Update N°2 of the Project **Understanding Capuchin Bark Stripping Behaviour: from Conflict to Primate-Friendly Forestry (ID 42099-2)**

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Background and Objectives

Pine plantations represent simplified and often suboptimal habitats for many mammal species (Iezzi et al. 2019). In these landscapes, primate populations are additionally threatened by habitat constraints and frequent conflicts with producers. Nevertheless, at least 67 primate species worldwide use tree plantations for essential activities such as foraging and resting (Galán-Acedo et al. 2019). Among these, 13 species, including black capuchins, have been reported to strip bark from planted trees in order to consume inner tissues such as phloem and cambium. While this behaviour may represent an adaptive response to resource limitations, it can cause significant economic losses for timber producers and often results in human–primate conflict (Di Bitetti 2019).

To date, the ecology of primates living in plantation-dominated landscapes remains poorly understood, and there is no evidence-based explanation for why primates engage in bark-stripping in commercial forests. This knowledge gap has likely contributed to the implementation of ineffective (and sometimes counterproductive) primate-friendly forestry practices (Mikich & Liebsch 2014a, b). In response to bark-stripping damage, some producers have resorted to unethical and frequently illegal actions, such as killing monkeys, thereby threatening local primate populations (Di Bitetti 2019).

This project aims to improve understanding of the ecology of black capuchin monkeys (*Sapajus nigritus*) inhabiting pine plantations in northeastern Argentina in order to support their conservation and promote coexistence with forestry producers. Specifically, we follow a three-step approach:

> **Objective 1:** Understanding the trophic ecology and movement patterns of black capuchins living in pine plantation landscapes.
>
> **Objective 2:** Testing a primate-friendly mitigation strategy to reduce bark-stripping and promote coexistence between primates and producers.

Objective 3: Disseminating findings and co-developing management recommendations with producers, adapting solutions to different scales of production.

To achieve these objectives, we have conducted monthly monitoring of seasonal variation in bark-stripping intensity over three years, surveying bark-stripping across nearly 2,000 pine trees. In parallel, we examined its relationship with resource profitability, which, according to Optimal Foraging Theory (Stephens & Krebs 1986), can be understood as the ratio between energy intake from a given resource and the handling time required to obtain it. To assess this, we measured seasonal variation in pine phloem thickness and nutrient content (as proxies of energy intake), as well as the force required to peel off bark (as a proxy of handling time). Nutrient analyses are still ongoing, but all biological samples have already been collected.

In addition, we studied the movement and space use of six black capuchin groups across plantation landscapes and compared these patterns with long-term behavioural and ecological data from a nearby protected population in Iguazú National Park (Di Bitetti 2001, Janson et al. 2012, Tujague & Janson 2017). In 2022 and 2023, we conducted two experimental trials to test the effectiveness of diversionary feeding as a primate-friendly strategy to reduce bark-stripping (Kubasiewicz et al. 2016). These trials included four capuchin groups in 2022 and two groups in 2023.

Finally, we are organizing participatory workshops with producers and other stakeholders to discuss the feasibility, opportunities, and challenges of implementing diversionary feeding in real production contexts. The outcomes of this work will be compiled into tailored manuals addressing:

- The ecological and behavioural drivers of bark-stripping;
- The ecological importance of black capuchins and other primates in plantation landscapes; and
- Practical and sustainable management strategies to mitigate bark-stripping while supporting coexistence.

Objective 1

Understanding the trophic ecology and movement patterns of black capuchins living in pine plantation landscapes.

Trophic Ecology – Why do they bark-strip?

Methods

To understand when and why black capuchins strip bark from pine trees, we monitored bark-stripping and seasonal food availability over a two-year period.

Bark-stripping monitoring

Each month, we surveyed 2,000 pine trees across 40 transects placed within the home ranges of four capuchin groups. Pine stands were classified into three age categories according to the forestry rotation cycle: young (0–4 years), medium (5–9 years), and old (10–14 years). For each bark-stripped tree, we estimated the total area of bark removed as an indicator of inner bark consumption.

Profitability of inner bark (energy vs. effort)

To test whether pine inner bark becomes more attractive at specific times of the year, we measured seasonal changes in inner bark thickness and sugar content (as indicators of potential energy gain), and how difficult the bark is to peel off (as an indicator of the effort required to access it). Measurements were taken approximately every six weeks across 28 pine trees of different ages, located within the same capuchin group areas.

Native fruit availability and energy

Because capuchins naturally rely on fruits, we also monitored how much fruit was available in nearby native forests, and estimated its seasonal energy value. This was based on repeated surveys of key fruiting tree and liana species consumed by capuchins, combined with measurements of fruit sugar content.

These surveys allowed us to evaluate two alternative hypotheses: (1) the inner bark profitability hypothesis, which predicts that pine inner bark becomes a seasonally high-quality resource and is consumed even when native fruits are still available; and (2) the fallback food hypothesis, the most common explanation in the literature, which proposes that pine inner bark is a low-quality resource that is consumed mainly when preferred native foods are scarce.

Key results

Our results show that seasonal changes in pine inner bark profitability were the strongest predictor of bark-stripping patterns, performing better than native fruit energy availability alone. In other words, capuchins appear to bark-strip mainly when pine inner bark becomes a temporarily "high-return" resource, rather than simply when fruits are scarce. Importantly, bark-stripping was highly concentrated in space and time: it occurred predominantly in medium-aged pine stands and peaked during late winter and early spring (mainly from July to

late September) (Fig. 1). This clear concentration is highly valuable for management, as it allows producers to anticipate when and where bark-stripping is most likely to occur and to better plan targeted mitigation actions, an approach we later applied and tested under Objective 2.

General Conclusions

Seasonal variation in pine inner bark profitability was the strongest predictor of bark-stripping patterns. Native fruit availability and energy also varied seasonally and partially overlapped with the bark-stripping peak, but these changes did not fully explain bark-stripping and were not as strong a predictor as inner bark profitability. Together, this suggests that although seasonal declines in native foods may contribute to the context in which bark-stripping occurs, capuchins are not simply responding to food scarcity. Instead, they appear to actively select pine inner bark when it becomes a temporarily profitable resource, supporting the view that bark-stripping reflects a strategic foraging decision rather than a purely fallback response. Moreover, bark-stripping is concentrated in specific stand age classes and specific months, which is key for planning and implementing targeted management strategies (Objective 2). This section is part of a research article submitted to Forest Ecology and Management, currently under revision.

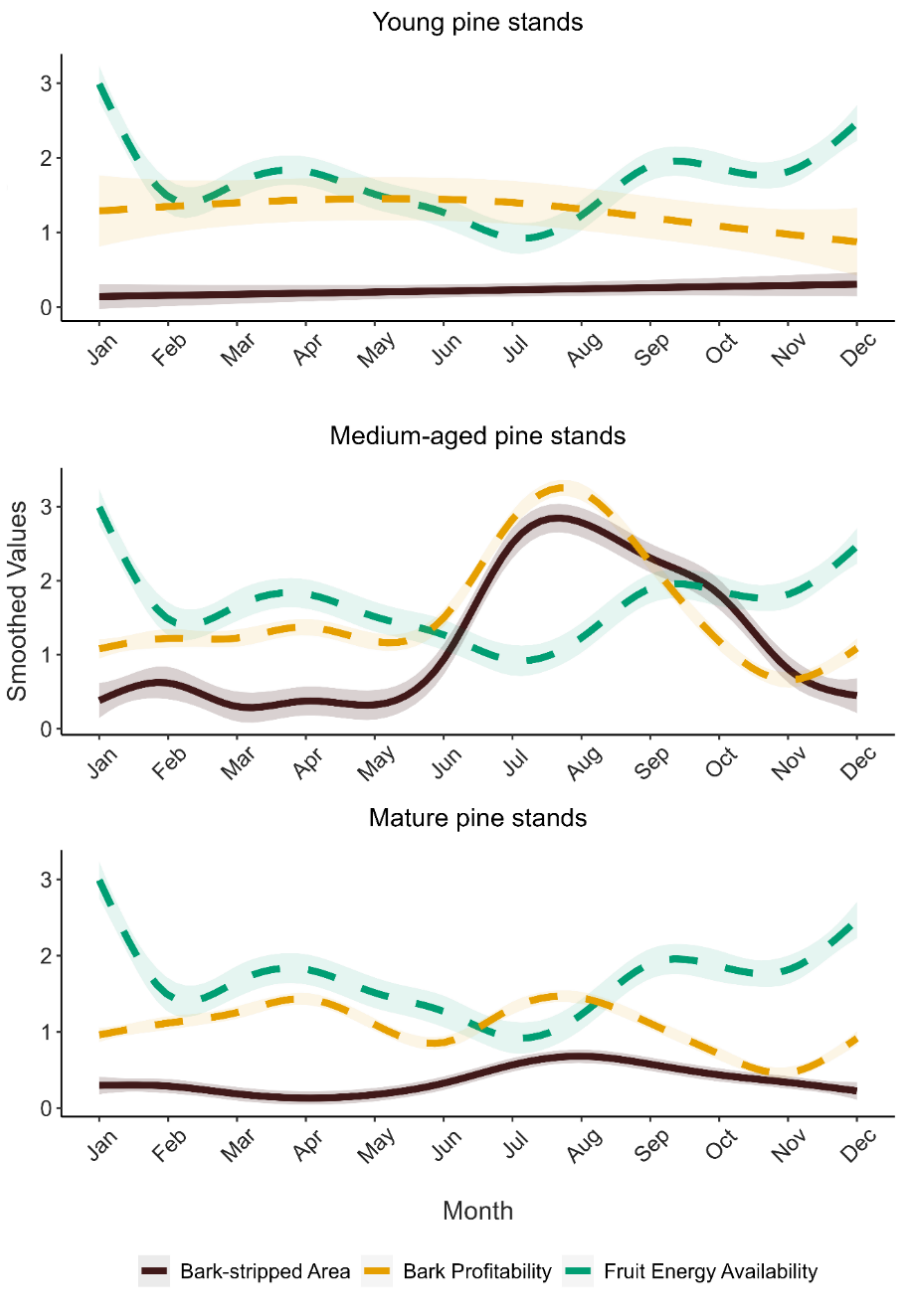

Figure 1. *Seasonal patterns of bark-stripping by black capuchins (Sapajus nigritus) in Pinus taeda plantations in northeastern Argentina, showing how bark-stripping intensity relates to changes in pine inner bark profitability and native fruit energy availability across different stand ages (young, medium-aged, and mature). Lines show seasonal trends with confidence bands.*

Movement Ecology – How capuchins navigate pine plantations?

Methods

To understand how black capuchins navigate pine plantation landscapes, we analyzed movement data from groups living in pine plantations and compared them with groups living in nearby protected native forest (Iguazú National Park).

In addition to other movement analyses (see Zárate et al. 2025), we specifically examined:

- Space use patterns of groups living in Iguazú National Park vs groups in pine plantations
- Seasonal changes in movement patterns across the year, and whether movement states shift during periods when bark-stripping peaks.

This allowed us to evaluate how capuchins adjust their space use in plantation landscapes, and whether bark-stripping periods are associated with more foraging-like movements, greater use of certain pine stands, or changes in the way groups move between native forest fragments and plantations. More details in Zárate et al. (2025).

Key Results

Capuchin groups living in pine plantations used much larger home ranges than groups in Iguazú National Park. On average, plantation home ranges were almost three times larger (≈392 ha) than those in the protected area (≈134 ha). Although plantation home ranges were dominated by pine stands (around 70% of the area), the remaining native forest fragments were a key component of their space use. Home range size slightly increased with group size, but not with seasonal fruit availability, and group sizes were similar between plantations and the protected forest.

Core areas (the most intensively used zones) also tended to be larger in plantations. However, unlike overall home ranges, plantation core areas were composed mostly of native forest fragments, even though these fragments represent only about one fifth of the landscape (Fig. 2).

Finally, movement behaviour changed seasonally in relation to bark-stripping. Capuchins showed the highest bark-stripping intensity between July and October, concentrating on medium-aged pine stands. During this period, groups were more likely to remain in a "resident" movement mode when they were closer to medium-aged stands, suggesting a direct link between seasonal

bark-stripping peaks and how capuchins navigate and use plantation areas (Fig. 3).

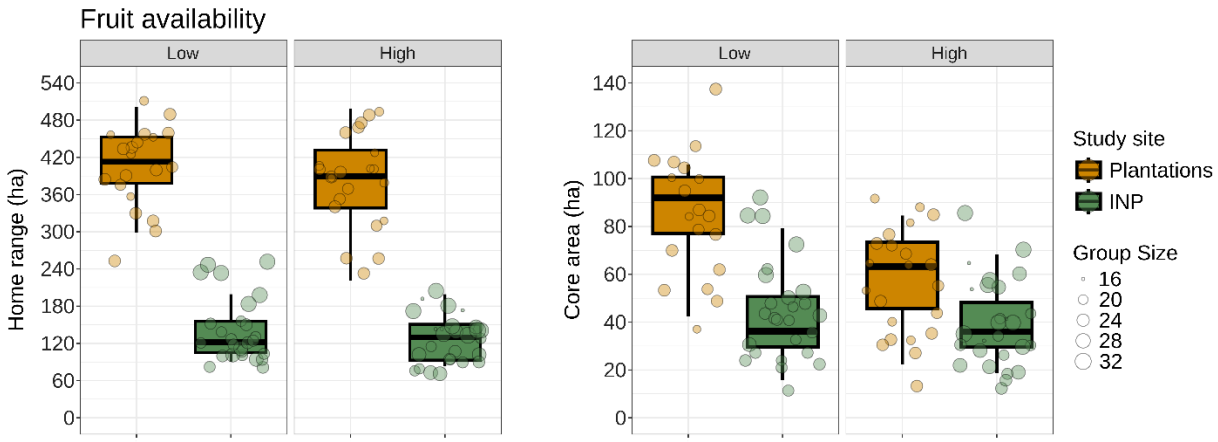

***Figure 2**: Monthly auto-correlated kernel density estimators (AKDE) for 95 % (home ranges, left panel) and 50 % isopleth (core areas, right panel) of black capuchins (Sapajus nigritus) in pine plantations (orange) and Iguazú National Park (INP, green) across low and high ripe fruit availability seasons. Point size reflects group size (i.e. number of individuals). The middle line within each box represents the median.*

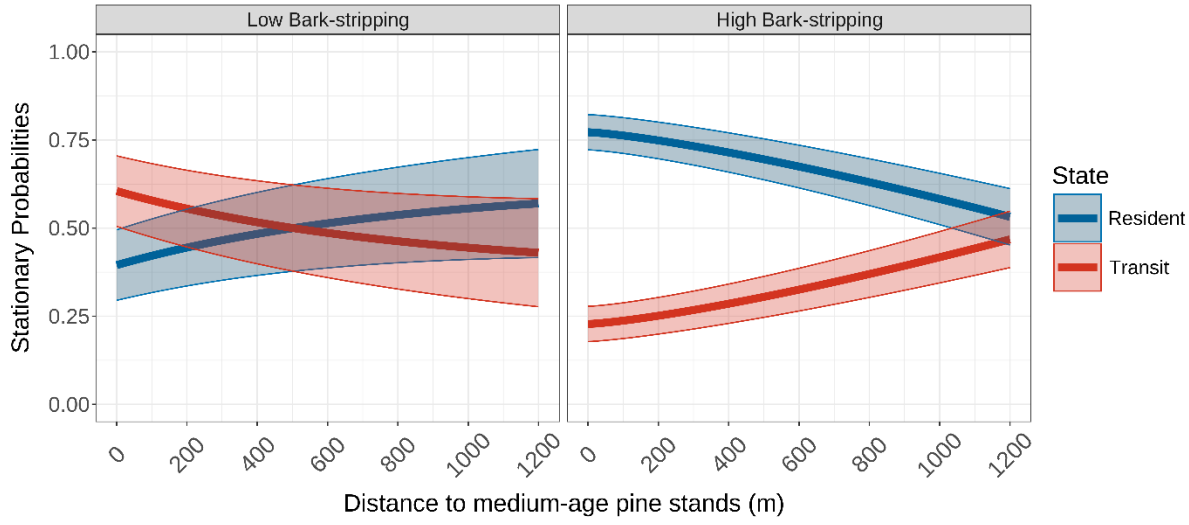

***Figure 3.** Predicted stationary probabilities for Resident and Transit states of black capuchins (Sapajus nigritus) in pine plantations from two-state Hidden Markov Models. Lines represent mean probabilities; shaded ribbons indicate 95% confidence intervals. Results are shown relative to the distance to medium-aged pine stands (5–9 years old), comparing low vs. high bark-stripping periods (March–May vs. July–October).*

General Conclusions

Overall, these results suggest that pine plantation landscapes have a lower carrying capacity for black capuchins. Capuchins showed a strong dependence on scarce native forest fragments, highlighting the conservation value of maintaining these fragments and improving landscape connectivity.

Inner bark consumption also appears to strongly shape seasonal movement strategies, influencing how capuchins allocate time and energy during the bark-stripping peak. During this period, groups were more likely to show resident (foraging-like) movement behaviour when they were closer to medium-aged pine stands, suggesting a direct link between seasonal bark-stripping peaks and how capuchins navigate and use plantation areas (Fig. 3). This seasonal shift in movement patterns is consistent with the trophic ecology results (Fig. 1).

Together, this information contributed to the efficiently planning and evaluation of mitigation actions such as diversionary feeding (see Objective 2 for further details).

Objective 2

Experimental test of a mitigation strategy to reduce bark-stripping

Methods

Experimental design

We tested diversionary feeding (Kubasiewicz et al. 2016) during the period when bark-stripping peaks (early August 1st to October 20th). We ran trials with four capuchin groups in 2022, and repeated the experiment with two of these groups in 2023. Within each group's home range, we installed feeding platforms (25 per group, set in clusters of five) placed strategically to redirect daily travel routes away from medium-aged pine stands (the most vulnerable stands; Fig. 1). Platforms were baited daily with fruit (locally-grown bananas). To strengthen inference, we used a cross-over design: at the midpoint of the trial, groups switched between experimental (platforms available) and control (no platforms) conditions. We also included short habituation and dishabituation periods around each switch so animals could adjust to the presence/absence of platforms (Fig. 4).

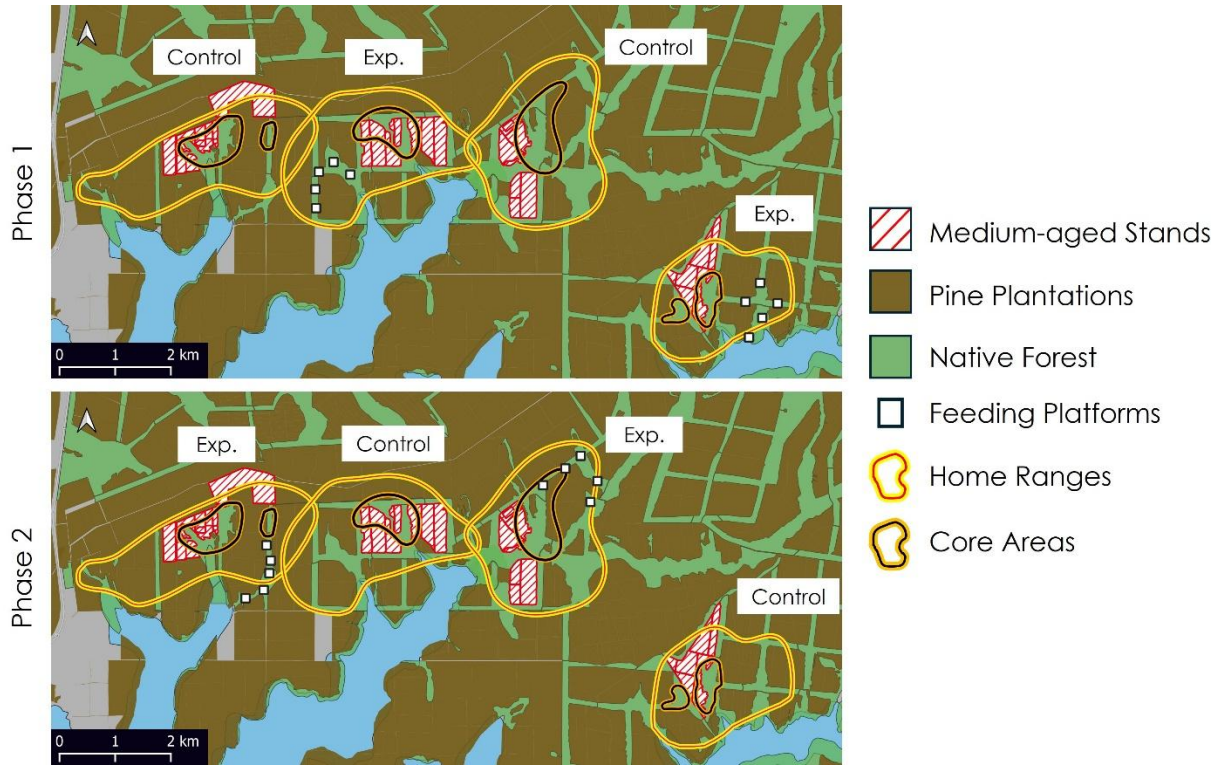

Figure 4. *Study area and experimental cross-over design used to test diversionary feeding during 2022 as a primate-friendly strategy to reduce bark-stripping. Maps show each group's home range and core area across two phases, switching between Control (no feeding) and Experimental (Exp.; feeding platforms available) conditions. Hatched areas indicate medium-aged pine stands (5–9 years old). White squares mark feeding platform sites, where each square represents a cluster of five platforms.*

Bark-stripping monitoring

In parallel, we monthly monitor 500 pine trees inside black capuchins home ranges, like done for objective 1. We then compared bark-stripping levels between periods/areas with versus without feeding platforms, focusing on whether the intervention reduced bark-stripping intensity during peak months.

Movement and space-use monitoring

To evaluate whether diversionary feeding changed how capuchins moved through plantations, we tracked one adult per group with GPS or VHF collars. Location data were collected throughout daylight hours, allowing us to compare habitat use and space-use patterns between control vs. feeding phases, especially use of native forest fragments versus medium-aged pine stands.

Key results

The diversionary feeding strategy produced a quick and clear behavioural response. Across groups, capuchins shifted their habitat use by an average of ~24% when feeding platforms were available, showing a consistent reduction in the use of pine plantations (especially medium-aged stands) and an increase in the use of native forest fragments.

Importantly, this movement change happened very rapidly: groups typically adjusted their space use within 5–10 days after the treatment switch. This shows that capuchins respond quickly to management interventions and that mitigation can work on short timeframes during the seasonal peak (Fig. 5).

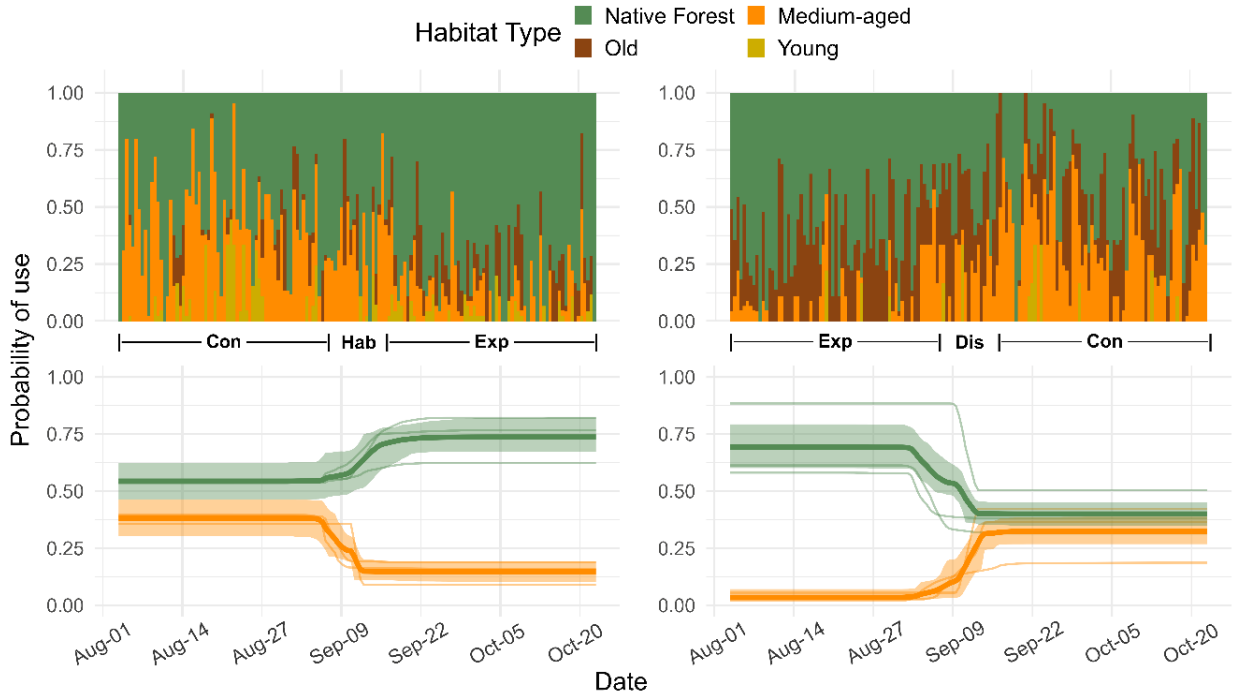

Figure 5. *Changes in habitat use by black capuchins (Sapajus nigritus) during the diversionary feeding experiment. The figure shows how groups shifted their daily space use when switching between Control (no feeding platforms) and Experimental (feeding platforms available) phases (including short habituation/dishabituation periods). Bars show the observed daily use of each habitat type (native forest and pine stands of different ages), while lines show the overall trend through time, highlighting how quickly groups adjusted their movements after the treatment switch.*

The experiment also resulted in a measurable reduction in bark-stripping. Transects with feeding platforms showed lower bark-stripping intensity compared to control areas, and overall bark-stripping levels were ~19% lower during experimental periods.

Together, these results indicate that a primate-friendly approach based on redirecting movements away from vulnerable stands during peak months can meaningfully reduce bark-stripping and offers a practical pathway to support coexistence between capuchins and producers (Fig. 6).

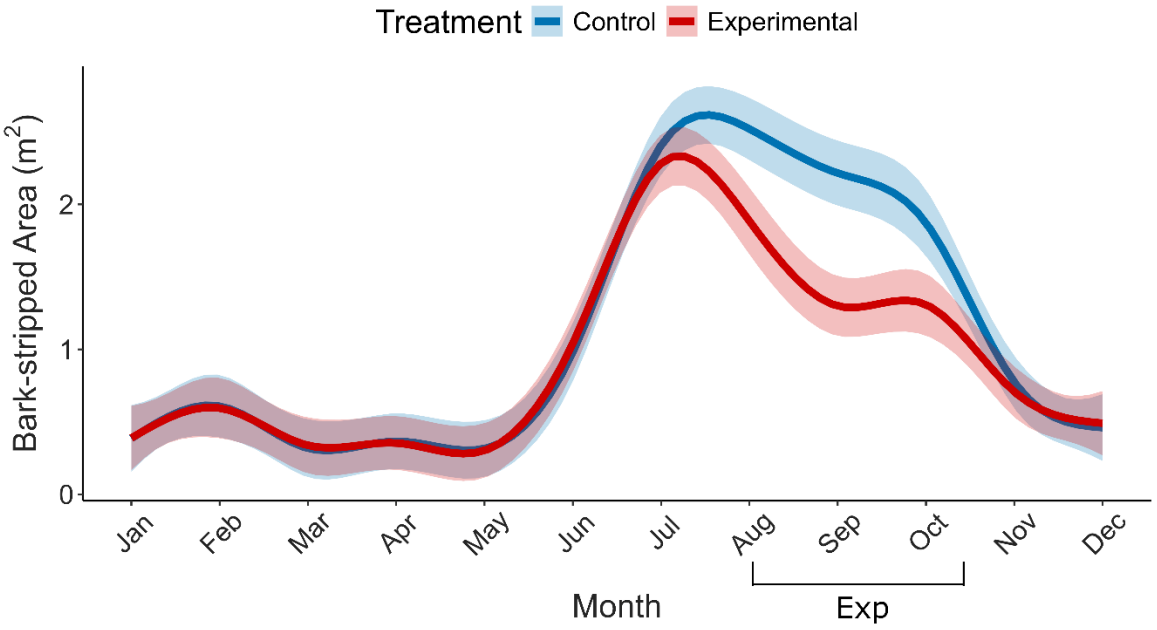

***Figure 6**. Seasonal bark-stripping intensity by black capuchins (Sapajus nigritus) comparing control periods (no feeding platforms) and experimental periods (diversionary feeding). The lines show the overall seasonal trend in bark-stripped area per transect, highlighting a lower bark-stripping intensity during months when feeding platforms were available. Shaded bands represent uncertainty around the trend.*

General conclusions

What worked, challenges, and refinements to share with producers

Our results show that diversionary feeding can be an effective and primate-friendly strategy to reduce bark-stripping in commercial pine plantations, when it is implemented during the seasonal peak and in a spatially targeted way. Capuchins responded quickly to the intervention by changing their movement patterns within days, and this behavioural shift was associated with an overall reduction of approximately 20% in bark-stripping intensity.

At the same time, our experiment highlighted key challenges and opportunities to improve effectiveness. First, the bark-stripping season may begin earlier than expected (e.g., July), meaning that mitigation efforts should cover the full seasonal window. Second, because neighbouring groups can potentially use the same pine stands, future strategies may be more effective if platforms are planned at the stand or landscape scale, rather than only within the home range of focal groups. Finally, capuchins showed a strong ability to move efficiently through pine stands, suggesting that platform placement must be carefully designed to reduce the chance that groups visit feeding sites and then return to vulnerable stands. Addressing these limitations in future applications is expected to further improve effectiveness and reduce bark-stripping.

These lessons provide a practical experience for guiding Objective 3, where we will work collaboratively with forestry producers to discuss feasibility, costs, and logistics, and to refine and adapt this approach into realistic management guidelines that can be implemented at different production scales

This objective was conducted in collaboration with Dr. Eliezer Gurarie during a three-month internship that I completed at the State University of New York (USA). The resulting study will be submitted to the *Journal of Applied Ecology* in March 2026.

Objective 3

Disseminating results and refining recommendations with forestry producers

A core goal of this project is to ensure that our ecological findings and mitigation results are translated into practical tools for forestry producers, supporting coexistence between black capuchins and production activities. As planned in the original proposal, we focused on sharing results through direct dialogue with producers and co-developing communication materials adapted to different production contexts.

In addition, we shared project outcomes in open community talks in May 2025, attended by a diverse audience including tourism guides, local entrepreneurs, and members of the general public. These outreach activities helped broaden awareness of the conflict and highlighted that primate-friendly strategies can reduce bark-stripping while supporting conservation goals.

To improve accessibility of our findings, we are currently developing visual outreach materials together with an experienced illustrator. These products are being compiled into tailored manuals and infographics specifically designed for

forestry companies. The infographics will be displayed in practical locations such as guard posts and company offices, supporting decision-making during the seasonal peak when bark-stripping risk is highest.

We have also produced initial technical infographics aimed at scientific dissemination (Figs. 7 and 8), which will serve as a foundation for translating the information into less academic and more applied communication products, including manuals and social media outreach. This final material will be in English, Spanish, and Portuguese.

Finally, we are organizing a participatory workshop in March (2026) at the Universidad Nacional de Misiones (Faculty of Forestry Sciences). This event will include approximately 40 participants representing large-, medium-, and small-scale producers, and will focus on discussing the feasibility and logistics of implementing diversionary feeding at different scales. This workshop is being co-organized with Paula Tujague, a key collaborator who works closely with forestry producers across Misiones and is leading research on producer perceptions of bark-stripping. Her strong and ongoing relationship with producers is essential both for outreach and for ensuring long-term follow-up, implementation, and refinement of primate-friendly practices, including the development of predictive risk maps to support targeted management.

Through these activities, we will ensure that the project generates not only ecological knowledge, but also realistic and scalable recommendations that can be adopted by forestry stakeholders in Misiones.

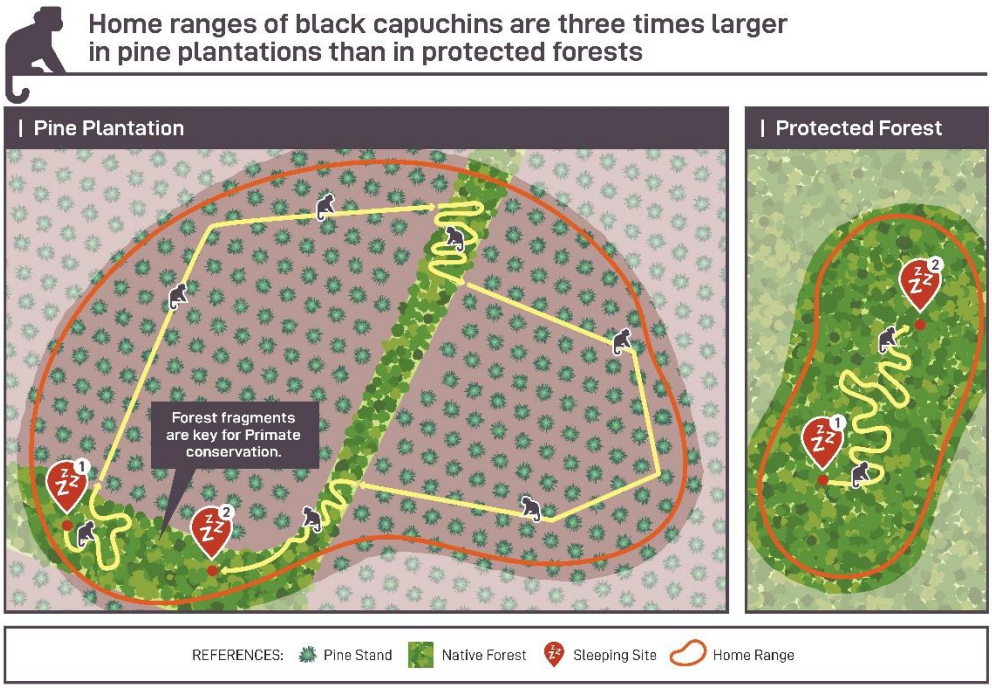

Figure 7. *Infographic illustrating how black capuchins (Sapajus nigritus) move and use space in pine plantation landscapes compared to protected native forest. The figure highlights the larger home ranges required in plantations and the key role of native forest fragments within production landscapes. This technical version will be adapted into a simplified, producer-oriented format to support outreach activities, communicate the main challenges capuchins face in plantation mosaics, and emphasize their ecological importance (e.g., seed dispersal).*

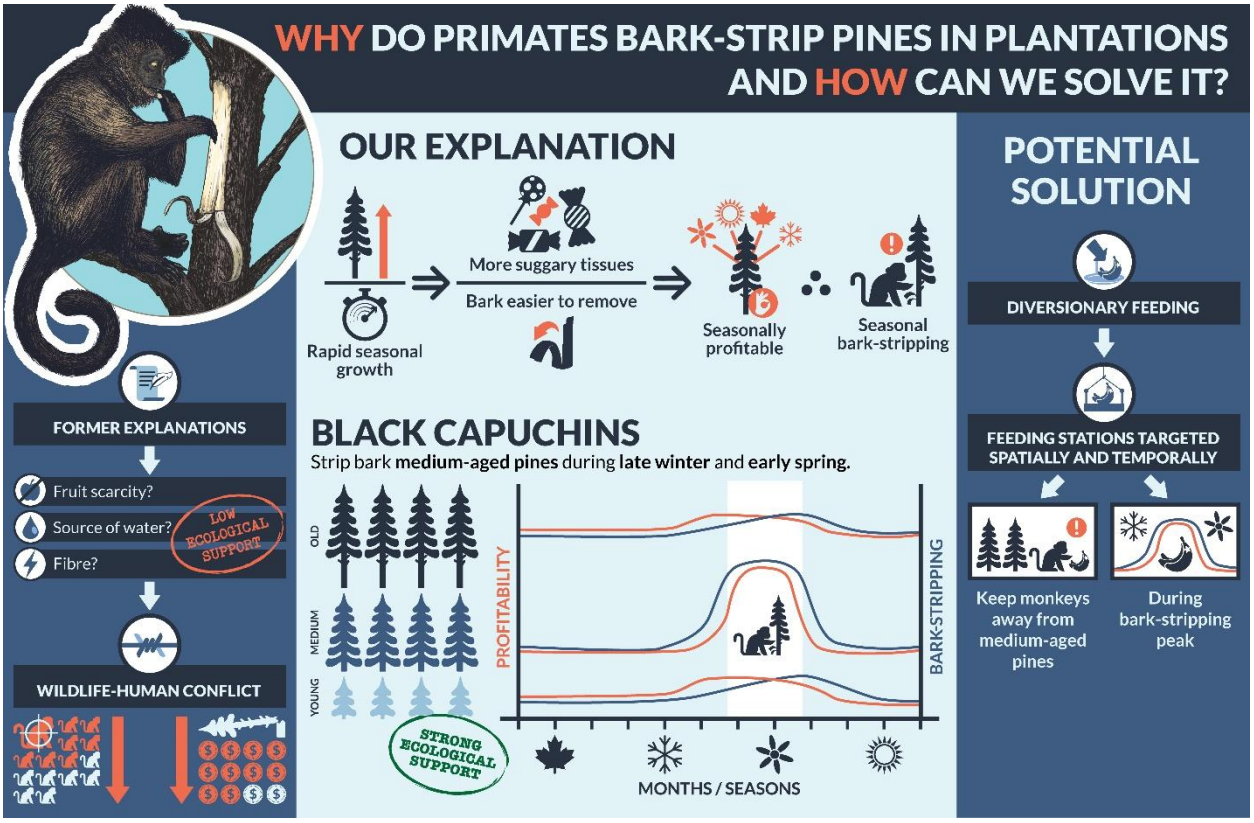

Figure 8. *Technical infographic summarizing our evidence-based explanation for why black capuchins (Sapajus nigritus) bark-strip pine trees in plantations, and how this understanding can be translated into a practical management strategy. The figure highlights the link between seasonal changes in inner bark profitability, peak bark-stripping periods, and the proposed primate-friendly solution of diversionary feeding targeted in time and space. This academic version will be adapted into simplified outreach materials (manuals and infographics) to discuss drivers of bark-stripping and feasible mitigation options with forestry producers and other stakeholders. Illustration: Walter Policelli.*

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