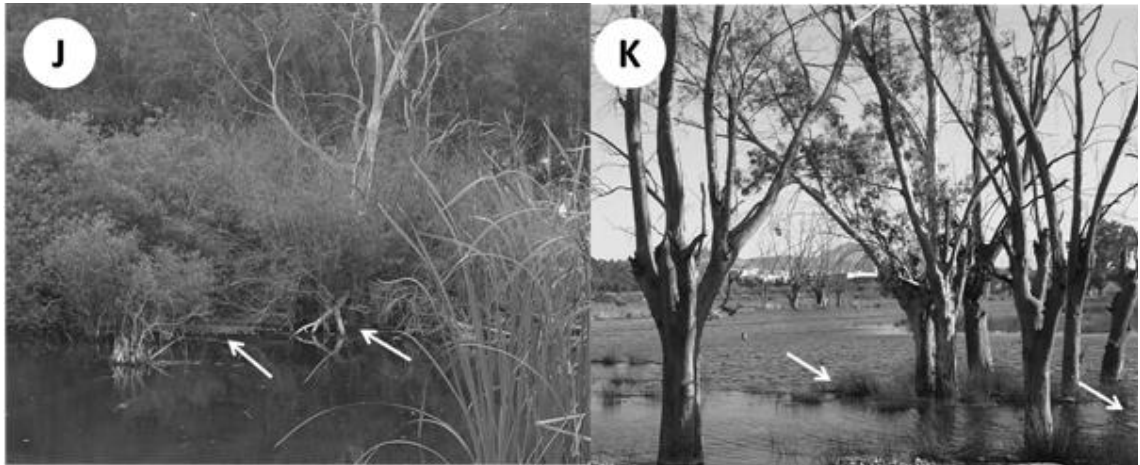


Figure 5. Vegetation regression of dewatered sites (e.g. *Juncus acutus* and *Eucalyptus* spp.), and massive arrival of aquatic and semi-aquatic plants (e.g. *Pistia stratiotes*, *Ranunculus aquatilis*, *Lemna minor*, *L. gibba*, *Typha angustifolia*, *Salix* spp.); S. 2 (J) and S. 8 (K); Fig. 1, Tab. 1.

The arrows indicate small communities of *Pistia*.



Figure 6. *Typha* bed bordering a rangeland (S. 3, Fig. 1, Tab. 1).

The arrows indicate remnants of destroyed homes, permanently flooded.

In the sites S.6-8 and 11, the overall slope is very low, allowing the development of *Pistia*-mats in *Typha*-beds (Fig. 4-E, G), or small ones around flooded *Juncus*-tufts (Fig. 5-K). *Pistia* is well represented from the end of December to the end of January (rainy season, moderate temperature, meso-eutrophic waters - Fig. 4-G), and cannot withstand successive competition of *Chraceae*, filamentous algae (Fig. 4- H), *Ranunculus aquatilis*, *Lemna minor* and *L. gibba* (Fig. 4-E), from February until the end of April. The arrival of *L. gibba*, indicative of polluted eutrophic environments (Ennabili & Gharnit 2003; Ennabili & Ater 2005), accelerates the suffocation of *Pistia* communities under such conditions.

*Pistia* is present permanently upstream of Al Jawahir Wadi, as indicated in 2012 (S.P.V. 2019), especially in the notable absence of overgrazing, urban pollution sources, and major planning actions of the water system. Spontaneous presence of this species currently concern about 10 km along Al Jawahir Wadi from upstream to downstream, twice that reported in 2012, in spite actions and measures taken to limit its spread beyond the first appearance site: manual weeding, narrow mesh installation through the river, and release of predatory insects (S.P.V. 2019). The proximity of the city of Fez (urban wastewaters without sufficient treatment) and the channelization of the river banks (removal of habitats by concretization)

seem to weaken vegetative expansion of this species towards Sebou Wadi (Fig. 1).

### Plant description

The biometric parameters of *Pistia* plants showed a very highly significant difference

between the upstream (Fig. 3) and downstream (Fig. 4) provenances of Al Jawahir Wadi, except ratios of “plant height/root length” ( $0.33 \pm 0.10$ ), leaf “length/width” ( $1.47 \pm 0.13$ ), and petiole “length/width” ( $2.34 \pm 2.29$ ), and the Primary root number ( $26.9 \pm 9.35$  roots) (Tab. 2).

Table 2. Mean biometric characteristics of *P. stratiotes* plants from upstream and downstream of Al Jawahir Wadi. SE, significant effects at  $p < 0.05000$  (N = 20): \*\*\*, very highly significant, and NS, non-significant. The averages followed by the same letter are not significantly different.

	Upstream	Downstream	F-ratio	F-prob.	SE
Plant size (plant height and root length)	48.4±6.57 a	11.4±2.20 b	284.97173	1.7581E-12	***
Plant (leaf rosette) height	10.0±1.99 a	3.14±0.33 b	116.016743	2.8139E-09	***
Global diameter of the “leaf rosette and offspring ones”	23.9±6.47 a	6.26±1.46 b	70.6910875	1.1986E-07	***
Diameter of the leaf rosette	14.9±2.46 a	4.62±0.81 b	155.831968	2.6658E-10	***
Stolons number per plant	5.14±1.27 a	3.10±0.99 b	16.0720906	0.00082316	***
Stolon length	8.52±1.52 a	1.09±0.37 b	224.359494	1.3201E-11	***
Number of outer leaves per leaf rosette	12.7±2.07 a	5.80±0.92 b	92.9976628	1.5567E-08	***
Leaf length	8.05±1.66 a	3.21±0.36 b	81.2323341	4.3113E-08	***
Leaf width	5.37±1.08 a	2.22±0.13 b	83.9545925	3.3705E-08	***
Leaf “length/width” ratio	1.48±0.04 a	1.45±0.19 a	0.23753666	0.63187362	NS
Rib number at the leaf underside	8.56±0.97 a	5.70±0.82 b	50.5468278	1.2605E-06	***
Petiole length	2.75±1.03 a	0.65±0.18 b	39.9899244	5.847E-06	***
Petiole width	1.18±0.44 a	0.45±0.07 b	26.5564784	6.6706E-05	***
Petiole “length/width” ratio	3.19±3.03 a	1.48±0.47 a	3.10542215	0.09500489	NS
Plant collar diameter	0.93±0.13 a	0.54±0.09 b	59.5173913	4.0941E-07	***
Maximum root length	36.5±5.70 a	8.72±2.66 b	195.772108	4.1048E-11	***
“Plant height/Root length” ratio	0.28±0.08 a	0.38±0.09 a	7.239542	0.014946	NS
Primary root number	23.5±9.64 a	30.2±8.18 a	2.7918159	0.11204221	NS
Root cap length of the primary roots	3.04±0.52 a	0.51±0.29 b	180.419981	8.0532E-11	***
Root cap length of the secondary roots	0.96±0.43 a	0.23±0.05 b	28.512095	4.4777E-05	***

Apparently under favorable conditions, plants upstream are olive-green and more developed compared to the pubescent-green ones growing on polluted eutrophic waters of downstream sites. The leaf rosette diameter (3.6-13.4 cm) is proportional to the outer leaf number, and to the leaf size, as reported by Šajna et al. (2007), closer to that reported in Serbia (10-17 cm) and USA (6-30 cm), but significantly exceeded by that underlined in Slovenia (65 cm) (Šajna et al. 2007; Thayer et al. 2019; Živković et al. 2019).

*Pistia* spreads vegetatively and can produce between 3 and 5 unequal stolons, about 1 to 8.5 cm in length each (Tab. 2). Offspring rosettes at the stolon distal-ends occupy between

26.2 to 37.8% of the water surface covered by this plant. The leaves are obovate to spatulate -about 1.5 longer than wide (2.9-10.2 cm × 2.0-6.7 cm)-, and shortly hairy above, densely pubescent with 5-9 prominent ribs below. The petiole is about 2.5 times longer than wide (0.4-4.5 cm × 0.4-1.8 cm). The collar diameter varies from 0.35 to 1.20 cm. The root hairs are up to twice as long as the leaf rosette, comprising 13-43 main roots, feathery and ending with a cap of 0.2.-3.7 cm.

The flowering peak of *Pistia* is observed from April in Al Jawahir Wadi. The inflorescence ( $1.62 \pm 0.30$  mm long) is carried by a peduncle of  $0.63 \pm 0.11$  mm in the leaf axils (Fig. 3-D). The spathe ( $1.03 \pm 0.14$  mm long) has an ap-

erture of  $0.88 \pm 0.10 \text{ mm} \times 0.50 \pm 0.09 \text{ mm}$ , with a fimbriated margin. A constriction of the inflorescence separates a basal part containing the single female flower -ovary ( $0.42 \pm 0.03 \text{ mm}$  long) and style ( $0.19 \pm 0.02 \text{ mm}$ )-, from an upper one that corresponds to upper part of spadix ( $0.22 \pm 0.03 \text{ mm}$ ) carrying 7 to 8 male flowers.

### *Invasion Risks*

The invasion risks of local wetlands by *P. stratiotes* are related to the climatic hazards, spread characteristics of this species, wet habitat modifications because of planning actions, surface water pollution, and means of control implemented. In addition to its vegetative propagation by stolons, a female flower of *Pistia* can release under water up to 30 viable seeds (Dray & Center 1989; Šajna et al. 2007; Kurugundla 2014; E.P.P.O. 2017; C.A.B.I. 2019). Floating seeds, just after their dispersal, could be transported by water, and waterfowl (C.A.B.I. 2019). The diversity of *Pistia* communities in Al Jawahir Wadi (mono-specific or co-dominated communities within *Typha* beds and riparian forests) makes its manual and/or mechanical collection very difficult.

Several factors can favor the *Pistia* spreading, including freshwater with low flow, neutral or slightly acid, slightly brackish, or polluted because of the urbanization (Pieterse et al. 1981; Akinbile et al. 2012; Passarelli et al. 2014; A.D.B. 2019). The climatic warming detected in the Fez Region, from the Mediterranean semi-humid to the Mediterranean semi-arid since the eighties (Driouech 2010), would be another factor favoring *Pistia* invasion in Al Jawahir Wadi, also emphasized by Šajna et al. (2007).

Wetlands along Al Jawahir Wadi experience major changes due to multiple modifications of the water system, in particular the planning of open and underground channels, and diversion ones. Two hydrological hazards also interfere with these modifications, including tributaries coming from the Tabular Middle-Atlas, with a sudden and violent hydrological character, and floods mainly following the outcropping of groundwater (Reynard et al. 2011). This could lead to the creation of new fa-

vorable habitats for *P. stratiotes*, and the overflow of mesh barriers installed for its interception.

The quality status of the surface waters of the Sebou Wadi watershed, characterized in March-May 2013 (A.B.H.S. 2015) by referring to the Moroccan quality standards (S.E.D.D. 2019), classifies the surveyed sites into excellent (S.24), good (S.1-S.19, S.20-S.21), medium (S.29), poor (S.25), and very poor (S.22-S.23, S.26-S.28) qualities (Fig. 1). According to the field surveys, the water quality mentioned above for the sites 6-8 and 11 does not seem to be conserved and turns towards a pronounced eutrophication, apparently slowing down the vegetative propagation of *Pistia* downstream of this river. This very poor water quality concerns about 12 km of this river -of which about 9 km in full urban fabric- and consequently would probably prevent the germination of *Pistia* seeds, transported by water or buried in the sediments. However, by 2030, A.B.H.S. (2015) aims to reduce water pollution by 80%, improving the surface water quality at downstream sites: poor (S.22-S.23) and good (S.24-S.28) qualities. This would undoubtedly favor the vegetative propagation of *Pistia* if control means in progress eventually do not allow its eradication by then.

Dams in the Sebou Wadi watershed, of high socio-economic value, are the most threatened by this species, because of their large surface area, nutrient richness, waterfowl, and the low flow of feeding rivers, where communities of eutrophic hygrophytes are easily recognizable (*Potamogeton nodosus*, *Typha angustifolia*, *Phragmites australis* ... S.21, S.24 and S.29, Fig. 1). In addition to the socio-economic damage that could be caused by such an invasion of water infrastructure, natural aquatic ecosystems would not be protected: biodiversity decline, evapotranspiration increase, fishing activity dip, and waterborne disease spread (e.g. Carpenter & Lodge 1986; Šajna et al. 2007; Brundu et al. 2012; Rodríguez-Merino et al. 2017).

### **Conclusions**

*Pistia stratiotes* has a great intrinsic capacity to invade water bodies even under unfav-



favorable hydrological and quality conditions, if we except optimal habitats of *Lemna gibba*. In addition, the spreading of *P. stratiotes* looks to be slowed by the concreteization of river banks near the city of Fez, thus eliminating its potential habitats. However, in the absence of an effective control, *Pistia* could spread where the conditions would be favorable.

This current diagnostic of the invasion risk of Al Jawahir Wadi by *P. stratiotes* is a deci-

sion-making tool for local actors. A multi-criteria approach should be locally implemented to limit the spread of *Pistia* in particular and possible other exotic hygrophytes such as *Eichhornia crassipes* and *Salvinia molesta*, by launching research programs on the inventory of introduced or naturalized flora of the Moroccan wetlands, identifying potential areas for their distribution, and developing environmental and socio-economic measures to limit their expansion.

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