Plant Invasions in South America

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Abstract

Although South America is the fourth largest continent, it houses about 60% of the global terrestrial life and the highest number of plant species. Besides its great native biodiversity, there are an unknown number of introduced non-native plants and at least 2,677 known naturalized non-native plants in South America. Despite the growing knowledge on the richness and general status of non-native species, the real extent of distribution, abundance, and effects of invasive plants in South America are largely unknown. Here, we used country-level data on the number and identity of naturalized plant species to test which factors were related to non-native plant naturalization in the continent. To do so, we (i) compiled a list of the most prominent invasive plants in the continent and (ii) reviewed the existing legislation in place to prevent and manage plant invasions. We found that mean latitude and number of bioclimates were good predictors of naturalized plant richness. We also found that plant invasions have pervasive impacts in South American ecosystems, but that the real magnitude of the impacts was vastly unknown because very few invasive species and invaded ecosystems have been studied. We also found that South American countries have legislations in place to manage plant invasions, but there were no integrated efforts across the countries to collaboratively address biological invasions. In conclusion, we show that there is information about the identity and distribution of most invasive

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plants, but there is a lack of comprehensive understanding of the impacts and future consequences on biodiversity and human well-being. We also highlight the importance of a more collaborative approach to prevent and manage invasions in the continent.

Keywords

Biological invasions · Invasive alien species · Invasive non-native species · Naturalized plant species · Established plant species

9.1 Introduction

South America is one of the most diverse continents on Earth with a wide range of geological formations, climates, and ecosystems. Even though it is the fourth largest continent, it houses about 60% of the global terrestrial life and the highest number of vascular plant species. South America is home to more than 82,000 plant species, 90% of which are endemic to the continent (Zappi et al. 2015; Ulloa et al. 2017). However, there are an unknown number of introduced non-native plants and at least 2677 known naturalized non-native plants in South America according to the Global Naturalized Alien Flora (GLONAF) (van Kleunen et al. 2019; Pyšek et al. 2019) and 1720 species according to the Global Register of Introduced and Invasive Species (GRIIS) (Pagad et al. 2018). If non-native plants were added to the regional floras, they would represent at least 1.4% of the total flora of the continent (Pyšek et al. 2019) and up to 7% of the flora of some South American ecosystems (e.g., Brazilian Pampas) (Zenni 2015).

Despite existing comprehensive lists of naturalized species for South America (van Kleunen et al. 2015; Pagad et al. 2018; Pyšek et al. 2019), there is currently a lack of a comprehensive list of invasive non-native plants at a continent level. There are continent-level lists of invasive plant species only for specific groups (e.g., Simberloff et al. 2010). Also, there are several country-level lists of naturalized and invasive non-native species. For instance, published reports indicate 573 naturalized plant species and 194 invasive plant species for Brazil (Zenni and Ziller 2011; Zenni 2015; Ziller et al. 2018). Fuentes et al. (2013) and Pauchard et al. (2019) listed 743 naturalized plant species for Chile, but the number of invasive species is currently unknown. A recent publication indicated the occurrence of 1,401 non-native plant species in Argentinean National Parks, but there was no classification in terms of naturalized or invasive species (Gantchoff et al. 2018). Moreover, these reports are not consistent in terms of breadth and depth of data collection or in terms of definitions adopted to classify species as invasive. For instance, the I3N-Hórus Institute database of invasive species in Brazil (http://i3n.institutohorus.org.br/www) includes both species that are currently invasive in the country and species that are currently naturalized in Brazil but invasive elsewhere. The same was done for Chile (Fuentes et al. 2013), but not for Argentina (Gantchoff et al. 2018).

Despite the growing knowledge on the richness and general status of non-native species in South America, the real extent of distribution, abundance, and impacts of invasive plants in the continent is largely unknown. Here, we aimed to (1) synthesize the main patterns and correlates of naturalized plants in South America; (2) summarize the status of the most relevant invasive species in different ecosystems of South America; (3) synthesize the current knowledge on the impacts these species are having on native species, communities, and ecosystems; and (4) synthesize the existing legislation in place to manage invasive plants and invasion processes. Our approach was limited by data availability, as comprehensive data was lacking for several countries.

9.2 Data Sources

9.2.1 Main Patterns and Correlates of Naturalized Plants in South America

We used the GRIIS database for South American countries to list the naturalized non-native plant species on the continent. GRIIS was hosted at http://griis.org, and the search was performed on April 23, 2019. Data were available for Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Uruguay, and Venezuela. We included all records, instead of verified records only, because of the heterogeneity in number of experts validating data for each country. First, we collected geographic and demographic data for each country using official online sources (e.g., government websites). We collected area of the country (km^2), population size, number of bioclimates as a proxy for environmental heterogeneity in the country, mean latitude, and 2017 Human Development Index (HDI) as a proxy for country economic wealth. Ecological, geographical, and historical factors have been shown to contribute to non-native biotas.

To test if the geographic and demographic data had an effect on the richness of each naturalized flora, we performed a linear model using naturalized species richness as the dependent variable and area of the country, number of bioclimates, mean latitude, and HDI as independent variables. We did not include population size and European colonizing country because of the high correlation of the former with country area and the extremely low variability of the latter. From the full model, we chose the best model by AIC (Akaike information criterion) using a stepwise algorithm. These analyses were performed in the software R version 3.5.2.

To evaluate patterns of the community of naturalized species in South American countries, we first performed a non-metric multidimensional scaling (NMDS) analysis using a matrix of presence and absence of naturalized species per country (community matrix). To analyze possible mechanisms explaining similarities among naturalized floras, we performed a permutational multivariate analysis of variance (Permanova) using the community matrix as dependent variable and area of the country, population size, number of bioclimates, mean latitude, HDI, and European colonizing country as independent variables. These analyses were performed in R version 3.5.2 using the package vegan version 2.5-4 (Oksanen et al. 2019).

9.2.2 Status and Current Knowledge of the Most Relevant Invasive Plants in the Native Ecosystems of South America

After the initial analysis of naturalized floras in each country, we used our expert knowledge to select the most relevant invasive non-native species in ecosystems of each country. We did not aim for a comprehensive list of invasive species, but for a representative list of the species with more information available and the highest perceived invasiveness and impact on native ecosystems. For each invasive species identified, we gathered and reviewed the published literature on the impacts of these species. We did this for Argentina, Brazil, Chile, Ecuador, and Venezuela because these were the countries for which we had expert in-depth knowledge. Attempting this method for countries we lack in-depth expertise would be a futile effort and probably result in incorrect assumptions and views.

9.2.3 Existing Legislation to Manage Invasive Plants and Invasion Processes

Finally, we reviewed the existing legislation of each country for managing plant invasions, including regulation of prevention, early detection, rapid response, control, use, and eradication efforts. We also did this only for Argentina, Brazil, Chile, Ecuador, and Venezuela.

9.3 Main Patterns and Correlates of Naturalized Plants in South America

GRIIS registered 553 naturalized plant species in Argentina, 247 in Bolivia, 503 in Brazil, 723 in Chile, 265 in Colombia, 348 in Ecuador, 166 in Guyana, 72 in Paraguay, 288 in Peru, 61 in Uruguay, and 219 in Venezuela (Figs. 9.1 and 9.2) for a total of 1720 naturalized non-native plant species (some species are naturalized in multiple countries). The linear model with the lowest AIC (most parsimonious model) included mean latitude and number of bioclimates as predictors of naturalized plant richness ($F_{2,8} = 5.431$, $p = 0.03$). Country size and population size did not relate to naturalized species richness. The model explained 57.6% of the variation in the data ($r^2 = 0.5759$). Naturalized species richness was negatively related to mean latitude and positively related to number of biomes, and these effects were independent of country size or population size (Fig. 9.2).

Tropical South America (between zero and −23.5° latitude) has two or three times fewer naturalized non-native plants than temperate South America (latitude below −23.5°) despite its greater area. Previous research for Brazil at the biome level confirms a similar tendency of fewer naturalized species towards the Amazon and Pantanal regions (Zenni 2015). This difference probably results from long-term and more widespread anthropogenic-related pressures on natural ecosystems in the southern and southeastern regions of the continent. On one hand, Chile has lost 55% of the native forests to human-related activities, and 34% of the remaining native forests occur in fragmented landscapes (Neira et al. 2002), whereas in Argentina large areas of Chaco and Espinal have been converted into agriculture and cattle pastures and some estimates indicate less than 40% of the native forest still exists (Guida-Johnson and Zuleta 2013 and references within). On the other hand, the Amazon region (including large parts of Brazil, Colombia, Ecuador, Peru, and Venezuela) is estimated to have 80% of its tropical forest remaining (WWF 2019). Pantanal is the least converted biome in Brazil with 85% of the ecosystem remaining (CSR/IBAMA 2011). Considering current and historical anthropogenic effects on natural ecosystems across South America and the existing synergies between non-native species and habitat degradation (Richardson and Pyšek 2012), it is expected that more naturalized species are found on more ecosystems with higher human pressure. However, we are also aware that GRIIS is currently incomplete for several South American countries, including Ecuador and Venezuela. For instance, GRIIS does not register *Trifolium repens* and *Roystonea oleracea* for Ecuador, two known naturalized species. Also, there are several studies dedicated to non-native species in the southern regions of the continent (e.g., de Andrade Frehse et al. 2016).

Among naturalized plants in South America, 41.2% were reported for more than one country (n=709), but only one species, *Sorghum halepense*, was reported for all countries from which we had data. Thirty-three plant species were reported for seven or more countries (Table 9.1). The most widespread grouping of non-native plants in the continent according to this analysis was grasses, followed by trees. Most of the species (~59%), however, were reported for a single country, possibly suggesting that most plant introductions in South America were independent introductions from other continents rather than movement (intentional or accidental) within South America by human-related routes or pathways. The country-level variation of the naturalized flora of South America varies by latitude and number of bioclimates in a country (Fig. 9.3), showing that climate and environmental heterogeneity have an important role on the identity of species that are introduced and naturalized in different regions.

The Convention on Biological Diversity defined invasive species as “species whose introduction and/or spread outside their natural past or present distribution threatens biological diversity.” GRIIS lists 783 naturalized plants in South America (45.5% of the total 1720) as having evidence of impacts published in the peer-reviewed literature or technical reports. Therefore, from this perspective, these species could be classified as invasive. However, the current population status for most of the species is poorly known, and most of the evidence gathered so far for impact are qualitative and indirectly observed (Zenni et al. 2016). For example, for Argentina 47.6% of the naturalized species were reported in GRIIS as having a negative impact, but for Paraguay (a neighboring country) none of the species were reported as having evidence of any negative impact. Both countries share many invasive species. In the tropical region of the continent, 1.8%

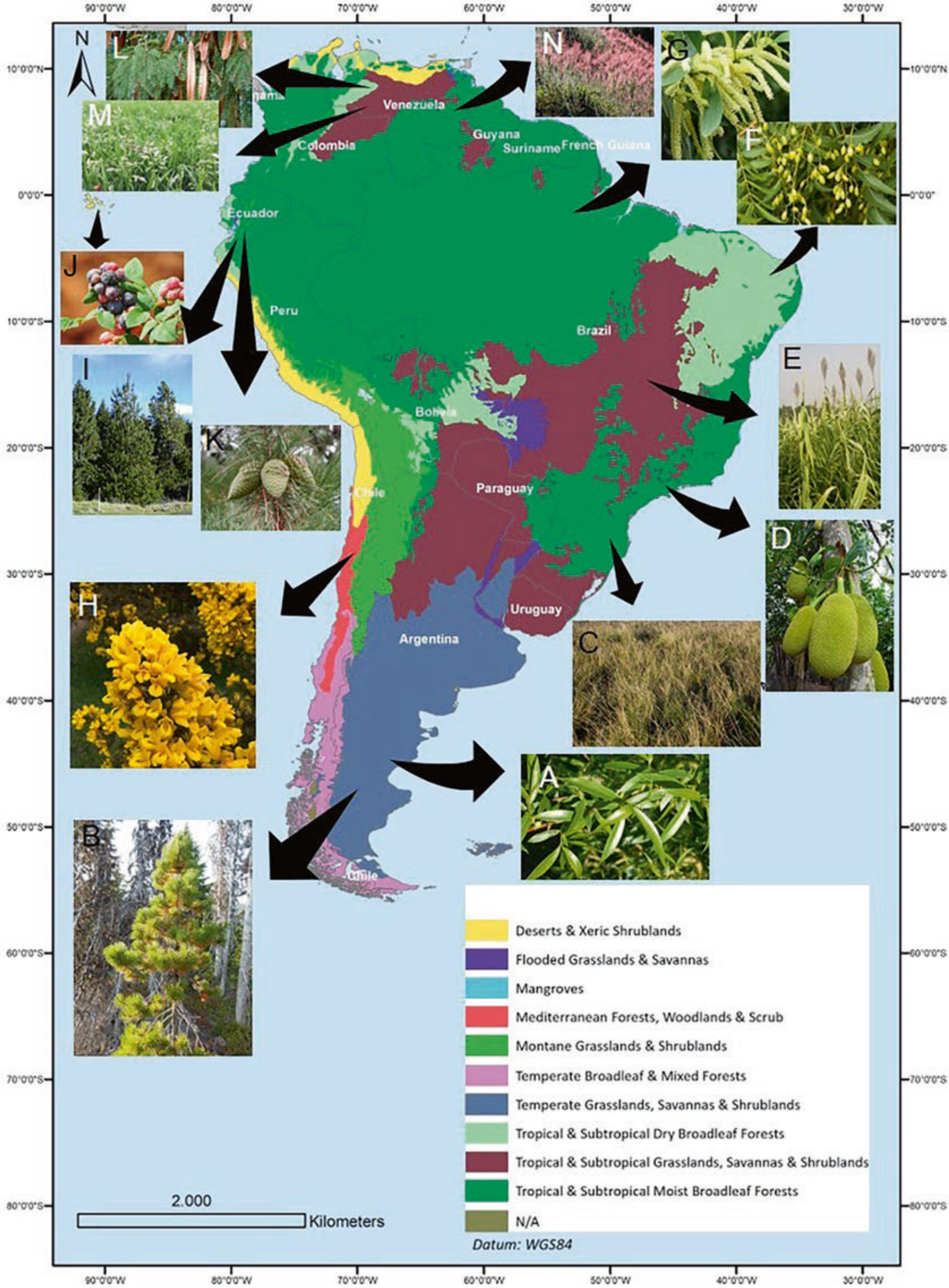

Fig. 9.1 Infographic of invasive non-native plants in South American biomes. Each letter on the picture corresponds to an invasive non-native plant in a South American country. A, *Salix fragilis – Salix alba hybrid complex*; B, *Pinus contorta*; C, *Eragrostis plana*; D, *Artocarpus heterophyllus*; E, *Arundo donax*; F, *Azadirachta indica*; G, *Acacia mangium*; H, *Ulex europaeus*; I, *Pinus patula;* J, *Rubus niveus*; K, *Pinus radiata*; L, *Leucaena leucocephala*; M, *Poa annua*; N, *Melinis minutiflora*. (Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community)

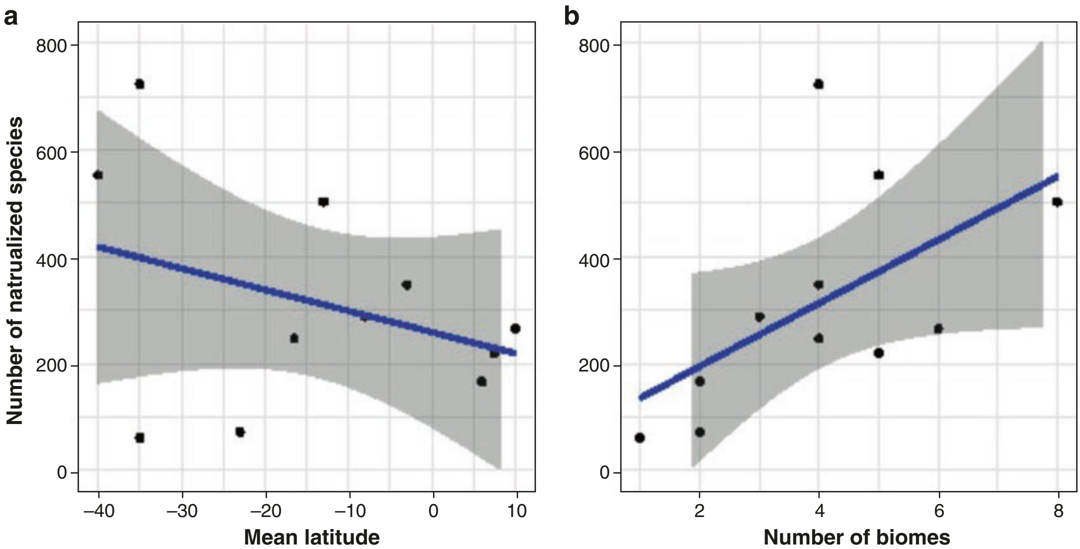

Fig. 9.2 Variation in naturalized species richness in South American countries as a function of (**a**) mean latitude of the country and (**b**) number of biomes (environmental heterogeneity). Dots are South American countries; lines represent the linear model adjustments, and gray areas are 95% confidence intervals

of the naturalized species were said to have evidence of negative impacts, whereas for Peru none of the naturalized species were reported as displaying any evidence of negative impact. Consequently, we are still unable to quantify at the continent level, with an acceptable degree of confidence, the actual number of invasive species (the subset of naturalized species that are threatening ecosystems, habitats or species) and their impacts on natural ecosystems.

9.4 Status and Current Knowledge of the Most Relevant Invasive Plants in the Native Ecosystems of South America

We identified 46 species as the most relevant invasive plants in the South American ecosystems (Table 9.2). Most of the non-native species were identified as prominent invaders only for one country. Five species were considered prominent invaders in more than one country (*Melinis minutiflora*, *Azadirachta indica*, *Leucaena leucocephala*, *Ulex europaeus*, and *Pinus contorta*) suggesting that, although there are many shared naturalized plants among South American countries, the invasive species are more regionalized. Seven of these species (16%) are also among the most widespread naturalized species in the continent including *Calotropis procera*, *Hyparrhenia rufa*, *Leucaena leucocephala*, *Pennisetum clandestinum*, *Poa annua*, *Ricinus communis*, and *Ulex europaeus* (Table 9.1). Interestingly, while most of the widespread naturalized plants were grasses (46%), the majority of the most relevant invasive species were trees (41%). Only 21% of the most widespread plants were trees. It is unclear if trees indeed have larger impacts than grasses and shrubs, or if trees are more easily perceived as invasive species.

9.4.1 Southern Argentina

Impacts have not been the main focus of research on invasive species in western Patagonia, but there are some key studies on the topic centered on woody species. Some of the clearest examples, due to extension of their invasions, are *Salix* and Pinaceae. The *Salix fragilis*-*Salix alba* hybrid complex invades large number of streams and rivers, and currently it is rare to see a river with-

Table 9.1 Non-native plant species with the most records of naturalization in South American countries

Species	Family	Life form	Number of countries
Sorghum halepense	Poaceae	Grass	10
Arundo donax	Poaceae	Grass	9
Cynodon dactylon	Poaceae	Grass	9
Ricinus communis	Euphorbiaceae	Shrub	9
Cenchrus ciliaris	Poaceae	Grass	8
Cyperus esculentus	Cyperaceae	Grass	8
Echinochloa colona	Poaceae	Grass	8
Eichhornia crassipes	Pontederiaceae	Herb	8
Eleusine indica	Poaceae	Grass	8
Gliricidia sepium	Fabaceae	Tree	8
Leucaena leucocephala	Fabaceae	Tree	8
Melia azedarach	Meliaceae	Tree	8
Melinis repens	Poaceae	Grass	8
Pennisetum clandestinum	Poaceae	Grass	8
Plantago major	Plantaginaceae	Herb	8
Poa annua	Poaceae	Grass	8
Bidens pilosa	Asteraceae	Herb	7
Brachiaria mutica	Poaceae	Grass	7
Calotropis procera	Apocynaceae	Tree	7
Cenchrus echinatus	Poaceae	Grass	7
Cyperus rotundus	Cyperaceae	Grass	7
Datura stramonium	Solanaceae	Shrub	7
Delonix regia	Fabaceae	Tree	7
Eucalyptus camaldulensis	Myrtaceae	Tree	7
Grevillea robusta	Proteaceae	Tree	7
Hyparrhenia rufa	Poaceae	Grass	7
Kalanchoe pinnata	Crassulaceae	Herb	7
Momordica charantia	Cucurbitaceae	Herb	7
Oeceoclades maculata	Orchidaceae	Orchid	7
Pennisetum polystachion	Poaceae	Grass	7
Pistia stratiotes	Araceae	Palm	7
Portulaca oleracea	Portulacaceae	Shrub	7
Ulex europaeus	Fabaceae	Shrub	7

Data from GRIIS for Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Uruguay, and Venezuela

out *Salix* in the steppe biome (the largest biome in Patagonia). This invasion modifies hydrology and threatens the native *Salix humboldtiana*, as only a few populations still remain in the region. The non-native species *Salix* is threatening *S. humboldtiana* both by occupying the area where the native *Salix* grows and by hybridizing, which can have irreversible impacts (Datri et al. 2017).

Pinaceae has been introduced in the region for forestry purposes, and some of them are currently highly invasive in both open areas (steppe) and in forests. Pinaceae invasion in native forest (like *Pseudotsuga menziesii* in Nothofagus forests) presents a unique challenge since pines can replace the native vegetation in the forest, and they can also change the structure of the native vegetation in the areas they colonize (Paritsis et al. 2018). In the steppe, other pine species invade, mainly *Pinus contorta*, and these have been shown to reduce native biodiversity and increase risks of fires, cause threats to human well-beings and forestry plantations, and, in turn, promote further pine invasions (Taylor et al. 2016; Taylor et al. 2017).

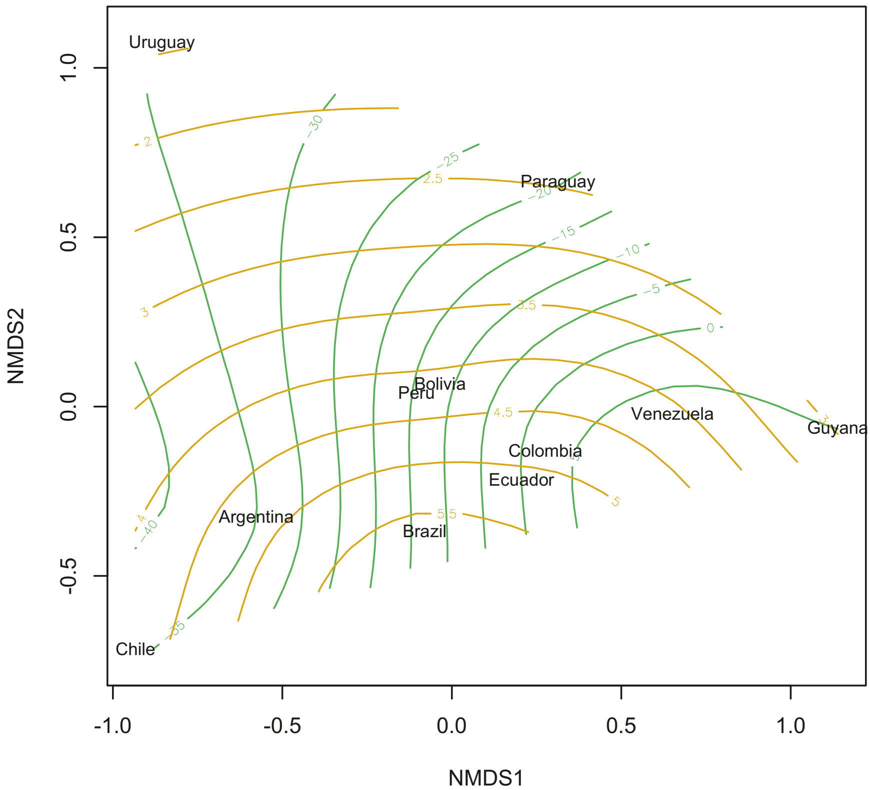

Fig. 9.3 NMDS (non-metric multidimensional scaling) of the naturalized flora of South American countries ($k = 3$, stress= 0.03). Green lines are latitude isoclines, and brown lines are number of bioclimates isoclines. Latitude explains most of the variation in the first axis (NMDS1), whereas number of bioclimates (environmental heterogeneity) explains most of the variation in the second axis (MNDS2)

9.4.2 Brazil

Invasive trees can have pervasive negative impacts on different tropical and subtropical ecosystems in Brazil (de Abreu and Rodrigues 2010; de Sa Dechoum et al. 2015b; Lazzarin et al. 2015; Bergallo et al. 2016). Those impacts are better documented for the Atlantic Rainforest and for the Seasonal Deciduous Forest in South and Southeastern Brazil. Although it is common to associate the impacts of invasive trees to treeless ecosystems such as grassland and coastal scrub, most papers about the impacts of invasive trees in Brazil have reported negative impacts on the structure and dynamics of forest ecosystems. Invasive non-native trees can change abiotic conditions and regeneration patterns of invaded ecosystems. They may also change species abundance, richness, and composition and the structure of different vegetation types in Brazil (e.g., de Sa Dechoum et al. 2015a; de Sa Dechoum et al. 2015b; de Abreu and Durigan 2011).

The environmental impacts more often associated with biological invasions by herbs and grasses refer to dominance and displacement of indigenous species, as well as direct impacts on ecosystems (Pivello et al. 1999; Gorgone-Barbosa et al. 2015; Zenni et al. 2019). Allelopathy by invasive herbs prevents germination by other species, facilitating dominance (Gorgone-Barbosa et al. 2008; Mello and Oliveira 2016), while some species, especially grasses, alter natural fire regimes (Rossi et al. 2014; Gorgone-Barbosa et al. 2015) in fire-prone savannas and grasslands. Tall grasses such as *Arundo donax* generate structural habitat changes that affect and displace native animals (Simões et al. 2013). The impacts of

Table 9.2 Most prominent non-native plant invaders in South American ecosystems and the list of studies on ecology and impacts of these species

Country	Species	Region where invasive in the country	Biomes	References on impacts
Argentina	*Acacia longifolia*	East-central		Stellatelli et al. (2013)
Argentina	*Pinus contorta*	West-central	Temperate grasslands/ steppe; alpine habitats, temperate forests	Urrutia et al. (2013), Taylor et al. (2016), and Franzese et al. (2017)
Argentina	*Salix fragilis – Salix alba hybrid complex*	West-central	Temperate grasslands/ steppe; alpine, temperate forests	Datri et al. (2017)
Brazil	*Acacia mangium*	North; Southeast	Savanna; Atlantic rainforest	Aguiar et al. (2013) and Heringer et al. (2019)
Brazil	*Artocarpus heterophyllus*	Southeast; Northeast; South	Atlantic rainforest	Boni et al. (2009), de Abreu and Rodrigues (2010), Oliveira et al. (2011), Fabricante et al. (2012), Mileri et al. (2012), Fabricante (2014), Bergallo et al. (2016), Freitas et al. (2017), and de Oliveira (2018)
Brazil	*Arundo donax*	Central	Cerrado	
Brazil	*Azadirachta indica*	Northeast	Caatinga	
Brazil	*Casuarina equisetifolia*	South	Atlantic rainforest – coastal areas	
Brazil	*Elaeis guineensis*	Northeast	Atlantic rainforest	
Brazil	*Eragrostis plana*	South; Southeast	Pampa	Barbosa et al. (2012)
Brazil	*Furcraea foetida*	Northeast; Southeast; South	Atlantic rainforest – coastal areas	Barbosa et al. (2017a, 2017b)
Brazil	*Hedychium coronarium*	South; Southeast	Atlantic rainforest; Cerrado	de Castro et al. (2016)
Brazil	*Hovenia dulcis*	South	Atlantic rainforest	Dechoum et al. (2015a) and Lazzarin et al. (2015)
Brazil	*Leucaena leucocephala*	Southeast	Atlantic rainforest	Marques et al. (2014) and Mello and Oliveira (2016)
Brazil	*Ligustrum lucidum*	South	Atlantic rainforest	Hummel et al. (2014)
Brazil	*Megathyrsus maximus*	South	Atlantic rainforest; Cerrado	Mantoani et al. (2012)
Brazil	*Melia azedarach*	South	Atlantic rainforest	
Brazil	*Melinis minutiflora*	South, Central	Atlantic rainforest; Cerrado	Klink (1994), Hoffmann and Haridasan (2008), Martins et al. (2011), Lannes et al. (2012), de Mello et al. (2014), Rossi et al. (2014), Damasceno et al. (2018) and Zenni et al. (2019)
Brazil	*Pinus elliottii*	South; Southeast	Cerrado; Atlantic rainforest; pampa	de Abreu and Durigan (2011), Zenni and Simberloff (2013), and Bechara et al. (2013)
Brazil	*Pinus taeda*	South; Southeast	Atlantic rainforest; Pampa	Falleiros et al. (2011) and Zenni and Simberloff (2013)
Brazil	*Prosopis juliflora*	Northeast	Caatinga	
Brazil	*Prosopis pallida*	Northeast	Caatinga	
Brazil	*Tecoma stans*	South	Atlantic rainforest	
Brazil	*Terminalia catappa*	Southeast; South	Atlantic rainforest	

(continued)

Table 9.2 (continued)

Country	Species	Region where invasive in the country	Biomes	References on impacts
Brazil	*Tradescantia zebrina*	Southeast; South	Atlantic rainforest	
Brazil	*Ulex europaeus*	South	Pampa; Southern grasslands in Atlantic rainforest	
Brazil	*Urochloa decumbens*	South; Southeast; Central; North	Cerrado; Atlantic rainforest; Amazon Forest	Gorgone-Barbosa et al. (2008) and Lannes et al. (2012)
Brazil	*Urochloa brizantha*	Southeast; Central; Northeast; North	Cerrado; Atlantic Rainforest; Amazon Forest	Gorgone-Barbosa et al. (2015) and Damasceno et al. (2018)
Chile	*Pinus contorta*	South-central	Temperate grasslands/steppe; alpine habitats, temperate forests	Urrutia et al. (2013), Taylor et al. (2016), and Franzese et al. (2017)
Chile	*Acacia dealbata*	South-central	Temperate and Mediterranean forests	Fuentes-Ramírez et al. (2010), Fuentes-Ramírez et al. (2011) and Aguilera et al. (2015)
Chile	*Teline monspessulana*	South-central	Temperate and Mediterranean forests	García et al. (2007), Pauchard et al. (2008), and García et al. (2015)
Chile	*Ulex europaeus*	South-central	Temperate and Mediterranean forests	Altamirano et al. (2016)
Ecuador	*Roystonea oleracea*	Southwestern	Flooded grasslands and savannas	Herrera et al. (2017)
Ecuador	*Pinus patula*	Southern	Tropical and subtropical moist broadleaf forests	Aguirre et al. (2006), Chacón et al. (2009a), Narváez Riofrío (2015), Quichimbo et al. (2017), and Castillo et al. (2018), and Quiroz Dahik et al. (2018)
Ecuador	*Cinchona pubescens*	Galapagos	Deserts and xeric Shrublands	Jäger et al. (2007) and Jäger et al. (2013)
Ecuador	*Rubus niveus*	Galapagos	Deserts and xeric shrublands	Rentería et al. (2012)
Ecuador	*Setaria sphacelata*	South	Tropical and subtropical moist broadleaf forests	Günter et al. (2009), Palomeque et al. (2017), and Castillo et al. (2018)
Ecuador	*Eucalyptus saligna*	South	Tropical and subtropical moist broadleaf forests	Narváez Riofrío (2015) and Castillo et al. (2018)
Ecuador	*Pinus radiata*	South	Montane grasslands and shrublands	Middendorp et al. (2016)
Ecuador	*Melinis minutiflora*	South	Tropical and subtropical moist broadleaf forests	Palomeque et al. (2017)
Venezuela	*Kalanchoe x houghtonii (Kalanchoe daigremontiana)*	Northwestern; Margarita Island	Tropical and subtropical dry broadleaf; deserts and xeric shrublands	Chacón et al. (2009b), Herrera and Nassar (2009), Herrera et al. (2012), Herrera et al. (2016), and Herrera et al. (2018)
Venezuela	*Hyparrhenia rufa*	Central	Tropical and subtropical grasslands, savannas, and shrublands	San Jose and Farinas (1991), Baruch (1996), Bilbao et al. (1996), and Pieters and Baruch (1997)

(continued)

Table 9.2 (continued)

Country	Species	Region where invasive in the country	Biomes	References on impacts
Venezuela	*Pinus caribaea*	North central	Tropical and subtropical moist broadleaf forests Tropical and subtropical grasslands, savannas, and shrublands	Fassbender et al. (1979), Suarez et al. (2000), Gómez et al. (2008), Hernández-Hernández et al. (2008), Hernández Gil et al. (2009), Bueno and Baruch (2011), Aguilera et al. (2015), Baruch et al. (2016), Baruch et al. (2019)
Venezuela	*Melinis minutiflora*	Northwestern	Tropical and subtropical moist broadleaf forests	Bilbao and Medina (1990), Baruch (1996), Barger et al. (2003), and Ataroff and Naranjo (2009)
Venezuela	*Pennisetum clandestinum*	Northwestern	Tropical and subtropical moist broadleaf forests	Ataroff and Naranjo (2009)
Venezuela	*Azadirachta indica*	Northwestern	Tropical and subtropical dry broadleaf forests	Vera et al. (2007) and Villarreal et al. (2010)
Venezuela	*Leucaena leucocephala*	Northwestern	Tropical and subtropical dry broadleaf forests	Razz and Clavero (2006)
Venezuela	*Calotropis procera*	Northwestern; Margarita Island	Tropical and subtropical dry broadleaf forests; deserts and xeric shrublands	Johnston (1908) and Tezara et al. (2011)
Venezuela	*Ricinus communis*	Northwestern	Tropical and subtropical dry broadleaf forests; deserts and xeric Shrublands	Alfonso (2003) and Villarreal et al. (2010)
Venezuela	*Poa annua*	Southeast	Tropical and subtropical grasslands, savannas, and shrublands	Chitty and Nozawa (2010)
Venezuela	*Polypogon elongatus*	Southeast	Tropical and subtropical grasslands, savannas, and shrublands	Chitty and Nozawa (2010)
Venezuela	*Rumex acetosella*	Northwestern	Montane grasslands and shrublands	Llambí et al. (2018)

greater concern directly affect ecosystem functioning, including significant changes in the nutrient pool and flux, changes in habitat, and disturbance regimes (Barbosa et al. 2010; Rossi et al. 2014; Gorgone-Barbosa et al. 2015; de Castro et al. 2016; Damasceno et al. 2018; Zenni et al. 2019). Invasion by grasses and herbs generates economic impacts due to the costs of intensive control in agricultural areas as well as, for example, along roads, especially privatized toll roads, and environmental restoration projects.

Currently in Brazil, two of the most prominent invasive non-native conifers are *Pinus taeda* and *Pinus elliottii* (Simberloff et al. 2010; Zenni and Ziller 2011). The aspects related to the success of biological invasions of these two *Pinus* species are seed dispersal by wind, intensive cultivation, and the capacity to tolerate high levels of anthropogenic disturbance (Falleiros et al. 2011; Valduga et al. 2016). One of the impacts established for *P. elliottii* is the change in growth dynamics of native plants by altering its vegetation coverage (Falleiros et al. 2011). Additionally, it is also known that *P. taeda* and *P. elliottii* can cause changes in composition and functional traits of native vegetation (de Abreu and Durigan 2011).

9.4.3 Ecuador

The state of knowledge of plant invasions in Ecuador contrasts significantly between the continent and the insular region, represented by the Galapagos Islands. Most of the scientific articles on biological invasions in Ecuador are on the Galapagos; very few studies have assessed invasion status of exotic species in mainland Ecuador. There is no complete official list of exotic plant species for Ecuador yet. A preliminary version of this list suggests that there are 677 introduced plant species in mainland Ecuador. Of these, 13% (88 species) have been reported as invasive in other regions of the world, e.g., *Arundo donax*, *Ulex europaeus*, and *Leucaena leucocephala*. Species of temperate origin such as *Cerastium glomeratum*, *Poa annua*, *Holcus lanatus*, *Trifolium repens*, *Plantago lanceolata*, and *Rumex acetosella* have a wide distribution and occur very frequently in mainland Ecuador (Sandoya et al. 2017). However, the impacts of these invasive species on the structure and functions of ecosystem are still unknown.

In Montane Forests (also mainland Ecuador), non-native tree species of the genera *Pinus* and *Eucalyptus* are the most frequent species used in reforestation programs. Previous studies have suggested that these forestry plantations (e.g., *Pinus patula*) could affect the fertility of the soil, by reducing the cation exchange capacity (Chacón et al. 2009a), and have negative effects on the hydrological balance and biodiversity. In Dry Broadleaf Forests, located in the coastal region, *L. leucocephala* and *Urochloa maxima* can be observed naturalized along highways and roads; but there are no studies that formally assess the status of these species. At Santay Island, a Ramsar wetland and a national protected area in this region (Flooded Grasslands and Savannas), the invasion by an ornamental palm species (*Roystonea oleracea*) native from Caribbean was reported (Herrera et al. 2017), but the impact of this invasion is unknown.

In the Ecuadorian Amazon, the state of plant invasions is almost completely unknown. There have been reports in Napo province (Tropical Lowland Humid Forest) that, along streams, naturalized populations of *Hedychium coronarium* and *Pennisetum purpureum* can be observed, but there are no publications on this. In the Biosphere reserve of Podocarpus (Tropical Montane Humid Forest) in Zamora Chinchipe province (southern Ecuador), eight non-native species of trees and herbs have been reported to have been introduced for agricultural purposes, but the abundance and the potential impacts of these introductions are unknown (Schüttler and Karez 2008).

Contrary to mainland Ecuador, the Galapagos Islands have a detailed and permanently updated inventory of non-native plant species and their current status. In the Islands, 881 non-native plant species have been recorded (Jaramillo Díaz et al. 2018). Guézou et al. (2010) reported at least 264 naturalized plant species in Galapagos. Biological invasions are considered the most serious threat to the biodiversity of Galapagos, where the non-native taxa now outnumber the native ones.

9.4.4 Venezuela

The first and only official list of exotic species in Venezuela was published in 2001 by the Ministry of Environment (Ojasti et al. 2001). The report listed 985 non-native plant species, of which 165 (~17%) were considered naturalized. From these, 49 plant species had been reported to have invasive status in Venezuela (5% of all non-native species and 30% of the naturalized species). The data is well aligned with the GRIIS data shown above. A revision of the list provided by Ojasti et al. (2001) shows that the region with the highest number of invasive plants is the Venezuelan Llanos (15 species), followed by Venezuelan Andes (14 species). The revision also suggested that there are at least 1,305 non-native plant species in Venezuela (Herrera, I. et al. unpublished data), but there are currently only 20 scientific publications regarding the presence of non-native plant species in the country.

The invasive species reported as having definite impacts on Venezuelan ecosystems were *Eucalyptus robusta*, *Hyparrhenia rufa*, *Kalanchoe x houghtonii*, *Melinis minutiflora*, *Pinus caribaea*, *Stapelia gigantea*, and *Rumex acetosella*. In the Biome Deserts and Xeric Shrublands, the hybrid *Kalanchoe x houghtonii* forms dense patches with several populations in the western part of the country and Margarita Island. This species can inhibit the recruitment rates of native plants (Herrera et al. 2016) and can also modify the nitrogen and carbon cycles in the soil (Herrera et al. 2018). Despite the negative impacts caused by *Kalanchoe x houghtonii* in the continent, the consequences of this invasion in Margarita Island are still unknown.

In the Dry Broadleaf Forests, including Margarita Island Dry Forests, the invasive species with the widest distribution is *Leucaena leucocephala*. Despite its record as a noxious invasive plant in several parts of the world, studies in Venezuela are focused on improving its production and propagation as an alternative forage for cattle (e.g., Sánchez-Paz and Ramírez-Villalobos 2006; Medina et al. 2007). In the Savannas and deforested Moist Broadleaf Forests in mid-elevation areas over 600 m a.s.l., located in the Coast and Andean Cordillera, the African grass *M. minutiflora* generates monospecific patches after any disturbance (e.g., fire, overgrazing), which limits the regeneration of native vegetation (Barger et al. 2003). In Los Llanos, lowland savannas, another African grass, *H. rufa*, is the dominant invasive species and replaces the native grass *Trachypogon* spp. Baruch (1996) suggested that anthropogenic fire regime was the main facilitator for the establishment of this species. Once established, *H. rufa* replaces native savannas by modifying the microclimate, decreasing the availability of nutrients, and increasing the intensity and frequency of fire cycles. In Alpine ecosystems of the Venezuelan Andes, *Rumex acetosella* invades a broad altitudinal range from 2800 to 4300 m (I. Herrera, unpublished data). In this ecosystem, *R. acetosella* can be a dominant species, reaching up to 45% of the total plant density (Llambí et al. 2018). High densities of *R. acetosella* can have a negative effect on abundance and richness of native plant species (Llambí et al. 2018).

9.5 Existing Legislation to Manage Invasive Plants and Invasion Processes

All countries mentioned in this review have legislations in place to manage biological invasions (Table 9.3). The legislation ranges from international conventions (e.g., Convention on Biological Diversity), National Constitutions (e.g., right of the people to a sustainable and clean environment), laws (e.g., prohibition of non-native species in strictly protected areas), and action plans (e.g., Brazilian national plan for *Sus scrofa*). Several countries (e.g., Brazil, Argentina) also have official national strategies for invasive non-native species (Table 9.3).

Some countries and territories also have official lists of invasive species. The southern states of Brazil (Rio Grande do Sul, Santa Catarina, and Paraná) have official lists of invasive species. Venezuela also has an official list (Ojasti et al. 2001). For Ecuador, only the Galapagos Islands has such a list, and a complete analysis of the biological invasions in the archipelago was recently published (de Lourdes Torres and Mena 2018). Additionally, the Galapagos Islands has a special administrative regime with institutions in charge of the prevention, monitoring, and control of non-native species as the Galapagos Agency for Biosecurity (ABG) and research institutions such as the Charles Darwin Foundation (CDF) or the Galapagos National Park.

In continental Ecuador, the Ministry of Environment with the support of other state institutions is responsible for the regulation and management of non-native species in the country, and they have developed several legal instruments in recent years. However, the risk assessments have not been put in practice, illustrating the lack of articulation between the laws and the practical application of the monitoring and management of introduced species. As mentioned before, this has led to a lack of completeness of information and uncertainty of the role of invasive plant species in Ecuador.

The legal framework for invasive non-native species in Venezuela is based on article 127 of the Constitution, which states that it is a right and

Table 9.3 Existing legislation related to plant invasions in South America

Country	Type	Government body	Number	Year of publication	Short description
Argentina	Constitution	Federal		1994	National Constitution
Argentina	Law	Federal	22415	1981	Customs law
Argentina	Law	Federal	22351	1981	National Parks legislation
Argentina	Law	Federal	24375	1994	Convention on Biological Diversity
Argentina	Law	Federal	27346	2015	Nagoya Protocol
Argentina	Law	Federal	26331	2007	Creates the "Unidad de Coordinación del Programa MAB" (UCPMAB), El hombre y la Biósfera Program
Argentina	Law	Federal	26815	2012	Federal system of fire management
Argentina	Law	Federal	25675	2002	Environmental Protection Law
Argentina	Resolution	Federal	460/1999 SAyDS	1999	Aprueba el "Programa Nacional de Gestión de la Flora"
Argentina	Resolution	Federal	1766/2007 SAyDS	2007	Regulates importation and exportation of wildlife
Argentina	Decree	Federal	234/12 COFEMA	2012	Management and control of *Didymosphenia geminata* and *Undaria pinnatífida*
Brazil	Decree	Federal	148	2010	Approves the text of the International Convention for the Control and Management of Ships' Ballast Water and Sediments
Brazil	Decree	Federal	6514	2008	Establishes sanctions and punitive measures for environmental issues
Brazil	Decree	Federal	4340	2002	Regulates the National Protected Area System
Brazil	Decree	Federal	2	1994	Approves the text of the International Convention on Biodiversity
Brazil	Normative Instruction	Federal	23	2014	Provides guidelines for the destination of wild animals that are apprehended, rescued by authorities, or handed in by the general public, including non-native species
Brazil	Normative Instruction	Federal	3	2013	Acknowledges wild boar as a harmful invasive species and provides guidelines for control
Brazil	Normative Instruction	Federal	141	2006	Regulates the management of synanthropic harmful animals, including invasive non-native species
Brazil	Normative Instruction	Federal	73	2005	Prohibits sales or breeding of giant African snails *Achatina fulica* in Brazil
Brazil	Law	Federal	9985	2000	Establishes the National Protected Area System, including a prohibition for the introduction of non-native species in protected areas
Brazil	Law	Federal	9605	1998	Defines actions as crimes against the environment, including the introduction of species without permits from the Federal Environmental Agency and the spread of non-native species
Brazil	Ordinance	Federal	58	2019	Approves the Action Plan for the control of cats (*Felis catus*) in the Fernando de Noronha – Rocas – São Pedro and São Paulo Environmental Protection Area and in the Fernando de Noronha National Park

(continued)

Table 9.3 (continued)

Country	Type	Government body	Number	Year of publication	Short description
Brazil	Ordinance	Federal	3639	2018	Approves the National Plan for the prevention, control, and monitoring of golden mussels (*Limnoperna fortunei*) in Brazil
Brazil	Ordinance	Federal	3642	2018	Approves the National Plan for the prevention, control, and monitoring of sun corals (*Tubastraea coccinea* and *T. tagusensis*) in Brazil
Brazil	Ordinance	Federal	3	2018	Approves the National Strategy on invasive non-native species
Brazil	Ordinance	Federal	4	2018	Institutes the Technical Advisory Group to oversee the implementation of the National Strategy on invasive non-native species
Brazil	Ordinance	Federal	232	2017	Approves the National Plan for the prevention, control, and monitoring of wild boars (*Sus scrofa*) in Brazil
Brazil	Ordinance	Federal	145	1998	Defines rules for the introduction, reintroduction, and transfer of fishes, crustaceans, mollusks, and aquatic macrophytes for aquaculture, excluding ornamental animals
Brazil	Ordinance	Federal	142	1994	Prohibits the introduction, transfer, cultivation, and sale of African catfish (*Clarias gariepinus*) and channel catfish (*Ictalurus punctatus*) in the Amazon and Paraguay river basins
Brazil	Resolution	Federal	7	2018	Instates the National Strategy on invasive non-native species (2nd edition), cancelling the former version
Brazil	Resolution	Federal	429	2011	Provides guidelines for the restoration of permanent preservation areas, acknowledging the benefits of invasive non-native species control
Brazil	Ordinance	State	14	2018	Establishes a State Program for the control of invasive non-native species
Brazil	Ordinance	State	59	2015	Publishes the official list of invasive non-native species for Parana state
Brazil	Ordinance	State	84	2015	Establishes a Technical Committee to review and formalize the State Program for invasive non-native species and deliver legal regulations
Brazil	Ordinance	State	79	2013	Publishes the official list of invasive non-native species for Rio Grande do Sul state
Brazil	Ordinance	State	19	2009	Establishes a State Committee for invasive non-native species
Brazil	Ordinance	State	192	2005	Regulates the control of invasive non-native species in protected areas managed by the state authority
Brazil	Resolution	State	8	2012	Publishes the official list of invasive non-native species for Santa Catarina state
Brazil	Resolution	State	151	1997	Prohibits yellow bells (*Tecoma stans*) as a noxious weed in the state

(continued)

Table 9.3 (continued)

Country	Type	Government body	Number	Year of publication	Short description
Chile	Law	Federal	19300	1994	Environmental protection law
Chile	Decree	Federal	90	1999	Regulates the importation of forestry products
Chile	Decree	Federal	53	2007	Accession to the World Organization for Animal Health and the International Plant Protection Convention of the United Nations Organization for Agriculture and Food
Chile	Resolution	Federal	1551	1998	Regulates transit of plant material
Chile	Law	Federal	Criminal law	1874	Criminal law (art. 291)
Chile	Law	Federal	20283	2008	Protection of native forests
Chile	Law	Federal	3557	1981	Prevention, control, and management of cattle diseases
Ecuador	Constitution	Federal		2008	Federal Constitution
Ecuador	Law	Federal	983	2017	Organic Code of the Environment (COA)
Ecuador	Protocol-Normative	Continental Ecuador	AM-007-2019	2019	The Ten-Year Action Plan for the prevention, management, and control of exotic species in continental Ecuador
Ecuador-Galápagos	Regulation	Galapagos	3,516	2003	Regulation of total control of species introduced of the Province of Galapagos
Ecuador-Galápagos	Decree	Galapagos	1.319	2012	Creates the Agency for Regulation and Control of Biosecurity and Quarantine for Galapagos (ABG)
Ecuador-Galápagos	Law	Galapagos	67	1998	Law of the special regime for conservation and sustainable development of the Province of Galapagos
Venezuela	Constitution	Constitution		1999	National Constitution
Venezuela	Law	Federal	5468	2000	Law of biological diversity
Venezuela	Law	Federal	39070	2008	Law of the management of biological diversity
Venezuela	Law	Federal (Orgánica)	39913	2011	Criminal Law of the Environment (Amendment of the Law of Biological Diversity)
Venezuela	Law	Federal	38946	05/06/2008	Law on Forestry and Forest Management
Venezuela	Law		40222	06/08/13	Forest Law

duty to protect the environment. The most specific regulation is the Law of management of biological diversity (year: 2008; Number: 39070), which has a chapter on the management of non-native species (Chapter IV. Articles from 75 to 81). In this chapter, the responsibilities of who controls the introduction, prioritizes, and manages non-native species at a national level are described. Environmental Criminal Law also states economic sanctions to prison terms for environmental crimes caused by the introduction of non-native species. In 2006, the National Strategy for the Conservation of Biological Diversity was published, which includes seven strategic lines, among which the strategic line number 5 is related to non-native species: "Prevention, control and eradication of exotic species." In this strategic line, the steps for the successful management of invasive species are indicated, but methodological details to complete each step are not described.

Argentina and Chile have a more limited legal framework to tackle biological invasions compared to the other South American countries. For the most part, regulations on biological invasions in Argentina and Chile are embedded within general environmental laws and commercial regulations (Bustos and Jacksic 2017). There is no legislation in place specifically designed to deal with biological invasions (Table 9.3). Coincidentally, these two countries also have the greatest number of non-native naturalized plant species.

9.6 Conclusions

There are thousands of naturalized invasive plants, of which, hundreds of species would qualify as being in the invasive non-native plant category in South America. Patterns of plant invasion in the continent seem to be related to habitat heterogeneity and land degradation. Also, there are legislations in place to manage invasive species (e.g., prevention, control, or eradication). However, there are immense knowledge gaps on the impacts of invasive plants. For some prominent invaders in the continent, both in terms of actual distribution and expert perception, we were unable to find a single study on their impacts in South American ecosystems or development and evaluation of management strategies. Research on biological invasions has increased in the continent over the last two decades, as well as legislation and management efforts (Zenni et al. 2016; de Andrade Frehse et al. 2016; Zenni et al. 2017; de Sa Dechoum et al. 2018), but there is clearly a long road ahead to achieve the level of knowledge and action required to reduce and mitigate impacts of biological invasions in the continent. Furthermore, the continent lacks bilateral or multilateral agreements to prevent the spread of invasive species between South American countries. Each country has been dealing with biological invasions on its own, and there is a need for greater integration across the continent.

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