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The alien boatman *Trichocorixa verticalis verticalis* (Hemiptera: Corixidae) is expanding in Morocco

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ABSTRACT

The alien boatman *Trichocorixa verticalis verticalis* (Hemiptera: Corixidae) is expanding in Morocco

This paper updates the presence of the Nearctic "water boatman" *Trichocorixa verticalis verticalis* in North Africa, showing a new range of the alien species that strongly have increased its distribution area in Morocco since its first record in 2010. Statistical analyses confirm a significant correlation between salinity and abundance of *T. v. verticalis*, highlighting the halobiont behavior of this invasive species, being this trait one of the main causes of its expansion success in the Atlantic and Mediterranean coast of the study area.

Key words: *Trichocorixa verticalis verticalis*, aquatic bug, exotic species, invasion, Ramsar wetlands, salinity, Morocco

RESUMEN

El chinche acuático invasor* Trichocorixa verticalis verticalis *(Hemiptera: Corixidae) se está expandiendo en Marruecos

Este trabajo actualiza la presencia del "chinche acuático" Nearctico Trichocorixa verticalis verticalis *en el norte de África, mostrando un nuevo rango de la especie exótica que ha aumentado considerablemente su área de distribución en Marruecos desde su primer registro en 2010. Los análisis estadísticos confirman una correlación significativa entre la salinidad y la abundancia de* T. v. verticalis*, destacando el comportamiento halobionte de esta especie invasora, siendo este rasgo una de las principales causas de su éxito de expansión en la costa atlántica y mediterránea del área de estudio.*

Palabras clave: Trichocorixa verticalis verticalis*, insecto acuático, especie exótica, invasión, humedales Ramsar, salinidad, Marruecos*

INTRODUCTION

Humans have assisted the movement of other species beyond their natural ranges for centuries (Wilson *et al.*, 2009). However, their role in shaping biota increased exponentially over time, especially throughout the 20th century (Hulme *et al.*, 2009). Biological invasions are one of the top threats to biodiversity and ecosystem functioning worldwide, and freshwater systems are among the most invaded ecosystems in the world (Fenoglio *et al.*, 2016), having proportionally more invaders than terrestrial systems (Vitousek *et al.*, 1997). In fact, globally freshwaters have been subjected to periodic deliberate and accidental introductions of alien species. Typical sources of invader introductions are ballast waters, pet, aquarium and ornamental trade, sport fishing and aquaculture (Nunes *et al.*, 2015). In addition, exploitation and pollution of these waters and conversion to agriculture or urbanization also increase the likelihood of the alien species establishment and spread worldwide throughout degraded habitats (Dudgeon *et al.*, 2006).

Nonetheless, for the majority of these invaders, the effects on the occupied systems are largely unknown. Although not all alien species have appreciable effects on the invaded ecosystems, many of them have been often implicated in species extinction, habitat degradation and ecosystem alteration (Clavero & García-Berthou, 2005). Invasive species can bring serious threats to the conservation of protected areas (Lonsdale, 1999; Lovejoy, 2006). The "cordgrass" *Spartina densiflora* Brongn, the "water hyacinth" *Eichhornia crassipes* (Mart.), the "crayfish" *Procambarus clarkii* (Girard), the "zebra mussel" *Dreissena polymorpha* (Pallas), and the "mosquitofish" *Gambusia holbrooki* Girard are good examples of invaders that have detrimental effects on protected ecosystems (Caiola & Sostoa 2005; Pimentel *et al.*, 2005; Castillo *et al.*, 2008; Cruz *et al.*, 2008; Laranjeira & Nadais, 2008; Savini *et al.*, 2010). Whilst some taxonomic groups are well represented in alien invertebrate species lists, insects are highly under-represented (Balian *et al.*, 2008), particularly aquatic ones, which do not seem to show this kind of behavior (Fenoglio *et al.*, 2016).

A recent addition to these lists is the North American "water boatman" *Trichocorixa verticalis verticalis* (Fieber, 1851) (hereafter *Tvv*). This subspecies represents one of the few alien aquatic insects found in the world (Carbonell *et al.*, 2017). *Tvv* inhabits brackish and saline water bodies, even occurring in the open sea (Hutchinson, 1931). Originally, it was widely distributed through the Atlantic coast of North America and the Caribbean islands (Carbonell *et al.*, 2012). However, this corixid has also been recorded quite far from its area of distribution, such as New Caledonia (Jansson, 1982), KwaZulu-Natal in southern Africa (Jansson & Reavell 1999), and recently, Spain, Portugal and Morocco (Guareschi *et al.*, 2013).

In Spain, it was detected in the southwest (Günther, 2004), including wetlands from Doñana (Millán *et al.*, 2005; Rodríguez-Pérez *et al.*, 2009). In Portugal, it was primarily recorded from the South (Sala & Boix 2005; Kment, 2006). Since its first detection in the Iberian Peninsula, *Tvv* has moderately increased its distribution area (Carbonell *et al.*, 2012), being dominant in permanent saline waters, but rare in freshwaters, where native corixids are dominant (Coccia *et al.*, 2013). In Morocco, it was discovered for the first time in irrigation channels in the Tahaddart river basin, posteriorly in the lowland of the Loukkos river and finally in the swamps of Smir lagoon (L'Modhi *et al.*, 2010), apparently showing a halobiont behavior (see Hutchinson, 1993).

In this study, we aim to upgrade the available data of *Tvv* in Morocco and to determine the main environmental factors favoring its distribution and expansion in this country, trying to confirm its halobiont behavior.

MATERIAL AND METHODS

Surveys

Several campaigns were carried out between 2014 and 2017, on both Mediterranean and Atlantic coasts of Morocco seeking the alien species. Sampling sites were selected to cover all of the different environmental conditions and water-body types (mouth rivers and streams, irrigation channels, lagoons, ponds, salt marshes and salt-pans) in the coast or near it, where the alien species finds the most favorable habitats (Guareschi *et al.*, 2013). All the sampling campaigns were carried out following the same protocol (see below) and supervised by the senior author of this study (AM), including those achieved in L'Mohdi *et al.* (2010) and L'Modhi (2016).

At each sampling site, all macroinvertebrates were collected from a representation of mesohabitats, always applying a multihabitat protocol (Jáimez-Cuéllar *et al.*, 2002). The procedure consisted of dragging a kick-net of 0.10 mm mesh pore (diameter of the opening 25 cm and depth 45 cm) and "D" shape. Each kick-sample was examined in the field until no new taxa were found with cumulative net strokes. For each sample, all the individuals belonging to the Corixidae family found were extracted and preserved in separate vials and fixed with alcohol 96 %. The remaining material was also preserved in vials with alcohol 70 or 96 %. In the lab, corixids were carefully examined looking for individuals of *Tvv*, which were subsequently counted, thus obtaining a comparable relative estimate of the abundance of this species for each sampling site.

Harvested corixids were identified in the laboratory using specialized literature (Jansson, 1986; Gheit, 1994; Nieser *et al.*, 1994; Günther, 2004; L'Modhi *et al.*, 2010). The recorded species were preserved in duly labeled tubes and deposited in the collection of aquatic macroinvertebrates at the Laboratory of Water Sciences, Environment and Sustainable Development of the University Mohammed Premier from Oujda (Morocco), and the Department of Ecology and Hydrology, Faculty of Biology, University of Murcia (Spain).

Parallel to the sampling fauna, each sampling site was subjected to *in situ* measures of five physicochemical parameters (mean water depth, temperature, pH, electrical conductivity and salinity), all considered of special concern in the distribution of aquatic macroinvertebrates, particularly corixids (Carbonell *et al.*, 2011). The last four parameters were measured with a multiparametric measuring device (WTW, Multi-Line P4).

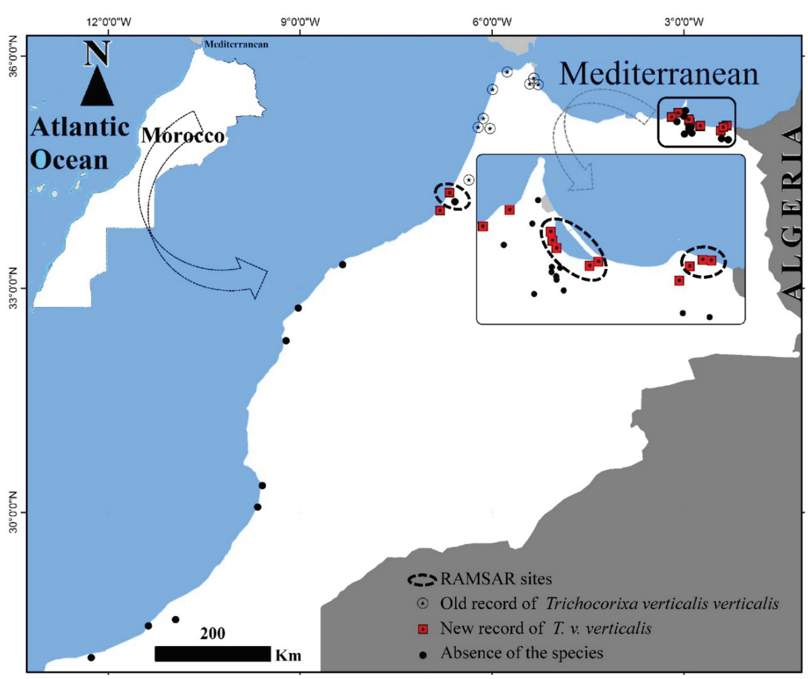

Figure 1. Distribution of *T. v. verticalis* in North Africa. Note the eastern and southern range expansion of *Tvv* in Morocco (red squares). *Distribución de* T. v. verticalis *en el Norte de África. Destaca la expansión del rango este y sur de* Tvv *en Marruecos (cuadrados rojos).*

Table 1. The corixid species collected together with *T. v. verticalis* in the study area. *Tvv: Trichocorixa verticalis* (Fieber, 1851); *Sl: Sigara lateralis* (Leach, 1817); *Ss: Sigara selecta* (Fieber, 1848); *Sc: Sigara scripta* (Rambur, 1840); *St: Sigara stagnalis* (Leach, 1817); *Pt: Parasigara transversa* (Fieber, 1848); *Pf: Parasigara favieri* (Poisson, 1939); *Ca: Corixa affinis* Leach, 1817; *Cp: Corixa panzeri* Fieber, 1848. See Table S1 for sampling sites name. *Las especies de corixidos recogidos junto con* T. v. verticalis *en el área de estudio. Tvv: Trichocorixa verticalis* (Fieber, 1851); *Sl: Sigara lateralis* (Leach, 1817); *Ss: Sigara selecta* (Fieber, 1848); *Sc: Sigara scripta* (Rambur, 1840); *St: Sigara stagnalis* (Leach, 1817); *Pt: Parasigara transversa* (Fieber, 1848); *Pf: Parasigara favieri* (Poisson, 1939); *Ca: Corixa affinis* Leach, 1817; *Cp: Corixa panzeri* Fieber, 1848. Ver Tabla S1 para el nombre de las estaciones de muestreo.

Sampling sites	*Tvv*	*Sl*	*Ss*	*Sc*	*St*	*Pt*	*Pf*	*Ca*	*Cp*
S51	2	-	-	-	-	-	-	-	-
S52	143	-	-	-	-	-	-	-	-
S53	1	-	-	-	-	-	-	-	-
S54	165	-	-	-	-	-	-	-	-
S55	35	-	-	-	-	-	-	-	-
S56	264	-	4	-	-	-	-	-	-
S57	25	-	75	-	-	-	-	-	-
S57	39	-	-	-	-	-	-	-	-
S59	1	-	-	-	-	-	-	-	
S70	6	-	12	-	-	-	-	-	-
S71	4	-	5	-	-	-	-	-	-
S86	2	-	-	-	-	-	-	-	-
S98	1	-	-	-	-	6	-	-	-
S100	1	-	-	-	-	22	-	-	-
S104	2	-	-	-	-	-	-	2	-
S104	-	3	-	-	-	-	-	-	-
S104	1	2	-	-	-	-	-	2	-
S105	1	-	-	-	-	-	-	-	-
S105	2	-	-	-	-	-	-	-	-
S105	4	-	-	-	-	-	-	-	-
S158	10	-	-	-	-	-	-	-	-
S161	12	-	-	-	-	7	-	-	12
G11	34	112							
G10	12		7	-	-	-	-	-	-
O7	52	33		-	-	-	-	-	-
O19	147	10		-	-	-	-	-	-
N2	65	110		-	-	-	-	-	-
N7	4	39	3	-	-	-	-	-	-
N8	6	-		1	77	-	-	-	-
N18	129	5	-	-	-	-	-	-	-
N19	4	1	-	-	-	-	-	-	-
N20	5	2	-	-	-	-	-	-	-
N21	4	-	-	-	-	-	-	-	-
M21	7	-	1	-	-	-	2	-	-
M22	6	-	3	-	-	-	-	-	-

Statistical processing of data

In order to determine the ecological factors addressing the distribution of *Tvv*, we built a matrix (see Appendix) showing, for all sampling sites visited combined with those compiled by L'Mohdi *et al.*, (2010) and L'Mohdi (2016), the abundance of *Tvv* and measures of four of the five abiotic parameters considered. Since the conductivity and salinity are almost proportional, we preferred to keep the last factor. For homogenizing variances and minimize the non-normality effects, abundance and the remained parameters selected were log (x + 1) transformed.

We used Pearson's correlations (R > 0.7) to discard variables collinearity and as a first step to understand the relationship between the abundance of *Tvv* and salinity. We further used Multiple Linear Regression (GLM, McCullagh & Nelder, 1989) to estimates the relationship between salinity and the remained variables. GLM is one of the best known and most applied method in statistics for the analysis of quantitative data determining the dependence between the variable response or dependent numeric variable and several factors or independent numeric variables. Thus, the recorded abundance values of *Tvv* were regressed against the selected environmental variables assuming a Poisson distribution for the dependent variable. Statistical analyses were carried out using R version 3.3.1 software.

RESULTS

The alien species *Tvv* have been detected in 30 of the 50 water bodies prospected (Fig. 1 and Table S1, available at http://www.limnetica.net/en/limnetica), most of them saline or moderately mineralized, near to the coast and, always, at low altitude. We found it for the first time in two Ramsar sites on the Mediterranean coast, the lagoon of Nador and its surroundings, and the wetlands of the Moulouya mouth, respectively. On the Atlantic coast, we also discovered it in the Ramsar site of Sidi Boughaba Lake and in the lower part of Oued Bouregreg (Fig. 1).

Tvv was usually accompanied by other species of corixids (Table 1) but mainly by *Sigara lateralis* (Leach, 1817) in moderate saline or fresh waters, and *S. selecta* in saline waters.

The results of multiple linear regression of abundance versus salinity, altitude, temperature and depth, showed the existence of a clear statistically significant relationship ($p < 0.05$) between abundance and salinity (Table 2 and Fig. 2). In other words, a more saline sampling site is more likely to have a higher abundance of *Trichocorixa verticalis verticalis* than a less saline one.

DISCUSSION

Since the first time that the alien species *Tvv* was recorded in Morocco, it has significantly increased its distribution range. After this study,

Table 2. Coefficients of multiple and simple linear regression. *Coeficientes de regresión lineal múltiple y simple.*

	Estimate	Std. Error	t value	Pr(>|t|)
Multiple linear regression				
(Intercept)	99.662	96.788	1.03	0.312
Sal	**1.024**	0.465	2.20	**0.036***
Alt	-0.655	0.949	-0.69	0.496
Temp	-2.752	3.694	-0.75	0.462
Dep	-0.210	0.243	-0.87	0.393
***P* < 0.05**				

the number of Moroccan Ramsar sites invaded by this species would be five, including Smir and Loukkos wetlands, previously mentioned in L'Modhi *et al.*, (2010). The mouth of the Bouregreg river remains so far the southernmost limit known in the Atlantic coast for this species. In the Mediterranean coast, the mouth of the Moulouya and the city of Saidia were the easternmost limits, also expanding its previously known range (Chavanon *et al.*, 2004; L'Modhi *et al.*, 2010). However, it is probable that the species has already exceeded this limit because of the near presence of available habitats for this species in Algeria. These results give support to the predictions pointed by Guareschi *et al.* (2013), which expected a wide spread of *Tvv* in several regions of the world, including the coast of the Mediterranean and Atlantic Africa.

Tvv seems to be a high-performance as an invader in mineralized wetlands at low altitudes (ranging from 0 to 54 m), corroborating the information pointed in previous Iberian studies (Rodríguez-Peréz *et al.*, 2009, Van De Meutter *et al.*, 2010a, Guareschi *et al.*, 2013). Thus, saline stagnant waters near the coast were the most preferred habitat. Nevertheless, it can also colonize artificial channels, and standing and running freshwaters, also showing a euryoic behavior (Carbonell *et al.*, 2017). In fact, the populations studied here were capable to colonize water bodies with strong mineralization differences, fluctuating between 0.1 and 100 g/l. This ability to tolerate a broad salinity range should be a key feature of its success as an invader too. Its capability to live in hypersaline environments, for instance by osmoregulation mechanisms, but also

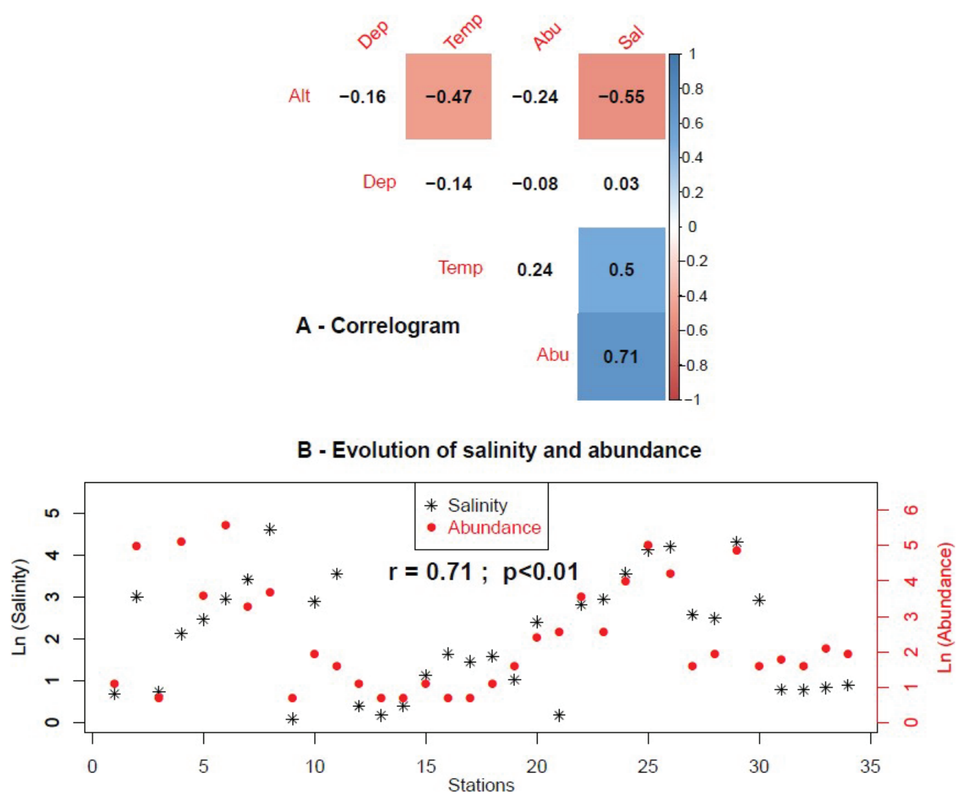

Figure 2. A. Correlogram of the variables (Dep: mean water depth; Temp: temperature; Abu: abundance; Sal: salinity; blue: positive correlation; red: negative correlation) analyzed in the study; B: Evolution of salinity and abundance, showing the Pearson's coefficient value and significance level. *A. Correlograma de las variables (Dep: profundidad media del agua; Temp: temperatura; Abu: abundancia; Sal: salinidad; azul: correlación positiva, rojo: correlación negativa) analizadas en el estudio; B: Evolución de la salinidad y la abundancia, mostrando el valor y nivel de significación del coeficiente de Pearson..*

to colonize different types of habitats, including brackish, freshwater, standing or running water bodies (Günter & Christmas, 1959; Kelts 1979) probably gives an advantage to *Tvv* against other native corixids.

The capacity of *Tvv* to live in hypersaline waters would also play a key role allowing it to fill a relatively empty niche (Van De Meutter *et al.*, 2010b; Coccia *et al.*, 2013). Nevertheless, the successful invasion of *Tvv* cannot be simply explained on the basis of the mentioned osmoregulation ability to cope with saline aquatic habitats, but other factors such as release from enemies, higher plasticity, elevate reproductive rate and great dispersal capability may account for its success (Carbonell *et al.*, 2015). Although, its range closely linked to coastal areas and low altitudes, with little variability in climatic conditions, could be a limitation for its aquatic inland expanding success.

Van De Meutter *et al.* (2010b) also indicate the important role of salinity for the occurrence of *Tvv* may also be mediated by disturbance. It appears that despite salinity mainly explains the presence of *Tvv*, the anthropogenic disturbance could explain the absence of other corixid species because of the reduction of salinity by dilution. In Larache salt-pans, in 2002, *Sigara selecta* populations were more abundant than those of *Tvv*. In 2004 *S. selecta*, was found in very low density (L'Modhi *et al.*, 2010). This change may be due to the *Tvv* competence, but also by the fact that these active salines are suffering an important human pressure.

Furthermore, *Tvv* is capable to live and reproduce in freshwater (Carbonell *et al.*, 2015). A recent study suggests that this pattern is common in species inhabiting saline waters, which are generalists in their fundamental niches, with a predominance of high specimen survival in freshwater or low salinity conditions, where their fitness tends to be similar or even higher than in saline waters (Arribas *et al.*, 2019). Thus, the reasons for its low abundance in these freshwater habitats are still poorly understood. Some suggested reasons included those related with the limited ability of the alien species to withstand the extreme cold in continental areas and at high altitudes (Guareschi *et al.*, 2013), which could explain its absence or rare presence in inland freshwater bodies. In addition, the stronger competitiveness in freshwater with native species (Rodríguez-Pérez *et al.*, 2009), or the pressure by predators such as Odonata larvae could be other factors explaining why *Tvv* is particularly dominant in saline habitats and rare in freshwater anywhere (Coccia *et al.*, 2014). In low salinity conditions, *Tvv* also showed higher parasitism rate by water mites *Hydrachna skorikowi* Piersig 1900 and *Eylais infundibulifera* Koenike 1897 than native *Sigara species* (Sánchez *et al.*, 2015).

Despite the mentioned advantages that makes *Tvv* more competitive than the native corixids, it seems that its expansion affects slightly the corixids community in saline waters but not freshwater habitats. It has been proven that the presence of the alien species modifies the distribution and co-occurrence patterns of the native corixids (Carbonell *et al.*, 2017). This study states that, the mechanism that allows coexistence between the alien and the native species appears to be related with niche differentiation, enabling resource partitioning and, consequently, less impact on the native community.

However, its apparent low impact on native corixids, mainly focused on most saline specialists, might change under a scenario of climatic warming, where greater evapotranspiration rates are likely to cause further intensification of saline stress (Green *et al.*, 2002; Moss *et al.*, 2009), and as a consequence, species able to cope with higher salinities, like *Tvv* may benefit from ongoing global change expanding its distribution range. In this new framework, the effect of *Tvv* on the entire community, either saline or freshwater, might change significantly. Monitoring the presence and expansion of *Tvv* within invaded areas, as well as studies improving its biological and ecological knowledge, seems of crucial concern to palliate its possible impact on the native community.

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Con el patrocinio de: