Trade-offs among ecosystem services under different pinion harvesting intensities in Brazilian Araucaria Forests

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ABSTRACT
Assessing the consequences of human exploitation at different intensities on ecosystem services is important in the Brazilian Araucaria Forest biome, because it has been drastically reduced, mainly due to the exploitation of Araucaria angustifolia (Bertol.) Kuntze for wood. The inclusion of A. angustifolia on the list of Brazilian endangered plant species places the harvesting of Araucaria nuts as the most important provisioning service in this type of ecosystem. The aim of this study was to determine the trade-offs related to provisioning, supporting and regulating ecosystem services in the Araucaria Forest at different intensities of nut harvesting, by addressing ecosystem attributes that assure forest sustainability. Six indicators of ecosystem services were evaluated in harvested and non-harvested areas in Brazilian Araucaria Forest fragments. Trade-offs were examined under five harvesting intensities. The supporting services were the most sensitive to the harvesting intensity. The results indicate that a harvesting threshold of between 60% and 85% of the nuts produced guarantees forest sustainability. In addition, areas under higher harvesting intensities provide more short-term benefit services at the local scale that can be included in the formal market.

Introduction

Ecosystem management has increasingly focused on the challenge of ecosystem services provision that does not compromise ecological processes and functions (De Groot, et al. 2010a). The discussion on this topic must be based both on the perception of the value of benefits and on the understanding of the ecological relationships involved in the provisioning of goods (Foley, et al. 2005; De Groot, et al. 2010b; Van Oudenhoven, et al. 2012).

To provide support for this discussion, some authors have suggested methods to valuate ecosystem services, which enable highlighting the ability of ecosystems to provide long-term benefits. According to such methods, biophysical indicators directly related to ecosystem services are measured against ecosystem degradation (Daily, et al. 1997; De Groot, et al. 2010b; Van Oudenhoven, et al. 2015b; Kim, et al. 2016), and valuation must highlight the trade-offs among competing ecosystem services (Costanza, 2000; De Groot, et al. 2010b; Howe, et al. 2014) to find critical limits for maintaining each service under alternative management stages (Braat, et al. 2008; De Groot, et al. 2010a; b; Van Oudenhoven, et al. 2012; Van Oudenhoven, et al. 2015b). Based on such premises, we can indicate the point at which stress begins to affect a given service or when the optimal combination of services is reached (Haines-Young, & Potschin 2010; Deng, et al. 2016).

We applied these considerations to the Brazilian Araucaria Forest, which originally covered nearly 20 million hectares in the southern part of the country, and is now been reduced to approximately 2% of the original area (Rizzini, 1978; Guerra, et al. 2002). The intense exploitation of this tree species has impacted ecosystem properties and all ecosystem services offered, including the supply of wood. This situation has led to the inclusion of Araucaria angustifolia in the official Brazilian list of endangered species, and logging of this species has been prohibited (IBAMA 1992, 1992).

The prohibition of the felling of Araucaria trees for wood has resulted in that their seeds – a kind of nut called the pinhão or pinion, consumed as food – became the main provisioning ecosystem service from Araucaria Forest, as the native forests can produce as much as 75 kg plant⁻¹ year⁻¹ (Guerra, et al. 2002). Although pinion collection does not directly affect the survival of adults, it should follow the planning criteria for sustainable harvesting, considering the high fragmentiation of the Araucaria Forest into small remnants (Guerra, et al. 2002), the regeneration capacity of Araucaria trees, and the impacts of harvesting on other ecosystem functions and services (Foley, et al. 2005).

In addition to pinion provisioning, the Araucaria Forest contributes to climate regulation (regulating service) by removing carbon dioxide (greenhouse gas) from the atmosphere and storing it in tree biomass.
Although the dynamics of forest remnants is not spatially homogeneous – as a response to differences in land use history and successional stages – emergent species such as *A. angustifolia* have significant carbon stocks (Paula, et al. 2011; Rosenfield, & Souza 2014) because they are large in diameter and taller than other angiosperms (Souza, 2007).

The maintenance of *A. angustifolia* populations depend on its seedlings, which are shade-tolerant in the early development stages (Duarte, & Dillenburg 2000) but require light in the subsequent stages (Reitz, & Klein 1966). This behaviour normally results in a J-inverted distribution pattern, i.e., a high concentration of individuals in the smaller diameter classes and a sharp reduction towards larger classes (Paludo, et al. 2009). Therefore, a bank of seedlings is expected in a healthy environment as a regenerative strategy. On the other hand, the absence of seedlings limits resilience and indicates repetitive regeneration failures, that will affect the primary production, biological and biochemical cycles, which can be described as supporting services. With the forest maintenance being at risk, all its functionality will automatically be jeopardized (Lewis, et al. 2013), which implies in the inadequate provision of all other ecosystem services, in a cascade effect. The dispersal of seeds to new environments by animals – such as birds, rodents, domestic pigs and peccaries – away from their parental shadow is also directly related to species (*A. angustifolia*) and forest maintenance. The disruption of this regulating ecosystem service can leave large areas without seedlings, and is consequently unable to recover from human impacts (Daily et al. 1997).

Based on several studies (Albert, et al. 2014; Braat, et al. 2008; De Groot, et al. 2010b; Van Oudenhoven, et al. 2012;15a), we argue that the ecological valuation of supporting, provisioning and regulating services provided by the Araucaria Forest at different intensities of pinion harvesting can be the basis for understanding the relationships among ecosystem properties, processes and services, and their benefits to society in relation to human management or lack thereof.

In this context, this study aimed to determine the trade-offs among supporting, provisioning and regulating ecosystem services in Araucaria Forest remnants at different intensities of pinion harvesting, considering ecosystem attributes as indicators to ensure sustainability. Based on previous studies (Braat, et al. 2008; De Groot, et al. 2010b; Howe, et al. 2014; Lee, & Lautenbach 2016); we expected that (a) trade-offs would exist between an increase in the provisioning service (pinion extraction) and a decrease in other services and (b) the reduction would be more strongly revealed by indicators directly affected by trampling and harvesting and would be less strong for indicators indirectly affected by forest disturbance over time.

**Materials and methods**

The study was conducted in fragments of the *Araucaria* Forest biome in the southern region of Minas Gerais State (Brazil) inside the Fernão Dias Environmental Protected Area, a protected area for sustainable use (Figure 1). This area holds high biological importance and shelters several endemic,
endangered and rare species. However, the conserved forest remnants are threatened by anthropogenic pressures such as intensive and subsistence agriculture, urban expansion and cattle-raising activities (Drummond, 2005).

Regional altitudes vary between 1500 m and 2000 m a. s. l. Temperatures in the warmer months are under 17°C, and the annual mean is under 14°C, achieving negative values during the winter (Mesotérmico Médio Superimídio climate domain). There is no dry season (Horn, 2001).

In addition to A. angustifolia, the predominant flora in the region includes species with timber potential such as Machaerium villosum (jacarandá-tã), Podocarpus lambertii (pinheirinho), Anadenanthera peregrina (angico) and Piptadenia gonoacantha (pau-jacaré), and species with ornamental potential, especially those belonging to the families Bromeliaceae, Orchidaceae, Liliaceae, Begoniaceae, Araceae and Gesneriaceae (Oliveira, 2008).

The predominant fauna in the region includes primates such as Alouatta guariba (bugio-ruivo), Callicebus nigrifrons (saúá), Callithrix aurita (sagüi) and Brachyteles hypoxanthus (muriqui), and birds such as Odontophorus capoeira (uru), Penelope obscura (jacuacu), Spizaetus tyrannus (gavião-pegamaco) and AMAZONIA vinacea (papago-de-peitroxo) (Oliveira, 2008). These species potentially contribute to the dispersal of Araucaria seeds.

The landscape of this area is predominantly covered by grazing lands, potato farms, as well as commercial pine plantations of Eucalyptus spp. and A. angustifolia, interspersed with small remnants of native Araucaria Forest (Oliveira, 2008).

Pinion harvesting is carried out on both private and commercial properties in the study region. In private areas, harvesting is usually conducted by one or two persons, and because the harvesting area is in the harvester’s property, the collecting area is usually close to the harvester’s home. On the other hand, harvesting in commercial areas is conducted by a group of harvesters that have been authorized by the company, and the harvesting areas are far from the harvesters’ homes. In both cases, the distance from a harvester’s house to the harvesting area is covered by foot. Because pinion production occurs only during the winter season and the harvesting can only be conducted during 1 month, this practice is a secondary source of income that helps harvesters when other products are scarce (approximately US $310 to US $620 for each family). This product is commercialized to local tourists and at a greater scale to cities nearby, especially Sao Paulo (400 km away).

Meetings and interviews were conducted to identify the sites of pinion harvesting. We interviewed 35 stakeholders from the region, including resident harvesters as well as representatives of the local municipality and of the State Forestry Institute (IEF) of Minas Gerais State. The stakeholders were identified by the rural extension agency (EMATER) staff, including those who were most involved with pinion harvesting. The interviews allowed for the identification of (i) the average number of pinion harvested per Araucaria tree (declared amount), (ii) the number of people involved in harvesting, and (iii) the harvesting history over the last 5 years.

We selected eight areas under pinion harvesting where the extraction of the product was controlled, and two areas without harvesting as a reference. The eight controlled harvesting areas included all those indicated by the community members where the extraction of the product was controlled and that had been used for more than 5 years; we discarded those areas without minimum control standards (with no knowledge regarding the amount of pinion harvested or the presence of domestic animals). Therefore, the eight controlled harvesting areas composed 100% of the properties where the extraction of the product was controlled, with the same climate, altitude, soil type and declivity. Three sampling plots of 20 m × 10 m (200 m²) were then delimited within each of the 10 selected areas (8 controlled harvesting areas + 2 areas without harvesting), totalling 30 plots. The plots of the areas without harvesting were established where there was a similar concentration of female Araucaria trees.

We selected six indicators to evaluate the effects of ecosystem properties on supporting, regulating and provisioning ecosystem services (Figure 2). Since the maintenance of A. angustifolia population depends on the existence of individuals at younger ages (germinated seeds – pinions – and seedlings) we selected as supporting services indicators both the number of germinated pinions and the number of seedlings. The germinated seeds and seedlings per square metre in each plot were estimated by counting them in 10 random 1 m² subplots. The mean value of these 10 plots was used to estimate the value for each 200 m² plot. We considered seeds to be germinated when the coleoptile had emerged and was shorter than 5 cm. We considered seedlings as being plants that were already established in the ground, were shorter than 50 cm, and had leaves.

The maintenance of the Araucaria Forest depends on continuous regeneration, which can be measured by the biomass of young trees (DBH = 5–10 cm) and the existence of animal species from local trophic chains, which can be estimated by the amount of pinions consumed by fauna. These measures give us another two indicators of supporting services: the biomass of young trees (DBH = 5–10 cm) and the number of pinions consumed by fauna. To calculate biomass, we used an allometric equation developed for a fragment of Araucaria Forest that was similar in
terms of species composition and structure to the one studied here (Ratuchne 2010). The amount of pinions consumed by fauna per square metre in each plot was estimated by counting them in 10 random 1 m² sub-plots. The mean value among these 10 plots was used to estimate the value for each 200 m² plot. We measured every young tree in each plot, and we considered pinions to have been consumed by fauna when they showed evidence of being bitten.

As indicator of provisioning services we considered food production, measured through the amount of harvested pinions, calculated as the sum of harvested pinions from each female Araucaria tree. The declared amount of pinions harvested from each female Araucaria was obtained from the interviewees.

Lastly, as indicator of regulating services we considered carbon sequestration, calculated by the carbon stocked in trees of DBH > 5 cm. Biomass was calculated according to Ratuchne (2010), and the carbon stock was calculated according to EMBRAPA (Arevalo, et al. 2002). We measured all the trees of DBH > 5 cm in each plot (Table S1 and Figure 3).

The parameters defined to compose these six indicators of ecosystem services were measured in each of the 30 sampling plots after the season of pinion harvesting (June and July 2013).

Considering a possible influence of the distance covered by harvesters on their harvesting efficiency, we also measured the distance to harvester’s homes from harvesting areas.

The harvesting intensity of each area was defined as the ratio between the declared amount of pinions harvested and the total pinions produced in the plot (declared harvest + number of pinions consumed by fauna + number of germinated pinions + number of intact pinions). The values were grouped into four harvesting intensity classes: low (60–85%); medium (85–95%); high (95–97%); and very high (above 97%). There were no harvesting areas in which people harvested less than 60% of the pinions produced, as this is the minimum value that compensates for the efforts of the harvesters. A differentiation between the high and very high-intensity classes was needed due to the effort necessary to harvest more than 97%. In this case, harvesters select areas having a high concentration of Araucaria trees and cut down the understory (Figure 4).

The effect of the harvesting intensity on the selected indicators, the correlation among indicators and the correlation between harvesting intensity and the distance from harvesters’ homes to the harvesting areas were analysed through the non-parametric Kruskal–Wallis test and post hoc Mann–Whitney tests using the software R (Core Team, 2014) and Past version 2.17 (Hammer, et al. 2001). No difference among the harvesting intensities was considered.

**Figure 2.** Diagram showing the steps adopted in the methodology.
as the null hypothesis, which was rejected when \( p \leq 0.05 \).

To visualize the trade-offs among indicators of ecosystem services in controlled harvesting areas we plotted the average value (not considering outliers) of each indicator at the different harvesting intensities and drew tendency curves (values were standardized to fit on a 0–100 scale).

**Results and discussion**

**Correlation among indicators**

Harvesting intensity showed a positive correlation with the declared amount of harvested pinions and a negative correlation with the number of seedlings, number of germinated pinions, number of pinions consumed by fauna and carbon storage. In addition, significant correlations were found among all indicators except for the biomass of young trees.

The negative correlations between harvesting intensity and the indicators of *A. angustifolia* maintenance (number of seedlings and germinated pinions) were stronger than those with the other indicators (related to the regulating service and the maintenance of Araucaria Forest). This is most likely due to the direct effect of harvesting on the tree species. The positive correlation between the number of seedlings and the number of germinated pinions reflects the dependence of seedlings on the germinated pinions, which is essential for ensuring the provisioning service over the long term.

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**Figure 3.** Parameters measured in the field. a. Harvested pinions (PHAR); b. Seedlings (SEED); c. Germinated pinions (PGER); d. Pinions consumed by fauna (PFAU).

**Figure 4.** Vegetation structure of the study plots under different harvesting intensities. NH: No harvesting; L: Low; M: Medium; H: High; VH: Very high.
A negative correlation between the distance from a harvester’s home to the harvesting area and the number of pinions harvested ($p = 0.03$) was found, indicating a limitation in the capacity of transporting pinions by the harvester.

**Thresholds**

It is important to highlight the significantly lower number of seedlings and germinated pinions in areas without harvesting (Figure 5(d,e)). The high number of small trees (<5 cm in diameter) in these locations reduces light penetration and limits pinion germination and seedling development. The biomass of this vegetation class, however, was not measured in this study, and should be considered in future studies. In addition, the number of pinions consumed by fauna in these areas is higher than in the controlled harvesting plots (Figure 5(c)), which reduces the number of pinions suitable for regeneration, as suggested by Duarte, et al. (2002), Sanquetta, (1999) and Solórzano-Filho (2001).

Regarding the pinions consumed by fauna (Figure 5(c)), the greatest variation in the data were found under the low intensity, and especially in the areas without harvesting. This indicator also showed the lowest correlation with harvest intensity. Taking these two responses together, it is probable that factors other than pinion harvesting itself influence the presence of fauna in the region, especially in the least disturbed environments. For example, the thinning of the forest understory as well as trampling or noise likely more directly affect the animal species that feed specifically on pinions, and may also impact other animal species that depend on plant resources other than *Araucaria* pinions. This should also be considered in future studies. Prevedello, et al. (2016) also found that the availability of seeds of *A. angustifolia* had limited influence on the short-term demography of their main consumer group.

The biomass of young trees and the number of seedlings in the controlled harvesting areas tended to gradually decrease from the low to very high intensities (Figure 7(b,e)). A significant decrease was observed for the number of pinions consumed by fauna in the very high-intensity areas, and for the number of germinated pinions under the medium intensity (Figure 5(c,d)). Carbon storage was higher under the medium intensity (Figure 5(f)).

Unlike the predictions of Braat, et al. (2008), even at the very high harvesting intensity, the impact on the environment still did not affect the declared amount of pinions harvested. We should highlight, however, that the indicator response time is not immediate (Riley, 2000; De Groot, et al. 2010b). Pinion productivity can be reduced in the future due to *Araucaria* aging (which can take centuries) and the impossibility of population renewal caused by harvesting impacts at the medium, high and very high intensities when the number of germinated

![Figure 5](image-url)  
**Figure 5.** Indicators of ecosystem services for no harvesting (NH) and four controlled harvesting classes: low (L, 60–85%); medium (M, 85–95%); high (H, 95–97%); and very high (VH, above 97%). Different letters indicate a significant effect of the treatment ($p \leq 0.05$); n.s. indicates no significant difference. a) Harvested pinions; b) Biomass of young trees; c) Pinions consumed by fauna; d) Germinated pinions; e) Seedlings; f) Carbon storage.
Considering the service of climate regulation (estimated by carbon sequestration and storage), its optimum was not achieved in the less impacted systems in this study, as predicted by Braat, et al. (2008) or obtained by Van Oudenhoven, et al. (2015) for mangrove ecosystems, but rather occurred under the medium harvesting intensity (Figure 5(f)). This may be related to the low number and small size of the Araucaria trees in the plots of low and absent harvesting intensities.

At the very high intensity, despite the higher number of Araucaria trees per plot, the carbon stored is lower because there is a drastic decrease in the biomass of young trees and a greater thinning of A. angustifolia individuals with low diameter at breast height related to the management strategy in these areas. The impact of thinning will be reflected in the persistence of the forest because it harms species regeneration, including that of Araucaria trees and all other species. It will also limit harvesting activity – and thus the provisioning service – over the lifetime of the existing Araucaria trees.

The number of germinated pinions was the indicator that showed the greatest significant decrease as a result of lower harvesting intensities (the most sensitive indicator), which significantly decreased from 85% of the harvested pinions (medium-intensity areas). This can be defined as a key indicator in establishing a critical threshold for management, and a minimum percentage of pinions that should be left in the ground after harvesting should be determined to allow for the maintenance of supporting services over the long term (Riley, 2000; De Groot, et al. 2010b).

A continuous decrease in seedlings under higher harvesting intensities even after the stabilization of the number of germinated pinions could be explained by the trampling effect by harvesters on seedlings, as suggested by Sanquetta, et al. (2005).

**Trade-offs and landscape planning**

Considering harvesting at the medium intensity in only the controlled harvesting areas, the curves show trade-offs between the provisioning service and the other services (Figure 6(a)). As germinated pinions is the most sensitive indicator, with a sharp decrease already shown at the medium harvesting intensity, carbon storage increased at the low and medium intensities with a sharp decrease at the high and very high intensities.

The comparison among the different harvesting intensities (Figure 6(b)) shows that the very high intensity resulted in a marked decrease in all indicators except in the declared amount of harvested pinions. However, greater amounts of carbon stored and pinions consumed by fauna – which are regulating and supporting services, respectively – are found under the medium intensity. Under the low harvesting intensity, there are more germinated pinions (supporting service) and a better balance among all services.

Once the performance of each indicator has been analysed according to the different management intensities and trade-offs from the perspective of different scales, we can think about planning to ensure the balanced delivery of all services (Layke, 2009; Van Oudenhoven, et al. 2012). In this study, the indicators show that the critical point for preserving the supporting services is the transition from low to medium harvesting intensities, indicating that harvesting should not exceed 85% of the pinions produced. This threshold reflects a more cautious approach and is based on the significant decrease in the number of germinated pinions at that point as well as the decline in other services (Figure 5(a)). Therefore, this cautious approach considers the uncertainties of quantitative indicators, the high cost of ecosystem recovery and the possible irreversibility of the negative impacts at the human scale (Daily, et al. 1997). From the point of view of pinion provisioning, even if this threshold provides a lower amount, it is important to note that the categories of low harvesting intensity do not include percentages of harvested pinion that are lower than 60% because this is the point at which harvesting becomes advantageous for harvesters. It is also important to consider that pinion harvesting is a secondary and seasonal activity and not the harvesters’ main source of income.

As proposed by several authors (Braat, et al. 2008; Haines-Young, et al. 2012; Reyers, et al. 2012; Van Oudenhoven, et al. 2015b), rather than defining a single harvesting intensity for all the managed areas, it is worthwhile to develop strategies that balance trade-offs at a combination of different harvesting intensities throughout the collecting area, properly combining natural and managed ecosystems, so that different services are available within the landscape mosaic. This landscape composition should include low harvesting intensity sites that do not exceed the limits of the number of germinated pinions, number of seedlings and young tree biomass, which are necessary to guarantee forest maintenance, as well as medium harvesting intensity sites, which are able to provide higher carbon storage and enough pinions for fauna (Figure 6(b)). This strategy can contribute with the conservation of smaller fragments of Araucaria Forest, scattered across the landscape, which may contain numerous important species that contribute to regional biodiversity (Lacerda, 2016).
Spatial and temporal scales for management

Aiming at finding a sustainable planning and management strategy for natural resources, it is important to analyse the trade-offs among different classes of services (provisioning, regulating and supporting) from both a spatial and temporal perspective (MA 2003; Hein, et al. 2006; De Groot, et al. 2010b; Van Oudenhoven, et al. 2012).

Taking into account the temporal scale, Layke, (2009) and Van Oudenhoven, et al. (2012) consider indicators to be performance indicators when they indicate the benefits that are used in the present or near future, or state indicators when they denote the benefits the ecosystem can potentially generate in the distant future. From this perspective, the germinated pinions and seedlings, which denote supporting services, are state indicators because the services they reflect are distant from the final benefit (Figure 2), and the benefits are perceived over the long term. However, the pinions harvested compose a performance indicator because the service provided is close to the final benefit, which is perceived over the short term.

Because society tends to consider only short-term consequences, state indicators are generally not included in the planning of the use of natural resources. This study shows that areas that are more

Figure 6. Trade-offs among indicators of ecosystem services in controlled harvesting (CH) areas. a) Tendency curves; b) Scenarios of ecosystem services at each of the harvesting intensities. L: low (60–85%); M: medium (85–95%); H: high (95–97%) and VH: very high (above 97%). PHAR: Harvested pinions; BIOM: Biomass of young trees; SEED: Seedlings; PGER: Germinated pinions; CO2: Carbon storage; PFAU: Pinions consumed by fauna.
heavily used scored higher in performance indicators (which bring short-term benefits) to the detriment of the state indicators (which could guarantee benefits in the future, Figure 6(a)), as also observed by Balmford, et al. (2002). To address the trade-offs between the immediate satisfaction of human needs and the maintenance of an ecosystem’s ability to provide goods and services in the future, it is necessary to implement strategies that consider both state and performance indicators, and to balance the supply of ecosystem services with the resilience of managed landscapes (Foley, et al. 2005; MA 2005).

Considering the carbon already stored as a performance indicator, although there is high amount of carbon stored under the medium harvesting intensity – which indicates a high contribution already provided to climate regulation – the reduced biomass of young trees indicates a future decline in this service because older trees will die and there will be no new trees to replace them (Figure 6(a)). Under the low harvesting intensity, a greater amount of young tree biomass indicates a potential rise in carbon sequestration in the future (Stephenson, et al. 2014).

At the spatial scale, the benefits from provisioning services (the declared amount of pinions harvested) occur locally, while the benefits from regulating services (carbon storage) occur at the regional scale. Consequently, the provisioning service is delivered to a particular beneficiary, while the whole society benefits from climate regulation. These results corroborate the Deng, et al. (2016) study that shows the importance to take the ecosystem services trade-offs at different scales into consideration during decision-making for sustainable land use management to avoid negative effects and achieve synergetic outcomes. These factors make the benefit derived from food provisioning to be easily included in the market as it is exclusive and rival, which does not occur with stored carbon (De Groot, et al. 2010a). As predicted by Braat, et al. (2008) and Balmford, et al. (2002), the trade-off between these two services (Figure 6(a)) shows more private and marketable benefits in areas with a greater intensity of use in contrast to the unmarketable social benefits in the natural environments. According to these authors, the fact that benefits from natural environments retain the characteristics of public goods (not rival and non-exclusive) makes them not valuable. Therefore, the broad involvement of different stakeholders interested in the different services offered by the Araucaria Forest is essential in the decision-making process to avoid only private and marketable benefits being considered when planning for pinion harvesting in the study region.

Although the high intensity harvesting sites deliver more provisioning services, they generate a sharp drop in other services that can undermine the balance between state and performance indicators. Therefore, high-intensity harvesting should be carefully considered by harvesters when planning their activities because it directly affects the maintenance of species, and, consequently, pinion provisioning over the long term.

Conclusions
Our results indicate that different intensities of pinion harvesting impact the indicators of A. angustifolia maintenance more heavily than those related to ecosystem conservation and carbon storage. There is a critical harvesting intensity of up to 85% of the pinions produced above which even the pinion harvesting activity becomes jeopardized. Therefore, pinion harvesting in Araucaria Forest can be a sustainable practice provided it does not exceed that threshold. Low and medium intensities of pinion harvesting ensure provisioning services, which deliver local and short-term benefits, and maintain the regulating and the supporting services, which guarantee the continuity of all these services over the long term.

Disclosure statement
No potential conflict of interest was reported by the authors.

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