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Rapid Communication

A new invasive species in South America: *Pinus oocarpa* Schiede ex Schldl.Emilia P. Braga^{1,3}, Rafael D. Zenni^{2*} and John D. Hay^{1,4}¹Department of Ecology, The University of Brasilia, Campus Darcy Ribeiro, Asa Norte, Brasilia, DF, 70910-900, Brazil²Department of Ecology & Evolutionary Biology, The University of Tennessee, 569 Dabney Hall, Knoxville, TN, 37996, USAE-mail: rafaeldz@gmail.com (RDZ), bragaep@gmail.com (EPB), jhay@unb.br (JDH)

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Abstract

Conifers have a long history of introductions into many parts of the world and are among the most notorious plant invaders. At least 20 species of the genus *Pinus* are now considered to be invasive in at least one region of the southern hemisphere. Here, we present a quantitative report of invasion by *Pinus oocarpa* in a relatively undisturbed vegetation of the Cerrado region of Brazil. The invasion front of *P. oocarpa* was 458 m distant from the area of introduction, which represents a mean rate of spread of 12.72 m year⁻¹. The average density of invasive plants was 561 ind ha⁻¹, with a maximum density of 1,212 ind ha⁻¹. It is currently unknown if the studied invasive population has produced negative impacts on the invaded ecosystem. However, it would be safe to assume that with the observed densities and rate of spread, *P. oocarpa* could affect the native community that it invaded. An early response targeting the eradication of the invasive population could prevent these ecological costs.

Key words: plant invasion, Cerrado, neotropical savanna, Pinaceae, ocote, hazelnut pine**Introduction**

Conifers have a long history of introductions into many parts of the world and are among the most notorious plant invaders. In particular, at least 60 species in the Pinaceae have naturalization records outside their native ranges and 20 species of the genus *Pinus* are now considered to be invasive in at least one region of the southern hemisphere (Essl et al. 2010; Richardson and Rejmánek 2004; Simberloff et al. 2010; Zenni and Simberloff 2013). The successful naturalizations of pine species are largely associated with human factors (e.g., economic use), large propagule pressures, and sampling effects (McGregor et al. 2012). However, species traits, habitat characteristics, and the interaction between the non-native populations and the novel environment are key factors driving invasion successes or failures (Grotkopp et al. 2002; Nuñez et al. 2009; Zenni and Simberloff 2013; Zenni et al. 2014). For instance, pines are more often invasive in grasslands, shrublands, and open forests, but the lack of

belowground mutualists can prevent spread in some areas. Also, pines with short juvenile periods, high relative growth rates, and with small seed size are considered to have greater invasive potential (Grotkopp et al. 2002; Rejmánek and Richardson 1996).

Pinus oocarpa Schiede ex Schldl. is native to Mexico and Central America (Perry 1991). The species native range encompasses a 16° variation of latitude (between 12° and 28° N) and 2,000 m of altitude (between 350 and 2,500 m a.s.l.), which indicate *P. oocarpa* is a highly variable and plastic species (Dvorak 2002). *Pinus oocarpa* is the most common pine in the southern half of Mexico and Central America and is resistant to fire (Dvorak 2002). It was introduced to Central Africa (Kenya and Zimbabwe), South America (Brazil and Colombia) and Asia (India) mostly for forestry trials, and although *P. oocarpa* is noted as invasive in Brazil in at least two studies (Simberloff et al. 2010; Zenni and Ziller 2011), no actual empirical invasion reports exist. This is surprising since the species possess all the known requirements of invasive pine species (Essl et al.

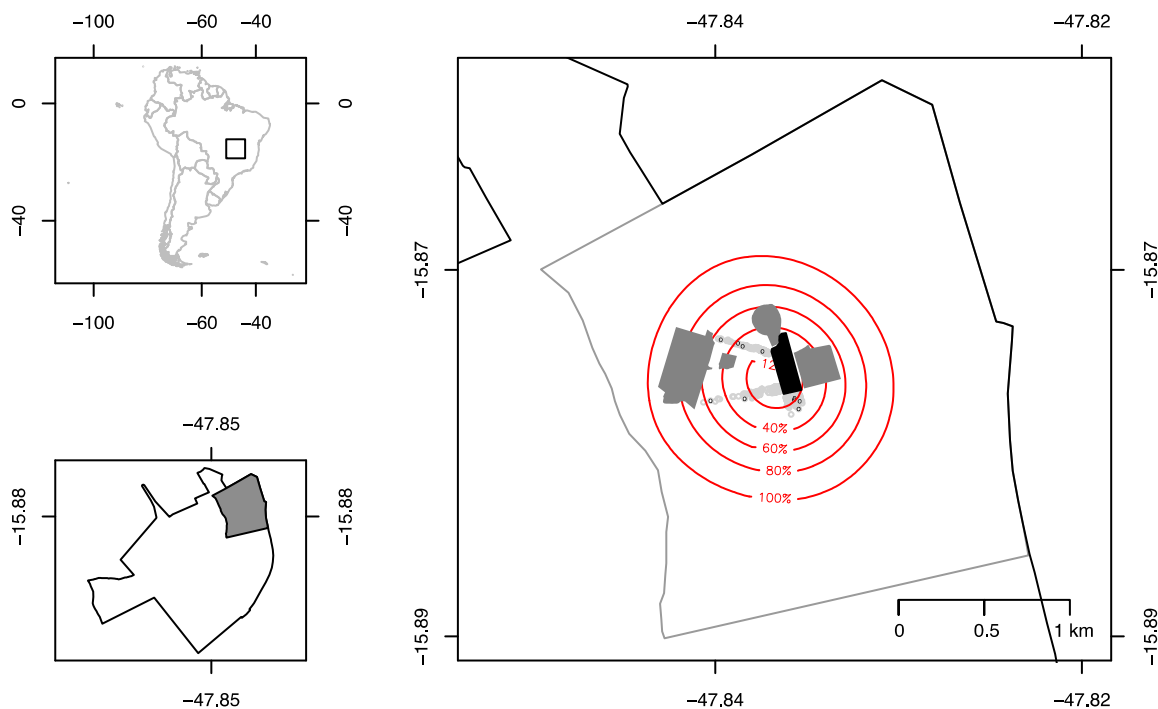


Figure 1. (A) The Botanical Garden of Brasília is located in the central region of Brazil, (B) and the studied site is located in the northeast part of the site (dark gray area). (C) *Pinus oocarpa* plants (light gray dots) were located up to 458 m away from the plantation (black polygon); reproductive plants are highlighted with black margins around the dot. Grey polygons represent areas not suitable for invasion (i.e., heavily managed areas). Red contour lines show the percentage of the population predicted to be in a given area. Axes for all panels are longitude and latitude in decimal degrees (see supplementary Table S1 for plants coordinates).

2010; Grotkopp et al. 2002; Rejmánek and Richardson 1996). In this paper, we provide the first empirical report of an invasion by *Pinus oocarpa* globally.

Methods

Study site: The Botanical Garden of Brasília was created in 1985 with an area of about 5,000 ha (Figure 1). Currently, around 10% of the total area is used for public visitation and the remaining 90% is part of a nature preserve (Estação Ecológica do Jardim Botânico de Brasília) where no human intervention is allowed except scientific research and prescribed management. The native vegetation of the area is savanna (Cerrado) and the climate is Aw (tropical savanna climate), according to the Köppen climate classification. Before the official creation of the Botanical Garden, in 1976, as part of a pedagogical

forestry provenance trial planted by the University of Brasília, 15 non-native trees species were planted (all pines) in an area of 10 ha. The species currently remaining are *Pinus caribaeae*, *Pinus oocarpa*, and *Pinus patula*. Of these, two species, *P. caribaeae* and *P. oocarpa*, became invasive in the adjacent Cerrado areas. *Pinus oocarpa* was planted in a stand of about 1,000 plants in the visitors' area of the Botanical Garden (lat -15.874974° , long -47.836300°). Currently, this stand is used for recreational purposes and is surrounded by native Cerrado vegetation subject to occasional fires (ca. 10 years between fires).

Sampling: In 2013, after initial observations indicated that *P. oocarpa* was present in the Cerrado outside the plantation, we established six transects (500 m long \times 5 m wide) starting at the border of the plantation and extending away from the stand in two directions: south and west.

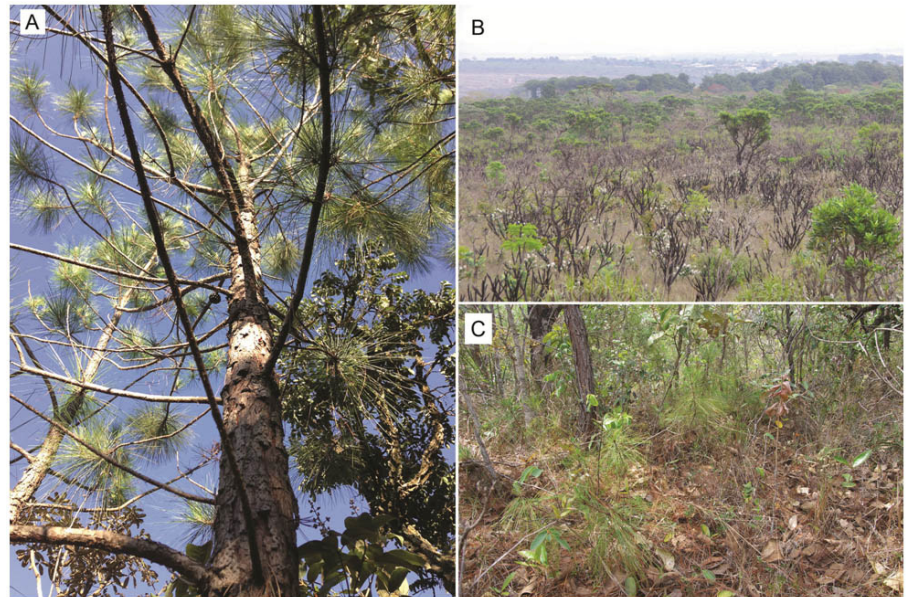


Figure 2. *Pinus oocarpa* present in the Botanical Garden of Brasília. (A) mature plant, (B) the invaded Cerrado vegetation with the *P. oocarpa* plantation on the back and some invasive pines topping out the Cerrado canopy, and (C) *P. oocarpa* seedlings germinating in the Cerrado vegetation.

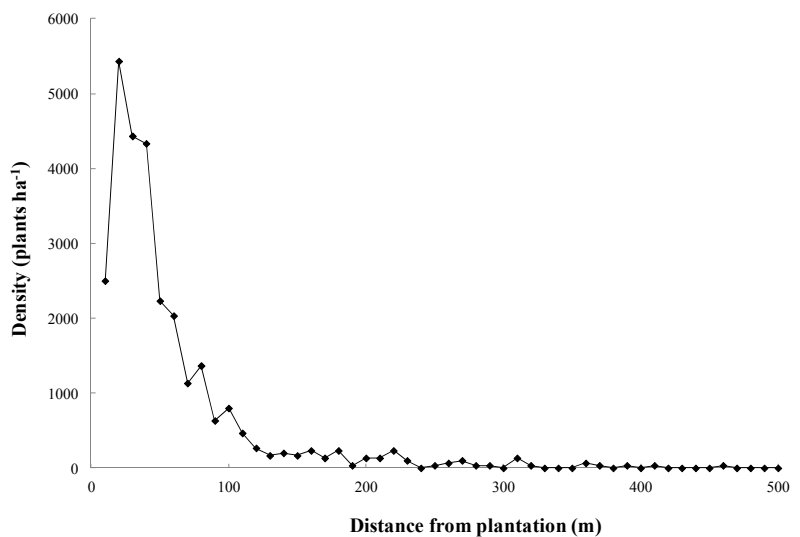


Figure 3. Transects established from the border of the plantation and extending for up to 500 m provide information on presence of plants outside the plantation as well as relative densities for the invasive population. *Pinus oocarpa* spread 458 m in 36 years, which represents a mean rate of spread of 12.72 m year⁻¹. The average density of invasive plants was 561 ind ha⁻¹, whereas the maximum density was 1.212 ind ha⁻¹.

We recorded all individuals of *P. oocarpa* found and measured their distance from the plantation and presence of cones (Figure 2). Using these data, we calculated maximum recorded distance of spread and density of plants in the invasive population. The transects were bounded by a road. A voucher specimen of *P. oocarpa* was collected from plants in the invaded area and deposited in the herbarium of the Botanical Garden (Ezequias Paulo Heringer Herbarium - HPEH; accession numbers 30339 and 30340).

Results

The maximum recorded distance of the invasion front of *Pinus oocarpa* was 458 m from the plantation, which represents a mean rate of spread of 12.72 m year⁻¹ since the plantation was established (Figure 3). Across all transects, we found a total of 841 plants, being 258 seedlings, 485 saplings (< 10 cm of DBH), 88 juvenile trees (> 10 cm of DBH, but not producing cones), and

10 adult trees (> 10 cm of DBH, and producing cones). The average density of invasive plants was 561 ind ha⁻¹, with a maximum density of 1,212 ind ha⁻¹. We found a great number of mature plants in the invasive population, confirming this is a self-sustaining population. The smallest diameter of a mature plant was 10.2 cm. Currently, the invasive population size is larger than the initial source pool and is in category D1 in the unified framework proposed by Blackburn et al. (2011): self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction; probably starting to transition to category D2 (self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction).

Discussion

Although clearly in the early stages of invasion, *P. oocarpa* introduced to the Botanical Garden of Brasília already conforms with the definition of invasive species proposed by Richardson et al. (2000): species producing offspring consistently and spreading considerable distances from parent plants (> 100 m in < 50 years). Also, this record gives support to the prediction made by Grotkopp et al. (2002) and Rejmánek (1996) that *P. oocarpa* has invasive potential (z-score = 6.5). *Pinus oocarpa* is also spreading faster in the studied area than other invasive pines in other areas of Brazil (Zenni and Simberloff 2013). To our knowledge, this is the first empirical report of an invasion by *P. oocarpa* globally. Without a doubt there is still chance for rapid response, since this is a window of opportunity for the eradication of this invasive population along with the source pool.

Climate is a major factor driving pine invasions, and this invasion may be the result of a match between adaptations present in the introduced genotypes and the climate of the introduction location (Zenni et al. 2014a; Zenni et al. 2014b). The high morphological variability of *P. oocarpa*, the diverse range of environments found in the native range, and the existence in Brazil of other non-invasive populations (Zenni and Simberloff 2013), seem to support the hypothesis that adaptations to climate exist in the native populations and, therefore, that invasions are driven by genotype-by-environment interactions (Zenni et al. 2014b).

It is currently unknown if the studied invasive population has produced negative impacts in the invaded ecosystem. Among the potential impacts of pines in native communities are decrease in species abundance and richness, change in soil properties, decomposition rates, and nutrient cycling (Abreu and Durigan 2011; Falleiros et al. 2011). However, it would be safe to assume that with the observed densities and rate of spread, *P. oocarpa* could definitely affect the Cerrado. An early response targeting the eradication of the invasive population could prevent these ecological costs.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Records of *Pinus oocarpa* plants of Botanical Garden of Brasilia that were located away from the plantation.

This material is available as part of online article from:

http://www.reabic.net/journals/bir/2014/Supplements/BIR_2014_Braga_et_al_Supplement.xls