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A new comprehensive database of alien plant species in Chile based on herbarium records

Nicol Fuentes · Aníbal Pauchard · Paulina Sánchez · Jocelyn Esquivel · Alicia Marticorena

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Abstract There is an urgent need for comprehensive national databases on alien plant species, especially in developing countries. Despite the fact that plant invasions are considered a major threat to biodiversity, they have been poorly studied or not considered a conservation priority in South America. We aim to assess alien plant distribution in Chile, using the first comprehensive public alien plant database, and discuss the implications of using herbarium records to develop national databases of alien plants. We used herbarium records to assemble a comprehensive national database of alien plants. We calculated the number of alien and native species and specimens recorded in each 10 × 10 km cell. We evaluated sampling efforts and tested for relationships between alien and native species collections, as well as other spatial patterns along the latitudinal gradient. Alien and native species richness was positively correlated. Alien plants were mostly collected in central Chile, with few species collected in both the extreme north and south. However, native plants were strongly collected in central Chile, as well as in both extremes of the country. Alien and native plants followed the same pattern of accumulation along the latitudinal gradient, with native plants being relatively more collected than alien plants. Herbarium records provide valuable baseline information to evaluate plant species distribution. However, there are important gaps in this database, (e.g. variable sampling effort for alien and native plants, incomplete information on life-history traits). Given scientists and land managers increasing demand for baseline information and the high cost of collecting such data in developing countries, herbarium records should be used more frequently for research and management of plant invasions.

Keywords Botanical records · Database · Invasive species · Non-native plant · Plant richness · South America

Introduction

Inventories of alien plants are not only fundamental to elucidate the causes and consequences of the invasion phenomenon (Mack et al. 2000; Pimentel et al. 2005), but are also important because of their relevance in

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N. Fuentes (✉) · A. Pauchard · P. Sánchez · J. Esquivel
Laboratorio de Invasiones Biológicas (LIB), Facultad de Ciencias Forestales, Universidad de Concepción, Casilla 160-C, Concepción, Chile
e-mail: nfuentes@udec.cl

N. Fuentes · A. Pauchard · P. Sánchez · J. Esquivel
Instituto de Ecología y Biodiversidad (IEB), Casilla 653, Santiago, Chile

A. Marticorena
Departamento de Botánica, Universidad de Concepción, Casilla 160-C, Concepción, Chile

regards to nature conservation (Reichard and Hamilton 1997; Goodwin et al. 1999; Khuroo et al. 2010). To properly manage alien plant invasions and preserve natural ecosystems, documentation and characterization of alien plants is essential (Pyšek et al. 2004; Wu et al. 2004; Cadotte et al. 2006). There is an urgent need for inventories or databases of alien plants, since they reflect alien species' local patterns, and provide critical information about invasive plant's distribution.

Thus, a national database of alien species would be the keystone for an early detection tool allowing for the potential elimination or control of invasive species through risk assessment protocols (Fuentes et al. 2010). Herbarium records can contribute to a wide range of studies and the development of alien plant databases, reducing the costs of collecting such information in complementary ways (i.e. specific systematic survey). Several studies have shown the significant strengths of herbarium records in plant invasion studies (Pyšek and Prach 1993; Mihulka and Pyšek 2001; Mandák et al. 2004; Wu et al. 2004; Fuentes et al. 2008). However, there have also been concerns about the biases and gaps that this information may contain (Funk and Richardson 2002; Moerman and Estabrook 2006; Crawford and Hoagland 2009) and the consequences these may have on policies for managing and controlling invasive alien plants (Aikio et al. 2010). Nevertheless, herbarium records of alien plants including life-history traits and spatial distributions have been shown to be a very useful tool for investigating invasion patterns in both the developed (Pyšek et al. 2008) and developing world (Stadler et al. 1998; Fuentes et al. 2008). However, in developing countries, where most biodiversity exists (Myers et al. 2000; Smith et al. 2003) a lack of inventories could reduce the chances of creating successful programs (Nuñez and Pauchard 2010; Khuroo et al. 2010).

In developing countries, alien flora's distribution is still poorly understood (Gardener et al. 2011; Speziale et al. 2012). Alien plants have been neglected in collections and studies due to a historical bias that found no scientific value in studying the alien component of plant communities (Pauchard et al. 2004). However, herbarium records are, at present, the main and most reliable source of historical information available in regards to alien plants (Fuentes et al. 2008). At regional scales, herbarium data provides unique insights into the spatio-temporal dynamics of alien plant introductions and can be useful when exploring large-scale patterns of plant distributions (Kühn et al. 2004; Pyšek and Hulme 2005; Seabloom et al. 2006). Herbarium records are heterogeneous in terms of location and habitat description, and their limitations are mostly due to different criteria and sampling efforts (Pyšek and Prach 1993; Delisle et al. 2003; Lavoie and Dufresne 2005). Nevertheless, they provide collection dates and geographical locations to estimate arrival, establishment and spatial characteristics of alien plants. Additionally, this information can be used as a baseline for comparing past and future changes in the distribution of alien and native species. Herbarium records' limitations should not undermine their potential to contribute to the study of alien plant threats (Fuentes et al. 2010).

Despite the fact that plant invasions are considered a major threat to biodiversity and have been extensively researched on a global scale (Mooney and Hobbs 2000; Mack et al. 2000; Pimentel et al. 2005), they have been poorly studied or not considered a conservation priority in South America (Gardener et al. 2011; Speziale et al. 2012). Plant invasions in South America are a relatively recent phenomenon (Fuentes et al. 2008; Ugarte et al. 2010); many alien plants are still in the early stage of invasion (Fuentes et al. 2010), while others have not yet been scientifically documented due to the scarcity of regional inventories (Gardener et al. 2011). Since there are few studies about plant invasions in South America and resources for this type of research are scarce in this part of the world, the greatest priority is to develop inventories of alien plants in order to first recognize threats, and then, develop programs to better control the invasive species. Herbarium records can be used as a significant source of data to fill information gaps and create inventories in developing countries.

In Chile, scientific descriptions and collections of flora date back to the eighteenth century (Figueroa et al. 2004), and recent checklists in the continental area have documented ca. 700 naturalized alien plants (Arroyo et al. 2000; Pauchard et al. 2004). However, until now, there has been an enormous lack of basic information on alien plants' spatial distribution and life-history traits (but see Arroyo et al. 2000; Castro et al. 2005). According to Arroyo et al. (2000), Chile has one of the best herbarium databases in all of Latin America; however no effort has been made to develop a complete database of alien plants using this information. Information on spatial distribution and life-history traits is particularly useful for conservation efforts, prevention, early detection, and control of alien plants in developing countries. A complete inventory of Chilean alien plants would help to promote a consistent strategy regarding alien plants, along with guidelines for sustainable land management directed at avoiding the expansion of alien invaders (Pauchard et al. 2004). Additionally, this type of inventory would be a useful example for other countries in Latin America, where increasing efforts are needed to advance the understanding and management of plant invasions (Gardener et al. 2011).

This paper aims to describe the first comprehensive database of Chile's alien flora, based mostly on herbarium records. Here, we release a new database with information on spatial distribution, historical records, and biological characteristics for each alien plant species; and we identify the database's principal information gaps, discussing the advantages and disadvantages of herbarium records for developing national databases of alien plants in developing countries.

Methods

Database

We used herbarium records (i.e. CONC Herbarium) to assemble the first comprehensive database of alien vascular plants in Chile. Even though some specific herbarium information was previously available upon request, no comprehensive alien flora database was publically available. We made a substantial effort to compile and organize a public database that integrates both species characteristics and spatial distribution information. We checked all records for their scientific names and spatial distribution. We used CONC Herbarium because it is the only herbaria in Chile (and South America), which has a digitized collection of alien and native plant species (Fuentes et al. 2008). Other Chilean herbariums were not included due to the high effort that would have been required to compile their records, which have not yet been digitized and are not publicly available. Additionally, several publications were used to complement the database (Matthei 1995; Peña et al. 2008; Bustamante and Simoneti 2005; Becerra 2006; Saldaña et al. 2009; Langdon et al. 2010; Fuentes et al. 2011). Each alien plant is provided with its original source, namely herbarium records or literature (see Online Resource 1).

Spatial distributions (geo-referenced distribution) were obtained from the records compiled within the ALARM Project (Settele et al. 2005), which are also based on the CONC Herbarium. The database includes all alien plants recorded in Chilean terrestrial habitats, which we consider naturalized (sensu Richardson et al. 2000). Additionally, we used expert criteria when the status of the plant species (sensu Richardson et al. 2000) was ambiguous or not supported by publications. Due to a lack of knowledge regarding the native ranges of several species in southern South America (i.e. among Chile, Argentina, Peru, and Bolivia) and to avoid problems in relation to their status (i.e. alien or native), we deliberately excluded alien plants whose natural distribution range fell within the neighboring regions and shared an immediate border with Chile. Scientific names followed Missouri Botanical Garden (2011) and Zuloaga et al. (2008).

The database has two units: one contains information on the species and their traits and the other is about their spatial distribution in Chile. We compiled information about thirteen traits (Table 1) for all reported alien species in Chile. Biological information was extracted from specialized literature (Matthei 1995; Holm et al. 1977, 1979; Weber 2003; DiTomaso and Healy 2007) and databases (see Online Resource 2). Using herbarium records, we developed a GIS layer (ArcGis) using a 10×10 km Universal Transverse Mercator (UTM) grid (7,423 total cells) and compiled all species present in each cell. The alien plants database has now been publicly released both in this article (species and traits) and on the internet page of the Laboratorio de Invasiones Biológicas (LIB) (www.lib.udec.cl), where the GIS layer can be downloaded.

Analyses

We calculated the number of alien and native plant species (hereafter referred to as richness) and specimens (hereafter referred to as abundance) recorded for each grid cell for Chile, based on the geo-referenced herbarium records (CONC herbarium). To reduce artificial spatial heterogeneity, we scaled up the data using the mean neighbourhood analysis for richness

Table 1 Alien plant traits, descriptions, and traits level included in the database of alien plants present in Chile

Plant traits	Description—Traits level, and main sources of information
Biological information	
Family	Taxonomic family
Life form	Tree, shrub, subshrub, herbs, and vines (Kühn et al. 2004)
Life span	Annual, biennial, and perennial (Matthei 1995)
Type of reproduction	Seed/spore, mostly by seed—rarely vegetatively, by seed—vegetatively, mostly vegetatively—rarely by seed (Kühn et al. 2004)
Fruit type	Berry, lomentum, legume, capsule, nut, aggregate follicles, aggregate berries, aggregate nutlets, aggregate drupelets, siliqua, schizocarp and drupe (Kühn et al. 2004; Matthei 1995)
Breeding system	Allogamous, facultative allogamous, mixed mating, facultative autogamous, autogamous, automixis (Kühn et al. 2004)
Raunkiaer form (Raunkiaer 1934)	Hydrophyte, Chamaephyte, Geophyte, Hemicryptophyte, Phanerophyte, Macrophanerophyte, Nanophanerophyte, Pseudophanerophyte, Hemiphanerophyte, Therophyte (Kühn et al. 2004)
Pollination mode	Wind, water, selfing, pseudocleistogamy, cleistogamy, geitonogamy, insects, bat pollination, bird pollination, slug, abiotic pollination and zoophily (Kühn et al. 2004)
Dispersal mode	Epizoochory, endozoochory, hydrochory, human activities, barochory, anemochory, autochory, myrmecochory, zoochory, unspecialized (Kühn et al. 2004)
Distribution and historical information	
First year report (number of years of residence)	The year of the first report in the country, based on herbarium records and publications
Native range	Noth America: USA, Western USA, Canada, Mexico; Central America: Tropical Souther America, Tropical America; South America: Argentina; Africa: East Africa, North Africa, Northern Africa, Northwestern Africa, South Africa, Southern Africa, Tropical Africa, Tropical and Southern Africa; Asia: East Asia, Tropical Asia, Temperate Asia, Minos Asia; Eurasia: Russia; Australia: Australia y New Zealand; Europe: Northern Europe, Central Europe, Southern Europe, Southwestern Europe, Temperate Europe, Western Europe, Mediterraean Europe, Coastal Europe, Europe and British Island; Other: Cosmopolita, pantropical (Holm et al. 1977, 1979; Matthei 1995; Weber 2003)
Invasive elsewhere	The species is a weed in agriculture, horticulture, turf, nurseries, elsewhere in the world (Holm et al. 1979)
Frequently invaded habitat	The information on habitats corresponds to those habitats invaded by alien plants in Chile (based on Matthei 1995) and information on invaded habitats in areas where the species is invasive (based on electronic databases, Online Resource 1). Roadsides, coasts, wetlands, disturbed sites, open sites, slopes, woodlands, riparian areas, disturbed sites, cultivated crops, grasslands, artificial plantation, urban areas, canals and irrigation ditches, many terrestrial habitats
Administrative Regions occupied by the plant (AR)	1 = Region 1; 2 = Region 2; 3 = Region 3; 4 = Region 4; 5 = Region 5; 6 = Region 6; 7 = Region 7; 8 = Region 8; 9 = Region 9; A = Region 10; B = Region 11; C = Region 12; M = Metropolitan Region.

and abundance (radius = 3 grid cells). We standardized richness and abundance by dividing by the maximum cell value for each variable (values between 0 and 1). Since neighbouring data points may not be spatially independent (e.g. Legendre 1993), we tested for spatial autocorrelation of both alien and native species richness, at grid cell, using the Moran index.

We calculated the differences between standardized alien species richness minus standardized native species richness for each cell (hereafter delta species richness). Positive values of delta species richness indicate that alien plant species are relatively better represented in that cell (either because more alien plant species occur in that cell, or because they have been better collected) than native plant species and vice versa. To provide an alternative way of assessing alien plant establishment (or introduction effort); we calculated the ratio of alien to native plant species for each cell (alien/native, hereafter A/N). Values of A/N ratio over 1 indicate that alien plant species are more abundant in that cell than native ones, and can be used to estimate successful establishment. Additionally, we evaluated the sampling effort (i.e. intensity of floristic collection sensu Delisle et al. 2003) for alien and native plant species independently. We used the relationship between the numbers of species divided by the number of specimens in each cell (hereafter sp/spm ratio; Squeo et al. 1998). Values of sp/spm ratio near 1 indicate a lack of sampling effort (i.e. cell not well-collected); values near 0 reflect that the cell is well collected (Squeo et al. 1998).

We evaluated the latitudinal patterns of alien and native plant species' distribution along Chile (4,270 km from north to south). We divided the territory into 19 latitudinal bands (2° latitude each), and calculated the density (number of species divided by the logarithm of the area of each band) of both alien and native plant species within each latitudinal band. This method avoids bias due to the different areas that make up each latitudinal band (Lonsdale 1999). All of the spatial analyses were performed on ArcGIS 9.3 (ESRI, Redlands, CA, USA).

Results

The new Chilean alien flora database

The database contains 743 naturalized alien plants, which have been recorded in continental Chile, of which 682 are from herbarium records and 61 from literature (see Online Resource 1). Alien plants are distributed in 361 genera and 74 families. Most alien plants belong to families of Poaceae, Asteraceae, Fabaceae, and Brassicaceae (Table 2). The genera with the highest number of alien plants are *Trifolium*, *Bromus*, *Poa*, *Cyperus* and *Polygonum* (Table 2).

Alien plants are predominantly herbs, most of them annuals and perennials, while shrubs and trees account for only a small number of species (Table 2). Regarding life form, hemicryptophytes are the most prominent group, followed by therophytes, and geophytes (Table 2). The dispersal of most alien plants is mediated by water, wind, and human activities (Online Resource 1). Most alien plants occur on human-made habitats, especially disturbed areas (17 %), agricultural areas (15 %), and roadsides (12.4 %) Additionally, more than half (66 %) of the total alien plants in the database are invasive elsewhere (Online Resource 1).

Most of the alien plants recorded in the database come from Europe and North America, followed by Africa and South America. There are, however, a relatively high percentage of alien plants whose origin is unknown (Table 2).

Distribution patterns

In the 10 × 10 km cells, the number of species and specimens are positively correlated for both alien and native plants ($P < 0.001$; $R^2 = 0.304$; $P < 0.001$; $R^2 = 0.923$ respectively), hence we used number of alien and native plant species for further analysis. More than fifty percent of the cells (7,423) lack data (3,672). 1,110 cells contain both alien and native plant species, cells with only native plant species account for 2,548, and cells with only alien plant species 1,203. Alien and native plant species richness are positively correlated ($P < 0.01$; $R^2 = 0.334$), indicating that both groups follow an overall similar pattern of distribution (Fig. 1a). However, alien plants have mostly been collected in central Chile, with few species collected in both the northern and southern extremes (Fig. 2b), while native plants have been strongly collected in central Chile, and also in both extremes of the country (Fig. 2c).

The Moran's index shows low levels of spatial autocorrelation, with values of 0.27 (z-Normal = 101, $P < 0.05$) for alien plant richness, and 0.23 (z-Normal = 84, $P < 0.05$) for native plant richness. Delta species richness (i.e. alien minus native species richness) showed that, overall, the collection of native plants is more diverse (853 negative values) than the collection of alien plants (257 positive values; Fig. 2d). The A/N ratio was in 160 cells over 1, distributed mainly in the central area of Chile, as well as a low number of cells in the south of Chile. The sp/spm ratio showed mostly values near 1 (aliens and natives), indicating a low sampling effort for both alien and native plant species and specimens (Figs. 1b, 3a, b). Alien and native plant species follow the same accumulation pattern along the latitudinal gradient, with native plants being more collected than alien ones (Fig. 4). Areas with high numbers of alien and native plant species are associated with large cities and herbarium locations (Fig. 4).

Table 2 Summary (number and percentage—in parenthesis) of the main traits listed in the database of naturalized alien plants of Chile

Family	Genera	Native range	Life form	Life span	Raunkiaer form	First year report (range)	Administrative regions (13 in total range)
Poaceae 152 (20.46)	*Trifolium* 16 (2.15)	Europe 385 (51.8)	Herb 657 (88.4)	Annual 394 (53)	Hemicryptophytes 386 (52)	Before 1900 214 (28.8)	1–3 326 (43.8)
Asteraceae 106 (14.27)	*Bromus* 12 (1.62)	North America 48 (6.5)	Shrub 27 (3.6)	Perennial 309 (41.6)	Therophytes 192 (25.8)	1901–1920 52 (6.9)	4–6 165 (22.2)
Fabaceae 72 (9.69)	*Poa* 11 (1.48)	Africa 47 (6.3)	Tree 24 (3.2)	Biennial 37 (5)	Phanerophytes 44 (5.9)	1921–1940 136 (18.3)	7–9 136 (18.3)
Brassicaceae 41 (5.52)	*Cyperus* 10 (1.35)	South America 39 (5.2)	Vines 21 (2.8)	No data 3 (0.4)	Geophytes 42 (5.7)	1941–1960 79 (10.6)	10–13 87 (11.7)
Amaranthaceae 32 (4.31)	*Polygonum* 10 (1.35)	Eurasia 30 (4)	Subshrub 10 (1.2)		Chamaephytes 19 (2.6)	1961–1980 41 (5.5)	No data 29 (3.9)
Caryophyllaceae 26 (3.50)	*Chenopodium* 9 (1.21)	Asia 20 (2.7)	No data 4 (0.5)		Hydrophytes 19 (2.6)	1981–2012 68 (9.2)	
Polygonaceae 24 (3.23)	*Euphorbia* 9 (1.21)	Central America 16 (2.2)			No data 41 (5.5)	No data 153 (20.6)	
Scrophulariaceae 24 (3.23)	*Rumex* 9 (1.21)	Australia 9 (1.2)					
Apiaceae 19 (2.56)	*Veronica* 9 (1.21)	Other 16 (2.2)					
Boraginaceae 17 (2.29)	*Acacia* 8 (1.08)	No data 133 (17.9)					
Others 230 (30.96)	Others 640 (86.13)						

Due to the high number of family, genera, and native range, only the most numerous categories are listed. For details see Online Resources 1

Discussion

Documentation and characterization of alien plants is essential to formulate strategies for their management or control. Compared to developed countries (Pyšek et al. 2008), alien plant inventories are alarmingly scarce in developing countries (i.e. Latin America; Gardener et al. 2011). Few countries in Latin America are working on generating regional alien plants inventories (but see Zuloaga et al. 2008) to formulate policies and integrated programs to control these plants negative impacts (Gardener et al. 2011). Currently, in Latin America most of the information is dispersed in grey literature and field observations with poor geographical information, which has not been scientifically checked (Gardener et al. 2011). This study is the first in Chile and among the first in Latin America to evaluate the spatial patterns of alien and native plants, and to create a spatially explicit inventory of alien plants. In Chile, inventories like this one will help not only to increase the low research effort devoted to alien plants, but will also aid in the assessment of the current and future threats that face natural ecosystems.

In Chile, the number of alien plants has notably increased from 700 (Arroyo et al. 2000) to 743. The

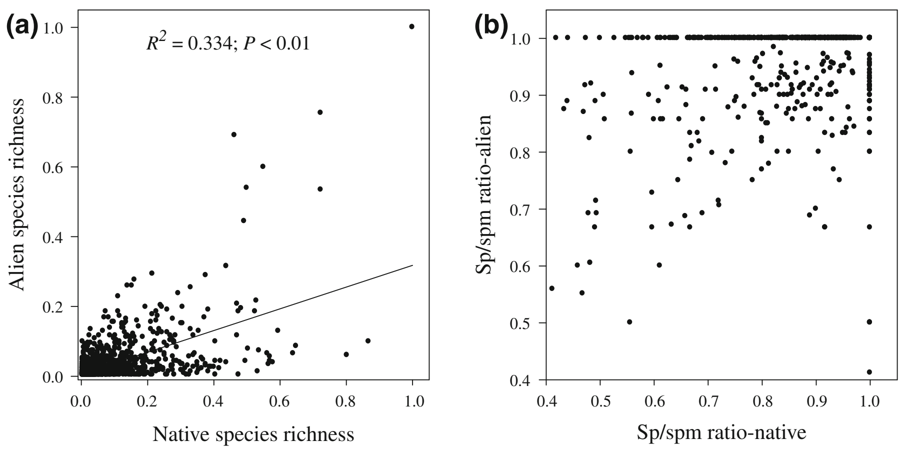

Fig. 1 **a** Relationship between alien and native species richness; analysis based on 1,110 cells containing information on both groups of plants (1 = 232/232; 242/242 for alien and native respectively). **b** Alien and native sp/spm ratio (no. species/no. specimens 10 × 10 km). Values near 1 indicate a lack of sampling effort and values near 0 reflect that the pixel is well collected

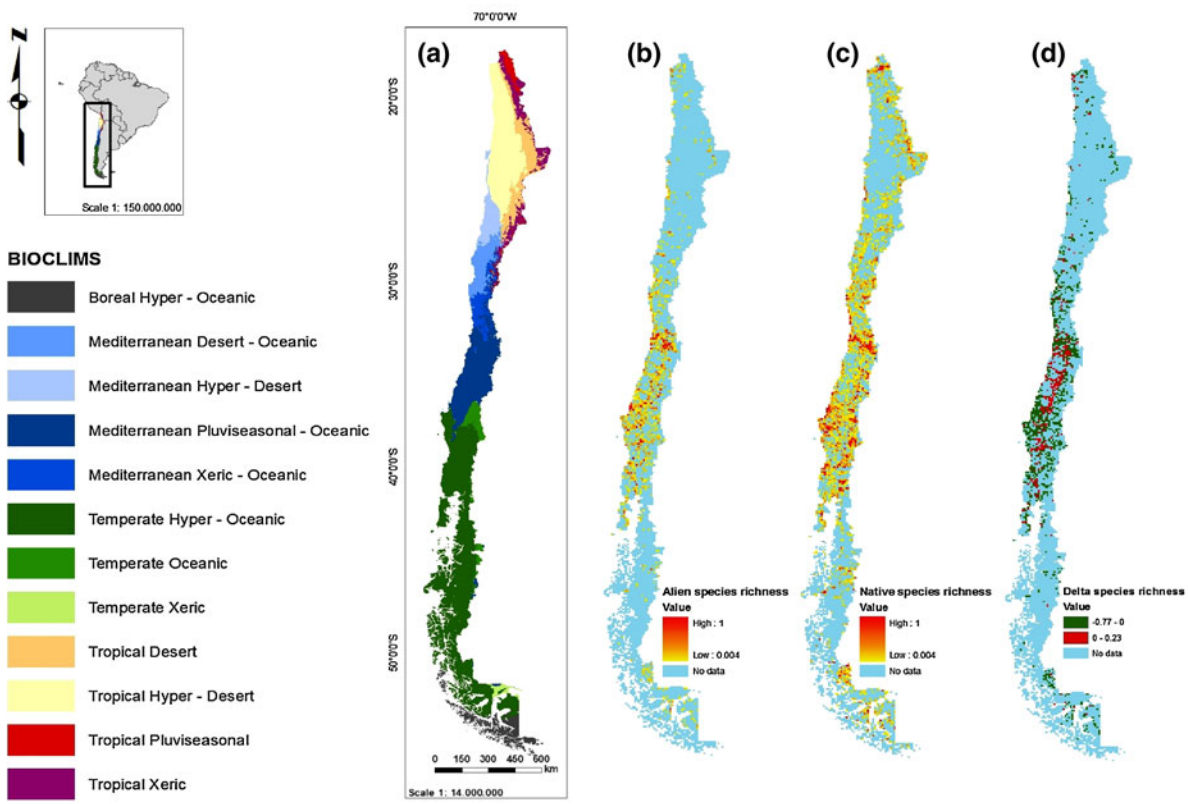

Fig. 2 **a** Geographic location and climate zones of continental Chile (source: Luebert and Pliscoff 2006, 2009). **b**, **c** Distribution of alien and native species richness (cell 10 × 10 km). **d** delta species richness (alien species richness minus native species richness), positive values indicate that alien species are relatively better represented in that cell than native ones and vice versa. Data projected in Universal Transverse Mercator Zone 19S, and Datum WGS84

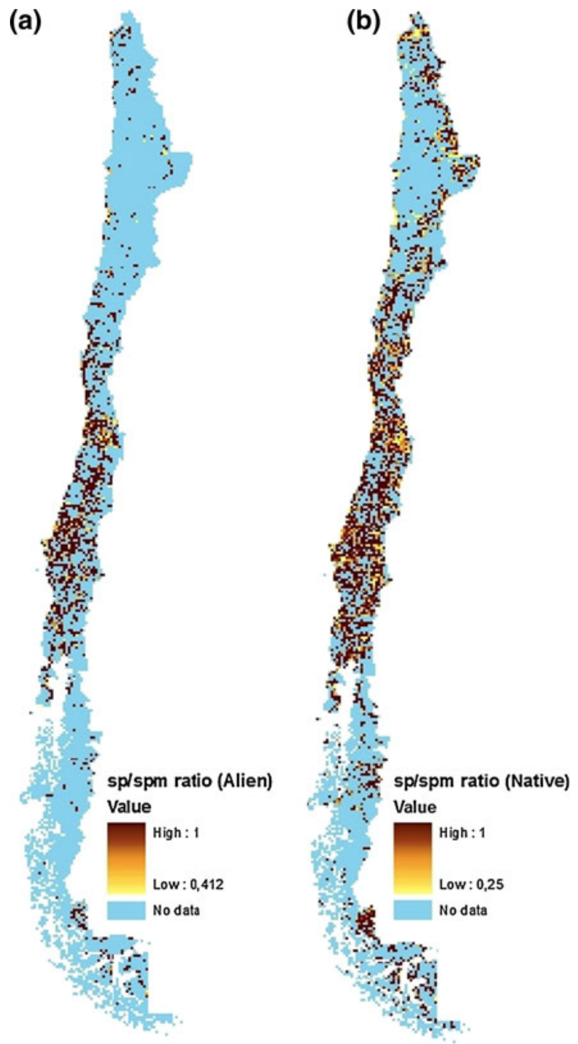

Fig. 3 **a** Alien and **b** native sp/spm ratio (numbers of species divided by the number of specimens in each cell); values near 1 indicate a lack of sampling effort and values near 0 reflect that the pixel is well collected. Data projected in Universal Transverse Mercator Zone 19S, and Datum WGS84

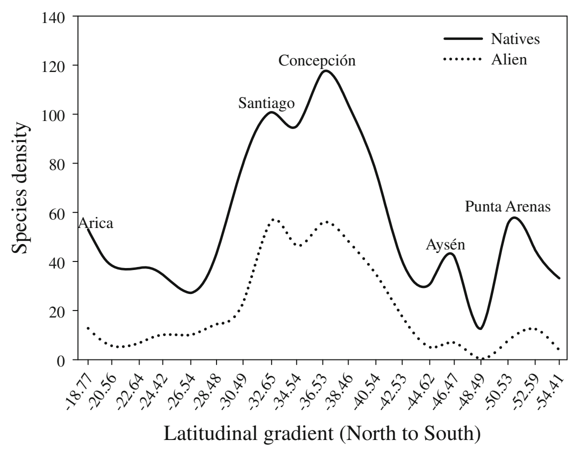

Fig. 4 Alien and native species densities (number of species/log (area) along the latitudinal gradient in Chile; the territory was divided into 19 latitudinal bands (2° of latitude each). Peaks of species density represent the geographic position of large cities in Chile

number is higher than in neighboring countries such as Argentina (587 alien plants; Fuentes et al. 2010), Bolivia (92 alien plants; IABIN Inter-American Biodiversity Information Network 2011), and Ecuador (595 alien plants; Jørgensen and León-Yánez 1999). However, differentiations among alien floras in Latin America cannot only be explained by the differences in what we know about them (Speziale et al. 2012), but also by differences in propagule pressure (quantity and diversity) and land uses, which are closely related to divergent human immigration histories (Ugarte et al. 2010).

Most of the alien plants in this database (682) came from herbarium records (i.e. CONC), while few came from literature (61). Difference in the number of alien plants recorded in the herbarium and the literature is due to the fact that: (1) earlier reports of alien plants in Chile were not published in literature, but only in the herbarium (C. Marticorena, personal communication, 05 August, 2011); and (2) previous research on alien plant distribution in Chile has used, in most cases, only the CONC herbarium as a source of information (see Arroyo et al. 2000; Fuentes et al. 2008; Jiménez et al. 2008). The use of herbarium records as the main source of information highlights its role in alien plant studies at large spatial and temporal scales in Chile, where data collections always represent a difficult task. Certainly, in Chile, much can be gained by integrating other herbarium records (not yet digitized) in a centralized source of information to obtain a more realistic pattern of plant distributions. For instance, data from other national (e.g. Museo Nacional de Historia Natural—SGO) and regional herbariums located in the north (e.g. Universidad de la Serena—ULS) and south of Chile (e.g. Universidad de Magallanes—HIP) would be useful to clarify if alien plants have arrived to those areas, where the number of records is particularly low.

Distribution patterns

Alien and native plants showed different patterns of spatial ordering and accumulation in this Chilean database. However, there was a fairly significant relationship between alien and native plants (ca. 30 %). Three questions emerge from this relationship: Which factors explain this 30 %? Do native and alien plant respond similarly to climatic, edaphic and disturbance gradients? Or is this relationship just an artifact of sampling efforts? Unfortunately, with the available information, it is impossible to answer these questions and further work is needed in smaller landscapes or regional contexts to clarify which factors determine this relationship. For that reason, studies require comparable sampling efforts for both alien and native plant species, which, unfortunately, is lacking in this database.

Clearly, alien plants have been less collected than native plants, which are reflected in a higher concentration closer to 1 in the sp/spm ratio. However, it is impossible to say whether or not this represents the species' abundance in that particular pixel or if it represents a low sampling (collection) effort for alien plants due to botanical bias. There is a clear differentiation between well-collected areas (low species/specimen ratio) for native and alien plants. For native plants, a bimodal pattern was found. Distant areas, probably protected areas, as well as areas closer to cities showed some of the highest collection efforts of native plants, but in less accessible areas there were important "hotspots" of native richness (i.e. higher elevations), probably associated with specific collection efforts (e.g. research projects or expeditions). For alien plants, areas close to cities showed the highest collection effort. Cities represent areas where universities and herbariums are located; therefore, this bias for native and alien plants is certainly influenced by the distance to the collection center (botanist effect sensu Moerman and Estabrook (2006); i.e. species diversity increases with the presence of botanists). This bias can be seen in the two latitudinal peaks (Fig. 4), which represent Santiago and Concepción, cities with the highest concentration of botanists and herbariums (Arroyo et al. 2000).

This database shows a lack of a systematic collection effort along the latitudinal gradient. The northern and southern portions of the country exhibit large areas without records (i.e. more than fifty percent of all cells lacked data). Alien plants are distributed in Mediterranean and Temperate climate regions (i.e., south-central Chile), with few records collected in both extremes of the country. Castro et al. (2005) and Fuentes et al. (2008) showed similar distribution patterns for alien plants. The high concentration of alien plants in the south-central area can be associated to the fact that since Spanish colonization most Chileans have lived in this area (ca 80 % population). Consequently, the area has been strongly transformed by human activities (logging, burning, grazing, etc.) incrementing propagule pressure by alien plants (Arroyo et al. 2000; Fuentes et al. 2008). On the contrary, the northern and southern area have been relatively isolated, with low frequency and intensity of human activities, mainly due to their climatic conditions and remoteness from the main cities in south-central Chile (Arroyo et al. 2000; Fuentes et al. 2008). The question remains as to whether the small number of alien plants collected in both extremes is related to the so-called botanist effect (see above), or to the fact that alien plants have not yet arrived to those areas due to low propagule pressure. Both explanations must be considered simultaneously. Although collections have been carried out in the northern region for the last three decades (Marticorena et al. 1998; Squeo et al. 1998), they have lacked an oriented systematic survey, making it difficult to accurately determine which species are established there. Additionally, gaps of alien plants in the Atacama Desert may be attributable to the harsh climatic conditions there, which may operate as an important filter limiting alien plant distribution in this zone. On the other hand, the lack of alien plants in the southern area may be the result of a combination of inaccessibility (therefore, low sampling effort) and lower levels of industrialization, resulting in low levels of propagule pressure (Fuentes et al. 2008). Clearly, integrating herbarium records from these areas (see above) where the sampling effort has been particularly low will be necessary to answer these questions.

Taking advantage of herbarium records

Spatially explicit herbarium records allow for analyses at multiple scales of resolution and extension. Here, we worked at a national scale with a relative fine resolution of 10 × 10 km. considering the serious gaps in both native and alien plant collections; this resolution may have added unnecessary noise to the analyses. Nonetheless, this spatial resolution allowed for the understanding of landscape variations as a product of topography and specific landscape features (e.g. highways, urban areas). The latitudinal belts of two degrees showed a simpler pattern of distribution for alien and native plants, which clarifies the role of the latitudinal climatic gradient and the inter-regional differences in land-use and development (e.g. Arroyo et al. 2000; Jiménez et al. 2008).

One of the major impediments to the development of an effective management strategy against biological invasions is the lack of a comprehensive characterization of all alien flora. This work represents the first comprehensive compilation and analysis of available records of alien plants in Chile, representing an important tool for further research in identifying traits related to invasiveness. However, the compilation of the database allowed us to identify and recognize important gaps which must be addressed: (1) sampling efforts of both alien and native plants is highly variable across the country; (2) the database has incomplete information on species life-history traits; and (3) the database has no information on the ecological and economic impact of the alien plants in Chile. Thus, major efforts are needed to fill these gaps and complete herbarium records of alien plants across the country.

We recognize the limitations of herbarium data, and accept that a systematic and intensive survey is likely to be a more powerful tool to detect new invasive plants, and could also assist in alien plant management. For instance, Fuentes et al. (2010) combined systematic surveys of alien plants in Chile and Argentina, herbarium records, and catalogs to evaluate the risk of alien plant invasions between both countries through risk assessment protocols (WRA-Ch). While this study represents an example of combining information to obtain a more realistic pattern of species' distributions, we demonstrated here that herbarium records can help to generate a national biodiversity inventory including native and alien plant species in developing countries. However, to create comprehensive local and national herbariums it will be necessary to develop a long-term monitoring program by intensively using public and private resources in coordination with universities and institutes, with ad-hoc funding. In several developed countries, alien plant information has been systematized from numerous sources and is now publically available. In this sense, we can learn from successful programs like those in Europe, to obtain fine resolution species information (i.e. Florkart in Germany; birds in Catalonia Brotons et al. 2007; DAISIE-Delivering Alien Invasive Species Inventories for Europe). Therefore, given land managers' increasing demand for baseline information and the cost of collecting such data in developing countries (Nuñez and Pauchard 2010), we highlight that the information stored in herbarium databases should be utilized as much as possible as the starting point for research in invasion ecology in developing countries.

Availability

The database was generated with the financial support of the Institute of Ecology and Biodiversity (IEB), and will be available and maintained on the Internet page of Laboratorio de Invasiones Biológicas (LIB) at http://www.lib.udec.cl. The database will be regularly updated from collections and literature to extend the coverage of species and number of traits. Contributions will be appreciated, and will be checked by experts for its inclusion in the database. To request the entire database, including number of specimens per species and spatial information, contact the principal author at nfuentes@udec.cl and lib@udec.cl.

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