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Effect of large-scale environmental variables and human pressure on distribution patterns of exotic continental fish in east Algeria

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This study aims to identify large-scale environmental variables that explain the distribution of continental exotic fish across five bioclimatic regions in east Algeria (160,000 km^2), North Africa. Fish communities were sampled at 39 sites from 2007 to 2010. Seven environmental variables were investigated: habitat type, altitude, latitude, longitude, bioclimatic region, minimum and maximum air temperatures and human pressure. The common carp (*Cyprinus carpio* Linnaeus, 1758) and the silver carp (*Hypophtalmichthys molitrix* Valenciennes, 1844) were the most widespread exotic species. Almost all exotic fishes were distributed over desert and sub-humid bioclimatic scales. Reservoirs represent the type of habitat that houses the greatest exotic species richness. The distribution pattern of exotic fishes was mainly predetermined by the type of habitat. Alien ichtyofauna colonizes primarily man-made hydrosystems regardless of environmental variables or the degree of human pressure, making these habitats more vulnerable to invasion.

Buvo įvertinta stambaus masto aplinkos veiksnių įtaka svetimkraščių žuvų rūšių paplitimui Šiaurės Afrikoje, penkiuose bioklimatiniuose Rytų Alžyro regionuose (160,000 km^2). Žuvų bendrijų tyrimai buvo vykdomi 2007–2010 metais 39 tyrimo vietose, atsižvelgiant į buveinės tipą, aukštį virš jūros lygio, ilgumą ir platumą, bioklimatinį regioną, minimalią ir maksimalią oro temperatūrą ir antropogeninio poveikio mastą, Išaiškinta, kad iš svetimkraščių rūšių labiausiai paplitusios yra paprastasis karpis (*Cyprinus carpio* Linnaeus, 1758) ir baltasis plačiakaktis (*Hypophtalmichthys molitrix* Valenciennes, 1844). Beveik visos svetimkraščių žuvų rūšys yra paplitusios dykumos ir sausringo klimato regionuose, didžiausia svetimkraščių rūšių įvairovė rasta dirbtiniuose vandens telkiniuose. Nustatyta, kad svetimų žuvų rūšių paplitimui didžiausią įtaką turi buveinės tipas. Nepriklausomai nuo aplinkos kintamųjų ar žmogaus poveikio masto, svetimos žuvų rūšys pirmiausia įsitvirtina dirbtiniuose vandens telkiniuose; todėl šios buveinės yra jautresnės svetimų rūšių invazijos poveikiui.

Keywords: alien fish species; distribution scheme; continental hydrosystems; Algeria

Introduction

Invasive species pose the third largest threat to global biodiversity after habitat destruction and overexploitation of species. It is a long-recognized problem (Vitousek et al. 1996), as biological invasions have been involved in half of all extinctions that occurred over a period of 400 years (Vié, Hilton-Taylor, and Stuart 2009). Nowadays, biological invasions are considered to be an environmental problem of public concern in conservation and management of natural ecosystems (Blackburn and Jeschke 2009). In this context, it is essential to predict locations at the greatest risk of invasion in order to target monitoring efforts effectively (Mack et al. 2000; Leung, Drake, and Lodge 2004). However, some geographic areas remain devoid of explicit schemes, such as distribution patterns in relation to explanatory variables, because of their low accessibility and/or because taxonomic limitations have prevented ecological studies in particular bioclimatic regions or habitat types (e.g. in arid or desert areas). Numerical patterning is therefore needed to provide basic, practical decision tools for managers faced with sets of exotic species that are likely to generate local and/or regional nuisance (Céréghino et al. 2005). More specifically, distribution patterns of exotic species must be derived from environmental conditions with emphasis on simple, easily accessible variables that could reduce the effort and cost of data collection for environmental management.

Freshwaters provide a habitat for many exotic species (Moyle and Light 1996), and the most frequently introduced freshwater organisms worldwide are fishes (Gozlan et al. 2005; Leprieur et al. 2008). Exotic fishes were introduced for several reasons such as sport fishing, aquaculture, food resource and orna-

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mental purposes (Keith et al. 2011) or even for biological control.

In Algeria, about 27 fish species were introduced and at least 303 introduction events, either intentional or accidental, were recorded in the literature (Kara 2011). Three periods can be distinguished in the introduction of invasive species: (1) the 1858–1931 period characterized by the introduction of Cyprinidae (mainly carps) and insectivorous species of the genus *Gambusia*; (2) the 1935–1961 period marked by several introductions of Tilapias *Oreochromis macrochir* Boulenger 1912 and *Oreochromis mossambicus* Peters 1852; and (3) the 1985–2009 period characterized by the introduction of both carps and nile tilapia *Oreochromis niloticus* Linnaeus 1758 (Doadrio 1994; Kara 2011). On the other hand, the native continental ichtyofauna was estimated at 29 species for Algeria (Bacha and Amara 2007).

The distribution scheme of alien fish species is generally related to the hydrological infrastructure and flow regimes (Brown and Bauer 2010); river health (Kennard et al. 2005); elevation and human pressure (McKinney 2001; Kopp et al. 2009); and elevation and river typology (Céréghino et al. 2005). However, little is known about the spatial distribution and the ecological impact of non-native fishes' introductions both in Algeria and in North Africa. This especially holds true for large-scale areas, where the climate shows great north–south variations and where a significant increase in the construction of artificial water reservoirs (dams, reservoirs, etc.) has been recorded in recent years.

Our specific aim was to identify large-scale environmental variables that explain the distribution of exotic freshwater fish across five bioclimatic regions in North Africa. We focused on a large area of east Algeria covering about 160,000 km² and used a limited set (i.e. easily mapped) of physical and environmental variables. Assuming that increased anthropogenic impact contributes to the success of exotic fishes' dispersal and invasion (Lodge 1993; Kopp et al. 2009), we hypothesized that the degree to which habitats were colonized by exotic species would differ across bioclimatic regions in response to environmental variables and human pressure.

Material and methods

Study area and data collection

This study was conducted at 39 sites distributed over five bioclimatic regions (according to UNESCO 1963) and located from 32°10′N to 36°30′N and from 3°25′E to 7°55′E (Figure 1). These five regions include sub-humid, semi-arid, arid, sub-desert and desert bioclimatic scales (Table 1). According to Mebarki 2010, this area is spread over six watersheds (Table 1), and it holds an ecosystemic diversity of wetlands (natural/artificial, permanent/temporary, fresh/brackish/salt, etc.).

All the sites were sampled between 2007 and 2010, being visited with irregular frequency (from one to three visits per site). Sampling was conducted using traps, lines and nets. The list of exotic species per site was compiled as the sum of recorded species throughout the whole study period.

Seven environmental variables were investigated: habitat type (natural, i.e. 'river' or 'lake' vs. artificial, i.e. 'reservoir'), altitude (m), latitude, longitude, bioclimatic region (see below), annual mean of minimum air temperature (°C), and annual mean of maximum air temperature (°C) and human pressure, which was assessed according to the degree and/or frequency of human activities (agricultural, industrial, commercial and transport units). Three degrees of human pressure were distinguished: (1) absence of pressure for the sites located far from cities and without any human disturbance, (2) medium level for the sites with temporary and/or seasonal visits by the local population and (3) high level for the sites located near human habitations with daily visits.

Data analysis

Species diversity was assessed by the total specific richness (S), which corresponds to the total number of identified species at each site. Occurrence frequency for each species was calculated as a percentage of sites, where the species was recorded, of the total number of the investigated sites. The effects of environmental and human pressure variables on the distribution of exotic fish species expressed as the number of exotic species were analysed using a generalized linear model. Environmental variables were log transformed to normalize their distributions. The calculations were done with *R* (*R* Development Core Team 2006) using a Poisson-distributed error and a log link function. Only variables with $p < 0.05$ were interpreted as statistically significant.

Results

Exotic fish species were found at 23 sites out of 39. Of the 10 introduced species recorded, seven were found in the desert bioclimatic area. The sub-humid scale was also well represented by six species. The highest number of exotic species was observed in reservoirs (eight species), which proves that this type of artificial habitat provides the most favourable living conditions for these species (Table 1). The common carp *Cyprinus carpio* was the most common exotic species in east Algeria (occurrence = 41%). Other Asian carps, the silver carp (*Hypophtalmichthys molitrix*) and the bighead (*Hypophtalmichthys nobilis* Richardson 1845) were also common, with occurrences of 30.7 and 17.9%, respectively (Table 2).

The distribution patterns of exotic fish species were mainly predetermined by the type of the habitat. The surveyed variables were not found statistically significant except for the type of habitat (GLM: Z-value = 3.375, $p = 0.0008$) (Table 3). More specifically, exotic species

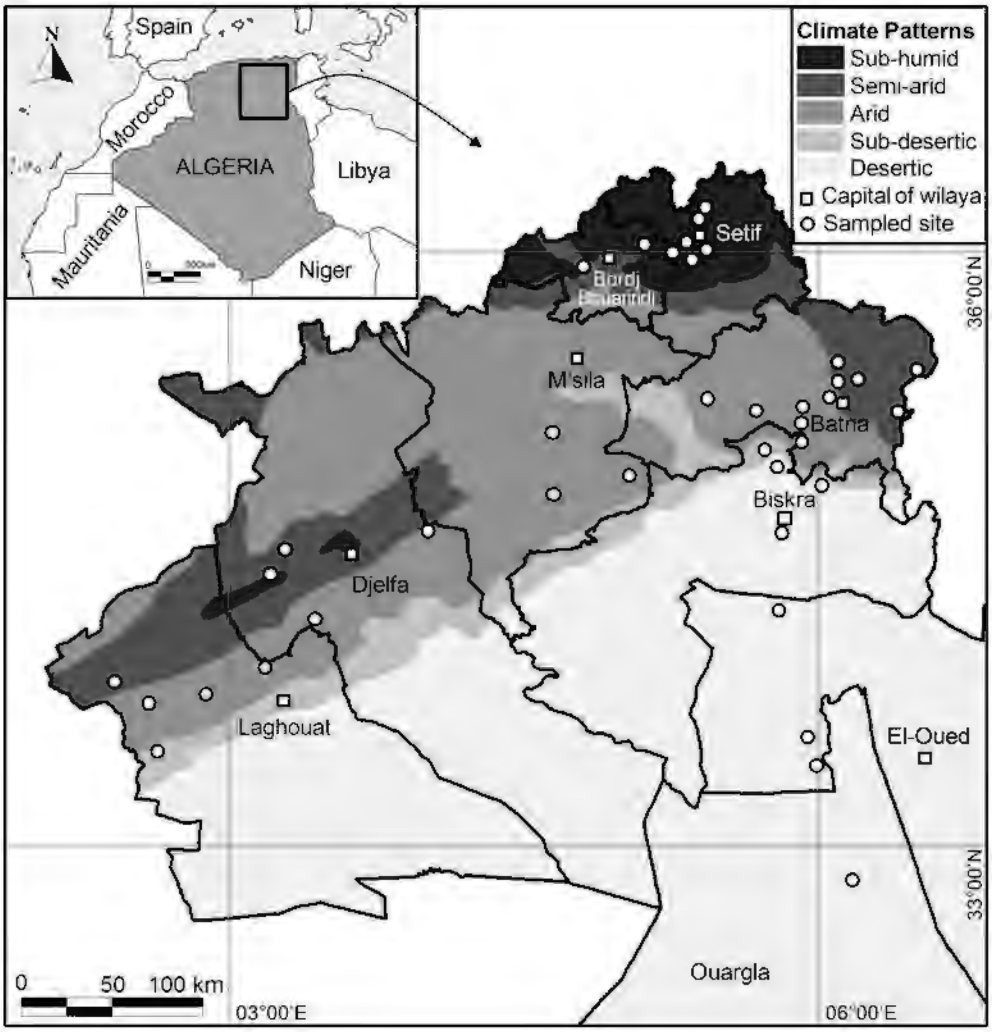

Figure 1. Location of the 39 sampled freshwater sites in east Algeria according to bioclimatic scales (following UNESCO 1963).

Table 1. Species richness of exotic fishes and distribution of sampled sites per habitat type and bioclimatic scale.

Bioclimatic scale	River	Lake	Reservoir	Total of sites	Species richness (S)	Watershed
Desertic	3	2	1	6	7	6, 13
Sub-desertic	1	1	1	3	1	5, 6
Arid	6	2	4	12	2	5, 6, 7
Semi-arid	7	–	4	11	4	5, 6, 7, 15
Sub-humid	1	–	6	7	6	3, 10, 15
Total of sites	18	5	16	39	10	
Species richness (S)	3	3	8	10	10	

Notes: Watershed codes: 03 – Côtier Constantinois, 05 – Hodna, 06 – Chott Melghir, 07 – Hauts Plateaux Constantinois, 10 – Kebir Rhumel, 13 – Sahara, 15 – Seybouse.

were present in 80% of artificial habitats (reservoirs) and 20% of natural ones (lakes and rivers).

Discussion

The common carp is one of the most widespread introduced fishes in the world, as well as in east Algeria, due to its invasive potential (Zambrano et al. 2006). Its impact on aquatic ecosystems, such as increasing amounts of suspended solids in the water column, is well known (Zambrano, Scheffer, and Martinez-Ramos 2001). Introduced Asian carps were reported to impact on freshwater ecosystems by reducing phytoplankton and zooplankton biomass (Fukushima et al. 1999). Competition for food resources with other fishes, notably Cyprinidae and Cichlidae species, was also reported (Xie and Chen 2001).

Tilapia species were present at 10% of the studied sites. They are known for their ability to hybridize with native fishes (Lévêque 2006), causing genetic changes in surviving species, disease transmission (Gozlan et al. 2005) and habitat modification (McDowall 2006).

Table 2. Systematic list and occurrence frequency (%) of continental exotic fish species of east Algeria.

Family	Species	Common name	Occurrence (%)	Habitat type
Cyprinidae	*Carassius gibelio* (Bloch, 1782)	Gibel carp	2.5	Rv, Rs
	Cyprinus carpio carpio (Linnaeus, 1758)	Common carp	41	Rs
	Hypophtalmichthys molitrix (Valenciennes, 1844)	Silver carp	30.7	Rs
	Hypophtalmichthys nobilis (Richardson, 1845)	Bighead carp	17.9	Rs
	Pseudorabora parva (Temm. and Schlegel, 1846)	Topmouth gudgeon	2.5	Rs
Cichlidae	*Oreochromis. niloticus* (Linnaeus, 1758)	Nile tilapia	10.2	Rv, L
	Tilapia zilli (Gervais, 1848)	Redbelly tilapia	10.2	Rv, L
Poecilidae	*Gambusia affinis* (Girard, 1859)	Mosquitofish	7.7	Rv, L
Percidae	*Perca fluviatilis* (Linnaeus, 1758)	Perch	5.1	Rs
	Sander lucioperca (Linnaeus, 1758)	Pikeperch	2.5	Rs

Notes: Habitat type: L – Lake, Rs – reservoir, Rv – River.

Table 3. Generalized linear model analysing the effects of environmental and human pressure variables on the distribution of continental exotic fishes in east Algeria.

Effect	Estimate	*Z*-value	Std. error	*p*-value
(intercept)	−16.58	−0.944	17.56	0.345
Altitude	−0.0003	−0.160	0.0017	0.873
Longitude	0.2713	0.593	0.457	0.553
Latitude	0.2516	0.871	0.289	0.384
Bioclimatic scale	−0.1864	−0.146	1.275	0.884
Minimum air temperature	−0.0712	−0.454	0.157	0.650
Maximum air temperature	0.1933	0.618	0.313	0.537
Habitat type	1.6170	3.375	0.479	0.0008*
Human pressure	0.0912	0.337	0.270	0.736
Deviance	27.51			
Φ	0.92			

Notes: Deviance and dispersion (Φ – deviance/degree of freedom) of the final model are given.
*highly significant.

Gambusia affinis Girard 1859 (occurrence = 7%) was introduced into different regions of Africa, particularly in Algerian Sahara Desert, to control mosquitoes that act as vectors for malaria (Hammadi et al. 2009). Mosquitofish introduction was reported to cause changes in foodwebs (e.g. Hurlbert and Mulla 1981) and to lead to a decline in native populations (e.g. Hamer, Lane, and Mahony 2002). More generally, *G. affinis* may have strong impacts on the distribution of indigenous fishes. For instance, it caused the spatial displacement of *Aphanius* in Mediterranean freshwaters (Crivelli 1995).

Besides, it is clearly known that the occurrence of native species in young man-made systems is low, and in natural or anthropogenically undisturbed habitats it is high (Irwin et al. 2010). Therefore, our results support the idea that exotic species primarily settle in man-made aquatic ecosystems, even in arid and desert areas, regardless of the importance of human pressure. Although Saharan and Montane sites are less frequented by man, and, therefore, should be less subjected to human pressure, and, consequently, should be subjected to low levels of introductions; findings of the study carried out therein further suggest that man-made ecosystems are highly exposed to potential invasion, irrespective of the type and extent of human pressure. Literature data support the conclusion that exotic fish species could be predicted from the human population size (e.g. McKinney 2001) or that exotic species associated with humans predictably colonize ecosystems as agricultural and/or urban land cover increases (Kopp et al. 2009).

Among the 37 native freshwater species classified under a high threat of extinction in North Africa (Algeria, Morocco and Tunisia), 11 species are Cyprinidae including six *Barbus* species. Moreover, about 27.3% of the total taxa assessed in North Africa were found to be threatened according to the International Union for Conservation of Nature Red List category (García et al. 2010) as a result of groundwater extraction, dams, water pollution and drought (Pellegrin 1921). Furthermore, invasive species living in reservoirs represent an ‘ecological filter’, which contributes to the expulsion of most native species from these artificial hydro-systems (Clavero and Hermoso 2011). Other threats such as biological invasions make this fish fauna highly susceptible to extinction risks. Environmental managers generally ask for explicit schemes such as distribution patterns that allow them to identify areas at greater invasion risk, but also those areas are of high conservation value that bear endemics and/or high species richness. The surface area of water bodies is an important factor for the functions of growth and reproduction in fish. Indeed, growth of the fishes introduced into artificial water bodies is faster than that observed in populations of natural lakes and flowing waters (Tarkan et al. 2012).

Our results suggest that the combination of simple environmental variables should be relevant to delineate areas of conservation interest, while targeting efforts in human-impacted areas. Moreover, the absence of exotic fishes in many natural habitats, particularly in *wadis* (rivers), emphasizes the importance of these habitats for the conservation of rare and/or specialized/native species such as *Aphanius fasciatus* Valenciennes 1821 and *Barbus* spp. (García et al. 2010).

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