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Undesirable Neighbours: Eucalyptus and Protected Areas

*Sandra Daniela Manzano Guzmán, Jose Augusto Drummond
and Cristiane Gomes Barreto*

Abstract

Eucalyptus is the common name of a set of exotic species present in the Brazilian territory. They have a strong invasive potential which is detrimental to the preservation of native floral formations, particularly in protected areas. This research seeks to (i) understand the stage of eucalyptus invasion in the Brasilia National Park; (ii) identify the main vectors of the invasive populations and (iii) verify the possible role of the adjoining Brasília National Forest in the invasion and (iv) consider possible conflicts between the roles of these two different categories of protected areas. A set of phytosociological sample areas were defined inside the park to pinpoint different eucalyptus populations. Findings indicate that eucalyptus populations inside the park behave invasively, having advanced 186.30 meters from their point of origin over the span of 45 years. Among the possible contamination vectors are a neighbouring nursery run by the local government and eucalyptus plantations in the adjoining Brasília National Forest. Results indicate the need for management actions to avoid continual seed dispersal by examined populations. They also indicate that the distinct conservation goals of national forests and national parks must be considered, especially when they are neighbours.

Keywords: Biological invasions, Brasília National Park, Cerrado, vectors of contamination, Brasilia National Forest

1. Introduction

Eucalyptus is the common name of hundreds of tree species of the Myrtaceae Family, currently classified in the genera *Eucalyptus*, *Corymbia*, and *Angophora*, native to Australia, a part of Papua New Guinea, and Indonesia. However, because they have several features that are useful for humans, eucalyptus species have been intentionally introduced in dozens of countries, including tropical and subtropical areas of the entire planet. [1]

In 1823, Chile was the first South American country to introduce eucalyptus species. In Brazil, Federico de Albuquerque first introduced them in 1868 in the state of Rio Grande do Sul. From 1903 on, the Brazilian soil scientist Edmundo Navarro de Andrade (1881–1941) conducted systematic experiments to select tree species that could supply firewood as fuel for locomotives operating in the state of São Paulo. [2] He concluded that eucalyptus had greater energy efficiency than native Brazilian trees. He convinced railroad managers that the species should be planted in large scale in swaths along the railways in order to meet energy demands of locomotives.

This led to the establishment of numerous eucalyptus plantations along railways of the state of São Paulo. [3]

Andrade studied the behaviour of 250 different species of eucalyptus, their physiology and their response to different types of soil and temperature. His experiments were conducted in the municipalities of Jundiaí and Rio Claro, in the interior of São Paulo. [1] Andrade later directed the planting of approximately 24 million trees in several plots belonging to the Companhia Paulista de Ferrocarril (a powerful railroad company). In 1940, as locomotives fuelled by wood were substituted by more modern ones equipped with diesel engines, those tree plantations started to be used for other purposes, such as manufacturing of pulp and paper. [4]

Currently, eucalyptus represents 75% of all specimens found in Brazil's rather extensive commercially planted forests. In 2015, with almost 7.5 million hectares planted with eucalyptus, Brazil was one of the three largest eucalyptus growers in the world. 55.8% of all Brazilian plantations are concentrated in the Southeast region, especially in the states of Minas Gerais and São Paulo. [5] Globally, over the last 180 years, more than 200 eucalyptus species have been planted for several purposes outside their natural range. [6]

Despite its contribution to the history of industrial and railway development, eucalyptus currently stands out in scientific research as a major "villain" identified by conservation biology. In recent years, several studies have highlighted the effects of exotic and invasive species on the loss of biodiversity. [7–9] Eucalyptus has become, for many scholars, a noteworthy enemy of biodiversity conservation. As an exotic species with a strong degree of invasiveness, eucalyptus jeopardizes conservation goals, mainly in protected areas. [10]

In Brazil, the lack of control over the introduction of exotic species led to the dispersion of many species and to invasive processes in native formations. An example of this lack of control was the creation of fiscal incentives by the federal government, through Law 5,106 / 1966 and Decree-Law No. 1,376 / 1974, both of which stimulated commercial forest planting. One legal requirement was that supported projects should plant an annual minimum of 10,000 trees, but the species to be planted were not defined. As a result, extensive areas of Cerrado vegetation had their native flora replaced by extensive monocultures of eucalyptus and pinus. [11] Controversies about this type of afforestation gained importance when these species began to disperse spontaneously into natural areas, competing with native species. [12, 13]

Despite this, on a global scale only a few eucalyptus populations have become invasive in the numerous areas to which they were transferred. [14] It is thus necessary to distinguish three concepts. An exotic species is a "species that would not naturally occur in a given geographic region without human (intentional or accidental) transport to the new region". [15] An alien invasive species (AIS), on the other hand, is one that, once introduced (intentionally or not), has the ability (i) to reproduce autonomously and generate viable populations outside its natural range and (ii) to disperse a considerable distance from its point of introduction, in a short period of time, [16] without necessarily requiring additional human help. An exotic species is one that is found outside its natural distribution, with or without human assistance, but only those that can disperse at great distances in a short period of time are considered invasive.

Environmental problems emerge precisely when this invasive potential develops. Introduced populations become a more acute problem in areas designed to protect native ecosystems and biodiversity, such as officially protected areas (PAs). In these cases, invasive populations harm native biodiversity and hinder the achievement of PA objectives. The following eucalyptus species are currently present in several federal Brazilian PAs: *Eucalyptus angulosa* Schauer, *Corymbia citriodora*

Hook, *Eucalyptus crebra* F. Muell, *E. dunnii* Maiden, *E. grandis* W. Hill, *C. maculata* Hook, *E. paniculata* Sm., *Eucalyptus camaldulensis* Dnh., *Eucalyptus saligna* Sm., *E. viminalis* Labill, and *E. robusta* Sm. [17] Invasive populations of eucalyptus have been identified in PAs located in several Brazilian biomes and locations: Saltinho Biological Reserve (Pernambuco); Itapeva State Park (Rio Grande do Sul), Aratinga Ecological Station (Rio Grande do Sul), União Biological Reserve (Rio de Janeiro), and Vila Velha State Park (Paraná), among others. [18–20] Horowitz [20], surveying Brasília National Park (BNP), in the nation's Federal District, found eucalyptus populations that could behave as exotic invaders (in the initial stage of dispersion and colonization), while other populations were casual, that is, they have established themselves, but did not form long-term, viable populations.

The invasive potential of populations varies depending on the source of introduction, management practices, and the types affected ecosystems. Populations can behave invasively. This will influence management choices adopted by PA managers. These choices depend on how the invasive potential of the population is classified, on the identification of the source of contamination and, if it persists, on how the source can continue to influence dispersal and colonization of invading specimens.

The BNP is a highly restrictive type of PA - meaning that it is not open to any productive activities. Among its objectives is the maintenance of the integrity of native landscapes of the Cerrado biome. Despite this, activities carried out historically in areas adjacent to the park (human settlements, public works, road building, government buildings, depots, farms) created and left threats that affect the unit's native floral composition. Currently, in the immediate vicinity of the BNP there are industries, semi-rural housing complexes, agricultural and urban settlements. Other neighbours are two PAs - the Contagem Biological Reserve (also a strictly protected PA) and the Brasília National Forest - BNF (a multiple-use PA, which has plantations of exotic trees). The dominant landscape of the adjoining BNF is stands of planted eucalyptus and pine trees. [21] There is also a tree and shrub nursery run by nursery the local government (Novacap's Nursery) and associated with Brasília's urban landscaping policies. The nursery is used for growing a wide variety of exotic and native plants. A stretch of the area's major interstate highway (BR-040) and its heavy traffic pass quite close to the BNP (field observations). On account of all this, the BNP has been susceptible to the effects of many vectors that defy its conservation mandate, including invasions of exotic species. According to its managers, these invasions are the main challenge for the management of the BNP's native ecosystems.

Among the questions raised in this article, we seek to (i) understand the stage of eucalyptus invasion in the BNP; (ii) identify the main vectors of arboreal invasive populations; and (iii) verify the possible role of eucalyptus and pine plantations in the adjoining BNF in the invasions and thus (iv) consider the possible conflicts between the roles of these two different categories of PAs in view of the potential environmental risks generated by the proximity between them.

2. Materials and methods

In order to measure the invasive potential of a windbreaker planted with eucalyptus in 1960s along the boundary between the BNP and Novacap's nursery, 10 plots of 100 m² (10 x 10 m) were delimited inside the BNP area, within a sampling area of 5,589 ha. All plots of the sampling area were identified as belonging to the gallery forest physiognomy, corridors along rivers in Cerrado landscapes. Reconnaissance trails were marked out to define the sampling area. In order to encompass the entire eucalyptus population, the area was demarcated by using the outermost individuals of the group (**Figure 1**). We used the stratified systematic

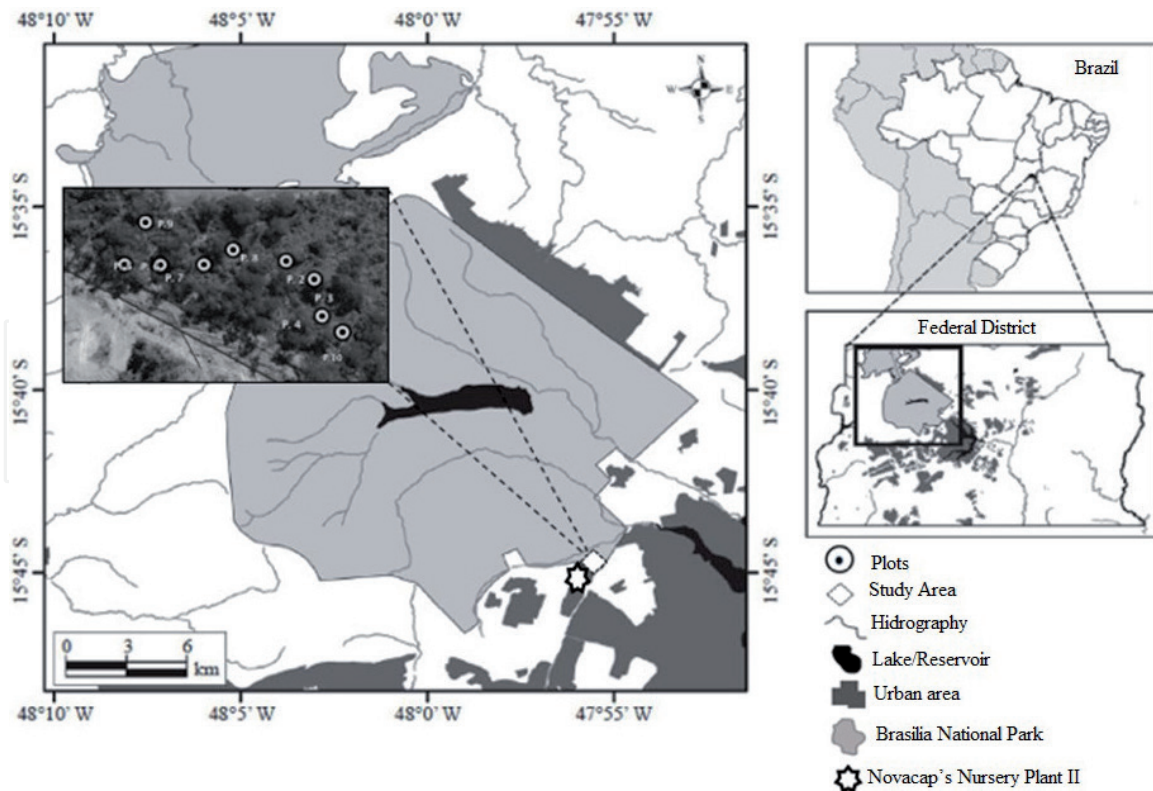


Figure 1.

Distribution of sampled areas in the Brasília National Park, close to Novacap's Nursery Plant II. Figure produced by the Authors. Source: Image adapted by the authors from [22].

sampling method, keeping a distance of 10 m between the plots. Plots were georeferenced with the GPS Garmin eTrex 10, version 3.1; the measuring point was placed on the central position of the plot. Eucalyptus individuals inside each plot were counted. Subsequently, phytosociological parameters of absolute taxon frequency, absolute taxon density, and absolute taxon dominance were computed.

Estimation of the rate of invasion as defined by [16] (more than 100 m covered in less than 50 years for plants with seed dispersal) required that we measure the distance between the windbreaker and the farthest eucalyptus within the polygon of the sampling area. Dispersion time was estimated from the age of the windbreaker. This age was determined with the help of aerial photographs. Local wind parameters (velocity, direction, and gust) were also considered for the period of August 2015 to August 2016. This was done to determine the period of the year in which wind favours dispersal of eucalyptus seed towards the BNP.

In our effort to determine the possible flow of exotic propagules from the BNF to the BNP, we marked out a trail inside the BNP, close to its border with the BNF. The location of eucalyptus or other trees found in the area was georeferenced; later the distances between each of them and the BNF were measured.

Data about wind speed, direction, and gust from August 2015 to August 2016 were provided by Brazil's National Institute of Meteorology. They were used to determine the period of the year that would favour seed dispersal in the BNP.

3. Results

We sampled 49 eucalyptus individuals near the Novacap nursery. The absolute frequency of the taxon (FAt) was 90%, which means that the species occurs in 9 of the 10 plots (there were no occurrences in plot 4). From the absolute density (DA_t), the number of individuals present in the BNP area was estimated at 2.394

(density of 0.049 ind /m²). In order to compute the absolute dominance (DoAt), the basal area (Gi) of each individual was estimated from the perimeter at breast height (1.30 m). The total measured basal area (GT) (equal to the sum of Gi) was 53,765.08 cm². Therefore, 53.76% of the sampled area was occupied by eucalyptus.

Invasive status of the studied populations.

To determine whether the eucalyptus population in the sampling area meets the invasion rate defined by [16], we measured the distance between the windbreaker (a parental eucalyptus individual) and the farthest individual located at one of the points of the polygon in the sampling area. This distance was 186.30 m. The Google Earth distance measurement tool was used, based on the geographical coordinates of the selected eucalyptus individual and the windbreak. As a second measurement of the invasiveness parameter, parental age was determined by analysing aerial photographs belonging to the Cartographic System of the Federal District. [23] We analysed a 1965 photograph (before the nursery was created) and a 1975 one from (after its creation). The 1965 photograph recorded several rural roads and vegetation in the current area of the BNP. However, the windbreak did not exist; no disturbance of its area is perceptible. In the 1975 photograph, the windbreak appears as a thickened fringe located on the limits between the nursery and the BNP. As the nursery itself was created only in 1971, the planting of the windbreak must have occurred between 1971 and 1975.

To determine the type of exotic species (naturalized, casual, or invasive) in which the group of eucalyptus is classified, we used the results of the computation of the rate of invasion, as per [16], and the results obtained from phytosociological parameters. Measurement of the invasion status, together with observation of individuals, allowed an estimate of eucalyptus in its first stages of invasion. Both the phytosociological parameters and the dispersal capacity (up to 186.30 m in less than 50 years) indicate that this is an expanding group. In addition, no type of control of the studied individuals was recorded; the trees do not display hacking or girdling marks. Absence of control also favours invasion.

Eucalyptus found in this location represent a problem for individuals of native species peculiar to the Cerrado and to gallery forest phytophysiognomies. On the other hand, eucalyptus control measures, such as chopping and girdling, were recorded in other places inside the park, farther away from the windbreak. However, it is a group with high population density (5 ind./100m²), when compared, for example, to similar values in *Eucalyptus urophylla* plantations in the Cerrado region of Minas Gerais (6.6 ind./100m²). [24] It is also reproductively active. [25] The data allow us to deduce that eucalyptus near the nursery is invasive and has the capacity to spread widely.

Since the nursery was created in 1971, it is assumed that the possible age of the eucalyptus in the windbreak is approximately 45 years. Therefore, eucalyptus trees in the park covered the distance of 186.30 m from the nursery in less than 50 years, which is substantially more than the 100 m in 50 years defined by the invasion index. [16] Concluding that the studied populations are invasive, we proceeded to investigate the possible vectors of invasion to be found in the area around the BNP.

3.1 Vectors of invasion

The BNF is composed by four neighbouring but disconnected areas. Area I is close to the BNP, at a distance of approximately 303.37 m; Area II is currently occupied by a rural settlement, created in 1996, and is located at a distance of approximately 46.51 m from the BNP; Areas III and IV are relatively distant from the BNP, at the approximate distances of 12,803 m and 3,403 m, respectively. [25]

The reconnaissance trail, leading from the area of the BNP near the BNF, was 64.5 km long; it stretches from the park's entrance and uses the unit's main and

secondary roads. In the area near the BNF the following trees were identified: A single eucalyptus individual (coordinates 15°45'9.69"S/48°2'7.46"W) and, also exotic, a juvenile and isolated pine tree (coordinates 15°44'20.23"-48°3'30.94"W). The first location corresponds to a distance of 42.44 m from Area II of the BNF, which was originally planted with eucalyptus. This area has been degazetted and is currently occupied by a rural settlement with a population of approximately 400 families. The pine tree is located 303 m from the BNF's Area I, which cultivates eucalyptus and pine. Other two pine trees were located in the park, but far from BNF areas.

Given the proximity of these individuals to the BNF area, historically planted with eucalyptus and pine, we can suppose, as park managers do, that it is a possible invasion vector. In order to corroborate this possibility, data on the region's wind characteristics (speed, direction and gust) provided by INMET (Brazil's National Meteorological Institute) were analysed for the period of September 2015 to August 2016. We sought to determine the possible role of wind in the dispersion of eucalyptus seeds from the BNF in the direction of the BNP. [26] Brazilian climatological data 1961–1990 for the study area point to a predominantly eastern wind direction, especially in the months of April to September. [26] This information was verified specifically for the period of September 2015 to August 2016. The record of monthly predominant winds can be seen in **Figure 2**.

Average wind speed was 1.57 m/s. The month with the highest gusts and the highest prevailing speed is January (2.2 m/s). January also stands out due to an inversion of the wind direction, which moves toward the NNW. January winds coincide with the peak of eucalyptus seed release. This may favour seed dispersion from the Viveiro II and Area II of BNF to the BNP (**Figure 3**).

Seed release occurs about six months after flowering, which in turn occurs in the dry season. Considering that the dry season occurs between April and September, seed release can go on from about November to March, the months in which the propagules can be dispersed to the BNP with the aid of winds. Based on the average predominance of the winds - to the East - and on the predominance of the winds in the month of greater speed and greater probability of dispersion - North-Northwest -, **Figure 3** illustrates the relation between wind directions and identifies the three potential sources of dispersion of eucalyptus seeds within the BNP: Area I of the BNF; Area II of the BNF; and Novacap's nursery.

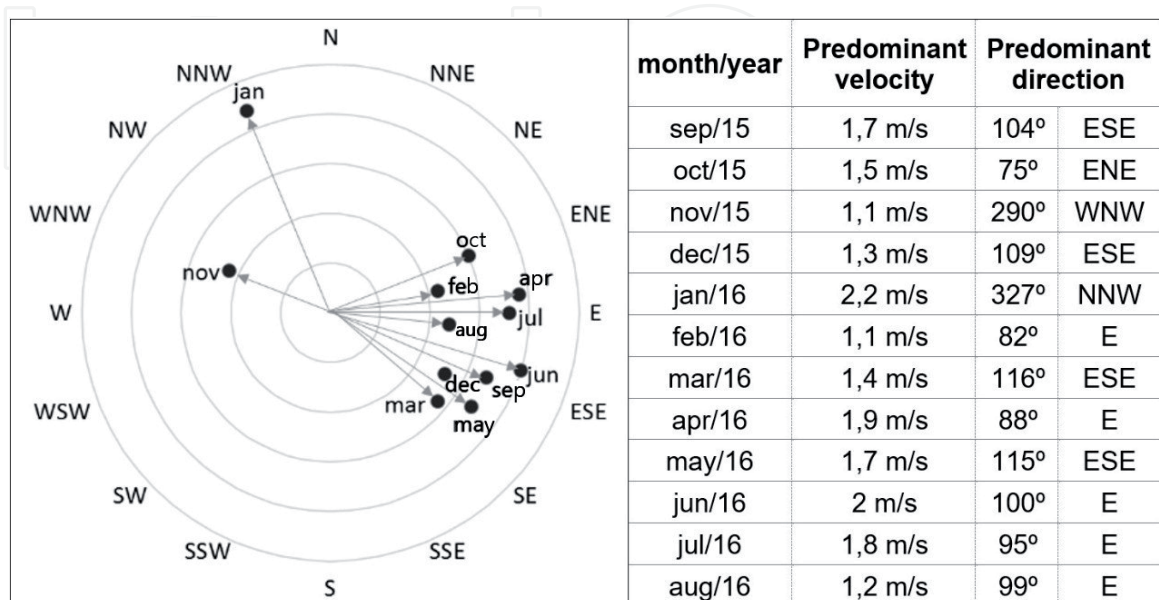


Figure 2. Wind speeds and predominant directions during one year in the Brasília National Park, from September (2015) to August (2016). Diagram produced by the Authors. Source: [26].

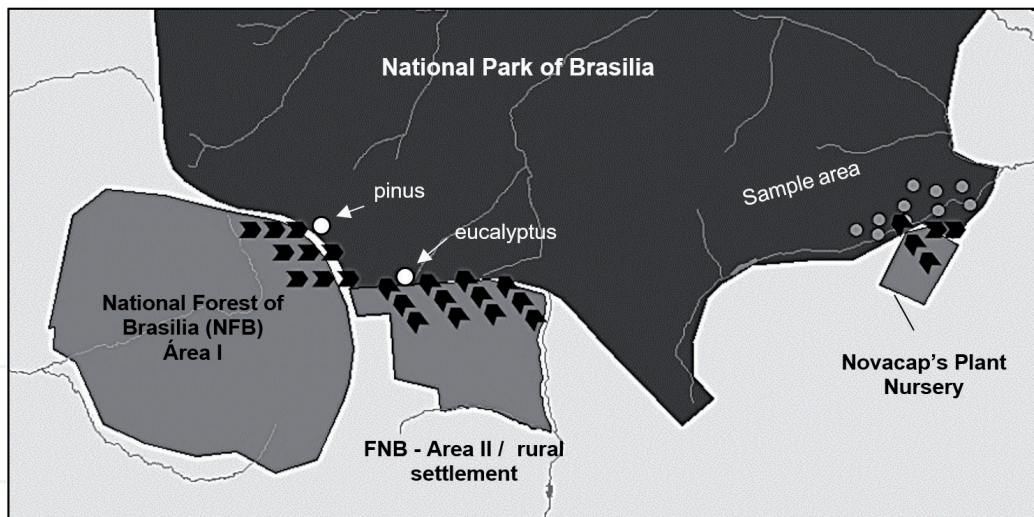


Figure 3.
Incidence of predominant winds as seed dispersion vectors into the Brasília National Park from eucalyptus sources located in the areas of the Brasília National Forest and the Novacap nursery. Figure produced by the Authors.

The predominant wind direction during the year, to the East, also directs the dispersion flow from the BNF's Area I to the BNP, which could favour the invasion of species from the first to the second. The predominantly Eastern direction also guides the dispersion flow of Novacap's nursery, reinforcing the invasive characteristics of eucalyptus in the BNP.

Our use of the reconnaissance trail near the BNF allowed us to evaluate its role in the dispersal of eucalyptus trees into the BNP. It was found that there is currently no group of eucalyptus in the BNP near its border with Area I of the BNF. Area I has pine and eucalyptus plantations. [21] The inference is that the relationship between wind speed, its direction, and the time of seed release, associated with the presence of a narrow trail between the two PAs, hinders or prevents the transfer of propagules from Area I of the BNF into the interior of the park.

However, a single eucalyptus individual was found at coordinates $15^{\circ}45'9.69''\text{S}/48^{\circ}2'7.46''\text{W}$, inside the park (**Figure 3**). As this location does not show remnants of recent dwellings or old farms, we assumed that this individual was introduced from some external source. Area II of the BNF is close by. As informed above, since 1996 Area II has been occupied by a rural settlement, although it still displays remnants of pine and eucalyptus plantations.

According to **Figure 3**, the NNW wind direction, predominant at the time of seed release, is also the direction that favours dispersion of Area II of the BNF to the BNP. This may have favoured specifically the establishment of the single identified individual within the park (**Figure 3**).

4. Discussion

The BNP was established in an area of the Cerrado biome, with native ecosystems of grasslands, savannas, and forests. However, this area was previously occupied by farms, dwellings; exotic species were cultivated in it. In addition, its proximity to (Novacap's nursery, created in 1971 to produce seedlings of native and exotic species) aided, and continues to aid, colonization of the park by propagules of exotic species used mostly for urban landscaping. This is the case of the eucalyptus planted to form the windbreak located on the boundary between the park and the nursery. [27]

Data generated by this research showed that eucalyptus populations in the BNP grew and dispersed since 1970s and, therefore, behaved as invasive. The lack of control and management reinforced this process. Most of the identified individuals are reproductively active and population density is high.

Regarding management options employed by the BNP staff to reduce or neutralize the risk and the influence of exotic species (the groups of eucalyptus within the park and in the windbreak), the most suitable one is eradication, because of the size of the groups. [25] According to observations of other groups of eucalyptus located inside the park, we found that the cutting method used to control the species does not result in eradication. The girdling method, observed in some individuals located elsewhere in the park, did manage to kill them. Therefore, we assume that girdling may work for the individuals studied.

On the other hand, the BNF displays a dominant anthropic landscape composed of stands of planted eucalyptus and pine trees – two exotic species with strong invasive potential. Although the BNF is managed under the same general regulations as national parks (Law 9,985, of July 18, 2000, and Decree 4,340, of August 22, 2002), its conservation goals differ from those of the BNP. While national parks, as “fully protected” areas, seek the preservation of nature, biodiversity, and ecosystems, national forests, as “sustainable use” areas, seek to combine conservation with the use of natural resources. To do so, national forests can plant and harvest commercially valuable exotic species, to the detriment of native species. In the case of the BNF, the area formerly occupied by Cerrado (open, savanna-like vegetation) was occupied by dense lines of tall pine and eucalyptus forests. This happened in the 1980s. Native flora was removed, and fauna was dispersed from the BNF area. Losses of biodiversity and native landscapes are obvious consequences. There are no gains in terms of environmental conservation.

Areas I and II of the BNF may be vectors of contamination of native vegetation inside the BNP, given their mutual proximity (**Figure 3**). According to the BNF’s management plan, its dominant vegetation consists of pines and eucalyptus trees that lack proper cultivation practices is, a fact that increases the risk of invasion of these species into the BNP area. [21] Most of the BNF’s Area I, which is closest to the park, is covered by eucalyptus plantations.

Although the park has followed its objectives consistently, the neighbouring BNF is a potential threat to its biodiversity by acting as a vector of contamination by exotic species. From the viewpoint of regional conservation, the BNF is a potential agent of environmental degradation than a protected area. The proximity of the BNF to the BNP generates no synergy or gains in terms of biodiversity protection. Brazilian PA law does allow the formation of “mosaics”. Mosaics are management models, predicted by Law 9,985 of July 18, 2000, and Decree 4,340 of August 22, 2002, which seek to integrate the management of different types of neighbouring protected areas. However, we consider them to be unfeasible in the cases of national forests covered by plantations of exotic species which are located next to fully protected PAs. Environmental planning should always consider species with strong dispersion potentials as a risk and, therefore, should define containment measures in the same way as it does in the case of private commercial plantations located in the buffer zones of PAs, as predicted by law.

5. Conclusion

Field surveys conducted in the BNP led to the conclusion that the studied groups of eucalyptus have invasive characteristics. The BNP area adjacent to Novacap’s nursery hosts a well-established and dispersing group of eucalyptus. If not controlled, it may become a very serious problem for the park. The populations of eucalyptus originated from windbreak propagules, located near the nursery, should

be eliminated. Eradication is feasible due to the size of the groups and to their initial stage of dispersion. Managing these populations is essential for the BNP to fulfil its objectives, among which the preservation of biodiversity is paramount.

Area I of the BNF, close to BNP, with its plantations of eucalyptus and pines, is an obvious contamination risk, even though the risk so far has not been strong. This may be due to the combination of wind velocity and wind direction with the timing of seed release. This combination does not favour dispersion from Area I of the BNF to the BNP. However, this section of the BNP, on account of its proximity to the BNF, should become a prime target for the monitoring and control of exotic species in the park. On the other hand, eucalyptus propagules from the nursery windbreak, as well as remaining populations of Area II of BNF, have their dispersion towards the BNP favoured by wind speed and direction in the month of January, coinciding with peak seed release. This mode of dispersion is corroborated by the data obtained in this study.

In terms of control and management of eucalyptus in the BNP, this work points to the necessity of strengthening (i) measures of species eradication inside the unit and (ii) the management and planning of the landscape surrounding the park. Concerning the BNF, its proximity to the park jeopardizes the park's preservation goals, even though the BNF is an officially created and managed PA. Therefore, regardless of the formal categories of land use and occupation, vectors of contamination by exotic species can come from the most varied and even unexpected sources, such as a neighbouring PA.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Sandra Daniela Manzano Guzmán, Jose Augusto Drummond
and Cristiane Gomes Barreto*

Observatory of Conservation Units and Related Social Policies, University of
Brasilia, Brasilia, Brazil

*Address all correspondence to: crisbarreto@unb.br

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