ELSEVIER

Biological Conservation 100 (2001) 397–401

BIOLOGICAL CONSERVATION

www.elsevier.com/locate/biocon

Short note

Land-use and socio-economic correlates of plant invasions in European and North African countries

Montserrat Vilà *, Jordi Pujadas

Centre de Recerca Ecològica i Aplicacions Forestals, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, Spain

Received 5 June 2000; received in revised form 28 December 2000; accepted 16 January 2001

Abstract

Biological invasions are causing significant ecological impacts and economical costs world-wide. Human activities are the primary cause of this conservation and environmental problem. We conducted a stepwise regression analysis between several land-use and socio-economic parameters and the density of alien species in European and North African countries. We found that the parameters that best explained the density of alien plants were the Human Development Index and imports. The extent of terrestrial transport networks and the percentage of protected areas were the land-use variables that best accounted for the density of alien plants. If we are going to influence policies dealing with biological invasions, more emphasis should be placed on the analysis of land-use and socio-economic determinants at different spatial scales and their changes throughout time.

Keywords: Alien plants; Developing countries; Drivers of invasion; Invasibility; Landscape

1. Introduction

The introduction of alien species is a world-wide phenomenon with recognised negative effects on the conservation of the native biota and the integrity of ecosystems (Lodge, 1993). It also incurs important economic costs (Pimentel et al., 2000). Research on the characteristics of the recipient regions is essential to understand the process of invasion (Vermeij, 1996). The number of studies on the ecological and biogeographic factors that determine the naturalisation and invasion of aliens at the local and regional level is increasing (Sandlund et al., 1996; Starfinger et al., 1998). For alien plants, analysis at the regional level has demonstrated that disturbed and man-made areas are invaded more than pristine areas (Hobbs and Huenneke, 1992; Pysek, 1994). For example, ruderal areas, roadsides and agroecosystems harbour a great number of alien species. Biogeographic surveys have also found that the size of land area and coast perimeter for islands is positively correlated with the number of alien species (Lonsdale, 1999).

Species introductions and invasion are mainly due to human activities (Elton, 1958), for example, through gardening, horticulture and human traffic (Lonsdale and Lane, 1994; Hodkinson and Thompson, 1997). Changes in land use are important means by which aliens spread and increase. For example, agricultural intensification in the US has led to an increased abundance of aliens in adjacent habitats (Boutin and Jobin, 1998). Fragmentation is another factor enhancing plant invasions (Saunders et al., 1991; Brothers and Spingarn, 1992). However, the protection of natural areas does not guarantee the exclusion of aliens (Lonsdale, 1999). The percentage of alien species is correlated with the number of visitors to protected areas (Chaloupka and Domm, 1986). Likewise, transport networks (e.g. highways, railways, etc.) also enhance immigration rates of new species and the spread of already existing ones (Ernst, 1998). The presumption that trading increases the introduction of aliens is also largely accepted among ecologists and land managers (Jenkins, 1996, 1999; Baskin, 1998). However, the quantification of such associations has scarcely been explored.

Overall, land-use and socio-economic factors directly influence the introduction and spread of alien species. There is a general perception that development and

* Corresponding author. Tel.: +34-93-5811987; fax: +34-93-5811312.

E-mail address: vila@cc.uab.es (M. Vilà).

0006-3207/01/$ - see front matter
PII: S0006-3207(01)00047-7

progress increase the number of alien species (Jenkins, 1996). However, this underlying hypothesis has not been tested on a regional scale. At present, there are international initiatives that incorporate an interdisciplinary approach in developing a comprehensive strategy for addressing the problem of biological invasions. The Global Invasive Species Programme (GISP) is addressing this issue by including the economic impacts of biological invasions as well as the economic activities that are likely to promote them. In this context, a recent publication by Baiocchi and Dalmazzone (2000) has analysed the relative influence of several economic variables on the share of aliens. They have found that disturbances associated with human activities and gross domestic product per capita (GDP) are important determinants of a given country's vulnerability to invasions.

In this paper we conduct a regression analysis between several land-use and socio-economic parameters and the density of alien plants in European and North African countries in order to explore the predictive power of parameters involving human activities on the abundance of alien plants. We chose this region because it constitutes a part of the Old World where the abundance and distribution of alien species has been fairly well documented (di Castri, 1989). Furthermore, this analysis allows us to explore the association between socio-economy and alien plant abundance for Mediterranean basin countries, a region with very marked north-south socio-economic differences (Groves and di Castri, 1991).

2. Methods

Alien plants are defined as species that have been introduced from another country and are naturalised in the recipient area. We used the density of aliens (i.e. number of aliens divided by $\log_{10}$ area of the country concerned) and not the number of aliens per se to avoid confounding effects with area (Lonsdale, 1999). Data on the density of alien plant species in European and North African countries were obtained from Weber (1997) and Vilà et al. (1999), respectively.

Socio-economic variables were extracted from the Central Intelligence Agency (CIA), World Development Reports, the Yearbook of Tourism and the United Nations Programme for Development (Table 1). The land-use variables tested were: % croplands, % woodlands,% protected areas, length of the terrestrial transport networks (roads, motorways and railways) and a land cover fragmentation index calculated as the length of the terrestrial transport networks divided by the area of the country. The socio-economic variables tested were population density, net immigration rate, imports, number of tourists per year, GDP and Human Development Index (HDI). The HDI is a United Nations estimation of the quality of life according to GDP, standard of basic education ('alphabetisation') and life expectancy; it ranges from 0 to 1. The full data set included 28 countries. However, for some countries in the Balkan region it was impossible to get information on some of the variables.

We conducted a stepwise regression analysis with the density of alien plants per country as the dependent variable and the five land-use and six socio-economic variables listed in Table 1 as independent variables. Previously a partial correlation matrix between each pair of independent variables was performed to check for multicollinearity (Zar, 1984; Nally, 2000). Data were not transformed because prior analysis with the Kolmogorov-Smirnov test confirmed normal distribution in the data.

Table 1
Sources of some land-use and socio-economic variables to analyse their relationship with alien plant abundance in European and North African countries

Parameter	Units	Source
Length of traffic routes	km	CIA[a]
Land fragmentation	1/km	[b]
Protected land cover	%	World Development Report[c]
Woodland cover	%	World Development Report
Crop cover	%	World Development Report
Population density	inhabitants/km^2	World Development Report
Net immigration rate	migrants/1000 people	CIA[a]
Tourists	1000s of people	World Tourism Org.[d]
Imports	millions of US$	World Development Report
Gross Domestic Product	US$	World Development Report
Human Development Index	–	PNUD[e]

[a] http://www.odci.gov/cia/publications/factbook.
[b] Calculated as the length of the terrestrial transport networks (km) divided by the area of the country (km^2).
[c] World Development Report (1998).
[d] World Tourism Organisation (1998).
[e] Programa de las Naciones Unidas para el Desarrollo (1998). Informe sobre el desarrollo humano. Mundi-Prensa, Madrid.

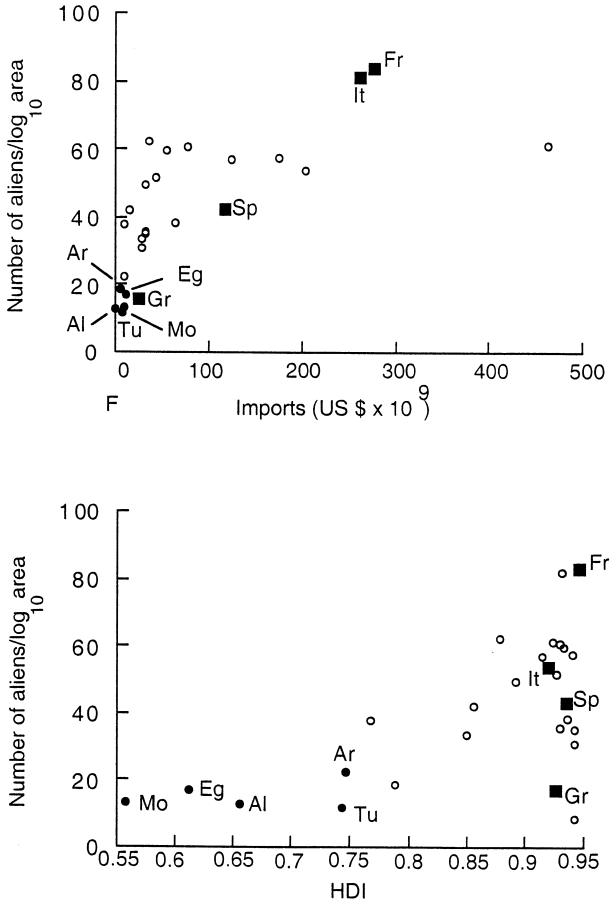

Fig. 1. Relationship between density of alien plant species in European and North African countries and % imports and the Human Development Index. Filled circles represent less developed countries: Al, Albania; Ar, Algeria; Eg, Egypt; Li, Libya; Mo, Morocco; Tu, Tunisia. Filled squares represent some European countries of the Mediterranean basin: Fr, France; Gr, Greece; It, Italy; Sp, Spain. Open circles represent the remaining countries.

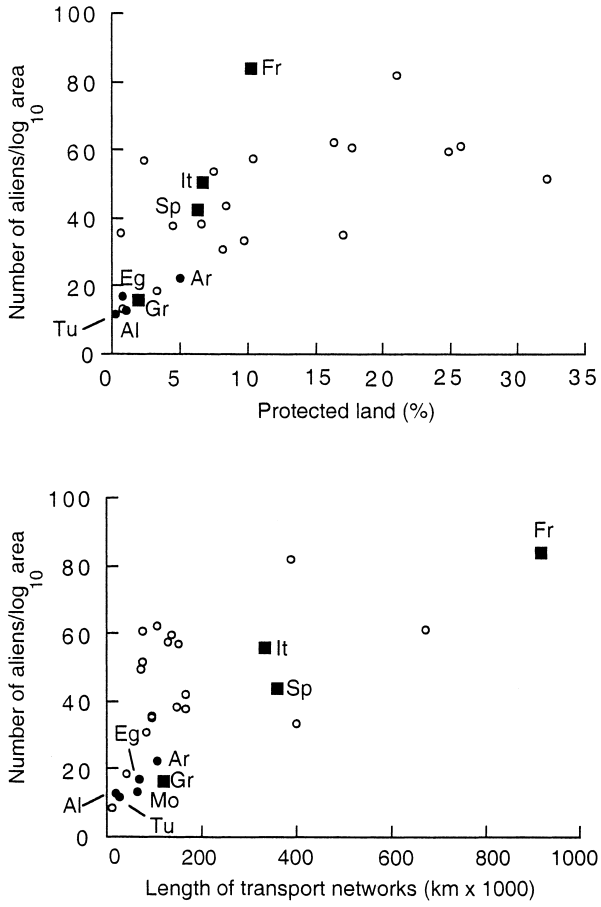

Fig. 2. Relationship between density of alien plant species in European and North African countries and % of protected land and terrestrial transport networks. Filled circles represent less developed countries: Al, Albania; Ar, Algeria; Eg, Egypt; Mo, Morocco; Tu, Tunisia. Filled squares represent some European countries of the Mediterranean basin: Fr, France; Gr, Greece; It, Italy; Sp, Spain. Open circles represent the remaining countries.

3. Results

We found significant relationships between the density of alien plants and some land-use and socio-economic variables for European and North African countries. However, the variability of the density of alien plant species explained by these parameters was low.

Of the 11 variables considered, only imports and HDI contributed significantly to explaining the variation in density of alien plants, with a combined value of 60.7% (Table 2). Fig. 1 shows that developing countries with low imports (i.e. North African countries and Albania) have a relatively low number of alien plants.

When land-use variables alone are considered in the analysis, percentage cover of protected land and the length of terrestrial transport networks together explained 57.2% of the variation in the density of alien plants (Table 2). This is because the length of the terrestrial transport networks was positively correlated with imports (partial correlation coefficient, $r=0.78$). The length of the terrestrial transport networks is also correlated with the number of tourists that visit the country ($r=0.75$). Mediterranean basin countries such as France, Italy and Spain that receive many tourists are the ones with the highest density of alien species. Contrary to our expectations the correlation between the density of alien plants and the percentage cover of protected land was positive (Fig. 2). The percentage of protected land was positively correlated to the welfare of the country measured by the GDP ($r=0.61$) and the HDI ($r=0.51$).

4. Discussion

Prior to the present study, some of these relationships had been found for smaller areas such as regions within countries or natural reserves. For example, areas adjacent to roads and railways are rich in alien species (Tyser and Worley, 1992; Pysek, 1994), which spread

Table 2
Stepwise regression between density of alien plants and land-use and socio-economic parameters

	Coefficient	*F*-value	% var.[a]
All predictors			
Intercept	−38.82	3.19	
Imports	0.00009	11.75	43.9
Human Development Index	85.49	10.85	60.7
Land-use predictors only			
Intercept	21.70	25.49	
Protected land cover	1.19	13.94	38.9
Length of traffic routes	0.00005	11.26	57.2

[a] % var. = % cumulative variation explained.

fast in these habitats (Ernst, 1998). This relation arises from the naturalisation of alien plants used to restore roadsides and railway banks, and to the turbulence created by passing cars and trains which enhances plant dispersal.

Protection of land does not prevent invasion. It has already been stated that some nature reserves are highly invaded by alien species, especially in insular regions and in disturbed areas (Usher, 1988). This may be directly related to the positive relationship between the number of visitors to protected areas and the number of alien species (Lonsdale, 1999) because propagules may be introduced on tourist vehicles (Lonsdale and Lane, 1994). Indirectly, accommodation services (i.e. hotels, holiday resorts) represent major foci of alien plant propagules from garden throw-outs and topsoil movement (Hodkinson and Thompson, 1997).

Developing countries have fewer alien species than developed countries. Although the causes of these low values can be confounded with differences in flora exploration and biogeography (e.g. the high proportion of arid land in North African countries), these patterns can also be explained by low importation rates compared to developed European countries. However, these patterns may change with time because increased standards of living in developing countries will be associated with increased demand for imported products, thereby increasing the likelihood of unintentional introductions through the import process (Jenkins, 1996).

The results presented in this study should be interpreted with caution. They do not imply the causal influence of the variables selected from the model on plant invasion. Similarly, some socio-economic variables not included in the analysis could have an effect on plant invasions (James and McCulloch, 1990; Nally, 2000). Furthermore, the pool of naturalised plants in Europe and North Africa is the result of centuries (even millennia) of human influence on the natural ecosystems (di Castri, 1998), and thus the density of alien plants within a country can not be simply described by contemporaneous human activities. However, these caveats do not invalidate our study because even if our approach is only statistically exploratory (James and McCulloch, 1990) it highlights the links between plant invasions and human activities, an analysis that has been anecdotal or speculative until now (but see Baiocchi and Dalmazzone, 2000).

Biological invasions are a global problem with solutions that may lie beyond the area of distribution of a particular alien species. There is an increasing international emphasis on providing techniques for the evaluation of the best management practices and strategies to control biological invasions. For example, GISP is identifying interdisciplinary issues involved in biological invasions (Mooney, 1999). Policy and management practices should be reinforced to deter propagule pressure of alien plants in European and North African countries. Recommendations should include avoiding the use of alien plants in restoration programs and promoting the use of native species in gardening, identifying invasion corridors in protected areas and improving screening protocols to detect foreign weeds in imported grains.

We advocate that if we are going to advise that policies and management practices should deal with biological invasions, more research should be conducted beyond the ecology of biological invasions. We envisage several avenues for future research on various spatial and temporal scales: (1) including more countries or regions in the analysis; (2) including or concentrating on other types of organisms (i.e. animals, pathogens); (3) discerning which components of development are more likely to influence the introduction and spread of species; (4) focusing on specific countries or regions (e.g. islands, coastal areas) and fine-tuning the relationship between alien species distribution and land-cover; (5) relating flows (rates of change in the abundance of aliens) rather than pools (abundance of aliens at a specific point in time) to economic changes (Baiocchi and Dalmazzone, 2000); and (6) relating rates of invasion to changes in land-use. This research agenda requires not only good data sets of alien species' abundance and distribution and how they have changed over time, but also offers an excellent arena for interdisciplinary research. Collaboration between ecologists, geographers, land-planners and economists is required to investigate in more depth the main (non-ecological) causes of biological invasions.

Acknowledgements

We thank B. Neches for inspiring this study. B.N.K. Davis, G. Oliveira and two anonymous reviewers for comments on an earlier draft of the manuscript, and J. Retana for statistical analysis advise. Financial support was provided by the Generalitat de Catalunya (CICYT).

References

Baiocchi, G., Dalmazzone, S., 2000. Economic factors affecting vulnerability to biological invasions. In: Perrings, C., Williamson, M., Dalmazzone, S. (Eds.), The Economics of Biological Invasions. Ed. Elgar, Cheltenham, pp. 15–30.

Baskin, Y., 1998. Winners and losers in a changing world. Bioscience 48, 788–792.

Boutin, C., Jobin, B., 1998. Intensity of agricultural practices and effects on adjacent habitats. Ecological Applications 8, 544–557.

Brothers, T.S., Spingarn, A., 1992. Forest fragmentation and alien plant invasion of Central Indiana old-growth forests. Conservation Biology 6, 91–100.

Central Intelligence Agency. 1997. The World Factbook. The US Government Printing Office, Washington DC. Available: http://www.odci.gov/cia/publications/factbook

di Castri, F., 1989. History of biological invasions with special emphasis on the Old World. In: Drake, J., Mooney, H.A., di Castri, F., Groves, R.H., Kruger, F.S., Rejmànek, M., Williamson, M. (Eds.), Biological Invasions, A Global Perspective. John Wiley, New York, pp. 1–30.

Chaloupka, M.Y., Domm, S.B., 1986. Role of anthropochory in the invasion of coral cays by alien flora. Ecology 67, 1536–1547.

Elton, C.S., 1958. The Ecology of Invasions. Methuen, London.

Ernst, W.H.O., 1998. Invasion, dispersal and ecology of the South African neophyte *Senecio inaequidens* in the Netherlands, from wool alien to railway and road alien. Acta Botanica Neerlandica 47, 131–151.

Global Invasive Species Program. Available: http://jasper.stanford.edu/gisp/

Groves, R.H., di Castri, F., 1991. Biogeography of Mediterranean Invasions. Cambridge University Press, Cambridge.

Hobbs, R.J., Huenneke, L.F., 1992. Disturbance, diversity and invasion: implications for conservation. Conservation Biology 6, 324–337.

Hodkinson, D.J., Thompson, K., 1997. Plant dispersal: the role of man. Journal of Applied Ecology 34, 1484–1496.

James, F.C., McCulloch, C.E., 1990. Multivariate analysis in ecology and systematics: panacea or pandora's box? Annual Review of Ecology and Systematics 21, 129–166.

Jenkins, P.T., 1996. Free trade and exotic species introductions. Conservation Biology 10, 300–302.

Jenkins, P.T., 1999. Trade and exotic species introductions. In Sandlund, O.T., Schei, P., Invasive Species and Biodiversity Management, pp. 229–235. Kluwer Academic Publishers, The Netherlands.

Lodge, D.M., 1993. Species invasions and deletions. In: Kareiva, P.M., Kingsolver, J.G., Hney, R.B. (Eds.), Biotic Interactions and Global Change. Sunderland, Massachussetts, pp. 367–387.

Lonsdale, W.M., Lane, A.M., 1994. Tourist vehicles as vectors of weed seeds in Kakadu National Park, Northern Australia. Biological Conservation 69, 277–283.

Lonsdale, W.M., 1999. Global patterns of plant invasions and the concept of invasibility. Ecology 80, 1522–1536.

Mooney, H.A., 1999. The Global Invasive Species Program (GISP). Biological Invasions 1, 97–98.

Nally, R.M., 2000. Regression and model-building in conservation biology, biogeography and ecology: the distinction between- and reconciliation of- "predictive" and "explanatory" models. Biodiversity and Conservation, 655–671.

Pimentel, D., Lach, I., Zuniga, R., Morrison, D., 2000. Environmental and economic costs associated with non-indigenous species in the United States. Bioscience 50, 53–64.

Programa de las Naciones Unidas para el Desarrollo, 1998. Informe sobre el desarrollo humano. Mundi-Prensa, Madrid.

Pysek, P., 1994. Ecological aspects of invasion by *Heracleum mantegazzianum* in the Czech Republic. In: de Waal, L.C., Child, L.E., Wade, P.M., Brock, J.H. (Eds.), Ecology and Management of Invasive Riverside Plants. John Wiley, Chichester, pp. 45–54.

Sandlund, O.T., Schei, P.J., Viken, A., 1996. Proceedings of the Norway/UN Conference on Alien Species. Dir. Nat. Manage. Norwegian Inst. Nat. Res, Trondheim.

Saunders, D.A., Hobbs, R.J., Margules, C.R., 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5, 18–32.

Starfinger, U., Edwards, K., Kowarik, I., Williamson, M., 1998. Plant Invasions: Ecological Mechanisms and Human Responses. Backhuys Publishers, Leiden.

Tyser, R.W., Worley, C.A., 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). Conservation Biology 6, 253–262.

Usher, M.B., 1988. Biological invasions of nature reserves: a search for generalizations. Biological Conservation 44, 119–135.

Vermeij, G.J., 1996. An agenda for invasion biology. Biological Conservation 78, 3–9.

Vilà, M., Meggaro, Y., Weber, E., 1999. Preliminary analysis of the naturalized flora of northern Africa. Orsis 14, 9–20.

Weber, E., 1997. The alien flora of Europe: a taxonomic and biogeographic review. Journal of Vegetation Science 8, 565–572.

World Development Report, 1998. The Europe World Yearbook. Europe Publications Limited, London.

World Tourism Organisation, 1998. Yearbook of tourism statistics. 5 ed. Vol. I. World Tourism Organisation, Madrid.

Zar, J.H., 1984. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs.