Impacts of Agriculture on Biodiversity within Neotropical Forests

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The ever-increasing demand for agricultural products has resulted in significant forest loss due to land conversions (Gibbs et al., 2010). In fact, the Food and Agriculture Organization of the United Nations (2021) indicated that almost 90% of deforestation at a global scale resulted from agricultural land conversions. For Neotropical Forests in particular, this scale of deforestation has substantial negative consequences in terms of degraded land and ecosystem services, biodiversity loss, and global warming (García-Barrios et al., 2009; Lewis, Edwards, & Galbraith, 2015).

Tropical forests provide habitats for 62% of global terrestrial vertebrate species with 29% of those species being endemic, and more than 20% being at risk for extinction. The neotropics account for 90% of the species diversity within tropical forests (Pillay, 2022). It is critical to preserve the biodiversity within neotropical forests because they serve as the foundation for the ecosystem services and functions that support human well-being (Pillay, 2022). As we continue to scale agriculture to meet demand, we need to consider these significant tradeoffs.

The purpose of this paper is to synthesize scholarly research pertaining to agricultural impacts on Neotropical Forests, particularly as it relates to species richness and culture transmissions, and to provide an evaluation of the current state with recommendations for practice and future research. It is important to note that the literature search was limited primarily to peer-reviewed journal articles, but some NGO and government articles are included as supplemental. Also, research focusing on impacts of agriculture on Neotropical forests was not limited in terms of publication date, but research focusing on mitigation strategies was limited to recent articles (published between 2018-2022) to ensure that the most relevant strategies and theories were synthesized.

Neotropical Deforestation and Species Richness and Abundance

Several studies have been conducted on the relationship between neotropical deforestation and species richness, but there are some conflicting results that may be explained by differences across the studies, such as the species observed or the spatial scale or distribution. For example, some researchers found negative effects on species richness as a result of land conversion to pastures while other studies did not. However, it is difficult to know why there were differences between the studies given that multiple variables differed across the studies (e.g., species, geography, spatial scale). Therefore many of the variables are confounded, which does not allow for the isolation of one variable at a time.

One research study that found significant differences in species richness when comparing land-use types was conducted by Alvarez-Alvarez et al. (2022). The researchers examined taxonomic diversity of birds across different cloud forest landscape use types in Mexico and found that species richness and diversity depended on land-use type as well as the spatial scale (local versus landscape level). Specifically, species richness of birds was greatest in late forests followed by coffee plantations and then cattle pastures; late forests and coffee plantations were more similar to each other than to cattle pastures. And the effect of spatial scale depended on the ecological requirements of the species resulting in some species being impacted at multiple spatial scales.

Similar to Alvarez-Alverez et al. (2022), Dunn (2004) found that land-use type moderated the effect of land conversion on species richness in that forests converted for agricultural purposes decreased species richness for three species observed (birds, lepidoptera, and ants) although logging did not affect species richness, and selective logging had a significantly lower effect on faunal diversity when compared to forest conversions. Dunn’s research consisted of analyzing 34 studies on tropical forests across the Americas, Asia, and Africa.

In contrast to Alvarez-Alverez (2022) and Dunn (2004), Amici et al. (2019) studied six forest and three pasture sites in Monteverde, Costa Rica and found that species richness was not different between land-cover types, although community composition (e.g., proportion of species relative to total number of species) differed significantly. Similarly, Picone (2000) examined species richness and abundance of spores in Nicaragua and Costa Rica after converting forests to pastures and found that there was no significant decline in species richness, and spore abundance was greater in pastures.

These results suggest that converting forests to pastures likely has a negative impact on species richness, but not across the board. Research from Ribeiro et al. (2019) on the effects of intensive agriculture and frequent use of fertilization on two different functional tree groups supports this conclusion. Their research found that intensive farming benefited the abundance of the sun-loving tree species but resulted in a decrease of species richness for the shade-tolerant tree species. These findings indicate that when converting land to pastures, we need to consider the species affected and their ecological requirements.

Neotropical Deforestation and Cultural Transmission

Cultural transmission has been found to be a significant factor in behaviors observed and behavioral differences within species (Hart et al., 2018; Keith & Bull, 2017). There are two primary ways in which culture can be transmitted, which includes horizontal transmission (learning from the same generation) and vertical transmission (learning from the prior generation).

Deforestation for agricultural purposes can have deleterious effects on cultural transmission. For example, Hart et al. (2018) found that deforestation influenced the cultural transmission of birdsongs in Costa Rica. Specifically, birds that learn culturally (oscine passerine) had declines in birdsong diversity when compared to those that do not learn culturally (suboscine passerine). Based on these results, the authors determined that learned cultural elements are negatively affected by fragmentation, making cultural diversity a key outcome of interest when designing conservation solutions.

Another example of cultural transmission was discussed in Keith & Bull's (2017) research where it can have both negative and positive effects. For example, vertical transmission was found to limit the behavior of a captured killer whale in terms of refusing to eat fish, which caused starvation. However, horizontal transmission was found to extend the behavior of two captured killer whales who ate the fish because they had observed other whales eating fish. The researchers concluded that one method for increasing horizontal transmission is to add a new population of species (conspecifics) to foster learning and potentially expand range shifts. However, this approach is not always feasible because of a lack of conspecifics of the target species.

Deforestation and Climate Change

Deforestation also affects climate change, which in turn can have its own deleterious effects on biodiversity (Keith & Bull, 2017). One obvious and significant effect of climate change is the potential impact it can have on habitat suitability. For example, many species have specific distributional ranges for mating and foraging, and their habitats are being negatively impacted by climate change. The shift in a species' suitable range can have negative impacts on a given species foraging and reproduction capabilities, particularly because the climate is changing at a faster rate than these species can naturally adapt and evolve to environmental and ecosystem changes.

Strategies to Support Biodiversity

One commonality across all the research reviewed is the belief that a sense of urgency needs to exist to solve the deforestation and the biodiversity problem. What differed across the research studies was the type of mitigation strategy used or suggested, which depended on the associated objective.

Communicating the importance of biodiversity, why it matters, and how it aligns with individual values and interests is the first place to start. We need to get people to care by finding common ground and connecting the problem to what people care about in their day-to-day lives (Christiano & Neimand, 2018). For example, Law et al. (2021) point out the substantial benefits associated with biodiversity and carbon, which can be more broadly communicated and linked to personal interests and behaviors. For example, Christiano & Neimand (2018) discuss how we can encourage people to eat less meat and dairy by relating that behavioral change to obtaining stronger and healthier bodies, using vegan elite athletes as examples.

In addition to linking the problem to what people care about, we also need to consider land use strategies. Law et al. (2021) point out that current zoning laws have the potential to lead to negative socio-ecological outcomes. What they suggest is to consider landscape strategies that support high landscape-scale multifunctionality. Similarly, Alfaro et al. (2022) suggest enacting rural policies that support the sustainable use of biodiversity, and to adopt business models that can simultaneously support the economic development of local rural communities (e.g., tourism, small to medium productive enterprises, family farms). Alfaro et al. (2022) highlight the importance of developing both social and natural capital within communities.

Finally, Rozendaal et al. (2019) purport that natural regeneration has the potential to be an effective strategy for maintaining tree biodiversity. However, species composition can take up to centuries to recover. Therefore, we need to consider the objective of the strategy when selecting the optimal approach. Rozendaal et al. (2019) also point out that conservation practices may be more effective when they include both old-growth and secondary forests to maximize biodiversity potential.

The research discussed in this section is just a sample from a larger body of research on this topic. These strategies, for the most part, cover a broad spectrum of strategies that can be classified into the following categories: (1) messaging strategy - getting people to care, (2) site selection for regeneration or land conversion for agricultural purposes, which includes policies that govern these selections, and (3) specific uses of the land once the site is selected. What is still needed is a more strategic discussion of what to do when given specific biodiversity objectives, and a more tactical discussion on how we can implement these strategies.

Discussion

The importance of biodiversity is universal and we therefore need to consider maximizing biodiversity at the local and landscape level. The consequences of biodiversity decline are substantial and severe. As such, we need to take immediate action. There are three major factors to consider when mitigating biodiversity loss, and those pertain to messaging strategy, site selection, and land use of the selected site. In this section, recommendations for practice are discussed followed by recommendations for future research.

Recommendations for Practice

When designing solutions, we need to first consider our key performance indicators (KPIs) or desired outcomes. For example, some KPIs to consider include species composition in addition to species richness, extent of cultural transmission and behavioral changes across time and space, ecosystem services such as carbon sequestration potential, water quality, soil quality, air quality, minimizing flooding, etc., and the development of both natural and social capital.

In addition to identifying measurable KPIS, the methodological approach is also of critical importance. Some methods to consider in practice include combining old and new forest growth to maximize biodiversity, factoring in the role of climate change and how that may impact species' ranges, considering the importance of spatial scales (local versus landscape scale) and elevation gradients when selecting sites, and using quantitative modeling and optimization techniques to identify optimal sites.

Recommendations for Future Research

While this study provided suggestions for practice, there is still a lack of clarity and research around which specific strategies to implement given specific biodiversity objectives, and how to implement those strategies. One recommendation for future research is to conduct a meta-analysis on the studies focusing on deforestation and species richness since different findings were found across different studies, and determine if a playbook can be written as a result. In addition, there needs to be more exploration and validation of climate change forecasting methods. While climate models are directionally accurate and have high levels of accuracy and precision at larger scales, they have greater limitations at smaller scales (Flato et al., 2013), which impacts our ability to select specific sites based on climate assumptions. Finally, more exploration of landscape strategies that support high landscape-scale multifunctionality and how they can be implemented is needed.

Conclusions

Agriculture is a significant driver of deforestation of neotropical forests, which leads to declines in biodiversity and degraded ecosystem services. The severity of the problem calls for a sense of urgency in designing conservation initiatives that mitigate these losses. The findings within this synthesis paper indicate that biodiversity is adversely affected by forest conversions in relation to species richness, cultural transmissions, and community composition. As part of the solution, conservationists need to consider their methods for communicating the problem and getting people to care, in addition to how conservation or agricultural lands are selected and used. However, more research is needed to better understand how and why forest conversion as a result of agriculture impacts different species differently, and how other factors such as spatial scale, elevation gradients, and climate change interact with those impacts.

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