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The distribution of the invasive *Acacia longifolia* shows an expansion towards southern latitudes in South America

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Abstract

Contemporary climate change, in particular higher temperatures, may greatly enhance the expansion of invasive species. *Acacia longifolia* (Fabaceae, subgenus *Phyllodineae*) is a native species of Southeast Australia and Tasmania, invasive in South Africa, Mediterranean Europe and South America. According to several records, this species has been introduced in Southern Brazil and Uruguay for fixation of dunes and for ornamental purposes in the mid-20th century and has since then caused several environmental and socio-economic problems. However, its current distribution in these south American countries is undocumented, as well as the types of habitats it has invaded since its introduction. In this context, during May 2019 we performed a study through a latitudinal and climatic gradient along the coast, from southern Brazil (Santa Catarina and Rio Grande do Sul states) to Uruguay, to evaluate the presence of *A. longifolia* taking into consideration previous records of this species. Our observations showed an increase in tree density along the coast, from Brazil to Uruguay, with a clear distribution southward. It was not possible to confirm earlier observations of this species in southern Brazil (with the exception of Florianópolis), which may be associated with changes in temperature and precipitation in this region.

Key words: invasive species, wattles, thermal barrier, climate change, tree density

Introduction

Australian *Acacia* species from the subgenus *Phyllodineae* (Fabaceae) are invaders in many countries of different continents (Richardson et al. 2011). In South America, *Acacia longifolia* (Andrews) Willd. and *Acacia mangium* Willd. are widespread invaders mainly along the Atlantic coast in areas disturbed by human activities. The former invades the southern Brazil, Uruguay and Argentina and the latter invades the tropical and equatorial coasts of Brazil and French Guiana (Zenni and Ziller 2011; Aguiar Jr et al. 2014; Celsi 2016; Lehmann et al. 2017; Meira-Neto et al. 2018; Heringer et al. 2019a, b). The distributions of these *Acacia* species are the result of different ecological, biogeographic and human induced factors that determine their invasive potential (Richardson and Rejmánek 2011; Richardson and

Pyšek 2012). In a fast-changing world, biogeographic shifting and changed human influence may alter niches and biome distributions of invasive plant species (Drenovsky et al. 2012; Bita and Gerats 2013; Donoghue and Edwards 2014).

During the 21st century, from 2016 to 2100, an increasing mean temperature of 0.5 to 2 °C and an increasing mean precipitation of 10% to 20% are forecasted for the coast from Florianópolis to Cabo Polonio in the southern Brazil and eastern Uruguay (i.e. the coast of the Rocha province). Accordingly, an increased mean temperature has been already observed from the last decades of the 20th century in that coast (IPCC 2013). As a consequence, we may observe an increased risk of biological invasions in areas where temperature has been a thermal barrier for invasions and where habitats may become more or less suitable for alien species as climate changes (Hellmann et al. 2008; Bellard et al. 2013).

Acacia longifolia was first introduced along the coast of South America during the mid-20th century for dune fixation in Florianópolis (Santa Catarina state) in Brazil, in the Cabo Polonio region in Uruguay, and in the Buenos Aires region in Argentina (Zenni and Ziller 2011; Celsi 2016). Since then, many herbaria and literature records registered its distribution from Brazilian State of Santa Catarina to Uruguay (e.g. Base de dados de espécies exóticas invasoras do Brasil, http://bd.institutohorus.org.br/www/; Tropicos.org, http://www.tropicos.org/Name/13024183; Boelcke 1946). However, the increase in temperature brought by climate change might have altered the thermal barrier of *A. longifolia* and, therefore, affected its distribution (Hellmann et al. 2008; Bellard et al. 2013).

Recently, the need to update the distribution and genetic information has led our team to check the recorded sites in order to find and collect biological material as well as ecological information on disturbances of *A. longifolia* habitats in South America. In this study we aimed to gather information about the presence and preference of coastal habitats by *A. longifolia*, along a latitudinal gradient from southern Brazil to Uruguay between two sites of introduction (i.e., Florianópolis and Cabo Polonio) to better understand its expansion and distribution.

Materials and methods

Study sites along a latitudinal gradient

Observations of *Acacia longifolia* were made on a latitudinal gradient along the coast from southern Brazil to Uruguay. In May 2019, we searched the sites with *A. longifolia* collections during the past decades, most of them recorded during the 20th century according to the description of Zenni and Ziller (2011) and Celsi (2016). In Brazil, *A. longifolia* was firstly recorded outside the sites of introduction in the state of Santa Catarina (SC) in 1979 (Burkart 1979), and since then observations of this species have been recorded

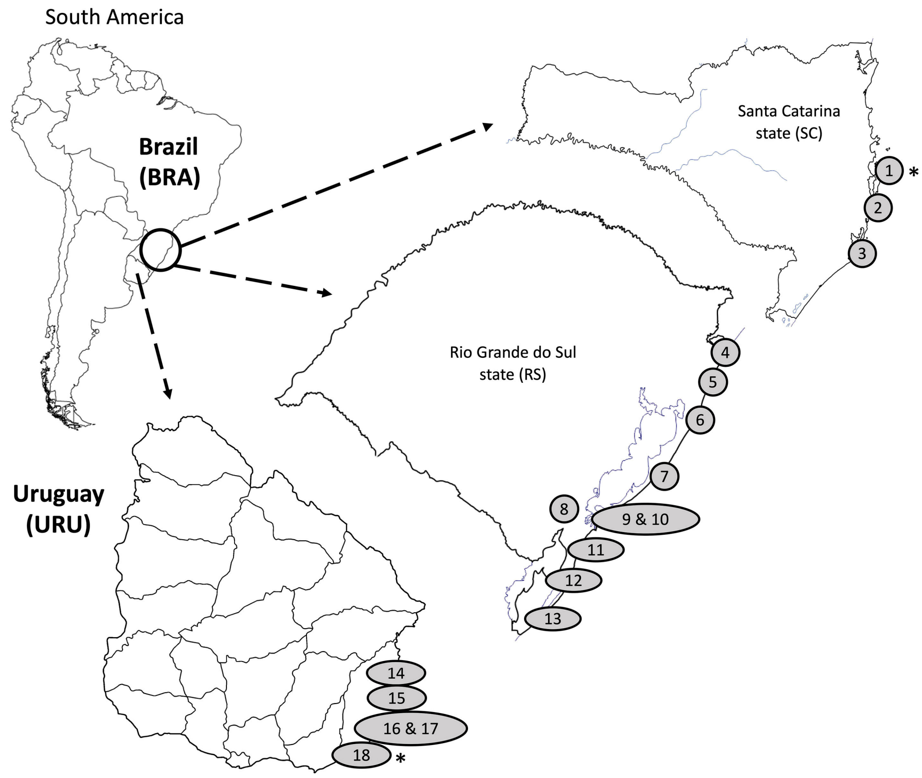

Figure 1. Map of the visited locations. Corresponding location for each number and further details can be found in Table S1. * Sites where *A. longifolia* was planted for dunes fixation. SC – Santa Catarina state. RS – Rio Grande do Sul state.

in online databases (Base de dados de espécies exóticas invasoras do Brasil, http://bd.institutohorus.org.br/www/; Tropicos.org, http://www.tropicos.org/Name/13024183) in other locations, including the state of Rio Grande do Sul (RS), which is located southwards of SC, bordering Uruguay. In Uruguay, this species was first recorded in 1946 (Boelcke 1946). We went along the coast from Florianópolis (SC) in Brazil to the southern region of Cabo Polonio in Uruguay gathering data to update the pattern of *A. longifolia*'s invasion in South America (see Figure 1 and Supplementary material Table S1). In this region, the climate gradient varies from sub-tropical (from SC to the south of RS) to temperate (south of RS and Uruguay). The annual mean temperatures between 1989 and 2019 for each location are registered in Table S1 (data from INMET, http://www.inmet.gov.br/).

Habitat characterization and vegetation observations

We classified the habitats at each site as: "Dunes", when acacias were located in secondary dunes near the beach; "Residential area", when acacias were located in areas near houses; "Roadside", when acacias were located close to roads; and "Plantation", when acacias were located inside *Eucalyptus* plantations. To better characterize the sampled locations, we registered the type of original vegetation as "Restinga" (sub-tropical coastal dunes), "Pampas" (sub-tropical/temperate grasslands) and "Temperate coastal dunes". Restinga is the local name of the tropical and sub-tropical vegetation on coastal dunes in Brazil that stretches along the coast mostly with floristic influence of neighboring forests (Oliveira et al. 2014; see Figure 1, sites 1–6). The coastal dunes located southwards between the second largest lagoon of South America, the Patos Lagoon, and the Atlantic Ocean were also classified as Restinga because of the physiognomic similarity with tropical and sub-tropical Restingas up to the Rio Grande municipality (Figure 1, sites 9–11). Inwards and southwards, out of the coastal dunes, the original vegetation was Pampas, a sub-tropical/temperate grassland widely used as natural pastures or changed into crop fields (Andrade et al. 2019; see Figure 1, sites 7, 8, 12–14 and 16–18). The southernmost sampled dunes were the temperate coastal dunes (Castiñeira Latorre et al. 2013), near and southwards of the border between Brazil and Uruguay up to Cabo Polonio (Figure 1, site 15).

Based on our field observations, photographic records and images of the sampled locations from Google Earth, we also noted if acacias were: (0) not observed, with an estimation of mean density of acacia trees of 0.1 individual per hectare (assuming that they were not missing, but with very low density); (1) ungrouped, with an estimation of mean density of acacia trees of 1 individual per hectare; (2) grouped, with an estimation of mean density of acacia trees of 10 individuals per hectare; or (3) strongly grouped, with an estimation of mean density of acacia trees of 100 individuals per hectare. At each sampling sites, we took two measures of the diameter of the canopy (for the estimation of the mean canopy cover area as a circle) and a measure of the height of each sampled acacia. We took two perpendicular measures of the diameter of the canopy at breast height, using a measuring tape. Height was measured using a measuring tape when plants were small enough, otherwise a visual estimation mas made. When acacias were grouped, we measured individual plants and not the group as a whole. Also, we registered the coordinates of every sampled individual using a GPS.

Statistical analysis

To check for the effects of latitude and mean temperature between 1989 and 2019 on the logarithm of tree density (estimated from the grouping classification, as explained above) we used a generalized linear model (GLM) with a Gaussian distribution in R (R Core Team 2016) using the "glm" function of Lme4 package and selecting models using the "dredge" function of MuMin package (Bates et al. 2014; Bartón 2018). The Moçambique Beach and Cabo Polonio sites were excluded from the model, since these were the places where the acacia plantation occurred.

Results and discussion

Very few studies on invasive species undertake latitudinal and climatic gradients in South America, despite the fact that these studies would be of

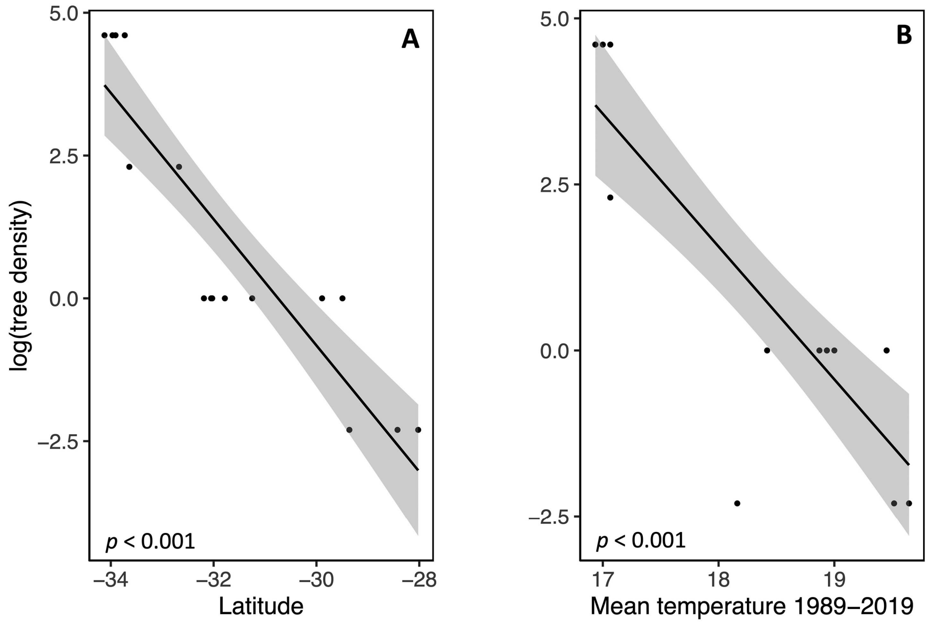

Figure 2. Correlations between (A) latitude and tree density, and (B) mean temperature and tree density, obtained from generalized linear models.

great importance to predict consequences of climate change. In this study, we searched for the presence of *A. longifolia* from Florianópolis in Southern Brazil to Cabo Polonio in Uruguay, an alien plant that is a recent invader in this region when compared with other locations where *A. longifolia* is invasive since a long time (e.g. South Africa and Portugal; Kull et al. 2011). We surveyed 18 sites in total (Figure 1, Table S1), with 8 of them located on dunes, 7 on roadsides, one in a residential area, one in an allotment and one in a *Eucalyptus* plantation. Our observations indicate that the distribution of *A. longifolia* has a tendency of persisting towards the south, as sites located more to the north with previous records of acacias have them in very low density or no longer have them (e.g. Gi Beach, Guarita Beach). The only exception is Moçambique Beach, the northmost site we visited, where acacias have been planted for dune fixation and ornamental purposes in the past (Zenni and Ziller 2011; Base de dados de espécies exóticas invasoras do Brasil) and are still present. Also, sites located further south in Brazil, which previously had no records of this species, are now becoming invaded (Rondinha and São José do Norte). The largest canopy cover area was located on the Cassino Beach (215.6 m^2), where the dunes are very extensive and individuals were ungrouped, while the smallest canopy cover area was located in the Fortress of Santa Teresa (6.3 m^2), where individuals where clustered together on the side of the road. This is explained by the grouping of the individuals: separated acacias tend to expand their canopies, while individuals tangled together have a more restricted expansion of the canopy, and this pattern can be generally observed with some exceptions.

Furthermore, we observed an effect of latitude and mean temperature of the sites on tree density (see Figure 2, panels A and B, respectively). Indeed, both variables are equal predictors of tree density (ΔAICc < 2, see Table S2), and their respective individual GLM models are significant (p < 0.001). These results show that tree density increases with decreasing latitude and mean temperature and, together with our observations mentioned above, indicate a shift of the distribution of *A. longifolia* towards the south.

In conclusion, our observations show that there is a correlation between tree density and both latitude and mean temperature for the exotic invasive species *A. longifolia*, which increases towards the south. Considering the present scenario of climatic changes affecting South America, our results indicate that we may expect a decreasing thermal barrier southward from Florianópolis to Cabo Polonio, and a consequent increase in this species expansion towards extreme southern latitudes. The current hypothesis that climate change along the South American coast is moving the thermal barrier of *A. longifolia* invasion southwards should be tested and monitoring of the progression *A. longifolia*'s invasion should be put into place, along with an awareness program to this environmental problem.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Description of the visited sites in Brazil and Uruguay. SC – Santa Catarina state. RS – Rio Grande do Sul state. Restinga – sub-tropical coastal dunes; Pampas – sub-tropical/temperate grasslands.

Table S2. Models ranked by AICc of the GLMs global models. Models with ΔAICc < 2 explain equally the relation of latitude, mean annual temperature between 1989 and 2019 with estimated tree density of *Acacia longifolia*.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_2020_Vicente_etal_SupplementaryMaterial.xlsx