

Invasibility of four plant communities in the Llobregat delta (Catalonia, NE of Spain) in relation to their historical stability

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Abstract

Presence and cover of alien plants were analysed in relation to recent naturalness changes (1956–1999) in the Llobregat delta by means of GIS techniques and field surveys. Two land cover maps of 1956 and 1999 were generated by photo-interpretation of orthoimages and they were then reclassified into naturalness classes, defined as the degree of preservation of the pristine state. The resulting naturalness maps were combined in order to obtain a naturalness change map, which was used to design field sampling in four pristine communities: reedbeds, rushbeds, halophilous scrubs and fixed dune communities. Two study areas were selected for each community and three stability regimes (stable, semi-stable and non-stable) obtained from the naturalness change map. Five vegetation inventories were performed on average in each of these areas using the classical sigmatist method. Results showed a negative relationship between stability and invasibility, with several variations between communities. No alien species were found in stable areas of all communities. Alien species number, species percentage and relative cover increased from semi-stable to non-stable regimes in reedbeds and dune communities, indicating that reversion towards the climax reduces opportunities for alien establishment in these communities. In contrast, halophilous habitats such as rushbeds and scrubs did not exhibit significant differences between semi-stable and non-stable plots, probably because saline stress makes their invasion by alien plants difficult, even under disturbance.

Introduction

Invasion by alien species is a worldwide phenomenon with recognised negative effects on the conservation of native biodiversity (Lodge, 1993). The close relationship between habitat disturbance and invasibility is widely accepted (di Castri, 1990; Vitousek et al., 1997; Hobbs, 2000). Disturbance reduces competition and increases the availability of safe sites, providing more opportunities for alien colonization and spreading (Hobbs &

Huenneke, 1992; Olenin & Leppänski, 1999). Aquatic ecosystems are particularly susceptible to invasion because of their intermediate to high disturbance regimes (di Castri, 1990; Rauchich & Reader, 1999), with a number of studies indicating the concentration of alien species in ponds and rivers (Pyšek & Prach, 1993; Alpert et al., 2000).

Land use changes driven by man are a main source of habitat disturbance, and consequently of alien introduction, in terrestrial ecosystems (Hobbs, 2000) but also in wetlands (Ewel, 1986).

Despite the major role of land use changes in habitat invasibility, there are few studies aimed at examining the association between stability and the risk of invasion of natural habitats from an historical perspective. The present study analyses long-term (1956–1999) changes (including persistence, recuperation and degradation) and their possible association with invasibility in several communities in the Llobregat delta (central coast of Catalonia, NE of Spain), in the metropolitan area of Barcelona. Because of intense land use change and trading, the Llobregat delta has become one of the regions most invaded by alien plants in Catalonia (Casasayas, 1990). In our study, GIS techniques have been used to find areas of contrasting habitat stability comparing 1956 and 1999. A field survey of main wetland and dune communities has been conducted in these areas in order to assess the relationship between their stability and invasibility.

Description of site

The study was done in the southern hemidelta of the Llobregat, adjacent to the city of Barcelona and still dominated by natural and agricultural habitats (Fig. 1). At present, marshlands and fixed dunes correspond to 13% of the total land cover, with reedbeds (*Phragmites australis* W. Koch), rushbeds (*Juncus maritimi* Br. Bl.), and secondary pine (*Pinus pinea* L.) forests as dominant plant communities. Fragments of halophilous scrublands (*Arthrocnemum fruticosum* Br. Bl.) and fixed dune communities (*Crucianellon maritimae* Rivas Goday and Rivas Mart.) with variable conservation status still persist. Despite some of the remaining natural areas having been declared Natura 2000 sites, their conservation is threatened by intense land-use change, water pollution and degradation. About 15% of the areas occupied by natural habitats exhibit moderate to intense degradation.

Material and methods

Two land cover maps of 1956 and 1999 of the study area were generated by photo-interpretation of orthophotomaps at 1:5 000 scale. The

map of 1956 was photo-interpreted on an orthophotomap generated *ad hoc*, by geo-correction and mosaic of black and white aerial photographs. In contrast, the 1999 map was directly photo-interpreted on colour orthophotomaps produced by the Cartographic Institute of Catalonia. Contrasting colour and quality of images, and the availability of ancillary information on vegetation categories for 1999 but not for 1956 determined a contrasting thematic resolution for both land cover maps. In order to homogenise the results of photo-interpretation, to facilitate map comparison and to reduce the number of land cover classes to be analysed, the land cover classes were reclassified into four naturalness classes. We defined naturalness as the degree of preservation of the pristine state (Figs. 1a,b): High (natural marshland habitats), medium (disturbed natural habitats and formerly abandoned fields), low (crops and recently mowed areas), and null (urban areas, roads and railways). A naturalness change map describing land stability was then obtained by combining the naturalness maps of 1956 and 1999 (Fig. 1c). Only three stability regimes were considered for the present study: stable (high naturalness in 1956 and 1999), semi-stable (medium or low naturalness in 1956, and high in 1999), and non-stable (medium naturalness in 1999).

The relationship between invasibility and stability was assessed in four plant communities representing several of the pristine habitats in the Llobregat delta (Bolòs & Bolòs, 1950) and responding to contrasting conditions of water availability and conductivity: reedbeds, rushbeds, halophilous scrublands, and fixed dune communities. Two study areas for each plant community and stability regime were selected using the naturalness change map and additional information on current vegetation. In each area, a mean of 5 10×10 m plots were marked out and vegetation inventories were performed therein following the classical sigmatist method. The number and percentage of alien species and their relative cover were compared among communities, stability regimes and areas, by means of ANOVA tests after normalisation by arcsin transformation. Pairwise comparisons between semi stable and non-stable regimes were carried out a posteriori for each community using Tukey's test.

Results

A total of 17 alien species were found in the study (Table 1). Fixed dune communities were invaded by most species (11), followed by reedbeds (10), rushbeds (4) and halophilous scrubs (2). *Aster squamatus* (Spreng.) Hieron. was the most frequent alien, growing in 25% of samples and colonizing all the

communities studied. *Cortaderia seloana* (Schultes ex Schultes) Asch. et Graetbn. was found in reedbeds and secondarily in fixed dune communities, whereas *Cuscuta campestris* Yuncker was mainly located in fixed dunes and occasionally in rushbeds. *Oenothera glazioviana* Minchx. and *Carpobrotus edulis* (L.) N.E. Br. were exclusively found in fixed dune communities. Seven species were found only once.

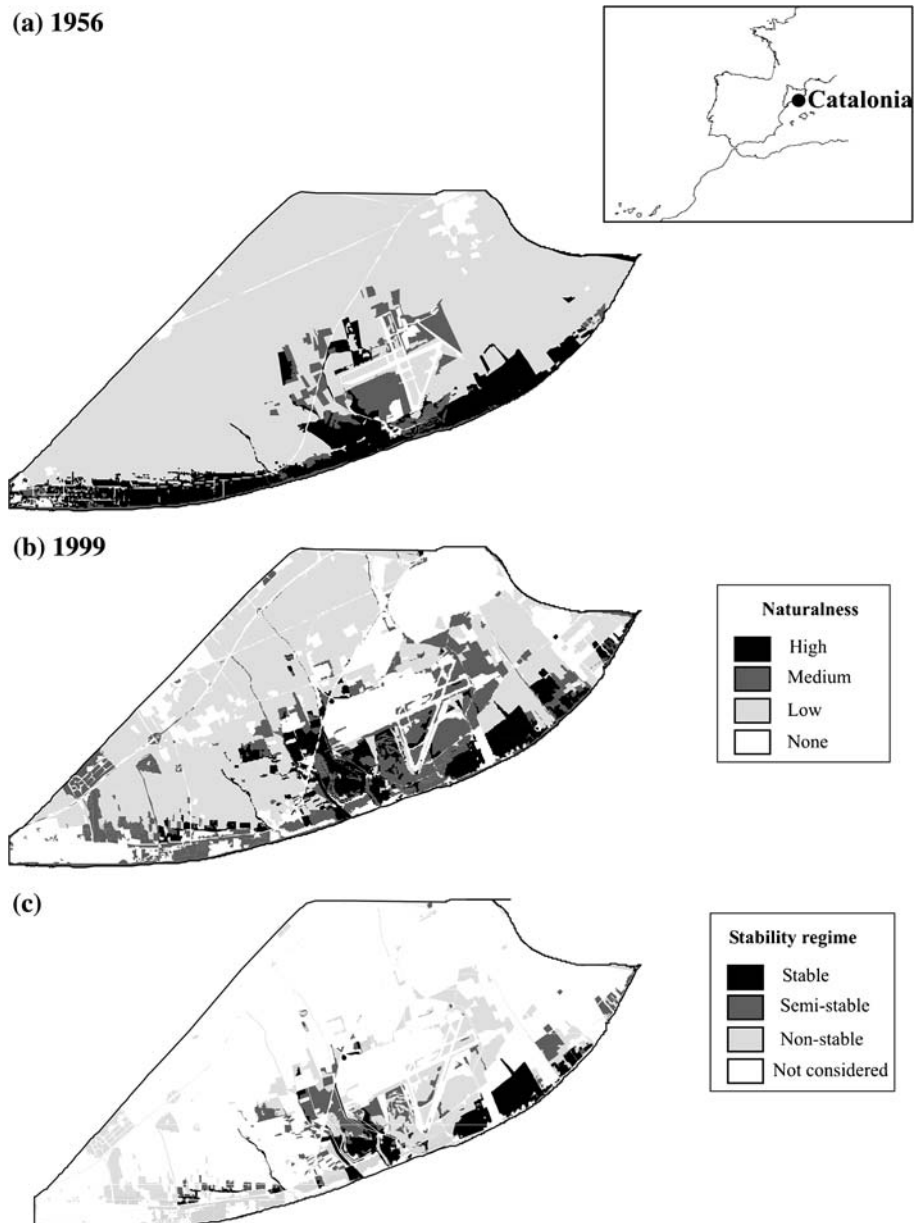


Figure 1. Habitat naturalness in (a) 1956, and (b) 1999 in the southern hemidelta of Llobregat, and (c) the associated naturalness change map showing the stability regimes selected for the study (see text for more details).

Table 1. Percentage of inventories of each community and stability regime with presence of each alien species. Stability regimes: SS, semi-stable; NS, non-stable. There were no alien species in the inventories of the stable regime

	Reedbeds		Fixed dunes		Rushbeds		Halophilous scrubs	
	SS	NS	SS	NS	SS	NS	SS	NS
<i>Amaranthus retroflexus</i> L.		7.7						
<i>Ambrosia coronopifolia</i> Torrey et A. Gray		7.7						
<i>Arundo donax</i> L.		23.1		7.7				
<i>Asparagus officinalis</i> L.				7.7				
<i>Aster squamatus</i> (Spreng.) Hieron.	18.2	23.1	9.1	38.5	75.0	83.3	45.5	50.0
<i>Carpobrotus edulis</i> (L.) N.E. Br.			9.1	30.8				
<i>Chenopodium ambrosioides</i> L.		7.7		7.7				
<i>Conyza bonariensis</i> (L.) Cronq.				7.7				
<i>Conyza sumatrensis</i> (Retz.) E. Walter		30.8	18.2	30.8	8.3			
<i>Cortaderia selloana</i> (Schultes ex Schultes) Asch. et Graetbn.		30.8		7.7				
<i>Cuscuta campestris</i> Yuncker			36.4	30.8		8.3		
<i>Ipomoea indica</i> (Burm.) Merr.		7.7						
<i>Lonicera japonica</i> Thunb. in Murray		7.7						
<i>Oenothera glazioviana</i> Minchx.			45.5	23.1				
<i>Phoenix canariensis</i> Chabaud			9.1					
<i>Rumex palustris</i> Sm		23.1						40.0
<i>Xanthium echinatum</i> Murray				38.5		33.3		

Non-stable plots concentrated the majority of alien citations in reedbeds and dune communities. *A. squamatus*, *C. edulis*, *Conyza sumatrensis* (Retz.) E. Walker, and *Xanthium echinatum* Murray were found in more than 30% of non-stable plots, but in less than 20% of semi stable ones in fixed dune communities. *C. sumatrensis* and *C. selloana* were found in more than 30% of non-stable plots in reedbeds, whereas *Arundo donax* L., *A. squamatus*, and *Rumex palustris* Sm colonised more than 20% of these plots. Semi stable plots were only colonised by *A. squamatus*, which was also commonly found in rushbeds and in halophilous scrubs, either in semi-stable or non-stable plots. *R. palustris* and *X. echinatum* were, respectively, frequent in non-stable plots in halophilous scrubs and rushbeds, but absent in semi-stable plots. There were no records of alien species in stable plots, despite *A. squamatus* being observed at times in areas nearby these plots.

Stability was significantly related to the number and the proportion of alien species, and also to their relative cover (Table 2). Differences between communities were significant for the number and the relative cover of alien species, and marginally

significant ($p = 0.057$) for the relative number of aliens. This was the only significantly different factor between areas. The interactions between stability and community, and between area and community were significant for both the number and the percentage of aliens, but not for the relative cover of aliens. The interactions between stability and area were never significant, whereas third-order interactions between all the parameters studied were always significant. Semi-stable and non-stable regimes exhibited contrasting invasibility patterns among communities (Fig. 2). Non-stable reedbeds and fixed dune communities showed significantly higher number, percentage and relative cover of alien plants than semi-stable ones. In contrast, there were no significant differences between non-stable and semi-stable plots in rushbeds and halophilous scrubs.

Discussion

Most of the Catalan alien species occur in heavily human-disturbed habitats, with few of them able to succeed in natural communities (Casasayas,

Table 2. Summary of ANOVA aimed at comparing the effects of stability regime, community, and area on the number and the percentage of alien species, and on the percentage of species cover corresponding to aliens

	df	MS	F	p
<i>Number of alien species</i>				
Stability	2	169.216	25.567	< 0.001
Community	3	481.798	72.795	< 0.001
Area	1	4.796	0.725	0.396
Stability × community	6	107.464	16.237	< 0.001
Stability × area	2	3.512	0.531	0.590
Community × area	3	86.410	13.056	< 0.001
Stability × community × area	6	34.821	5.261	0.001
<i>Percentage of alien species</i>				
Stability	2	8.383	63.063	< 0.001
Community	3	0.343	2.584	0.057
Area	1	1.010	7.597	0.007
Stability × community	6	0.461	3.471	0.003
Stability × area	2	0.323	2.429	0.093
Community × area	3	0.584	4.397	0.006
Stability × community × area	6	1.288	9.688	< 0.001
<i>Percentage of alien species cover</i>				
Stability	2	3.695	36.210	< 0.001
Community	3	0.290	2.840	0.041
Area	1	0.251	2.462	0.119
Stability × community	6	0.196	1.923	0.083
Stability × area	2	0.063	0.619	0.540
Community × area	3	0.186	1.825	0.146
Stability × community × area	6	0.745	7.296	< 0.001

1990). We have found that natural, coastal plant communities in the Llobregat delta are potentially invaded by a number of alien plants, which appear to be relatively non-specific with the exception of several characteristic aliens of dune communities (*C. edulis*, *O. erythrosepala*, and to a minor extent *C. campestris*). In addition, habitat invasibility was related negatively to stability. Communities enclosed in areas that have persisted unaltered since 1956 exhibited a very low invasibility, with only a single species, *A. squamatus*, growing at extremely low densities. It is well established that disturbed habitats are regarded to be more vulnerable to invasion than unaltered ones (di Castri, 1990; Vitousek et al., 1997; Hobbs, 2000). This is particularly true in perennial communities dominated by one or a few species, especially in reedbeds, but also in several rushbeds and even dune communities, whose vegetative regeneration mechanisms are responsible for a dense canopy that prevents

invasion. Disturbance might provide gaps that would enhance the establishment of invaders, as Jones & Doren (1997) reported for the exotic tree *Schinus terebinthifolius* in the Everglades.

Invasibility of reedbeds and fixed dune communities is related to historical stability, since alien species number and proportion and relative alien cover increased significantly from semi-stable to non-stable regimes. Assuming that historical change indicates how long ago main disturbances occurred, the decrease in invasibility from non-stable to semi-stable regimes would indicate a reversion towards the climax. During this process, the establishment of non-natives may be less opportune, basically as a result of decreasing resources or increasing colonization of clonal, dominant species that would reduce safe sites for alien germination and establishment (Hobbs & Huenneke, 1992). However, this pattern was not valid for rushbeds nor for

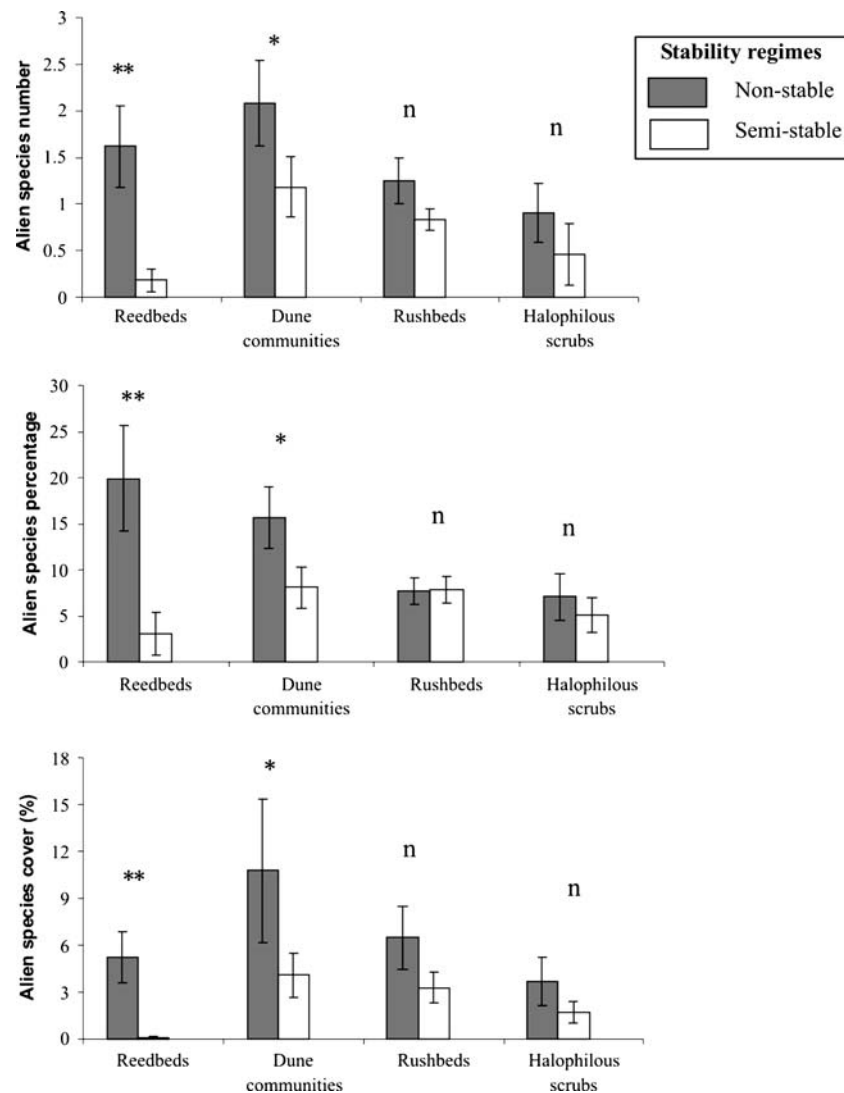


Figure 2. Number and percentage of alien species, and relative alien cover in four coastal communities in the Llobregat delta, in relation to the stability regimes selected for the study (see text for more details). Means and standard errors are shown. Significance of pairwise comparisons between semi-stable and non-stable regimes is shown (*: $p < 0.05$; **: $p < 0.01$; n: no significant).

Arthrocnemum scrubs in the Llobregat delta. Invasibility of a given habitat also depends on traits related to their adequacy for plant establishment, such as resource supply, non-biotic and biotic conditions (Alpert et al., 2000; Heger, 2001). Saline stress probably prevents these halophilous communities from invasion, as Alpert et al. (2000) reported for other harsh habitats such as xeric grasslands and desert vegetation in relation to drought and nutrient stress. Although bare soil might be abundant in halophilous communities, its colonisation by alien or

even native plants is extremely difficult, being restricted to vegetation patches and nearby areas with lower conductivity and higher water and nutrient contents (Rubio-Casal et al., 2001).

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