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Angelet Sylvéus

Mudança do uso e cobertura da terra no Parque Nacional Macaya, Haiti

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O presente trabalho em nível de Doutorado foi avaliado e aprovado, em 22 de novembro de 2024, pela banca examinadora composta pelos seguintes membros:

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Prof. Nivaldo Peroni, Dr.
Orientador

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RESUMO

As florestas tropicais abrigam uma grande biodiversidade e garantem o fornecimento de múltiplos serviços ecossistêmicos que asseguram o bem-estar humano. No entanto, perturbações antropogênicas e naturais cada vez mais intensas e mais frequentes têm ameaçado a resiliência destes ecossistemas. As florestas tropicais no Sul do Haiti apresentam um alta biodiversidade e fornecem serviços ecossistêmicos vitais para as populações locais. Contudo, a intensificação da agricultura itinerante e a exploração madeireira têm alterado seus atributos ecológicos ao longo do tempo. Além disso, estas florestas têm sido impactadas por eventos de furacão de diferentes intensidades. A combinação destas diversas perturbações pode levar o sistema a um estado degradado permanente e consequentemente, a uma redução da sua resiliência. Com o objetivo de proteger estas florestas, foi criado o Parque Nacional Macaya (PNM). Porém, estudos que avaliam os impactos da interação entre essas múltiplas perturbações são escassos. Nesse contexto, o presente trabalho procurou entender como a agricultura itinerante, a exploração madeireira e os eventos de furacão afetam a resiliência do Parque Nacional Macaya no sul do Haiti. Para alcançar esse objetivo, avaliamos as mudanças na cobertura do solo no PNM de 1985 a 2021 usando imagens de satélite Landsat e procuramos entender como a agricultura itinerante e a exploração madeireira interagem com os furacões e quais são os principais feedbacks que contribuem para reforçar ou enfraquecer a resiliência das florestas tropicais no PNM. Também foi integrado à análise espacial dados de entrevistas semiestruturadas, aplicadas juntos aos moradores locais, em combinação com uma revisão bibliográfica. Os resultados indicaram um aumento de 11,36% na cobertura florestal e uma redução de 75,34% na cobertura de terras agrícolas, apesar da passagem de sete furacões na região durante o período estudado. A regeneração das florestas refletiu a ação de iniciativas locais, como a implementação de um novo zoneamento, assistência financeira e técnica aos agricultores e de programas de conservação e restauração promovidos pela criação do PNM em 1983. Essas intervenções aparentemente contribuíram para aumentar a resiliência do sistema. No entanto, foram identificados alguns feedbacks que podem potencialmente manter o sistema em um estado degradado. O feedback positivo da erosão revela que a agricultura itinerante e a exploração de madeira reduzem a cobertura de árvores, o que aumenta a erosão do solo, isso reduz a fertilidade do solo que, por sua vez, diminui a taxa de crescimento das árvores, desacelerando assim a regeneração dos solos. Esses mecanismos tornam as florestas mais vulneráveis aos furacões que podem acelerar a degradação em curso. Portanto, o estudo aprofundado e contínuo e o devido manejo desses feedbacks são críticos para reforçar a resiliência do sistema no contexto das mudanças climáticas.

Palavras-chave: agricultura itinerante; exploração madeireira; resiliência; floresta tropical; furacão; feedback.

ABSTRACT

Tropical forests are home to a high biodiversity sustaining the provision of multiple ecosystem services that ensure human well-being. Nonetheless, increasingly intense and frequent anthropogenic and natural disturbances have been threatening the resilience of these ecosystems. Tropical forests in southern Haiti harbor a high biodiversity and provide crucial ecosystem services to the local communities. However, intensification of shifting agriculture and logging have been modifying their ecological attributes over time. In addition, these forests have been impacted by hurricane events of different intensities. The combination of these various disturbances can bring the system to a permanent degraded state, and consequently, to a reduction of its resilience. Aiming to protect these forests, the Macaya National Park (MNP) was created. Nevertheless, studies assessing the impacts of interaction between these multiple disturbances are scarce. In this context, the present study sought to understand how shifting agriculture, selective logging and hurricanes affect the MNP resilience in southern Haiti. To reach this goal, we evaluated land cover changes in the MNP from 1985 to 2021 and we sought to understand how shifting agriculture and selective logging interact with hurricanes and what are the major feedbacks contributing to enhance or lessen tropical forests resilience in the MNP. We also integrated to spatial analysis data of semi-structured interviews, applied to local dwellers, in combination with a literature review. Our results indicated an increase of 11.36% of forest cover and a decrease of 75.34% of agricultural lands, despite the occurrence of seven hurricanes in the region during the studied period. Forest regeneration reflected the action of local initiatives, such as the implementation of a new zoning, financial and technical assistance to the farmers and conservation and restauration programs promoted by the MNP creation in 1983. Such interventions apparently contributed to increase the system resilience. However, we identified some feedbacks that can potentially hold the system in a degraded state. The erosion positive feedback reveals that shifting agriculture and selective logging reduce tree cover, which increases soil erosion, this reduces soil fertility which in turn decreases tree growth rate, thus slowing down soil regeneration. These mechanisms make forests more vulnerable to hurricanes which can accelerate ongoing degradation. Therefore, extensive and continuous studies and proper management of these feedbacks are crucial to strengthen the system resilience in the context of climate change.

Keywords: shifting agriculture; logging; resilience; tropical forest; feedback.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

1 INTRODUÇÃO GERAL

As florestas tropicais desempenham um papel crucial na manutenção da biodiversidade global, na regulação do clima e na provisão de serviços ecossistêmicos essenciais (Barlow et al., 2018; Millenium Ecossystem Assessment, 2005a). No entanto, esses ecossistemas têm enfrentado perturbações cada vez mais intensos e mais frequentes devido tanto a atividades antropogênicas quanto a eventos climáticos extremos (Curtis et al., 2018; Malhi et al., 2014; Song et al., 2018). Essas perturbações podem alterar a biodiversidade, a estrutura e o funcionamento destas florestas e consequentemente o fornecimento dos serviços ecossistêmicos (Johnstone et al., 2016; Millenium Ecossystem Assessment, 2005b).

Dos múltiplos distúrbios antropogênicos que afetam as florestas tropicais, a intensificação da agricultura itinerante, com ciclos de pousio mais curtos e fases de usos mais longas, e a exploração madeireira estão entre os mais importantes e mais difundidos (Kadoya et al., 2022; Pinheiro et al., 2016; van Vliet et al., 2012). A agricultura itinerante ou agricultura de corte e queima é um sistema de produção onde os agricultores abrem diversas pequenas clareiras no meio da floresta derrubando a vegetação e queimando os resíduos (Malmer et al., 2005; Mertz et al., 2009). As cinzas são incorporadas ao solo e uma variedade de espécies são cultivadas por um período relativamente curto, depois do qual essas parcelas são abandonadas para regenerar-se naturalmente e outras parcelas são abertas para novos ciclos de cultivo (Jakovac et al., 2016; Mertz et al., 2009). A exploração madeireira muitas vezes é feita por meio de corte seletivo de árvores de espécies de alto valor comercial e as toras de madeira são transportadas para as serrarias onde serão processadas (Asner et al., 2005; Shenkin et al., 2015). Durante esse processo, outras árvores são também afetadas devido à abertura de estradas para o transporte e de pequenas áreas para o armazenamento temporário e carregamento da madeira (Uhl et al., 1991).

A agricultura itinerante é um sistema de produção alimentar que tem influenciado a estruturação de paisagens tropicais há milênios (Arroyo Kalin 2012; Iriarte et al. 2020), entretanto a intensificação de suas fases de uso e pousio pode provocar uma redução da cobertura florestal, perda de biodiversidade (Ding et al., 2012), mudança na composição de espécies (Pereira Cabral Gomes et al., 2020), alteração da hidrologia (Malmer et al., 2005) e a degradação dos solos (Hölscher et al., 2005). Essa intensificação pode ser induzida por mudanças socioeconômicas como o aumento da população (Padoch & Pinedo-Vasquez, 2010), o aumento da demanda do mercado por certos produtos, a escassez de terras cúltiváveis (Jakovac et al. 2016) e mudanças nas políticas ambientais (Mertz et al., 2009). Da mesma forma, a exploração madeireira pode causar mudanças significativas na extensão (Asner et al., 2009), biodiversidade, estrutura e composição de espécies das florestas (Cazzolla Gatti et al., 2015). Ao mesmo tempo que as atividades humanas podem impactar negativamente as florestas (Jakovac et al., 2015), iniciativas humanas como a implementação de medidas de proteção, conservação e de manejo sustentável podem contribuir para mitigá-los e manter ou reforçar sua resiliência (Biggs et al., 2012; Tagliari et al., 2021). A resiliência, no contexto dos sistemas socioecológicos, pode ser definida como a capacidade do sistema de absorver perturbações e reorganizar-se enquanto passa por mudanças, de maneira a manter essencialmente sua estrutura, suas funções e feedbacks (Folke et al., 2010; Nikinmaa et al., 2020).

As florestas tropicais no Sul do Haiti são de grande importância por abrigarem uma rica biodiversidade (Judd, 1987) e por fornecerem serviços ecossistêmicos vitais como o abastecimento em água, madeira para construção e fabricação de móveis, plantas medicinais, lenha para uso doméstico e proteção contra a erosão entre outros (Ministère de L’Environnement, 2015). No entanto, ao longo de várias décadas, a intensificação da agricultura de corte-e-queima devido ao crescimento populacional e a reudção das terras disponíveis (Sergile et al., 1992), a criação de gado e a exploração madeireira têm sido as principais atividades antropogênicas provocando mudanças nos atributos ecológicos destes ecossistemas (Hedges et al., 2018; PNUD, 2014).

Além disso, estas florestas são impactadas de maneira recorrente por eventos de furacão de diferentes intensidades (Robart, 1984; USAID, 2006). Furacões são complexas perturbações naturais acompanhadas por ventos e chuva de grandes proporções (Lugo, 2000, 2008). Eles podem provocar uma grande mortalidade repentina de árvores, grande rotatividade de espécies, renovação mais rápida da biomassa e dos nutrientes e oportunidades para mudança na direção da sucessão (Lugo, 2000). Ademais, as chuvas fortes podem causar inundações e interagem com a topografia local para induzir movimentos de massa como deslizamento de terra e de detritos, por exemplo (Lugo, 2000, 2008). Apesar de que os efeitos imediatos dos furacões parecerem assustadores, geralmente a vegetação desenvolve respostas adaptativas que facilita sua regeneração pós furacão e a manutenção dos seus atributos e funções a médio e longo prazo (Lugo, 2008). No entanto, considerando que o estado anterior da floresta influencia a sua resiliência a furacões (Laurance C Curran, 2008), e que a agricultura itinerante e a exploração madeireira alteram esse estado (Asner et al., 2009; Cazzolla Gatti et al., 2015; Ding et al., 2012), a combinação de perturbações antropogênicas e naturais podem levar o sistema a um estado degradado, e consequentemente uma redução da sua resiliência e dos serviços ecossistêmicos (Jakovac et al., 2015; Silvério et al., 2019).

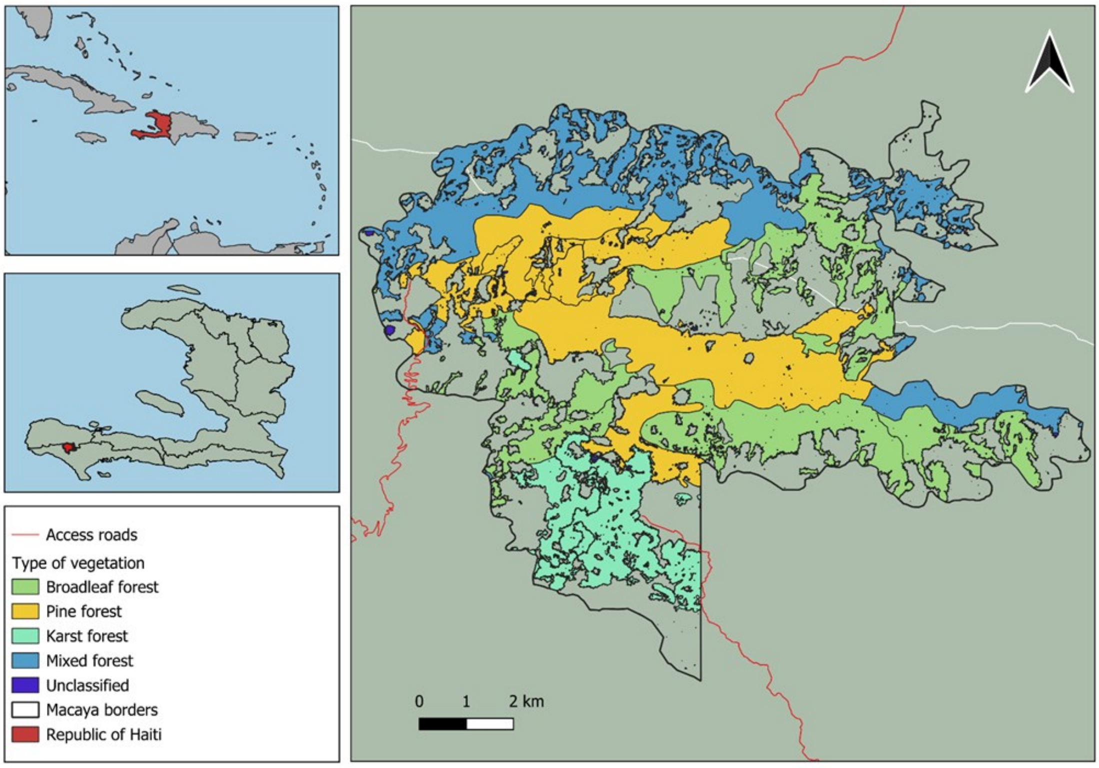
Para proteger as florestas tropicais no sul do Haiti, foi criado no ano de 1983, o Parque Nacional Macaya que representa a segunda maior unidade de conservação florestal do país (Le Moniteur, 1983; Ministère de L’Environnement, 2015). Considerando a sua importância para a proteção dos remanescentes de florestas primárias e o fornecimento de serviços ecossistêmicos, e os potenciais impactos da intensificação da agricultura itinerante, da exploração madeireira e dos furacões, estudos que avaliam os resultados da interação entre essas múltiplas perturbações são cruciais para garantir o manejo adequado e a conservação do Parque. No entanto, esses estudos são escassos. Nesse contexto, o presente estudo procurou entender como a agricultura itinerante, a exploração madeireira e os eventos de furacão afetam a resiliência do Parque Nacional Macaya no Sul do Haiti.

1.1 ÁREA DE ESTUDO

O Parque Nacional Macaya (PNM) localizado entre as latitudes 18°17’ e 18°26 Norte e as longitudes 73°55’ e 74°10’ Oeste, na parte sul da República do Haiti na região do Caribe, se estende sobre dez municípios de dois departamentos (divisão administrativa) totalizando uma área de 8.166,34 hectares (Figura 1), sendo uma das principais unidades de conservação florestal do país (Ministère de L’Environnement, 2015). O PNM foi criado pelo Decreto de 04 de abril de 1983 e faz parte da zona central da Reserva da Biosfera “La Hotte”, reconhecida pela UNESCO em 2016 (Le Moniteur, 1983; Unesco, 2023).

A topografia do parque, bastante acidentada, é caracterizada pelos picos Macaya (2347 m), Formon (2219 m), *le Ciel* (2170 m), *Civette* (1533 m) e *Grande Plaine* (1900 m), pelos relevos cársticos encontrados entre 900 e 1100 m, pelos declives abruptos e ravinas (Ministère de L’Environnement, 2015). O clima apresenta temperaturas moderadas variando de 5 a 20°C e duas estações úmidas bem definidas fornecendo uma pluviometria anual que varia entre 2500 e 3000 mm em Formon e mais de 4000 mm no Pico Macaya, a área mais alta (Sergile, 1994). Entre as altitudes de 800 a 2000 metros, encontra-se uma vegetação natural de floresta latifoliada (representando 38%) e a partir de 2000 m, é encontrada uma floresta de pinheiros (31%) dominada pela espécie endêmica *Pinus occidentalis* (Ministère de L’Environnement, 2015).

Figura 1 - Localização do Parque Nacional Macaya com seus diferentes tipos de vegetação.



Fonte: Plan de Gestion Parc National Naturel Macaya (Ministère de l'Environment, 2015)

A população rural total das diferentes comunidades na região do PNM é estimada a 125.000 habitantes das quais cerca de 15.000 moram dentro dos seus limites. Uma porcentagem de 88% da população economicamente ativa pratica essencialmente a agricultura itinerante tradicional; a outra parte pratica a criação de gado e o comércio (PNUD, 2014). São cultivadas principalmente algumas espécies anuais como inhame (*Dioscorea* sp), mandioca (*Manihot esculenta*), malanga (*Xanthosoma* sp.), taro (*Colocasia esculenta*), batata doce (*Ipomea batatas*), feijão e milho; e algumas espécies perenes como café, banana, e outras árvores frutíferas. O gado é constituído principalmente de bovinos e caprinos, e também de ovinos, equinos e suínos (AVSI, 2012). Devido a essas atividades humanas, a paisagem do parque é formada por um mosaico de fragmentos de florestas primárias e secundárias com pequenas parcelas agrícolas.

Entre os diferentes atores que participam no manejo e na administração do PNM figuram as instituições públicas como o Ministério da Agricultura e dos Recursos Naturais e do Desenvolvimento Rural (MARNDR), o Ministério do Meio Ambiente (MDE) e o Instituto de Proteção do Patrimônio Nacional (ISPAN); as

Organizações não Governamentais (ONGs) e instituições da sociedade civil (estruturas de pesquisa e organizações comunitárias) (Ministère de L'Environnement, 2015).

O PNM localiza-se na região Sul do país que apresenta a maior incidência de furacões e de fortes precipitações (Robart, 1984) (Tabela 1). Assim, o PNM tem sido afetado por vários furacões de diferentes categorias ao longo da sua história. Recentemente, em outubro de 2016, o furacão Matthew de categoria 4, causou grandes danos ecológicos e socioeconômicos na região (Stewart, 2017). Estes danos somados aos danos decorrentes da intensificação da agricultura e da exploração de espécies arbóreas e arbustivas para a produção de madeira, lenha e carvão ao longo do tempo podem comprometer o fornecimento de serviços ecossistêmicos as gerações futuras (Ministère de L'Environnement, 2015; Tarter et al., 2016).

Tabela 1 - Lista dos furacões que atingiram o Haiti de 1985 a 2021. A classificação segue a escala Saffir-Simpson, sendo a categoria 5 a mais forte.

Furacão	**Data**	**Categoria**
Gilbert	September/88	5
Georges	September/98	4
Lili	September/02	4
Ivan	September/04	5
Dean	August/07	5
Sandy	October/12	3
Matthew	October/16	4

Fonte: National Oceanic and Atmospheric Administration (NOAA) and Weather Underground.

1.2 ESTRUTURA DA TESE

Esta tese está dividida em dois capítulos organizados da seguinte maneira: o primeiro capítulo tem como título “A regeneração de florestas tropicais no sul do Haiti reflete mudanças na governança local”; nele, procuramos entender como a agricultura itinerante e a exploração madeireira influenciam as mudanças na cobertura do solo no Parca Nacional Macaya no sul do Haiti dos anos 1985 a 2021. Além disso, considerando a alta complexidade topográfica do parque, também analisamos a influência da elevação e do declive sobre essas mudanças. Este capítulo está formatado e foi submetido à revista *Land*. No segundo capítulo que tem como título “Como as perturbações múltiplas podem influenciar a resiliência de florestas no sul do Haiti?”, procuramos entender como a agricultura itinerante e a exploração madeireira interagem com os eventos de furacão e quais são os feedbacks dominantes contribuindo para reforçar ou enfraquecer a resiliência de florestas tropicais no sul do Haiti.

2 CAPÍTULO 1: RECOVERY OF TROPICAL FORESTS IN MACAYA NATIONAL PARK/HAITI REFLECTS SHIFT IN LOCAL GOVERNANCE

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2.1 ABSTRACT

Anthropogenic disturbances interacting with natural disturbances, ecological and socio-economic factors can provoke forest degradation and modulate ecosystem resilience. In Haiti, protected areas recently created to reduce forest loss, require studies about forest dynamics and land use to assure the development of sustainable management policies. We use Landsat satellite images to assess how shifting agriculture and logging influence land-cover changes in the Macaya National Park in Southern Haiti from 1985 through 2021. Considering the high topographic complexity of the study area, we also analyze the influence of elevation and slope on land-cover change. Our results indicate an increase of 11.36% in forest cover and a reduction of

75.34% in agriculture class cover, despite the passage of seven hurricanes in the region. Both elevation and slope were significant factors influencing forest recovery. Higher and steeper areas were more likely to be covered by forest. However, their interaction may reduce the chance of forest recovery at some point. Forest recovery also reflected the implementation of new zoning, financial and technical assistance to local farmers and the implementation of conservation programs promoted by the creation of the park in 1983. These interventions contributed to ensure access to financial resources, technical assistance and new technology, thus promoting a shift into a more resilient forest system. This study reveals an ongoing forest transition in the Macaya region due to changes in forest governance.

Keywords: shifting agriculture; logging; remote sensing; land-use change; resilience; social-ecological system

2.2 INTRODUCTION

In the context of social-ecological systems, healthy tropical forests are essential to provide goods and services that sustain human development and well-being (*1,2*). Nonetheless, increasing human activities and natural disturbances are inducing deep changes in ecological features threatening the persistence of such ecosystems in the future and the ecological services they furnish (*3,4*). To prevent future scarcity in ecological services, human communities can adjust forest governance based on local ecological knowledge by itself or in combination with well-established scientific knowledge (*5*–*7*). Forest governance incorporates “(a) all formal and informal, public and private regulatory structures, i.e., institutions consisting of rules, norms, principles, decisions procedures, concerning forests, their utilization and their conservation, (b) the interactions between public and private actors therein and (c) the effects of either on forests [and their landscapes]”(*8*).

Logging and shifting agriculture are two widespread and well-known human-induced disturbances in tropical forests *(9–13)*. By using fire, farmers open sites in primary or secondary forests for cropping, and as soon as these sites begin to lose productivity, other sites are opened *(14–16)*. Loggers degrade primary forests by harvesting massive trees of commercially valuable species and often damage others in the process *(17–19)*. These land uses are influenced by complex interactions between socioeconomic, political, demographic, technological, and biophysical variables and can generate either positive or negative outcomes in the long term *(20,21)*. For instance, human population growth or market demand can lead to expansion or intensification of agriculture and logging at the expense of natural forests *(22–24)*. On the other hand, changes in environmental protection policies can facilitate transition to forest *(25,26)*.

Shifting cultivation and logging normally operate in combination with natural disturbances such as hurricanes, that can exacerbate their impacts *(27,28)*. Hurricanes are frequent disturbances, accompanied by intense wind and heavy rain that can induce massive tree mortality depending on their intensity *(29–31)*. Forests previously impacted by human activities hit by hurricanes can experience important changes in ecological and social processes that may disrupt specific interactions and feedbacks maintaining the system resilient *(32)*. These changes may trigger other types of positive feedbacks *(33)*, potentially arresting the ecosystem in a degraded state *(34)*. Positive feedbacks are interactions in which the corresponding outcomes reinforce previous changes *(33,35)*. For instance, forest cover loss due to hurricane windthrow leaves the ecosystem vulnerable to topsoil erosion which further intensifies forest degradation and reduces forest resilience *(36)*. Considering that resilience is the capacity of social-ecological system to absorb disturbance and reorganize while undergoing changes so as to still retain essentially similar function, structure and feedbacks, thus assuring the continuous provision of desired sets of ecosystem services to human societies *(2,37)*, a good comprehension of the main drivers of social-ecological change and how they interact with the underlying variables at different levels is crucial for a proper management of forest ecosystems exposed to human and natural disturbances *(38)*.

Particularly in mountain landscapes, environmental factors such as elevation and slope play an important role in land-use change processes as they place physical limits on the types of land-use practices that are feasible in a region *(39,40)*. Higher terrains with steeper slope are more unlikely to be used for agriculture given that their productivity is frequently lower and greater resources and labor efforts are necessary to produce there, in addition to the fact that these lands are often less accessible *(24,41–43)*. Similarly, logging is also less likely to be practiced in higher and steeper forested areas for the same reasons *(43)*. Consequently, flatter areas at lower altitude are expected to be impacted first and more intensely during land-use change *(24,43)*. Local topography is also a complicating factor for hurricane-induced damage. Higher mountain slopes exposed to wind are usually most vulnerable to hurricane damage, whereas lower areas sheltered from the wind are generally least vulnerable *(44,45)*.

Tropical forests in Southern Haiti essentially provide timber for construction and furniture making, firewood for cooking and heating, foods, medicinal plants and water for domestic uses, livestock watering and crop irrigation *(46)*. Nevertheless, these ecosystems have been experiencing increasing pressures from shifting agriculture and logging *(46,47)*. Furthermore, the region is frequently affected by hurricanes (Table 1) *(30,48,49)* that can induce large-scale sudden tree mortality and changes in forest composition *(29,50)*. To protect substantial part of remaining patches of primary mountainous vegetation in Southern Haiti, the government of the country created the Macaya National Park (MNP) in 1983 *(51,52)*. This measure promoted significant changes in environmental policies that have been influencing land-cover changes in the region *(46,47)*.

The occurrence of shifting cultivation and logging in tropical mountainous forests with high topographic complexity and exposed to recurrent hurricanes, makes the MNP a special opportunity to study the mixed effects of such factors in the tropical belt of the Americas. However, studies about the dynamics of land-use/land-cover changes and how they can influence the resilience of the MNP and the provision of ecosystem services to local people are scarce. In this study, we use satellite data to assess how shifting agriculture and logging influence land-cover changes in the Macaya National Park in Southern Haiti from 1985 through 2021. Considering the high topographic complexity of the study area, we also analyze the influence of elevation and slope on land-cover changes.

Table 1 - Major hurricanes that hit southern Haiti from 1985 through 2021. Category on the Saffir-Simpson hurricane wind scale.

Hurricane	Date	Category
Gilbert	September/88	5
Georges	September/98	4
Lili	September/02	4
Ivan	September/04	5
Dean	August/07	5
Sandy	October/12	3
Matthew	October/16	4

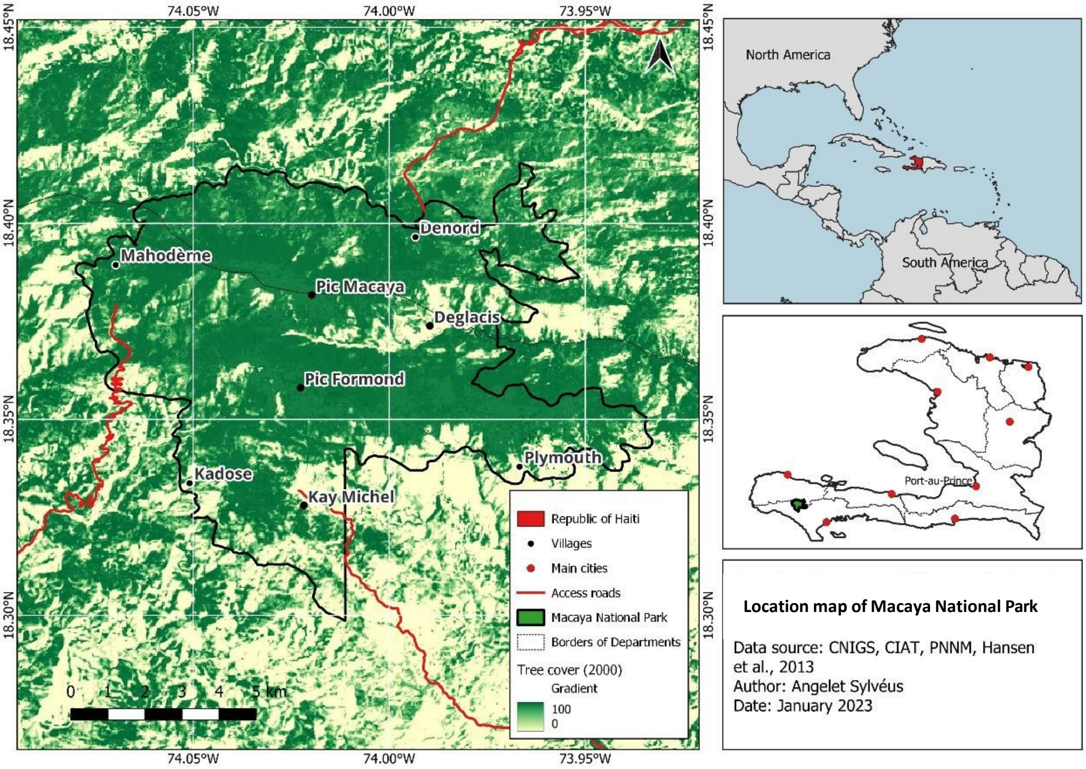
Sources: National Oceanic and Atmospheric Administration (NOAA) and Weather Undergroung *(53,54)*.

2.3 MATERIALS AND METHODS

2.3.1 Study area

The present study was conducted in the Macaya National Park (MNP) located in Southern Haiti (Figure 1). The park was created in 1983 and presently is considered the central zone of “La Hotte” Biosphere Reserve admitted by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2016 (*51,55*). The area of the MNP was 8,166.34 hectares until 2013 when it was extended to more than 13,000 hectares that protects the last fragments of original Southern Haiti vegetation and its fauna (*46*). For this study, we will consider only the older limits of the MNP as the other part was under a different protection regime until 2013.

Figure 1 - Location map of Macaya National Park. Here we show tree cover data from Hansen et al. for the year 2000 and six selected villages for deeper analysis of land-use change.



Sources: Hansen et al. (*56*) and *Ministère de l'Environment* (*46*)

The topography of the MNP is quite hilly, with numerous steep slopes and ravines (*57*). The MNP climate has moderate temperatures ranging from 5 to 20º C and two rainy periods – one from April to June, other from August to November – with an average of 2,500-3,000 mm of mean annual rainfall (*58*). The predominant soil types are dark red oxisols (with nearly neutral pH and moderate fertility levels) that occupy mostly flat plains and lowest slopes, and brown ultisols (with slightly acid pH and commonly deficient in nitrogen and phosphorus) present in many intermediate and upper slopes *(47)*. Between 800 and 2000 meters of altitude, broadleaf forests predominate, whereas above 2000 meters, pine forests predominate in the landscape *(46)*.

We selected six of the most populated local villages inside or near the borders of the park: *Kay Michel*, *Kadose*, *Mahodème*, *Denord*, *Deglacis* and *Plymouth* to assess land cover more deeply (Figure 1). We also selected two other locations inside the park: *Pic Macaya* and *Pic Formond* which are uninhabited as control areas (Figure 1). The village *Kay Michel* is in the southern part of the MNP at the end of one of the principal roads giving access to the park and has important administrative infrastructures used by researchers and state agents. It belongs to the rural district of *Carrefour Canon* which has a population of 10,433 inhabitants. The village *Deglacis* in the East of the MNP has more than 2,000 inhabitants. It is a remote village accessed only on foot through difficultly travelable trails starting from the southern villages. *Kadose* in the northwest of the park belongs to the rural district of Randel which has 6,550 inhabitants. Mahodème in the western zone of the MNP belongs to the rural district of Dejoie which has approximately 6,000 inhabitants. *Denord* is part of the rural district of Beaumont which has a population of little more than 12,000 inhabitants *(46)*. *Pic Macaya* (2,347 m) and *Pic Formond* (2,219 m) are both uninhabited places located in the central part of the MNP and represent the highest peaks in the region.

Although the Macaya region has been occupied before the colonial period in the 18th century, local human population has increased mostly through in-migration in the 1960s *(46,47)*. Historically, traditional shifting agriculture has been the most important economic activity for these communities *(46,47)*. Farmers alternate cropped and fallowed periods in plots initially open in areas of primary or secondary vegetation managing fire. They mostly grow annual crop species like *Manihot esculenta* (cassava), *Dioscorea* sp.(yams), *Xanthosoma* sp. (malanga), *Colocasia esculenta* (taro), *Ipomea batata* (sweet potatoe), *Zea mays* (corn) and a wide variety of beans *(46,59)*. They also grow perennial crop species like *Coffea arabica* (coffee), *Musa* sp. (bananas) and some other fruits *(59)*. In addition, local people practice livestock raising and logging to complement household income *(60)*. During the fallow period, plots are used as pastures for livestock which is made up mostly of cows and goats *(59)*. Fallows are often characterized by a naturally grown herbaceous vegetation *(47)*.

2.3.2 Data acquisition and pre-processing

To assess land-use change in the MNP, using Google Earth Engine, we selected Landsat 5 TM Collection 2, Tier 1 and Landsat 8 OLI Collection 2, Tier 1 (surface reflectance) images with low or without cloud cover from 1985 through 2021 applying a cloud cover filter (below 10% cover) to all the available Landsat images (scene 10/47) for this period *(61)*. The image selection process resulted in 136 suitable images that were organized into four time periods of approximately a 10 years each: the first from 1985 through 1995 with 16 images; the second from 1995 through 2005 with 25 images; the third from 2000 through 2012 with 14 images and the fourth from 2013 through 2021 with 81 images. These time periods therefore represent four points in time, respectively: ~1990, ~2000, ~2006 and ~2017. We computed the Normalized Difference Vegetation Index (NDVI) *(62)* and Normalized Difference Water Index (NDWI) *(63)* for all non-masked pixels for these images. These two indices are useful to define land-cover classes and have been previously used to assess land-cover changes in tropical forests *(64,65)*. Then, we performed image collection reductions taking the median of the spectral indices values per pixel over each time-period, which resulted in four images representing the four time points. This pre-processing step was performed to reduce the influence of outliers and to take the best pixels available for each time point *(66)*. All the images were cropped to the MNP area polygon to reduce processing time.

To assess the influence of elevation and slope on land-cover changes, we selected 1000 random points across the MNP area. We extracted their respective values of elevation and slope, and verified if there was a forest cover at the final period of the study or not. The elevation and slope data originate from the NASADEM digital elevation model *(67)*.

2.3.3 Data analysis

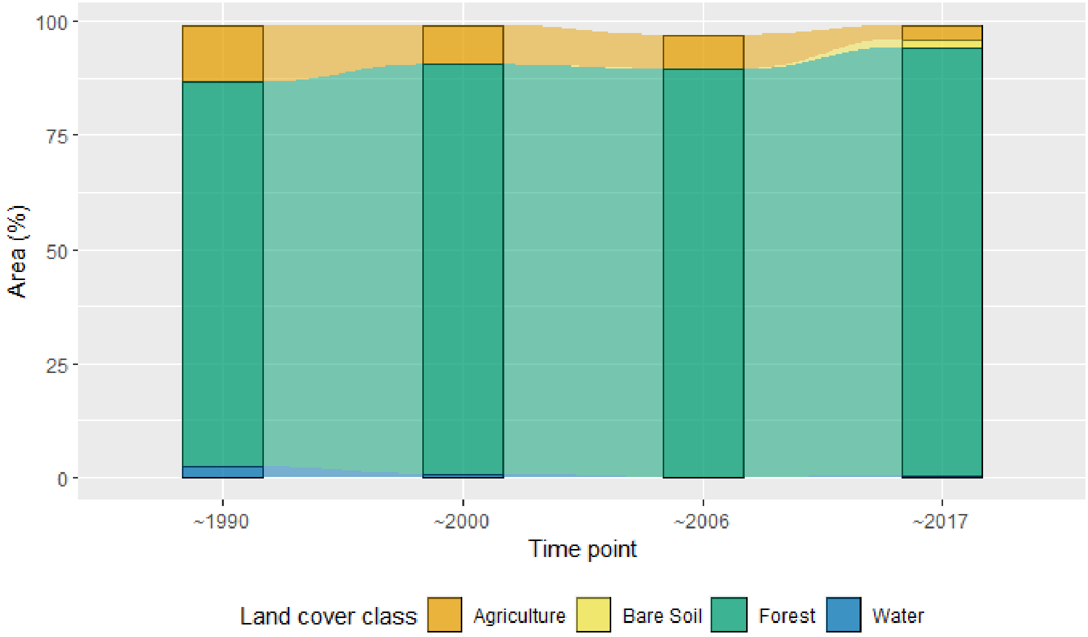
After the pre-processing step, we applied a supervised classification on the four images resulting from the image collection reduction process and representing each time point from ~1990 through ~2017. First, we collected polygon samples separately from each of the four images by on-screen digitizing in Google Earth Engine *(66)* for four land-use classes: agricultural land, forest, bare soil and water. Second, the polygon samples were divided into two data sets: one with 70% of the samples as training data and another one with the 30% remaining, to be used as validation data. We trained the RandomForest classifier using the training data set and performed a supervised classification of the four images. We estimated classification error with the independent validation data set *(68)*. We calculated the corresponding area of each land-use class for each of the four time points and compared the results to identify land-cover changes across the MNP. We delineated a 1,500 m buffer around the center of each selected local village (Figure 2) and calculated the proportional area covered by the different land-cover/land-use classes for each time point. We performed a Generalized Linear Model (glm) with binomial distribution to analyze the influence of elevation and slope on land-cover changes at the 1000 randomly selected pixels *(69)*.

All these analyses were performed using Google Earth Engine platform *(66)*, QGIS *(70)* and R software *(71)*, specifically the packages sf *(72)*, raster *(73)*, ggplot2 *(74)* and ggspatial *(75)* were used for showing the resulting maps and graphics.

2.4 RESULTS

The overall accuracies for the entire MNP area were: 0.95 for ~1990, 0.96 for ~2000, 0.98 for ~2006 and 0.97 for ~2017. For the producer and user accuracies of each class at each time point, see Table T1. For the entire MNP area, during the time span of this study (~1990 to ~2017), forest and agriculture land-cover classes occupied a much larger part than water and bare soil classes (Figure 2, Table T1). We detected an increase in 11.36% of the area covered by forest while agriculture area decreased 75.34% between 1985 and 2021 (Figure 2, Figure A1). For the whole MNP, forest expanded by 9.59 km^2, from 84.35 km^2 at the first time step (~1990) to 93.94 km^2 at the last one (~2017). At the same time, agriculture declined by 9,29 km^2, from 12.33 km^2 to 3.04 km^2. For the two remaining land use classes bare soil and water, we observed that bare soil increased from 0 to 1.76 km^2, while water reduced from 2.35 to 0.29 km^2 (Figure 2, Figure A1).

Figure 2 - Change in area covered by individual land cover classes over three time intervals in Macaya National Park. There was an increase in 11.36% of the area covered by forest from the first through the last time-period. Most of this increase results from the regeneration in agricultural areas.



Analysis of the six village surroundings (1.5 km buffers) revealed that forest and agriculture areas remained relatively stable over the three time intervals in *Denord* (Figure A2, b), *Mahodème* (Figure A2, e), *Pic Formond* (Figure A2, f), *Pic Macaya* (Figure A2, h) and *Deglacis* (Figure A2, a), whereas major land-cover changes took place in *Kadose*, *Kay Michel* and *Plymouth* (Figure A1; Figure A2, c, d and g). In *Kay Michel*, agricultural use that initially occupied 53% of the sampled area, dropped drastically to 3% in the last time-period (~2017). At the same time, forest area expanded from 47 to 95% from the first (~1990) to the last time point (~2017) (Figure A1; Figure A2, d). In *Kadose*, forest area increased from 66 to 86 % while agricultural area decreased from 17 to 2% (Figure A1; Figure A2, c). In *Plymouth* village, agricultural land cover increased from 3 to 17% in the first decade of the 2000's and then decreased to 7% by ~2017, whereas total forest cover decreased from 96 to 81% and then increased again to 87% (Figure A1; Figure A2, g).

The highest zones (Figure 3A) and areas with steepest slopes (Figure 3B) in our study area, for instance *Pic Macaya* and *Pic Formond*, remained relatively stable, with forest land cover dominance (see Table 2). In addition, our glm result indicated that both elevation and slope were significant factors affecting land cover (Table 2). Higher and steeper areas are more likely to be covered by forest. However, their interaction may reduce the chance of forest cover at some point. For instance, areas with higher elevation can be less likely to be covered by forest if they are very steep. Likewise, areas with intermediate slope can be less likely to be covered by forest if they are very high.

Figure 3 - Land-use changes (~1990 – ~2017) in relation to elevation (A) and slope (B) across the Macaya National Park. Blue circles indicate areas with major land-use changes. Black circles indicate areas remaining relatively stables, with low land-use changes.

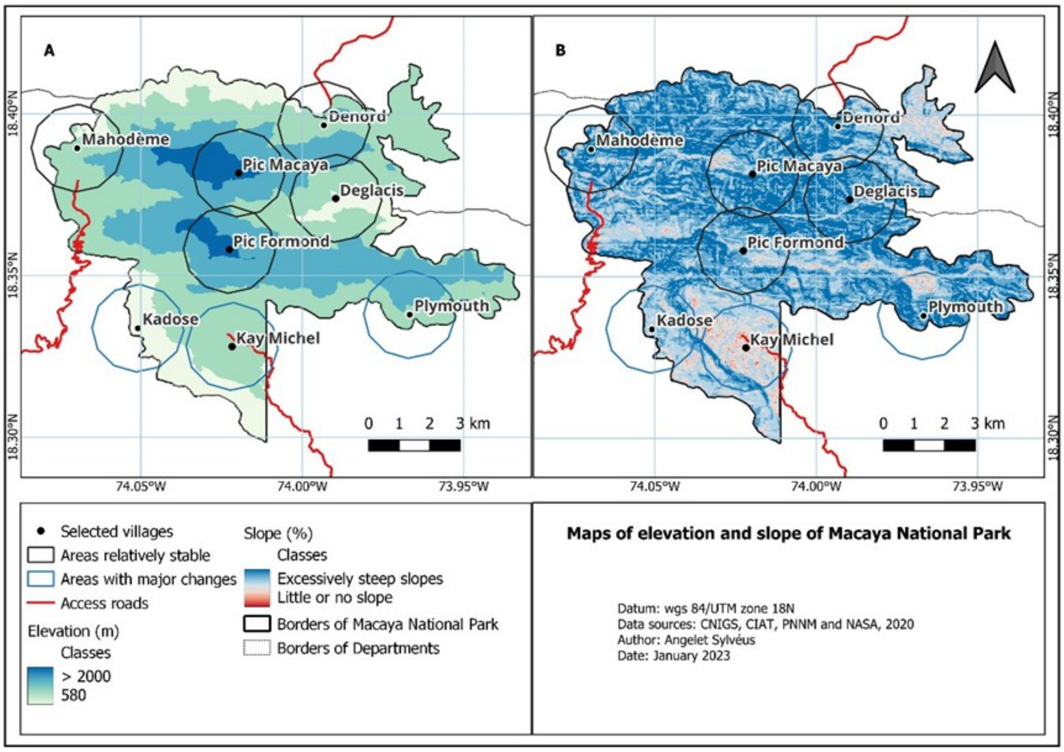


Table 2 - Outputs of the Generalized Linear Model with binomial distribution, for 1000 randomly chosen pixels. Both elevation and slope were important factors influencing forest recovery.

	Estimate	**Std. Error**	**Z value**	**P value**	**Significance**
Intercept	-1.192	0.967	-1.232	0.218	
Elevation	0.00264	0.00076	3.468	0.00052	***

Slope	0.0791	0.03014	2.625	0.0087	**
Elevation:slope	-0.00006	0.00002	-3.027	0.00247	**

*** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$, . for $p < 0.1$ and no asterix for $p > 0.1$

2.5 DISCUSSION

2.5.1 Socio-economic factors affecting land-use/land-cover changes

Our results revealed an increase of forest area within the MNP since 1985. This finding is congruent to changes occurring in many tropical landscapes under forest transition, i.e., a shift from forest loss to forest gain *(25,26,76)*. Forest transition has contributed to reduce tropical deforestation although the rates at global scale remain alarmingly increasing *(26,77)*. A deeper analysis demonstrated that major land-use changes occurred in Kay Michel, Kadose and Plymouth villages situated respectively in Southern and Southeastern zones of the MNP, where important gain in forest area occurred at the expense of agricultural land-use. To understand these changes, we examine a set of social-ecological factors that might be influencing land-use dynamics in the MNP region.

The creation of the MNP triggered significant changes in forest governance and socio-economic factors that in turn may have influenced land-cover changes in the region. To preserve and restore the unique relictual montane ecosystems in the Macaya region, the Macaya Biosphere Reserve Project (MBRP) was initiated five years after the creation of the MNP *(47)*. The MBRP got together a diversified team of researchers, technicians and volunteers from the University of Florida (UF), the Ministry of Agriculture and Natural Resources of Haiti (MARNDR) and local people, to prepare the initial guidelines aiming to ensure forest conservation, sustainable management and economic development of the MNP *(47)*. The village of Kay Michel hosted the MBRP headquarters (Table T2) which had a crucial role for the conservation efforts. The MBRP lasted four years – from October 1988 to May 1992 – and was almost totally financed by the United States Agency for International Development (USAID) to an amount greater than US$ 1,5 million *(47)*.

One of the first interventions of the MBRP team was a new zoning for appropriate land use. The five land use zones initially idealized – core zone, special use, forestry, agroforestry and agricultural zones - were refined over time and reclassified as four zones: brown, red, yellow and green zones *(46,47)*. Brown zones are conservation zone with a little or no human-induced forest degradation, where there is no need for restauration or active management and only research and observation are allowed; red zones are degraded area by human activities and areas with steep slopes and actives ravines where there is urgent for use change, restauration activities and active management; yellow zones are administrative zones with concentration of infrastructures (office, parking, warehouses, etc.…) used by the park personnel and residential areas; and green zones are valorization and exploitation areas where human activities like agriculture, livestock breeding and ecotourism are allowed *(46)*.

With the MBRP progress, important restoration activities were implemented in critical zones like steep slopes, springs and endangered habitats that have been environmentally degraded. Such degraded areas in *Kay Michel* and *Deglacis* received direct seedlings of native useful species such as *Pinus occidentalis*, *Didymopanax tremulus*, *Micropholis polita* ssp. *hotteana* and *Tabebuia conferta* (Table T2). Similar activities were also conducted in different villages such as *Dupouy* and *Kay Tilus*, dispersed across the MNP *(47)*. Also, the Alternatives for Sustainable Social-ecological Conservation in the Macaya Key Biodiversity Area project conducted by the “Fondation Macaya pour le Développement local – FMD” (Macaya Foundation for local Development) and financed by the Critical Ecosystem Partnership Fund (CEPF) at an amount of nearly US$ 90,000, facilitated the establishment of seedling nurseries and seedling transplanting in the Grande Plaine locality and its vicinity *(78,79)*.

As the new zoning of the MNP prohibited agriculture, grazing and logging in some areas that were once used for such purposes, reasonable economic alternatives were provided to local people. Farmers also received financial and technical assistance to improve agricultural productivity in areas where it was still allowed. MBRP technicians worked closely with local farmers providing training in improved production of beans, carrots, beets, onions and cabbage, conducting onfarm trials of vegetable and beans varieties and of soil improvement techniques *(47)*. At the same time, some farmers received selected vegetable and black beans seeds for free or at production costs and rustic pigs to improve livestock production. Moreover, local people were hired to maintain and supervise seedling nurseries, to transplant seedlings in critical zones under restoration and work as local guides for tourists and researchers *(47,78)*. In addition to the projects cited earlier, other projects such as the Environmental Education for Community Participation in Conservation of Macaya *(80)*, and the Ecosystem Threat Assessment and Protected Area Strategy for the Massif de la Hotte Key Biodiversity Area *(81)* which addressed respectively the creation of local environmental committees that advocate for a stronger participation of local communities in the management of natural resources in the MNP area, and for developing self-sustaining education and public outreach activities, contributed to improve forest conservation and sustainable development as they brought financial resources, technical assistance, new sources of technology and new ideas and networks of contacts to local communities *(82,83)*. Major challenges such as insufficient funding, lack of continuity, political instability and the terrible quality of roads which hinder the access to some targeted areas may have contributed to lessen the expected positive outcomes *(82,84)*. However, as our results show (Figure 2; Figure A1), these initiatives clearly had major positive impacts, allowing tropical forests in that region to recover.

2.5.2 Environmental factors affecting land-use/land-cover changes

Elevation and slope have been identified as constraints to the expansion of human activities over natural forests *(24,39,40)*. During degradation process, lowland forests on flatter terrains are more likely to be impacted first and more intensely, particularly when near human settlements *(24,41,43,85)*. Our results showed a similar pattern. The highest elevations (Figure 3A, Table 2) and areas with steepest slopes (Figure 3B, table 2) in our study area, for instance Pic Macaya and Pic Formond, remained relatively stable, with forest land cover dominance. This observation can be explained by low accessibility due to the inexistence of roads, but only narrow trails to reach such places, and difficulties created by steepness making logging and agriculture unprofitable there *(41,43)*.

Local topography has also an important influence on damage patterns induced by hurricanes in tropical forests *(44,86)*. The wind and rain that accompany hurricanes can cause massive tree mortality, due to windthrow, floods and landslides *(29)*. Tree mortality is expected to be greater on upper windward slopes than on leeward lower terrains as upper slopes are most vulnerable to hurricane damage *(45,86)*. Given that part of elevated steep terrains in the MNP is also exposed to logging and shifting agriculture, even to a lower level, combined impacts of hurricanes and land uses can eventually induce unexpected changes that undermine the MNP resilience.

Nonetheless, the forest transition we observed in the region may have contributed to increase forests resilience to hurricanes. Well conserved forests are likely more capable of overcoming disturbances by hurricanes because they often have higher biodiversity than degraded forests *(87–89)*. Biodiversity allows ecosystems to maintain various species, with complementary and redundant functions, which in the face of disturbances increase their response diversity; while some species die during hurricane events, others persist, keeping the ecosystem functioning *(87,90)*. Response diversity is therefore an important aspect of ecosystem resilience and by reducing biodiversity, agriculture and logging undermine ecosystem resilience. These mechanisms may have helped forests on higher elevations and steeper slopes, as well as restored forests to remain stable in the face of several hurricane events (see Table 1). However, other forest fragments in the MNP persisted degraded and relatively more exposed to these disturbances.

When hurricanes, such as the powerful hurricane Matthew in 2016, hit degraded forests areas in the MNP landscape, their impacts can be exacerbated as degraded forests are exposed to increasing wind speed, turbulence and vorticity *(44,91)*. These factors intensify tree mortality and reduce forest cover *(91)*, which further increases ecosystem exposure to other disturbances, such as fire *(92)*, and to other degrading mechanisms, such as topsoil erosion *(36)*. As a result, forests may persist in a degraded state *(34,91)*, which may not provide the desired set of ecosystem services necessary to ensure local people’s well-being. Although we observed an expansion of forests over agricultural land cover in the MNP, since forest land cover was a broad category including agroforests and multi-aged secondary forests, our study may not have detected ongoing homogenization and simplification processes. Therefore, future studies using images with finer resolution, greater number of land use classes, as well as accurate field information on species composition and diversity will help to elucidate more detailed aspects of forest dynamics in the MNP region.

2.6 CONCLUSIONS

Tropical montane forests in southern Haiti have been exposed to increasing need for food, timber and firewood in recent decades but this did not reflect on deforestation. The present research revealed that forest area has expanded at the expense of agricultural area from 1985 to 2021 in the MNP region. Such land-use changes in which forests expand are similar to the pattern observed in many tropical landscapes under forest transition and are mostly related to changes in environmental laws and policies that provide access to financial and technical assistance and new sources of technology. The creation of the MNP promoted changes in forest governance through a new functional zoning, technical assistance and financial support to increase crop productivity, and the implementation of restoration programs creating new jobs. These external interventions conducted by the government in collaboration with international institutions contributed to increase local communities' adaptive capacity, allowing them to reorganize their activities and initiate new forms of development, based on sustainable forest management. However, because of the inherent complexity of social-ecological tropical forest systems of Southern Haiti, more exhaustive studies assessing the feedbacks at play and the changing drivers are crucial to reveal potential future scenarios that may guide proper management in the MNP region under global change. Finally, this study reveals that a forest transition is underway in the MNP region due to changes in forest governance resulting from the combined efforts of central government, local and international institutions.

Author Contributions: A.S. conceived the initial idea and structure, drafted the manuscript, collected and analyzed field and satellite data. C.S.C. collected and analyzed satellite data and made contributions to their interpretation. B.M.F. and C.C.J. contributed to draft development and brought valuable ideas that improved the structure of the article. N.P. contributed to improve the initial idea and structure, draft development and reviewed early versions. All authors have read the manuscript and agreed to the final version for publication.

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Data Availability Statement: The present manuscript is part of an ongoing Ph.D. thesis in which were used satellite data provided by the United State Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) that can be found online at https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LT05_C02_T1_L2, https://developers.google.com/earthengine/datasets/catalog/LANDSAT_LC08_C02_T1_L2 and https://developers.google.com/earth-engine/datasets/catalog/NASA_NASADEM_HGT_001.

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Conflicts of Interest: The authors declare no conflict of interest.

APPENDIX

Table T1 – Confusion Matrix resulting from the validation of the supervised classification of the Macaya National Park Landsat images from ~1990 through ~2017.

		Observed					
	Predicted	Forest	Agriculture	Water	Bare Soil	Total	Producer's accuracy
~1990	Forest	302	7	1	0	310	0.974
	Agriculture	3	74	0	0	77	0.961
	Water	2	0	11	0	13	0.846
	Bare Soil	5	0	0	0	5	0
	Total	312	81	12	0	405	
	User's accuracy	0.967	0.913	0.916	0		
	Overall accuracy	0.955					
~2000	Forest	303	6	0	0	309	0.98
	Agriculture	1	86	0	0	87	0.988
	Water	4	0	8	0	12	0.666
	Bare Soil	4	0	0	0	4	0
	Total	312	92	8	0	412	
	User's accuracy	0.971	0.934	1	0		
	Overall accuracy	0.963					
~2006	Forest	287	2	0	0	289	0.993
	Agriculture	3	73	0	0	76	0.96
	Water	0	0	10	0	10	1
	Bare Soil	1	0	0	0	1	0
	Total	291	75	10	0	376	
	User's accuracy	0.986	0.973	1	0		
	Overall accuracy	0.984					
~2017	Forest	289	1	1	0	291	0.993
	Agriculture	8	73	0	0	81	0.9
	Water	0	0	9	0	9	1
	Bare Soil	1	0	0	3	4	0.75
	Total	298	74	10	3	385	
	User's accuracy	0.969	9.986	0.9	1		
	Overall accuracy	0.971					

Figure A1 – Land-use changes in Macaya National Park in four time points from ~1990 to ~2017.

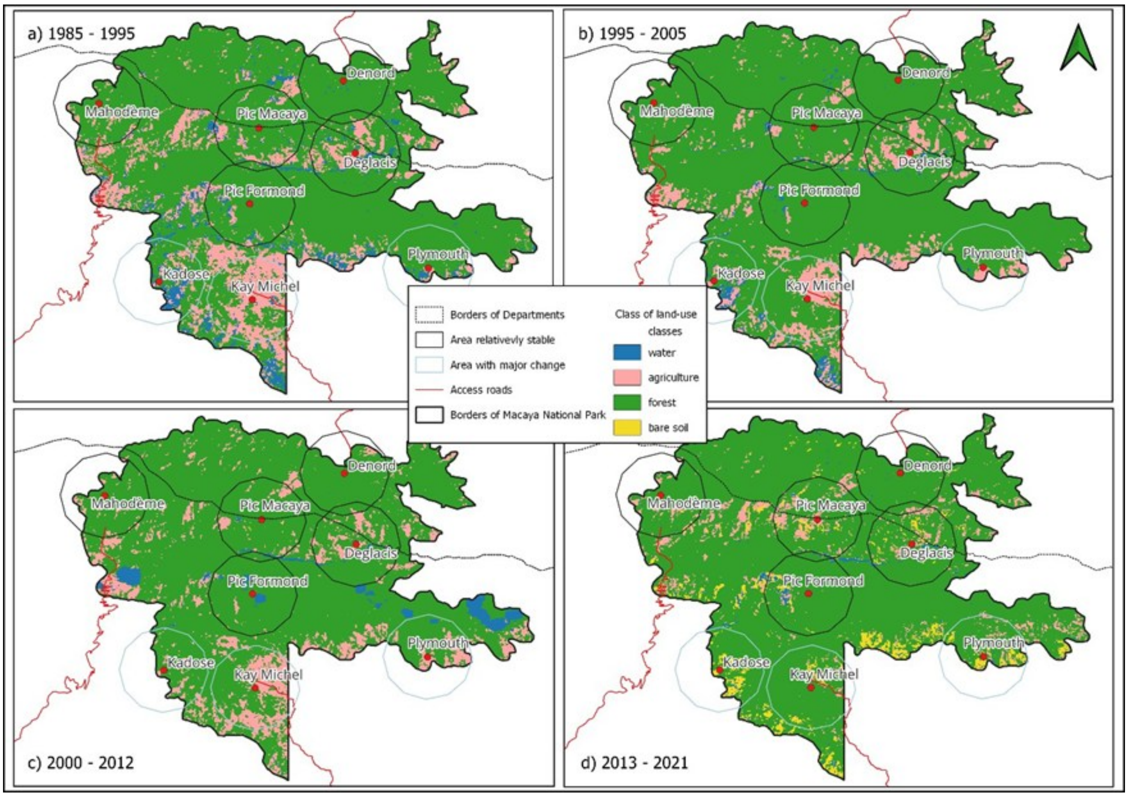
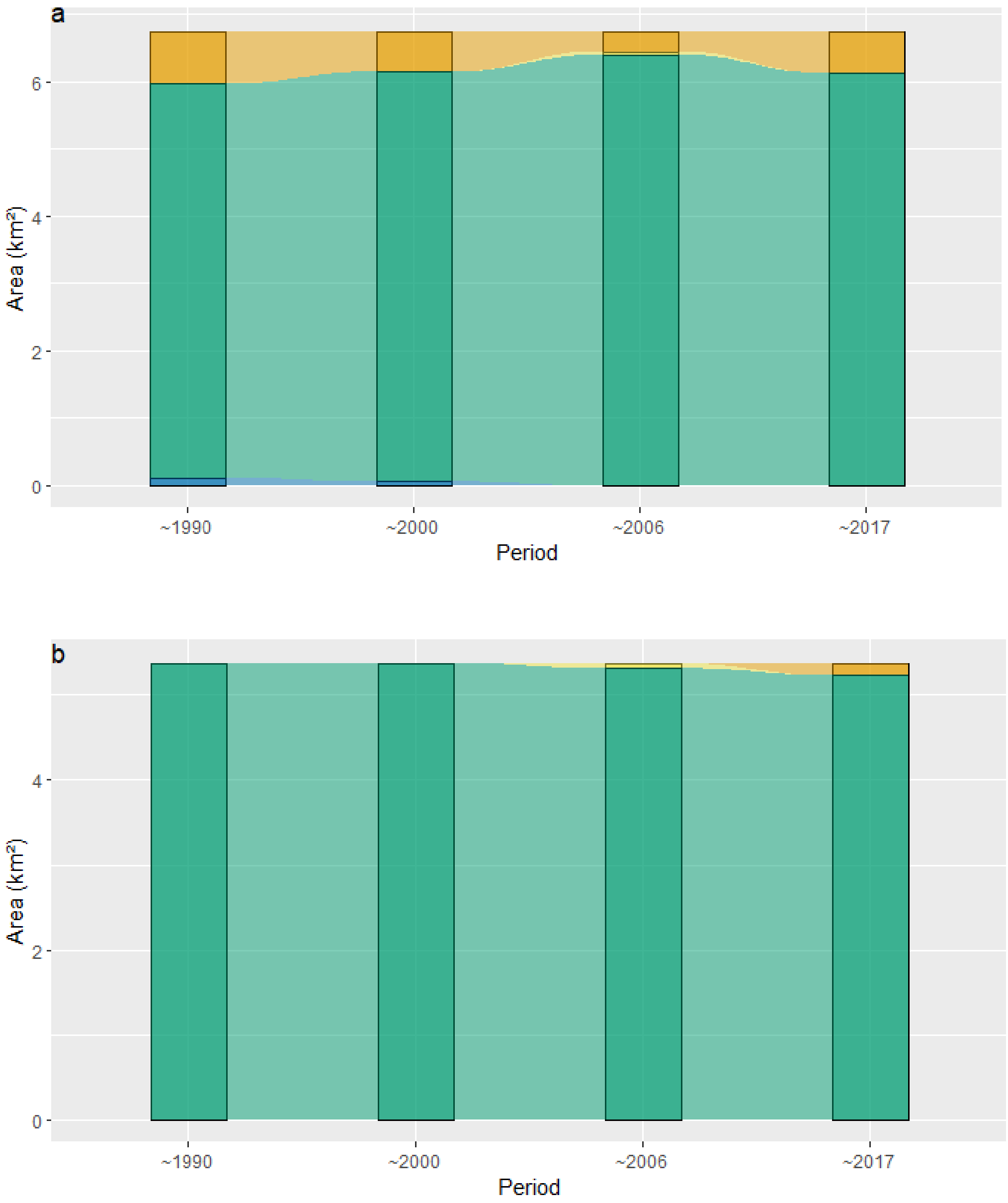
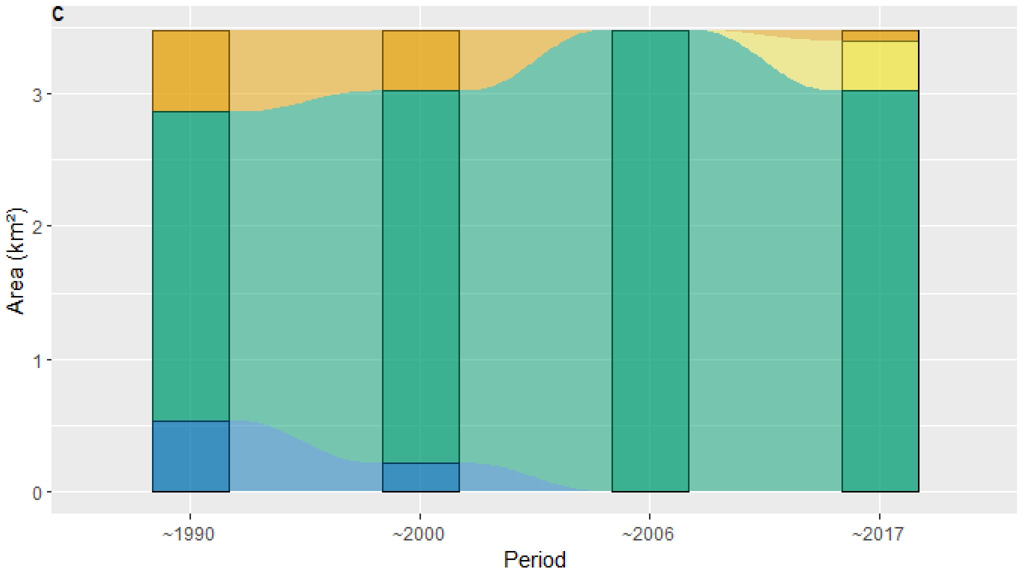
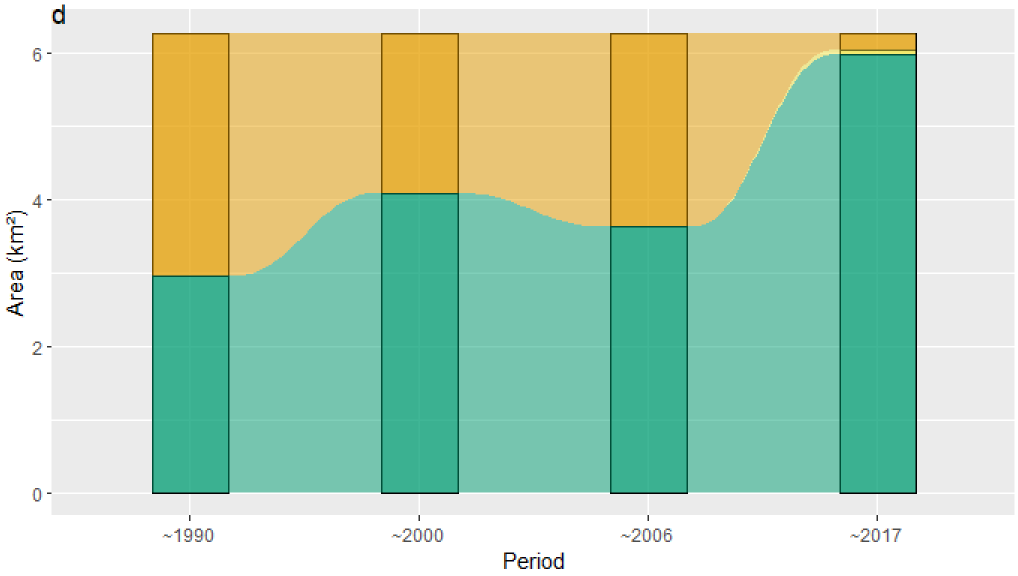
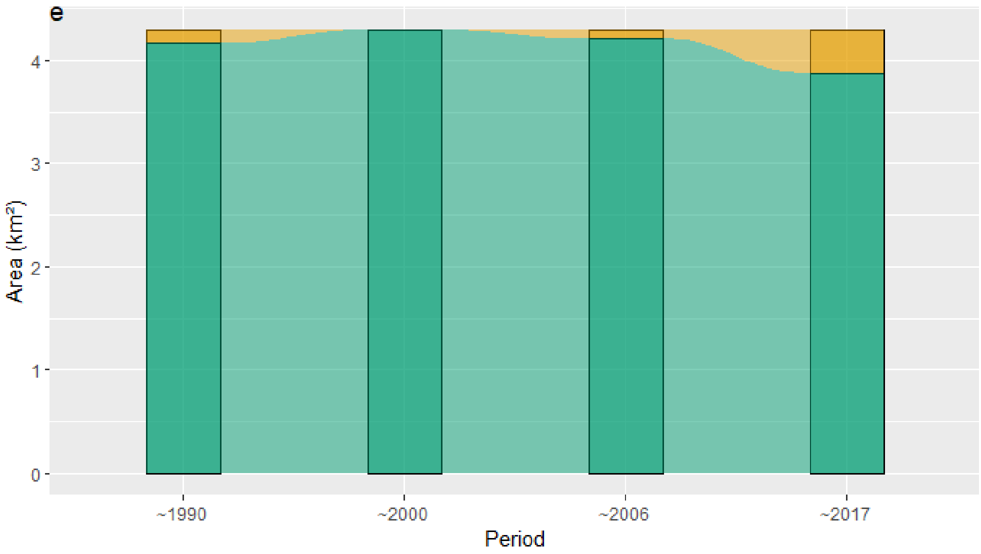


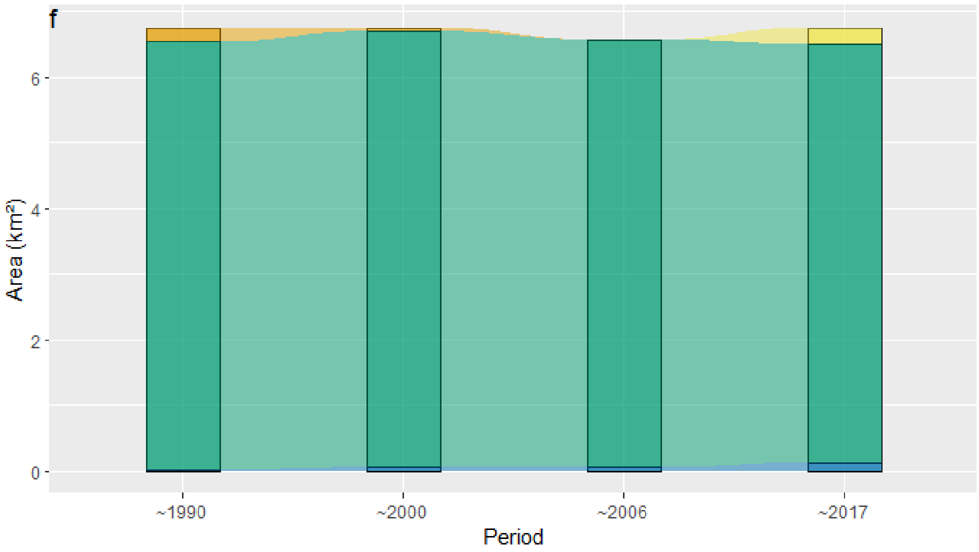
Figure A2 – Area covered by four land-use/land-cover classes in four time-periods, for the selected 419 villages from 1985 to 2021 in Macaya National Park. a) village of Deglacis; b) village of Denord; c) 420 village of Kadose; d) village of Kay Michel; e) village of Mahodeme; f) Pic Formond; g) village of 421 Plymouth; and h) Pic Macaya.




c
Area (km²)
0
1
2
3
~1990
~2000
~2006
~2017
Period


d
Area (km²)
0
2
4
6
~1990
~2000
~2006
~2017
Period


e
Area (km²)
0
1
2
3
4
~1990
~2000
~2006
~2017
Period


f
Area (km²)
0
2
4
6
~1990
~2000
~2006
~2017
Period

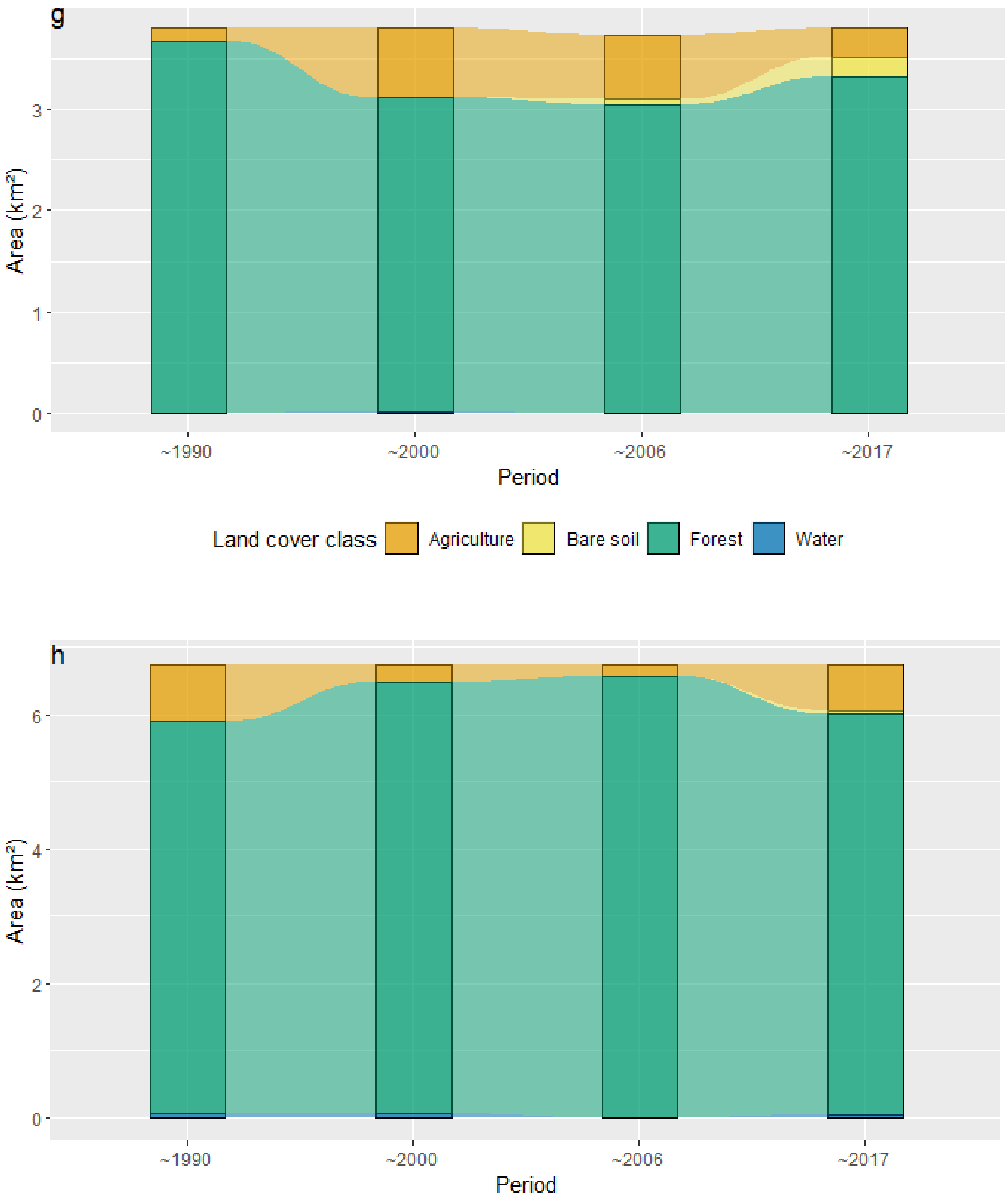

g
Area (km²)
0
1
2
3
~1990
~2000
~2006
~2017
Period
Land cover class
Agriculture
Bare soil
Forest
Water
h
Area (km²)
0
2
4
6
~1990
~2000
~2006
~2017
Period

Table T2 – Governance changes in the selected villages of the Macaya region. Dist. To hdqt: distance to headquarters (in km) as calculated measuring a straight line between two points.

Village	Seedling	Dist. To hdqt	Seedling nurseries
Deglacis	Yes	6.05	Yes
Denord	No	8.06	No
Kadose	No	3	No
Kay Michel	Yes	0.18	Yes
Mahodème	No	2.82	No
Plymouth	No	6.01	No
Pic Formond	No	3.18	No
Pic Macaya	No	5.19	No

REFERENCES

1. Millenium Ecossystem Assessment. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, 2005; Vol. 5. doi:10.1196/annals.1439.003.

2. Biggs, R.; Schlüter, M.; Schoon, M. L. *Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems*; 2015.

3. Malhi, Y.; Gardner, T. A.; Goldsmith, G. R.; Silman, M. R.; Zelazowski, P. Tropical forests in the anthropocene. *Annual Review of Environment and Resources* **2014**, *39*, 125–159. doi:10.1146/annurev-environ-030713-155141.

4. Barlow, J.; França, F.; Gardner, T. A.; Hicks, C. C.; Lennox, G. D.; Berenguer, E.; et al. The future of hyperdiverse tropical ecosystems. *Nature* **2018**, *559*(7715), 517–526. doi:10.1038/s41586-018-0301-1.

5. Reynolds, K.; Paplanus, S.; Miller, B.; Murphy, P. Design features behind success of the ecosystem management decision support system and future development. *Forests* **2015**, *6*(1), 27–46. doi:10.3390/f6010027.

6. Asmamaw, M.; Mereta, S. T.; Ambelu, A. The role of local knowledge in enhancing the resilience of dinki watershed social-ecological system, central highlands of Ethiopia. *PLoS ONE* **2020**, *15*(9 September), 1–18. doi:10.1371/journal.pone.0238460.

7. Saint Ville, A. S.; Hickey, G. M.; Locher, U.; Phillip, L. E. Exploring the role of social capital in influencing knowledge flows and innovation in smallholder farming communities in the Caribbean. *Food Security* **2016**, *8*(3), 535–549. doi:10.1007/s12571-016-0581-y.

8. Giessen, L.; Buttoud, G. Defining and assessing forest governance. *Forest Policy and Economics* **2014**, *49*, 1–3. doi:10.1016/J.FORPOL.2014.11.009.

9. Mertz, O.; Padoch, C.; Fox, J.; Cramb, R. A.; Leisz, S. J.; Lam, N. T.; et al. Swidden change in southeast Asia: Understanding causes and consequences. *Human Ecology* **2009**, *37*(3), 259–264. doi:10.1007/s10745-009-9245-2.

10. Asner, G. P.; Rudel, T. K.; Aide, T. M.; Defries, R.; Emerson, R. A contemporary assessment of change in humid tropical forests. *Conservation Biology* **2009**, *23*(6), 1386–1395. doi:10.1111/j.1523-1739.2009.01333.x.

11. Kleinman, P. J. A.; Pimentel, D.; Bryant, R. B. The ecological sustainability of slash-and-burn agriculture. *Agriculture, Ecosystems and Environment* **1995**, *52*(2–3), 235–249. doi:10.1016/0167-8809(94)00531-I.

12. Fox, J.; Truong, D. M.; Rambo, A. T.; Tuyen, N. P.; Cuc, L. T.; Leisz, S. Shifting cultivation: A new old paradigm for managing tropical forests. *BioScience* **2000**, *50*(6), 521–528. doi:10.1641/0006-3568(2000)050[0521:SCANOP]2.0.CO;2.

13. Kadoya, T.; Takeuchi, Y.; Shinoda, Y.; Nansai, K. Shifting agriculture is the dominant driver of forest disturbance in threatened forest species' ranges. *Communications Earth and Environment* **2022**, *3*(1), 1–8. doi:10.1038/s43247-022-00434-5.

14. Padoch, C.; Coffey, K.; Mertz, O.; Leisz, S. J.; Fox, J.; Wadley, R. L. The demise of Swidden in Southeast Asia? Local realities and regional ambiguities. *Geografisk Tidsskrift* **2007**, *107*(1), 29–41. doi:10.1080/00167223.2007.10801373.

15. Rerkasem, K.; Lawrence, D.; Padoch, C.; Schmidt-Vogt, D.; Ziegler, A. D.; Bruun, T. B. Consequences of swidden transitions for crop and fallow biodiversity in southeast asia. *Human Ecology* **2009**, *37*(3), 347–360. doi:10.1007/s10745-009-9250-5.

16. Dufour, D. L. Use of Tropical Rainforests by Native Amazonians. *BioScience* **1990**, *40*(9), 652. doi:10.2307/1311432.

17. Uhl, C.; Veríssimo, A.; Mattos, M. M.; Brandino, Z.; Guimarães Vieira, I. C. Social, economic, and ecological consequences of selective logging in an Amazon frontier: the case of Tailândia. *Forest Ecology and Management* **1991**, *46*(3–4), 243–273. doi:10.1016/0378-1127(91)90235-N.

18. Shenkin, A.; Bolker, B.; Peña-Claros, M.; Licona, J. C.; Putz, F. E. Fates of trees damaged by logging in Amazonian Bolivia. *Forest Ecology and Management* **2015**, *357*, 50–59. doi:10.1016/j.foreco.2015.08.009.

19. Asner, G. P.; Knapp, D. E.; Broadbent, E. N.; Oliveira, P. J. C.; Keller, M.; Silva, J. N. Ecology: Selective logging in the Brazilian Amazon. *Science* **2005**, *310*(5747), 480–482. doi:10.1126/science.1118051.

20. Lambin, E. F.; Meyfroidt, P. Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy* **2010**, *27*(2), 108–118. doi:10.1016/j.landusepol.2009.09.003.

21. Lambin, E. F.; Geist, H. J.; Lepers, E. DYNAMICS OF LAND-USE AND LAND-COVER CHANGE IN TROPICAL REGIONS. *Annual Review of Environment and Resources* **2003**, *28*(1), 205–241. doi:10.1146/annurev.energy.28.050302.105459.

22. Pinheiro, T. F.; Escada, M. I. S.; Valeriano, D. M.; Hostert, P.; Gollnow, F.; Müller, H. Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 region in southwestern pará, Brazil. *Earth Interactions* **2016**, *20*(17). doi:10.1175/EI-D-15-0016.1.

23. Jakovac, C. C.; Dutrieux, L. P.; Siti, L.; Peña-Claros, M.; Bongers, F. Spatial and temporal dynamics of shifting cultivation in the middle-Amazonas river: Expansion and intensification. *PLoS ONE* **2017**, *12*(7), 1–15. doi:10.1371/journal.pone.0181092.

24. Schmitt-Harsh, M. Landscape change in Guatemala: Driving forces of forest and coffee agroforest expansion and contraction from 1990 to 2010. *Applied Geography* **2013**, *40*, 40–50. doi:10.1016/j.apgeog.2013.01.007.

25. Costa, R. L.; Prevedello, J. A.; de Souza, B. G.; Cabral, D. C. Forest transitions in tropical landscapes: A test in the Atlantic Forest biodiversity hotspot. *Applied Geography* **2017**, *82*, 93–100. doi:10.1016/j.apgeog.2017.03.006.

26. Meyfroidt, P.; Lambin, E. F. *Global Forest Transition: Prospects for an End to Deforestation*; 2011; Vol. 36. doi:10.1146/annurev-environ-090710-143732.

27. Gay-des-Combes, J. M.; Robroek, B. J. M.; Hervé, D.; Guillaume, T.; Pistocchi, C.; Mills, R. T. E.; et al. Slash-and-burn agriculture and tropical cyclone activity in Madagascar: Implication for soil fertility dynamics and corn performance. *Agriculture, Ecosystems and Environment* **2017**, *239*, 207–218. doi:10.1016/j.agee.2017.01.010.

28. Chazdon, R. L. *Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation*; 2014; Vol. 134.

29. Lugo, A. E. Effects and outcomes of Caribbean hurricanes in a climate change scenario. *The Science of the Total Environment* **2000**, *262*, 243–251.

30. Pielke, R. A.; Rubiera, J.; Landsea, C.; Fernández, M. L.; Klein, R. Hurricane Vulnerability in Latin America and The Caribbean: Normalized Damage and Loss Potentials. *Natural Hazards Review* **2003**, *4*(3), 101–114. doi:10.1061/(asce)1527-6988(2003)4:3(101).

31. Uriarte, M.; Thompson, J.; Zimmerman, J. K. Hurricane María tripled stem breaks and doubled tree mortality relative to other major storms. *Nature Communications* **2019**, *10*(1). doi:10.1038/s41467-019-09319-2.

32. Flores, B. M.; Levis, C. Human-food feedback in tropical forests. *Science* **2021**, *372*(6547), 1146–1147. doi:10.1126/science.abh1806.

33. Flores, B. M.; Staal, A. Feedback in tropical forests of the Anthropocene. *Global Change Biology* **2022**, *28*(17), 5041–5061. doi:10.1111/gcb.16293.

34. Jakovac, C. C.; Junqueira, A. B.; Crouzeilles, R.; Peña-Claros, M.; Mesquita, R. C. G.; Bongers, F. The role of land-use history in driving successional pathways and its implications for the restoration of tropical forests. *Biological Reviews* **2021**, *96*(4), 1114–1134. doi:https://doi.org/10.1111/brv.12694.

35. Suding, K. N.; Gross, K. L.; Houseman, G. R. Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* **2004**, *19*(1), 46–53. doi:10.1016/j.tree.2003.10.005.

36. Flores, B. M.; Staal, A.; Jakovac, C. C.; Hirota, M.; Holmgren, M.; Oliveira, R. S. Soil erosion as a resilience drain in disturbed tropical forests. *Plant and Soil* **2019**, *450*(1–2), 11–25. doi:10.1007/s11104-019-04097-8.

37. Folke, C. Resilience (Republished). *Ecology and Society* **2016**, *21*(4). doi:10.5751/ES-09088-210444.

38. Levin, S.; Xepapadeas, T.; Crépin, A. S.; Norberg, J.; De Zeeuw, A.; Folke, C.; et al. Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics* **2012**, *18*(2), 111–132. doi:10.1017/S1355770X12000460.

39. Aide, T. M.; Clark, M. L.; Grau, H. R.; López-Carr, D.; Levy, M. A.; Redo, D.; et al. Deforestation and Reforestation of Latin America and the Caribbean (2001-2010). *Biotropica* **2013**, *45*(2), 262–271. doi:10.1111/j.1744-7429.2012.00908.x.

40. Mottet, A.; Ladet, S.; Coqué, N.; Gibon, A. Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture, Ecosystems and Environment* **2006**, *114*(2–4), 296–310. doi:10.1016/j.agee.2005.11.017.

41. Bax, V.; Francesconi, W. Environmental predictors of forest change: An analysis of natural predisposition to deforestation in the tropical Andes region, Peru. *Applied Geography* **2018**, *91*, 99–110. doi:10.1016/j.apgeog.2018.01.002.

42. Barrowclough, M.; Stehouwer, R.; Alwang, J.; Gallagher, R.; Barrera Mosquera, V. H.; Domínguez, J. M. Conservation agriculture on steep slopes in the Andes: Promise and obstacles. *Journal of Soil and Water Conservation* **2016**, *71*(2), 91–102. doi:10.2489/jswc.71.2.91.

43. Bax, V.; Francesconi, W.; Quintero, M. Spatial modeling of deforestation processes in the Central Peruvian Amazon. *Journal for Nature Conservation* **2016**, *29*, 79–88. doi:10.1016/j.jnc.2015.12.002.

44. Laurance, W. F.; Curran, T. J. Impacts of wind disturbance on fragmented tropical forests: A review and synthesis. *Austral Ecology* **2008**, *33*(4), 399–408. doi:10.1111/j.1442-9993.2008.01895.x.

45. Boose, E. R.; Foster, D. R.; Fluet, M. Hurricane Impacts to Tropical and Temperate Forest Landscapes. *Ecological Monographs* **1994**, *64*(4), 369–400.

46. Ministère de L'Environnement. *Plan de Gestion Parc National Naturel Macaya*; 2015.

47. Sergile, F. E.; Woods, C. A.; Paryski, P. E. *Final Report of the Macaya Biosphere Reserve Project*; Gainesville, 1992.

48. Robart, G. Végétation de la République d'Haïti, Université scientifique et médicale de Grénoble, 1984.

49. USAID. *Vulnérabilité Environnementale En Haïti: Conclusions et Recommandations*; 2006.

50. Crausbay, S. D.; Martin, P. H. Natural disturbance, vegetation patterns and ecological dynamics in tropical montane forests. *Journal of Tropical Ecology*. Cambridge University Press 2016, pp 384–403. doi:10.1017/S0266467416000328.

51. Le Moniteur. Décret du 4 Avril 1983 déclarant "Parcs Nationaux Naturels" les aires entourant le morne La Visite e le morne Macaya entourant le Pic Macaya au massif de La Hotte. *Le Moniteur*. Port-au-Prince 1983, p No. 41 de 23 Juin 1983.

52. Hedges, S. B.; Cohen, W. B.; Timyan, J.; Yang, Z. Haiti's biodiversity threatened by nearly complete loss of primary forest. *Proceedings of the National Academy of Sciences* **2018**.

53. National Hurricane Center; Central Pacific Hurricane Center. *Hurricanes in History*. <https://www.nhc.noaa.gov/outreach/history/> Accessed 24.01.24.

54. Weather Underground. *Hurricane and Tropical Cyclones*. <https://www.wunderground.com/hurricane/archive> Accessed 24.01.24.

55. Unesco. *La Hotte Biosphere Reserve, Haiti*. <https://en.unesco.org/biosphere/lac/lahotte> Accessed 23.08.06.

56. Hansen, M. C.; Potapov, P. V.; Moore, R.; Hancher, M.; Turubanova, S. A.; Tyukavina, A.; et al. High-resolution global maps of 21st-century forest cover change. *Science* **2013**, *342*(6160), 850–853. doi:10.1126/science.1244693.

57. Woods, C. A.; Ottenwalder, J. A. *The Natural History of Southern Haiti*; Florida Museum of Natural History: Gainesville, 1992.

58. Sergile, F. *Arbres et Arbustes de Macaya*; Florida Museum of Natural History: Gainesville, 1994.

59. AVSI. *Analyse et Étude Du Contexte Socio-Économique et Environnementale Du Parc Macaya, Haïti*; Port-au-Prince, 2012.

60. PNUD. *Rapport OMD 2013, Haïti: Un Nouveau Regard*; Port-au-Prince, 2014.

61. Leutner, B.; Wegmann, M. Pre-processing Remote Sensing Data. In *Remote Sensing and GIS for Ecologists: Using Open Source Software*. Wegmann, M., Leutner, B., Dech, S., Eds.; Pelagic Publishing: UK, 2016; p 333.

62. Rouse, J. W.; Haas, R. H.; Schell, J. A.; Deering, D. W. Monitoring Vegetation Systems in the Great Plains with ERTS (Earth Resources Technology Satellite). In *Proceedings of 3rd Earth Resources Technology Satellite Symposium*; Greenbelt, 1973; pp 309–317.

63. McFEETERS, S. K. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing* **1996**, *17*(7), 1425–1432. doi:10.1080/01431169608948714.

64. DeVries, B.; Verbesselt, J.; Kooistra, L.; Herold, M. Robust monitoring of small-scale forest disturbances in a tropical montane forest using Landsat time series. *Remote Sensing of Environment* **2015**, *161*, 107–121. doi:10.1016/j.rse.2015.02.012.

65. Anderson, L. O.; Malhi, Y.; Aragão, L. E. O. C.; Ladle, R.; Arai, E.; Barbier, N.; et al. Remote sensing detection of droughts in Amazonian forest canopies. *New Phytologist* **2010**, *187*(3), 733–750. doi:10.1111/j.1469-8137.2010.03355.x.

66. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. 2017.

67. NASA JPL. *NASADEM Merged DEM Global 1 arc second V001 [Data set]*. NASA EOSDIS Land Processes DAAC. <doi:10.5067/MEaSUREs/NASADEM/NASADEM_HGT.001> Accessed 23.08.07.

68. Horning, N.; Leutner, B.; Wegmann, M. Land Cover or Image Classification Approaches. In *Remote Sensing and GIS for Ecologists: Using Open Source Software*. Wegmann, M., Leutner, B., Dech, S., Eds.; Pelagic Publishing: UK, 2016; p 333.

69. Crawley, M. J. *Statistics: An Introduction Using R*; Second edition.; Wiley: Noida, 2015.

70. QGIS Development Team. QGIS Geographic Information System. Open Source Geospatial Foundation Project. 2022. <http://qgis.osgeo.org>.

71. Team, R. C. R: A Language and Environment for Statistical Computing. *R Foundation for Statistical Computing*. R Foundation for Statistical Computing: Vienna 2022, p 409. doi:10.1007/978-3-540-74686-7.

72. Pebesma, E. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal* **2018**, *10*(1), 439–446. doi:10.32614/RJ-2018-009.

73. Hijmans, R. J.; Etten, J. van. raster: Geographic analysis and modeling with raster data. 2012. <http://cran.r-project.org/package=raster>.

74. Wickham, H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag: New York 2016.

75. Dunnington, D.; Thorne, B.; Hernangómez, D. Spatial Data Framework for ggplot2. 2022. <https://paleolimbot.github.io/ggspatial/>.

76. Walker, R. The scale of forest transition: Amazonia and the Atlantic forests of Brazil. *Applied Geography* **2012**, *32*(1), 12–20. doi:10.1016/j.apgeog.2010.10.010.

77. Song, X. P.; Hansen, M. C.; Stehman, S. V.; Potapov, P. V.; Tyukavina, A.; Vermote, E. F.; et al. Global land change from 1982 to 2016. *Nature* **2018**, *560*(7720), 639–643. doi:10.1038/s41586-018-0411-9.

78. Fondation Macaya Pour le Développement local. *CEPF RAPPORT D'ACHEVEMENT DE PROJET FINAL*; 2015. <https://www.cepf.net/sites/default/files/final-report-62119.pdf> Accessed 24.01.27.

79. Critical Ecosystem Partnership Fund. *Alternatives for Sustainable Social-Ecological Conservation in the Macaya Key Biodiversity Area, Massif de la Hotte, Haiti*. <https://www.cepf.net/grants/grantee-projects/alternatives-sustainable-socio-ecological-conservation-macaya-key> Accessed 24.01.27.

80. Critical Ecosystem Partnership Fund. *Environmental Eduaction for Community Participation in Conservation of Macaya, Massif de la Hotte Key Biodiversity Area*. <https://www.cepf.net/grants/grantee-projects/environmental-education-community-participation-conservation-macaya-massif>.

81. Critical Ecosystem Partnership Fund. *Ecosystem Threat Assessment and Protected Area Strategy for the Massif de la Hotte Key Biodiversity Area, Phase 2*. <https://www.cepf.net/grants/grantee-projects/ecosystem-threat-assessment-and-protected-area-strategy-massif-de-la-hotte-0>.

82. Tarter, A.; Freeman, K. K.; Sander, K. *A History of Landscape-Level Land Management Efforts in Haiti: Lessons Learned from Case Studies Spanning Eight Decades*; 2016.

83. Folke, C.; Hahn, T.; Olsson, P.; Norberg, J. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* **2005**, *30*, 441–473. doi:10.1146/annurev.energy.30.050504.144511.

84. MDE. *Sixième Rapport National Sur La Biodiversité d'Haïti*; 2019.

85. Thompson, J.; Brokaw, N.; Zimmerman, J. K.; Waide, R. B.; Edwin, M.; Iii, E.; et al. Land Use History , Environment , and Tree Composition in a Tropical Forest. *Ecological Applications* **2002**, *12*(5), 1344–1363.

86. Boose, E. R.; Serrano, M. I.; Foster, D. R. LANDSCAPE AND REGIONAL IMPACTS OF HURRICANES IN PUERTO RICO. *Ecological Monographs* **2004**, *74*(2), 335–352. doi:10.1890/02-4057.

87. Oliver, T. H.; Heard, M. S.; Isaac, N. J. B.; Roy, D. B.; Procter, D.; Eigenbrod, F.; et al. Biodiversity and Resilience of Ecosystem Functions. *Trends in Ecology and Evolution* **2015**, *30*(11), 673–684. doi:10.1016/j.tree.2015.08.009.

88. Cazzolla Gatti, R.; Castaldi, S.; Lindsell, J. A.; Coomes, D. A.; Marchetti, M.; Maesano, M.; et al. The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. *Ecological Research* **2015**, *30*(1), 119–132. doi:10.1007/s11284-014-1217-3.

89. Barlow, J.; Lennox, G. D.; Ferreira, J.; Berenguer, E.; Lees, A. C.; Nally, R. Mac; et al. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature* **2016**, *535*(7610), 144–147. doi:10.1038/nature18326.

90. Elmqvist, T.; Folke, C.; Nyström, M.; Peterson, G.; Bengtsson, J.; Walker, B.; et al. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment* **2003**, *1*(9), 488–494. doi:10.1890/1540-9295(2003)001[0488:RDECAR]2.0.CO;2.

91. Silvério, D. V.; Brando, P. M.; Bustamante, M. M. C.; Putz, F. E.; Marra, D. M.; Levick, S. R.; et al. Fire, fragmentation, and windstorms: A recipe for tropical forest degradation. *Journal of Ecology* **2019**, *107*(2), 656–667. doi:10.1111/1365-2745.13076.

92. Van Nes, E. H.; Staal, A.; Hantson, S.; Holmgren, M.; Pueyo, S.; Bernardi, R. E.; et al. Fire forbids fifty-fifty forest. *PLoS ONE* **2018**, *13*(1), 12–17. doi:10.1371/journal.pone.0191027.

3 CAPÍTULO 2: HOW MULTIPLE DISTURBANCES INFLUENCE FOREST RESILIENCE IN SOUTHERN HAITI?

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3.1 ABSTRACT

Disturbance generally creates environmental heterogeneity that allows the existence of hyperdiverse tropical forests. However, increasing land uses interacting with natural disturbances can jeopardize their existence in the future. The Macaya National Park has been experimenting land changes due to intensification of shifting agriculture and selective logging in addition to hurricane disturbance, forces that can lessen its resilience and undermine the provision of ecosystem services. In this context, we investigate how shifting agriculture and logging interact with hurricanes and what are the dominant feedbacks contributing to reinforce or lessen the resilience of tropical forests in the Macaya National Park in Southern Haiti. To achieve this goal, we conducted semi-structured interviews with local farmers and loggers in conjunction with a comprehensive literature review. Considering the steep topography of the Macaya National Park, the erosion positive feedback loop is one of the most important in the region. Intensified shifting agriculture and logging lower tree cover which increase soil erosion, soil erosion decreases soil nutrients which slow down tree growth and consequently, further soil regeneration. When hurricane events hit the disturbed forests, they amplify the previous damage induced by logging and agriculture, undermining the resilience of the system. Understanding the importance of managing adequately these feedbacks is critical for any restoration or

conservation program in the Macaya National Park to be successful in the face of climate change.

Keywords: shifting agriculture, selective logging, hurricane, tropical forest, positive feedback, resilience.

3.2 INTRODUCTION

Disturbances play an essential role in the dynamics of tropical forest ecosystems (Johnstone et al., 2016; Pickett & White, 1985). They generate changes in the availability of resources, substrate or the physical environment, thus creating environmental heterogeneity that can reshape forest cover and alter biodiversity (Calderon-Aguilera et al., 2012; Crausbay & Martin, 2016; Pickett & White, 1985). As these biotic and abiotic changes can affect ecosystem functions that support the provision of ecosystem services (De Groot et al., 2002; Jakovac et al., 2015), it is mandatory to identify the prevailing disturbances affecting a given forest and understand their mechanisms for a sustainable forest management and for assuring human well-being (Millenium Ecossystem Assessment, 2005).

The disturbances that affect tropical forests are very diverse including everything from single tree-falls (Brokaw, 1985) to ecological catastrophes (Attiwill, 1994) and human activities (Cazzolla Gatti et al., 2015; Pinheiro et al., 2016). The consequences of a given disturbance depend on its type, intensity, frequency, duration, extent and the previous state of the ecosystem being affected (Franklin, 2007; Jakovac et al., 2021; Pickett & White, 1985). For example, tropical forests usually recover more rapidly and to a more similar pre-disturbance state from natural disturbances than from human-induced disturbances, considering that anthropogenic disturbances are usually more intense, frequent and long-lasting than natural ones (Chazdon, 2003; Franklin, 2007). However, as complex adaptive system (Levin, 1998), tropical forests are often impacted by multiples interacting disturbances, the outcomes of which can be unpredictable and are mediated by feedback (Chazdon, 2014; Li et al., 2020; Scheffer et al., 2001). Feedback is the phenomenon of reciprocal cause and effect that can be positive or negative (Flores & Staal, 2022). Positive feedback intensifies previous change while negative feedback lessens it

(Flores & Staal, 2022; Wilson & Agnew, 1992). These complex interactions can threaten the resilience of these forests, by contributing to maintain them in a degraded state (Flores & Staal, 2022; Scheffer et al., 2001). For instance, in cloud forests, taller vegetation on the hilltops captures fog precipitation which in turn provides moisture for a rich ecosystem. If the trees are cut down, water becomes less available, and the conditions can be too dry for the forest to recover (Wilson & Agnew, 1992). Likewise, windstorms interact with fire and fragmentation to influence recovery processes and damages (Silvério et al., 2019). In the Amazon forest, for example, it was observed that windstorms caused more tree damage and death close to the forest edge, among large trees, and in previously burned area (Silvério et al., 2019).

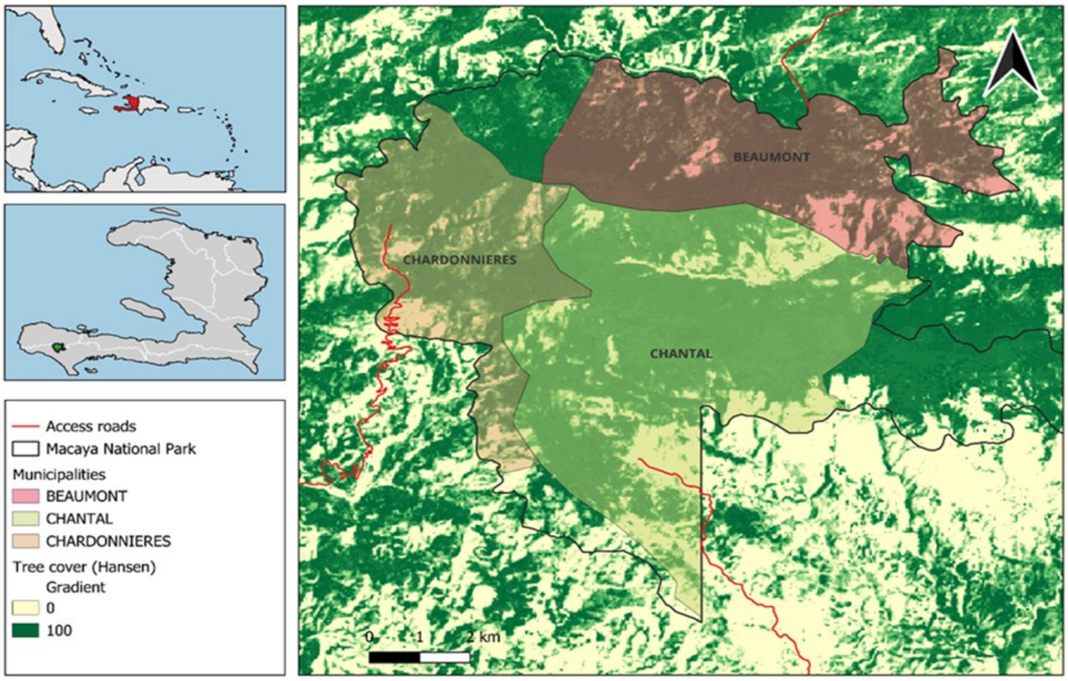
Southern Haiti harbors several relevant fragments of the natural tropical forests in the country. These ecosystems provide diverse ecosystem services such as timber for construction and furniture manufacturing, firewood and water for agriculture and domestic uses (Ministère de L'Environnement, 2015). Due to their importance, the Macaya National Park (MNP) was created to protect part of the last remnants of primary tropical forests in Southern Haiti (Le Moniteur, 1983; Sergile et al., 1992). Nonetheless, the vegetation has been undergoing recurrent anthropogenic and natural disturbances, of which the most relevant are intensification of shifting cultivation, selective logging and hurricanes, that can modulate the resilience of the MNP. In this context, understanding the dominant interactions and feedbacks driving forest dynamics in the MNP is crucial for the regeneration or restoration of the disturbed ecosystems and preservation of the undamaged part (Suding et al., 2004). In the present study, we seek to understand how shifting agriculture and logging – the major human disturbances in the MNP, interact with hurricanes – the major natural disturbance in the region and what are the dominant feedback loops contributing to reinforce or lessen the resilience of tropical forests in Southern Haiti. To achieve this goal, we carried out a systematic literature review combined with data of interviews with local community members. Here, we provide an overview of the impacts of the intensification of shifting cultivation, logging and hurricanes on tropical forests. Besides, in light of this knowledge, we analyze the data originating from the interviews to understand how anthropogenic and natural disturbances interact between them in the biophysical and socioeconomic contexts of the MNP to boost or lower resilience.

3.3 MATERIAL AND METHODS

3.3.1 Study area

The Macaya National Park (MNP) located in Southern Haiti was created in 1983 to protect natural resources and recover the region's ecosystem to ensure sustainable development (Le Moniteur, 1983) (Figure 4). Its territory has a very steep topography and is mostly covered by ombrophilous and pine forests (Ministère de L'Environnement, 2015; Woods & Ottenwalder, 1992). Its climate has temperatures varying from 5 to 20 °C and two distinct rainy seasons; the first extends from April to June and the other, from August to November totalizing about 3,000 mm of mean annual rainfall (Sergile, 1994). Due to its localization, the MNP has been recurrently impacted by several hurricanes (Judd, 1987; USAID, 2006). Local population essentially depends on traditional slash-and-burn agriculture, selective logging and cattle ranching (AVSI, 2012; Sergile et al., 1992).

Figure 4 - Localization map of Macaya National Park, showing three of the most crowded municipalities and tree cover for the year 2000 according to Hansen et al. (2013).



3.3.2 Literature review

We conducted a systematic literature review using the “Scopus” search engine (Li et al., 2020; Nikinmaa et al., 2020). We used the following combination of keywords: (“shifting cultivation” OR “shifting agriculture” OR “slash and burn agriculture” OR “slash and burn cultivation” OR “swidden agriculture” OR “swidden cultivation”) AND (“resilience” OR “resistance” OR “adaptability” OR “feedback loops” OR “conservation” OR “restoration” OR “management” OR “stewardship”) AND (“hurricane” OR “storm” OR “cyclone” AND “logging” OR “felling” OR “ tree cutting”). We did not put any additional restriction on publication date or language. This search, performed in February 2024, returns 49 published studies. We briefly analyzed all these papers using the title and abstract for a finer selection. We only retained studies that address the biophysical changes induced by shifting agriculture and selective logging, two widespread anthropogenic activities and hurricanes in tropical forests as well as how such changes influence natural regeneration or restoration processes. Studies that focus on the assessment of remote sensing methods to detect shifting agriculture and logging were also excluded. This refinement reduced the initial number of selected studies to 18. We also selected three more studies from the references of the previously selected papers to complement our revision, totalizing 21 articles (Table S1).

3.3.3 Interviews with local community

We selected three from the most crowded municipalities (*Chantal*, *Chardonnières* and *Beaumont*) (Figure 1) whose part of the territory integrates the MNP were we conducted 35 semi-structured interviews (Appendix A) with the local farmers and loggers during the first semester of 2019. To select the participants, we first contacted, in each village, local leaders or state employees that indicated the first interviewees. We retained only young people and adults older than 25 who are farmers, loggers or charcoal producers. We then proceeded using the snow-ball method, requesting each interviewee to indicate another one who matched our criteria (Albuquerque et al., 2019). In our questionnaires, we included questions about socioeconomic conditions, agricultural practices and the use of forest resources.

3.4 RESULTS AND DISCUSSION

3.4.1 Dynamics of land use in the Macaya region

3.4.1.1 Socio-economic profile of the participants

We interviewed a total of 35 dwellers of the Macaya region, being all men, of which 25.71% were from villages belonging to the municipality of *Beaumont*, 54.28% from *Chantal* and 20.0% from *Chardonnières*. The younger participant was 32 years old at the time of the interview, and the oldest was 86. Of all the participants, 34.28% went to school until they reached up to the fifth-grade elementary school, 5.71% reached the sixth grade, 5.71% studied up to the ninth grade, and 54.28% did not even go to school. All the participants were born in villages inside the MNP or near its border. 71.14% of them have been living there ever since and 22.85% of them left their place of birth, at some point, to emigrate to large urban centers for a period varying from a few months to several years, looking for better conditions of life. After facing serious adversities in their adventures, they came back to their homeland.

All 35 participants practice shifting agriculture. In addition, most of them have at least one more activity to complement household income. Of all the interviewees, 74.28% also practice cattle breeding, 31.42% selective logging, 25.71% produce charcoal and roughly 5% practice activities that are not directly related to land use such as voodoo priest, musician and tourist guide. As we observed from these results, shifting agriculture was the dominant land use in the MNP, being the principal source of income for most of the participants. This result is consistent with other studies conducted, for example, in Brazilian Amazon forest (Jakovac et al., 2017; Villa et al., 2018), in Laos (Chen et al., 2023), in West Kalimantan, Indonesia (Lawrence et al., 1998), and Mozambique (Nhiuane et al., 2024) recognizing shifting cultivation as an important traditional land use in tropical forests across the globe. (AVSI, 2012)

3.4.1.2 Shifting agriculture and its influence on forest attributes

Agriculture in the region varies in relation to the land tenure system, size of croplands, cultivated crop species, crop maintenance and fallow phase length. 54.28% of the farmers cultivate their own land. The remaining farmers cultivate rented land from landlords or state-owned lands. At the beginning of a new shifting cultivation cycle, farmers cut the regenerating vegetation using machetes and hoes to open space. The debris is usually piled up and burnt. These actions induce significant changes in environmental conditions, soil physical and chemical properties and streamflow (Malmer et al., 2005). Removing the canopy trees provokes an immediate increase of solar radiation (Lu et al., 2014) and higher temperature (Malmer et al., 2005). The burning process also contributes to a loss of soil organic matter and resulting changes in pore distribution (Malmer et al., 2005). Consequently, soil infiltration capacity is reduced and surface runoff, increased (Hölscher et al., 2005; Malmer et al., 2005). In addition, by felling and burning trees to open space for cultivation, farmers may generate sudden reduction of species diversity and change in composition. When plots are abandoned, species diversity and composition can gradually return to pre-disturbance level through natural succession or regeneration (Chazdon, 2003, 2013). Nonetheless, the rapidity of succession as well as the pathway that will succeed depend on species availability and the combination of local and landscape conditions (Jakovac et al., 2021) which result from the scale, frequency and intensity of previous land use (Chazdon, 2013). In general, species diversity and composition recover slower than structure attributes following shifting agriculture. It may take centuries for recovering forests to regain similar species diversity and composition to old-growth forests (Chazdon, 2003). In some cases, differences may remain even irreversible (Hölscher et al., 2005).

In a study conducted in Northern Amazon, the authors observed higher species richness in 10 years-old stands than in 5 years-old stands, but species richness decreased between 40 and 47% during early succession in plots after numerous cycles of shifting cultivation in comparison with plots after a single shifting cultivation cycle (Villa et al., 2018). It was also found that woody species composition varied considerably among successional stages and old-growth forests, with community dissimilarity between second- growth and nearest old-growth plots being greater than the dissimilarity between pairs of old-growth plots and increasing dissimilarity between second-growth and old-growth plots with intensification of shifting cultivation (Villa et al., 2018). Likewise, a study about seedling species composition and diversity over a chronosequence after shifting cultivation in tropical lowland forests in China revealed higher species richness and seedling abundance in 60 years-old forest plots than in 18 years-old and 30 years-old forest plots (Lu et al., 2016). Also, in their study on succession following shifting agriculture in the Atlantic Rain Forest in Southeastern Brazil, Gomes et al. (2020) found that species richness at the 40-60 years old plots was twofold that of the 2-4 years old plots.

Dominant trees species, stem density, canopy height and basal area change significantly between successional stages after shifting cultivation (Hölscher et al., 2005). Basal area increases with regeneration time, but decreases considerably with shifting cultivation intensity, i.e., number of cycles (Urquiza-Haas et al., 2007; Villa et al., 2018). For instance, Urquiza-Haas et al. (2007) in their study in the Yucatan

Peninsula in Mexico found that forest basal area was lower in early to mid-successional stands than in late-successional stands.

Some farmers related that they use part of or all the debris to make compost. Others use them to build terraces, i.e., flat areas on the side of a hill, as a way to reduce soil erosion on steep slopes. Then, the farmers tilled the soil using hoes and plant one or several crop species. The most cultivated species are *Ipomea batatas* (sweet potato), *Dioscorea* sp. (yams), *Phaseolous vulgaris* (black beans), *Xanthosoma* sp. (malanga), *Musa* spp. (bananas), *Zea mays* (corn), *Manihot esculenta* (cassava) and *Brassica oleracea* (cabbage).

Farmers use to prepare the lands from November to December for planting cabbage, from April to May for yams, and June for planting sweet potatoes, corn and beans. Cabbage is the crop species which receives fertilizer most of the time. Other crops rather receive compost only once at the time of planting. Compost is a mixture of cow or horse dung with plant debris and soil, left to decompose for about three months before being used. Fields activities such as planting and trampling can lead to soil compaction which increase surface runoff (Hölscher et al., 2005). Concentrated surface runoff may create heavy erosion depending on slope morphology (Malmer et al., 2005). For instance, high rate of soil loss (121 t ha-1 year-1) was found in paddy fields in northern Borneo, Malaysia (Vijith et al., 2018).

Normally, farmers that also practice cattle ranching use their fallows as pasture for livestock. After a few months or years, these lands are used again for cultivation and the lands previously at cultivation are then used for pasture. Fallow length varies from six months to seven years, being influenced by capital availability for buying agricultural inputs (fertilizers and seeds or sprouts) and paying field workers. Some farmers revealed that they are inclined to leave shorter fallow time when they have enough financial resources to buy fertilizers. Others report that they cultivate less land than they would like to due to the lack of money to pay workers. The previous management intensity determines the site’s nutrient status (Hölscher et al., 2005). Short fallow times and frequent burning can reduce soil nutrient availability (Chazdon, 2013). For example, Villa et al. (2018) noticed reduced soil fertility in second-growth forests plots after more shifting cultivation cycles in comparison to second-growth forests plots following only one cycle.

3.4.1.3 Selective logging and its influence on forest attributes

All the interviewees related that they use several tree species for different purposes. However, only 31.42% of the participants informed that they practice selective logging and only 11,42% have it as the principal source of income. The most cited species were *Pinus occidentalis*, *Ocotea* sp., *Mastichodendron foetidissimum* (Jacq.) Cronq. ssp. *foetidissimum*, *Micropholis polita* spp. *hotteana*, *Cedrela odorata*, *Prunus* spp. (*P. occidentalis*, *P. myrtifolia*), *Amyris* spp. and *Didymopanax tremulus*.

Pinus occidentalis is used for house construction, furniture manufacturing and firewood. *Ocotea* sp. and *Mastichodendron foetidissimum* are used for furniture manufacturing, house construction, charcoal production and firewood. *Micropholis polita* is used for food (edible fruits), charcoal production, firewood and house construction. *Cedrela odorata* is used for house construction, furniture manufacturing, firewood, coffin making and voodoo rituals. *Prunus* spp. is used for medicinal tea preparation, household utensils manufacturing (for ex., pestle), charcoal production, firewood and furniture manufacturing. *Amyris* spp. is used for house construction, firewood and voodoo rituals. *Didymopanax tremulus* is used for firewood, medicinal tea and voodoo rituals.

Loggers normally use hatchets to cut down selected trees. But, due to the lack of trafficable roads and the very rough topography of the MNP, they face some difficulties transporting their logs. To alleviate these problems, loggers build temporary structures near the site of extraction and use huge wood saws to execute manual primary wood processing. The wood boards, slats, rafters and beams, being lighter than the logs, are then transported by hand or on horseback to the local markets or buyers. The wood processing waste (sawdust) is left behind.

Selective logging can induce several changes in species diversity and composition, forest structure and soil properties that are modulated by the intensity of this land use (Chazdon, 2003). During the extraction of select valuable species, many individuals of commercially unprofitable plant species are damaged (Gorte, 2010). Such operations can immediately reduce tree basal area (Urquiza-Haas et al.,

2007) and further induce patchy pattern of soil disturbance and light availability due to the increase in canopy openings (Attiwill, 1994; Nepstad et al., 1999). For instance, basal area in late-successional plots (30 – 50 years) was gradually reduced with increased logging intensity in the Yucatan Peninsula, Mexico (Urquiza-Haas et al., 2007). Logging operations in West Kalimantan, Indonesia removed 43% of the total stand basal area and opened 45% of the canopy (Cannon et al., 1998). The increased light availability contributes to increased temperature, facilitating the drying of the lot of organic debris left behind by the timber extraction operations (Nepstad et al., 1999). As a result, the logged forests become more susceptible to natural or human-ignited fires than the unlogged forests (Chazdon, 2003; Nepstad et al., 1999). The high availability of light in logged forest plots may also facilitate the proliferation of disturbance specialist plants such as lianas (Garrido-Perez & Gerold, 2009).

The reduction of tree cover due to logging activity can substantially increase soil erosion vulnerability in tropical forests (Vijith et al., 2018). Forest trees protect the soil by breaking the force of falling raindrops and facilitating rainwater absorption by the soil and its further gradual release; when trees are cut down, water flow is disrupted, leading to surface runoff and flooding (Kozlowski, 2000). For instance, a study conducted in Northern Borneo, Malaysia, revealed high soil loss or erosion rates mainly in areas which undergo severe terrain modification due to timber harvesting. These areas became critical zones of sediment production and transport during heavy rainfall (Vijith et al., 2018). All these changes in water flow in logged forests also contribute to increase loss of soil nutrients by leaching (Kozlowski, 2000).

Most of the loggers (90.9%) affirmed that they started to practice logging because of the deterioration of their life conditions. According to the loggers, such deterioration is induced by the reduction of soil fertility and productivity, increase of living cost, reduction of their croplands due to the creation of the MNP, loss of livestock or harvests due to hurricanes such as Matthew.

3.4.2 Hurricanes and their influence on forest attributes

Hurricanes are large sporadic natural disturbances which can induce extensive, but short-term damage to the forest landscapes (Chazdon, 2003). As the hurricanes generally do not kill all the trees, the surviving ones become important sources of propagules influencing succession (Turner et al., 1998). For example, in a study in Tonga, South Pacific, it was observed that the overstorey composition of the mature plots disturbed by the cyclone Waka changed very little if at all when comparing pre- and post-cyclone surveys results (Franklin, 2007). On the other hand, as the intensity and scale of hurricanes as well as the pre-disturbance state of vegetation influence the subsequent successional pathway (Attiwill, 1994; Chazdon, 2013), powerful hurricanes by themselves or interacting with other disturbances or land uses can create large forest gaps, facilitating the recruitment and establishment of non-native species (Franklin, 2007). Franklin (2007) observed that plots that were also burned showed greater change between surveys and that the non-native early pioneer species *Carica papaya* was hyper-abundant in sites with multiple disturbances or large gaps.

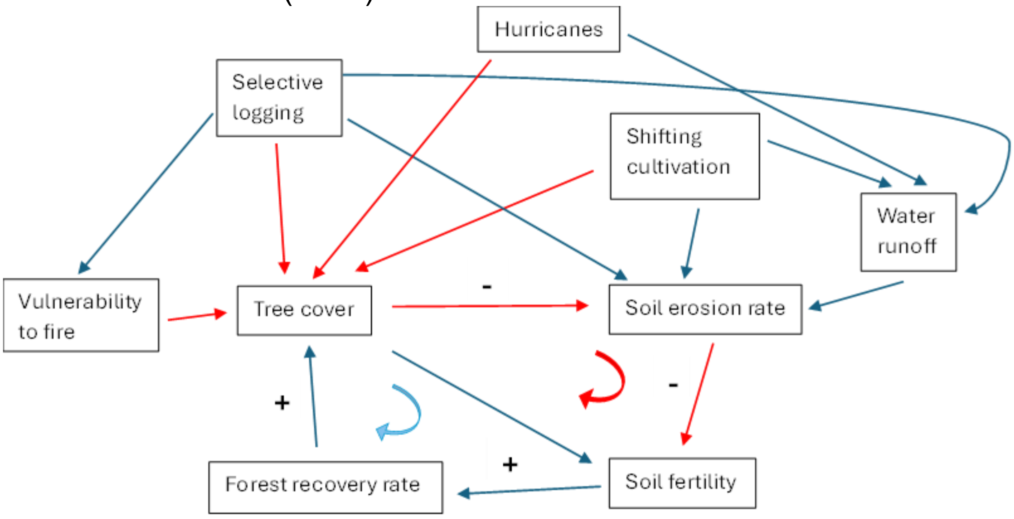
Species life-history traits interact with disturbance intensity to influence species composition of residuals (Turner et al., 1998). Many tropical tree species have the capacity of resprouting (Kammesheidt, 1998, 1999) and can lead to a rapid recovery of species composition following hurricanes (Chazdon, 2003). Within 40 days after the tropical cyclone Winifred around Innisfail, Queensland, a massive resprouting were observed; likewise, after the Hurricane Joan struck the east coast of Nicaragua in 1988, the forest regenerated rapidly and predominantly by resprouting from the damaged trees (Attiwill, 1994).

3.4.3 Feedback between shifting agriculture, logging and hurricanes

As we observed from our results, shifting agriculture was the dominant land use in the MNP, being the principal source of income for most of the participants. The other most cited land uses were cattle ranching followed by selective logging, which are practiced by some farmers as complementary activities to increase their incomes. Despite it was the second most cited human activity, cattle ranching by itself presumably does not cause relevant damage to forest landscape in the MNP, considering that livestock is very small in the region (AVSI, 2012). Likewise, logging by itself is unlikely to induce deep long-lasting changes in the forest as few loggers manually extract select trees of commercially valuable species (Gorte, 2010; Nepstad et al., 1999). Nevertheless, as these human-induced disturbances occur simultaneously and influence each other (Chazdon, 2014) while they interact with hurricanes which are recurrent in the region (Robart, 1984; USAID, 2006), the outcomes can be unpredictably devastating, threatening the resilience of the system (Flores et al., 2019; Flores & Staal, 2022).

Shifting cultivation decreases considerably soil nutrients level during the cropping period (Figure 5), reason why farmers move to other newly open adjacent plots after a relatively short period (Hölscher et al., 2005; Villa et al., 2018). In these conditions, the length of the fallow period plays an important role in the sustainability of this cultivation system (Kleinman et al., 1995). The fallow phase essentially ameliorates soil conditions for future cropping by increasing soil organic matter levels (Kleinman et al., 1995). When the fallow phase is long enough, succession can reach a state where soil fertility is similar to its pre-disturbance level (Hölscher et al., 2005; Lu et al., 2014). In contrast, too short fallow length can lead to rapid fertility depletion in such a way that traditional shifting cultivation would be no more profitable (Kleinman et al., 1995). Fallow length in the MNP varies from six months to seven years, being affected by the availability of capital. But, a two-years fallow was the most commonly practiced by local farmers. Therefore, a process of shifting cultivation intensification is apparently happening in the MNP (Jakovac et al., 2016; Villa et al., 2018). In this context, soil in the region is probably gradually losing its fertility (Kleinman et al., 1995). In fact, during field interviews, virtually all the farmers have complained about the relatively recent need of using fertilizers or increasing field labor for producing the same amount of crops than they used to. To compensate for the increasing need of capital, some farmers resort to alternative activities such as selective logging.

Figure 5 - Diagram of interactions between forest attributes and multiple disturbances, showing feedback loops that may influence resilience in the Macaya region. Blue arrows indicate positive effects and the red ones, negative effects. Adapted from Flores et al. (2019).



Logging reduces considerably the density of standing canopy trees and consequently allows sunlight to reach the forest floor (Cannon et al., 1998; Urquiza-Haas et al., 2007). Increased sunlight dries rapidly the organic debris created by timber extraction increasing forest vulnerability to fire (Figure 5) (Nepstad et al., 1999). As most of the farmers in the MNP region use fire to prepare their lands for cultivation, fire can eventually escape from croplands and burn previously logged forest patches. Besides, farmers normally begin to prepare their lands before the rainy period when likely soil and vegetation water content is already low. As forest flammability can be worsened during period of drought (Nepstad et al., 1999), the combination of increased flammability and the preparation of land in the dry season using fire can be a highly dangerous combination.

Logging can increase erosion vulnerability in tropical forests and environmental factors such as local topography can amplify it (Figure 5) (Flores et al., 2019; Vijith et al., 2018). The MNP has a highly rugged topography, with countless steep slopes, peaks, hills and gullies (Ministère de L’Environnement, 2015). If logging occurs uncontrollably in these slopes and hills, the increasing erosion there can slow down the forest regeneration, what in turn, hinder soil regeneration trapping the system in a degraded and less resilient state mediated by the erosion positive feedback loop (Figure 5) (Flores et al., 2019).

The MNP region has been affected by several hurricanes of diverse intensity over the years (Robart, 1984; USAID, 2006). Their impact on the vegetation depend on their intensity, duration and scale in addition to the pre-hurricane forest state and local topography (Chazdon, 2003; Laurance & Curran, 2008). Mature forest plots disturbed only by cyclones experienced very little change in their species composition over the year while the plot that was also previously burned showed greater change (Franklin, 2007). Fragmented forests are more vulnerable to wind disturbance because they offer less resistance to winds than do dense continuous forests, allowing wind speeds to accelerate and because they are exposed to increased turbulence due to the multiple artificial forest edges present in the landscape (Laurance & Curran, 2008). Furthermore, greater tree mortality is expected on upper slope exposed to the wind than on lower terrain protected from the wind (Boose et al., 1994, 2004). Therefore, considering that the intensification of shifting agriculture and selective logging are both causing forest fragmentation in some parts of the MNP, these fragmented forest plots in windward slopes can represent an Achilles' heel of tropical forests resilience in southern Haiti (Flores et al., 2017).

Finally, although its effect can be relatively small when compared with other large tropical forests, the interacting natural and human-induced disturbances can contribute to worsen climate change by releasing carbon in the atmosphere and interfere in its fixation through forest regrowth (Nepstad et al., 1999).

3.5 CONCLUSION

Disturbance plays an important role in forest dynamics as they create environmental heterogeneity which supports the high biodiversity in tropical forests. Nonetheless, increasing human-induced disturbances such as the intensification of shifting cultivation and logging interacting with natural disturbances such as hurricanes can threaten the future of these ecosystems by trapping them in a degraded state through positive feedbacks. Through interviews with local farmers in conjunction with literature review, we identified several important positive feedbacks that can potentially trap the MNP in an undesired and less resilient degraded state.

Shifting cultivation can reduce soil fertility and consequently, crop productivity which creates the need for more capital; as complementary sources of income, some farmers begin to practice logging activities which further decrease soil fertility. In the erosion positive feedback loop, logging and shifting agriculture reduce tree cover which increase soil erosion; increased erosion decreases tree growth which in turn slow down forest regeneration, therefore contributing to maintain a reduced tree cover state. When hurricanes hit such fragmented forest plots, they can amplify the ongoing effects of previous land uses. Such positive feedbacks need a very special attention in the elaboration of regeneration and conservation programs if policy makers and conservationists stakeholders want to succeed in their attempts to protect the MNP and increase its resilience in a scenario of climate change.

Supplement materials

Table S1. List of the selected papers for literature review.

Authors	Title	Year
Lu et al.	Variations and trade-offs in functional traits of tree seedlings during secondary succession in a tropical lowland rain forest	2014
Chazdon R.L.	Tropical Forest Regeneration	2013
Hölscher et al.	Forest recovery in the humid tropics: Changes in vegetation structure, nutrient pools and the hydrological cycle	2005
Villa et al.	Intensification of shifting cultivation reduces forest resilience in the northern Amazon	2018
Malmer et al.	Effects of shifting cultivation and forest fire	2005
Lu et al.	Changes in biotic and abiotic drivers of seedling species composition during forest recovery following shifting cultivation on Hainan Island, China	2016
Vijith et al.	Estimation of soil loss and identification of erosion risk zones in a forested region in Sarawak, Malaysia, Northern Borneo	2018
Franklin J.	Recovery from clearing, cyclone and fire in rain forests of Tonga, South Pacific: Vegetation dynamics 1995-2005	2007
Kammesheidt L.	Forest recovery by root suckers and above-ground sprouts after slash-and-burn agriculture, fire and logging in Paraguay and Venezuela	1999
Jakovac et al.	The role of land-use history in driving successional pathways and its implications for the restoration of tropical forests	2021

Zwartendijk et al.	Soil water- and overland flow dynamics in a tropical catchment subject to long-term slash-and-burn agriculture	2020
Urquiza-Haas et al.	Regional scale variation in forest structure and biomass in the Yucatan Peninsula, Mexico: Effects of forest disturbance	2007
Kozlowski T.T.	Responses of woody plants to human-induced environmental stresses: Issues, problems, and strategies for alleviating stress	2000
Gorte R.W.; Sheikh P.A.	Deforestation and climate change	2010
Pereira Cabral Gomes E. et al.	Post-agricultural succession in the fallow swiddens of Southeastern Brazil	2020
Garrido-Perez E.I.; Gerold G.	Land-use history and the origins and effects of lianas on tree-communities. The case of secondary forests in Northeastern Yucatan Peninsula, Mexico	2009
Attiwill P.M.	The disturbance of forest ecosystems: the ecological basis for conservative management	1994
Burley A.L. et al.	Demographic response and life history of traditional forest resource tree species in a tropical mosaic landscape in Papua New Guinea	2011
Cannon et al.	Tree Species Diversity in Commercially Logged Bornean Rainforest	1998
Turner et al.	Factors Influencing Succession: Lessons from Large, Infrequent Natural Disturbances	1998
Nepstad et al.	Large-scale impoverishment of amazonian forests by logging and fire	1999

Appendix A – Semi-structured questionnaire used for the interviews with local dwellers.

Dinâmicas de uso do solo na região do Parque Nacional Macaya no sul do Haiti

Município:

Localidade:

Data da entrevista:

A- Dados pessoais

A.1) Nome do participante:__________________________________

A.2) Idade:________ A.3) Sexo: ______

A.4) Escolaridade:

B- Situação econômica da população

B.1) Quais são as atividades que você desenvolve para ganhar dinheiro?

( ) Agricultura ( ) criação de gado ( ) comércio ( ) exploração de madeira ( ) exploração de lenha ( ) produção de carvão ( ) outros – descrever:

B.2) Quanto dinheiro você consegue ganhar em cada uma dessas atividades?

Agricultura	
criação de gado	
comércio	
exploração de madeira	
exploração de lenha	
produção de carvão	
outros	

B.3) Como você avalia a quantidade de dinheiro que você ganha em relação as suas necessidades? ( ) suficiente ( ) insuficiente

B.4) Desde quando você está praticando agricultura?

B.4.1) Desde quando você está praticando criação de gado?

B.4.2) Desde quando você está...?

B.4.3) Por que começou a desenvolver outras atividades?

....

B.5) Onde você nasceu? ....

B.5.1) Já morou em outras localidades? ( ) sim ( ) não. Onde:

B.5.2) Quais foram os motivos da mudança?..

B.6) Costuma receber alguma ajuda de familiares que estão morando em outras cidades ou em outro país? ( ) sim ( ) não.

B.6.1) Que tipo de ajuda?..

B.7) Na sua opinião, como estão as condições de vida na região atualmente em comparação aos anos passados?

( ) melhoraram ( ) pioraram ( ) continuam iguais.
Explique:...

C. Uso e manejo da paisagem

C.1 Práticas agrícolas

C.1.1) Onde ficam as terras que você cultiva?...

C.1.2) Qual é a distância dessas terras em relação à sua casa?
....

C.1.3) Você é o proprietário das terras que você cultiva? ( ) sim ( ) não.

C.1.3.a) Se não, sob quais condições você tem acesso a essas terras?....................................

C.1.4) Quais são as espécies cultivadas atualmente?

( ) inhame ( ) mandioca ( ) malanga ( ) taro ( ) batata doce ( ) feijão ( ) milho ( ) café

( ) banana ( ) repolho ( ) cenoura ( ) feijão-de-lima ( ) feijão guandu ( ) alho-poró ( ) outros:

C.1.4.a) Quais são os critérios utilizados para escolher as espécies cultivadas?

....

C.1.5) Qual a quantidade de terra que você está utilizando?
....

C.1.6) Sempre cultivou as mesmas espécies? ( ) sim ( ) não.

C.1.6.a) Se não, quais foram as mudanças efetuadas?...

C.1.6.b) Quais foram os motivos dessas mudanças?...

C.1.7) Quais são as formas de manejo que você pratica?

....

C.1.7.a) Com que frequência você realiza esses manejos?

....

....

C.1.8) Como aprendeu esses manejos?

( ) por tradição ( ) com os técnicos agrícolas ( ) por experiência própria ( ) outros:

C.1.9) Sempre praticou os mesmos tipos de manejo? ( ) sim ( ) não.

C.1.9.a) Se não, quais foram os motivos das mudanças efetuadas?

( ) furacão ( ) fortes chuvas ( ) ventos fortes ( ) proibição pelos funcionários do parque

( ) outros:

C.1.10) Na sua opinião, quais são os acontecimentos que causam mais problemas para as suas atividades?

C.1.11) Quais são as mudanças provocadas por esses eventos?

....

C.2 Utilização e manejo de produtos florestais

C.2.1) Quais são as espécies da floresta que você utiliza? Para qual finalidade? Qual parte da planta? Frequência de uso? A onde costuma encontrar essas espécies? Qual é a disponibilidade? (utilizar tabela em anexo)
C.2.2) Parou de utilizar alguma dessas espécies? ( ) sim ( ) não.

C.2.2.a) Se sim, quais são essas espécies?

C.2.3) Por que parou de utilizá-las?

( ) menos disponíveis ( ) proibição pelos funcionários do parque ( ) outros:

C.2.4) O que você faz quando uma espécie se torna menos disponível?

( ) substitui por outra ( ) maneja de maneira a aumentar a disponibilidade ( ) não faz nada

C.2.5) Poderia me indicar alguma outra pessoa daqui que desenvolve atividades de agricultura, criação de gado, exploração de madeira ou de lenha?

……

……

REFERENCES

Albuquerque, U. P., Lucena, R. F. P. de, Cunha, L. V. F. C. da, & Alves, R. R. N. (2019). *Methods and Techniques in Ethnobiology and Ethnoecology* (U. P. Albuquerque, R. F. P. de Lucena, L. V. F. C. da Cunha, & R. R. N. Alves, Eds.; Second Edi). Humana Press.

Attiwill, P. M. (1994). The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management*, *63*(2–3), 247–300. https://doi.org/10.1016/0378-1127(94)90114-7

AVSI. (2012). *Analyse et étude du contexte socio-économique et environnementale du Parc Macaya, Haïti*.

Boose, E. R., Foster, D. R., & Fluet, M. (1994). Hurricane Impacts to Tropical and Temperate Forest Landscapes. *Ecological Monographs*, *64*(4), 369–400. http://www.jstor.org/stable/2937142

Boose, E. R., Serrano, M. I., & Foster, D. R. (2004). LANDSCAPE AND REGIONAL IMPACTS OF HURRICANES IN PUERTO RICO. *Ecological Monographs*, *74*(2), 335–352. https://doi.org/10.1890/02-4057

Brokaw, N. V. L. (1985). Treefalls, regrowth and community structure in Tropical Forests. In *The Ecology of Natural Disturbance and Patch Dynamics* (pp. 53–69).

Calderon-Aguilera, L. E., Rivera-Monroy, V. H., Porter-Bolland, L., Martínez-Yrízar, A., Ladah, L. B., Martínez-Ramos, M., Alcocer, J., Santiago-Pérez, A. L., Hernandez-Arana, H. A., Reyes-Gómez, V. M., Pérez-Salicrup, D. R., Díaz-

Nuñez, V., Sosa-Ramírez, J., Herrera-Silveira, J., & Búrquez, A. (2012). An assessment of natural and human disturbance effects on Mexican ecosystems: Current trends and research gaps. *Biodiversity and Conservation*, *21*(3), 589–617. https://doi.org/10.1007/s10531-011-0218-6

Cannon, C. H., Peart, D. R., & Leighton, M. (1998). *Tree Species Diversity in Commercially Logged Bornean Rainforest*. *281*. www.sciencemag.org

Cazzolla Gatti, R., Castaldi, S., Lindsell, J. A., Coomes, D. A., Marchetti, M., Maesano, M., Di Paola, A., Paparella, F., & Valentini, R. (2015). The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. *Ecological Research*, *30*(1), 119–132. https://doi.org/10.1007/s11284-014-1217-3

Chazdon, R. L. (2003). Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics*, *6*(1–2), 1366–1368. https://doi.org/10.1078/1433-8319-00042

Chazdon, R. L. (2013). Tropical Forest Regeneration. In *Encyclopedia of Biodiversity: Second Edition* (pp. 277–286). Elsevier Inc. https://doi.org/10.1016/B978-0-12-384719-5.00377-4

Chazdon, R. L. (2014). Second Growth: The promise of Tropical Forest Regeneration in an Age of Deforestation. In *Development* (Vol. 134, Issue 4).

Chen, S., Olofsson, P., Saphangthong, T., & Woodcock, C. E. (2023). Monitoring shifting cultivation in Laos with Landsat time series. *Remote Sensing of Environment*, *288*. https://doi.org/10.1016/j.rse.2023.113507

Crausbay, S. D., & Martin, P. H. (2016). Natural disturbance, vegetation patterns and ecological dynamics in tropical montane forests. In *Journal of Tropical Ecology* (Vol. 32, Issue 5, pp. 384–403). Cambridge University Press. https://doi.org/10.1017/S0266467416000328

De Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

Flores, B. M., Holmgren, M., Xu, C., van Nes, E. H., Jakovac, C. C., Mesquita, R. C. G., & Scheffer, M. (2017). Floodplains as an Achilles' heel of Amazonian forest resilience. *Proceedings of the National Academy of Sciences*, *114*(17), 4442–4446. https://doi.org/10.1073/pnas.1617988114

Flores, B. M., & Staal, A. (2022). Feedback in tropical forests of the Anthropocene. *Global Change Biology*, *28*(17), 5041–5061. https://doi.org/10.1111/gcb.16293

Flores, B. M., Staal, A., Jakovac, C. C., Hirota, M., Holmgren, M., & Oliveira, R. S. (2019). Soil erosion as a resilience drain in disturbed tropical forests. *Plant and Soil*, *450*(1–2), 11–25. https://doi.org/10.1007/s11104-019-04097-8

Franklin, J. (2007). Recovery from clearing, cyclone and fire in rain forests of Tonga, South Pacific: Vegetation dynamics 1995-2005. *Austral Ecology*, *32*(7), 789–797. https://doi.org/10.1111/j.1442-9993.2007.01766.x

Garrido-Perez, E. I., & Gerold, G. (2009). Land-use history and the or igins and effects of lianas on tree-communities. The case of secondary forests in Northeastern Yucatan Peninsula, Mexico. *Erdkunde*, *63*(3), 211–227. https://doi.org/10.3112/erdkunde.2009.03.01

Gorte, R. W. (2010). *CRS Report for Congress Deforestation and Climate Change*. www.crs.gov

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., & Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, *342*(6160), 850–853. https://doi.org/10.1126/science.1244693

Hölscher, D., Mackensen, J., & Roberts, J. M. (2005). Forest recovery in the humid tropics: Changes in vegetation structure, nutrient pools and the hydrological cycle. In *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management* (pp. 598–621). Cambridge University Press. https://doi.org/10.1017/CBO9780511535666.031

Jakovac, C. C., Dutrieux, L. P., Siti, L., Peña-Claros, M., & Bongers, F. (2017). Spatial and temporal dynamics of shifting cultivation in the middle-Amazonas river: Expansion and intensification. *PLoS ONE*, *12*(7), 1–15. https://doi.org/10.1371/journal.pone.0181092

Jakovac, C. C., Junqueira, A. B., Crouzeilles, R., Peña-Claros, M., Mesquita, R. C. G., & Bongers, F. (2021). The role of land-use history in driving successional pathways and its implications for the restoration of tropical forests. *Biological Reviews*, *96*(4), 1114–1134. https://doi.org/10.1111/brv.12694

Jakovac, C. C., Peña-Claros, M., Kuyper, T. W., & Bongers, F. (2015). Loss of secondary-forest resilience by land-use intensification in the Amazon. *Journal of Ecology*, *103*(1), 67–77. https://doi.org/10.1111/1365-2745.12298

Jakovac, C. C., Peña-Claros, M., Mesquita, R. C. G., Bongers, F., & Kuyper, T. W. (2016). Swiddens under transition: Consequences of agricultural intensification in the Amazon. *Agriculture, Ecosystems and Environment*, *218*, 116–125. https://doi.org/10.1016/j.agee.2015.11.013

Johnstone, J. F., Allen, C. D., Franklin, J. F., Frelich, L. E., Harvey, B. J., Higuera, P. E., Mack, M. C., Meentemeyer, R. K., Metz, M. R., Perry, G. L. W., Schoennagel, T., & Turner, M. G. (2016). Changing disturbance regimes, ecological memory, and forest resilience. *Frontiers in Ecology and the Environment*, *14*(7), 369–378. https://doi.org/10.1002/fee.1311

Judd, Walter. S. (1987). Floristic study of Morne La Visite and Pic Macaya National Park, Haiti. *Bull. Florida Mus. Nat. Hist., Biol. Sci.*, *32*(1), 1–136.

Kammesheidt, L. (1998). The role of tree sprouts in the restoration of stand structure and species diversity in tropical moist forest after slash-and-burn agriculture in Eastern Paraguay. In *Plant Ecology* (Vol. 139).

Kammesheidt, L. (1999). Forest recovery by root suckers and above-ground sprouts after slash-and-burn agriculture, fire and logging in Paraguay and Venezuela. In *Journal of Tropical Ecology* (Vol. 15).

Kleinman, P. J. A., Pimentel, D., & Bryant, R. B. (1995). The ecological sustainability of slash-and-burn agriculture. *Agriculture, Ecosystems and Environment*, *52*(2–3), 235–249. https://doi.org/10.1016/0167-8809(94)00531-I

Kozlowski, T. T. (2000). Responses of woody plants to human-induced environmental stresses: Issues, problems, and strategies for alleviating stress. In *Critical Reviews in Plant Sciences* (Vol. 19, Issue 2, pp. 91–170). https://doi.org/10.1080/07352680091139196

Laurance, W. F., & Curran, T. J. (2008). Impacts of wind disturbance on fragmented tropical forests: A review and synthesis. *Austral Ecology*, *33*(4), 399–408. https://doi.org/10.1111/j.1442-9993.2008.01895.x

Lawrence, D., Peart, D. R., & Leighton, M. (1998). The impact of shifting cultivation on a rainforest landscape in West Kalimantan: Spatial and temporal dynamics. *Landscape Ecology*, *13*(3), 135–148. https://doi.org/10.1023/A:1007985915187

Le Moniteur. (1983). Décret du 4 Avril 1983 déclarant “Parcs Nationaux Naturels” les aires entourant le morne La Visite e le morne Macaya entourant le Pic Macaya au massif de La Hotte. *Le Moniteur*, No. 41 de 23 Juin 1983.

Levin, S. A. (1998). Ecosystems and the biosphere as complex adaptive systems. *Ecosystems*, *1*(5), 431–436. https://doi.org/10.1007/s100219900037

Li, T., Dong, Y., & Liu, Z. (2020). A review of social-ecological system resilience: Mechanism, assessment and management. *Science of The Total Environment*, *723*, 138113. https://doi.org/10.1016/J.SCITOTENV.2020.138113

Lu, X., Zang, R., Ding, Y., & Huang, J. (2016). Changes in biotic and abiotic drivers of seedling species composition during forest recovery following shifting cultivation on Hainan Island, China. *Biotropica*, *48*(6), 758–769. https://doi.org/10.1111/btp.12392

Lu, X., Zang, R., Ding, Y., Letcher, S. G., Long, W., & Huang, Y. (2014). Variations and trade-offs in functional traits of tree seedlings during secondary succession in a tropical lowland rain forest. *Biotropica*, *46*(4), 404–414. https://doi.org/10.1111/btp.12125

Malmer, A., Van Noordwijk, M., & Bruijnzeel, L. A. (2005). Effects of shifting cultivation and forest fire. In *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management* (pp. 533–560). Cambridge University Press. https://doi.org/10.1017/CBO9780511535666.028

Millenium Ecossystem Assessment. (2005). Ecosystems and human well-being: synthesis. In *Ecosystems* (Vol. 5). Island Press. https://doi.org/10.1196/annals.1439.003

Ministère de L’Environnement. (2015). *Plan de Gestion Parc National Naturel Macaya*.

Nepstad, D. C., Veríssimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M., & Brooks, V. (1999). Large-scale impoverishment of amazonian forests by logging and fire. *Nature*, *398*(6727), 505–508. https://doi.org/10.1038/19066

Nhiuane, O., Lisboa, S. N., Popat, M., & Sitoe, A. (2024). Quantifying the costs and benefits of forest conversion through slash-and-burn cultivation and conventional logging. *Trees, Forests and People*, *15*. https://doi.org/10.1016/j.tfp.2024.100504

Nikinmaa, L., Lindner, M., Cantarello, E., Jump, A. S., Seidl, R., Winkel, G., & Muys, B. (2020). Reviewing the Use of Resilience Concepts in Forest Sciences. *Current Forestry Reports*, *6*(2), 61–80. https://doi.org/10.1007/s40725-020-00110-x

Gomes, E. P. C., Sugiyama, M., Fernandes de Oliveira Junior, C. J., Medeiros Prado, H., Antunes Ribeiro Filho, A., & Adams, C. (2020). Post-agricultural succession in the fallow swiddens of Southeastern Brazil. *Forest Ecology and Management*, *475*. https://doi.org/10.1016/j.foreco.2020.118398

Pickett, S. T. A., & White, P. S. (1985). The Ecology of Natural Disturbance and Patch Dynamics. In *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press. https://doi.org/10.1016/B978-0-12-554520-4.50005-8

Pinheiro, T. F., Escada, M. I. S., Valeriano, D. M., Hostert, P., Gollnow, F., & Müller, H. (2016). Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 region in southwestern pará, Brazil. *Earth Interactions*, *20*(17). https://doi.org/10.1175/EI-D-15-0016.1

Robart, G. (1984). *Végétation de la République d'Haïti*. Université scientifique et médicale de Grénoble.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). *Catastrophic shifts in ecosystems*. *413*(October). https://doi.org/10.1038/35098000

Sergile, F. E. (1994). *Arbres et arbustes de Macaya*. Florida Museum of Natural History.

Sergile, F. E., Woods, C. A., & Paryski, P. E. (1992). *Final Report of the Macaya Biosphere Reserve Project*.

Silvério, D. V., Brando, P. M., Bustamante, M. M. C., Putz, F. E., Marra, D. M., Levick, S. R., & Trumbore, S. E. (2019). Fire, fragmentation, and windstorms: A recipe for tropical forest degradation. *Journal of Ecology*, *107*(2), 656–667. https://doi.org/10.1111/1365-2745.13076

Suding, K. N., Gross, K. L., & Houseman, G. R. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution*, *19*(1), 46–53. https://doi.org/10.1016/j.tree.2003.10.005

Turner, M. G., Baker, W. L., Peterson, C. J., & Peet, R. K. (1998). *Factors Influencing Succession: Lessons from Large, Infrequent Natural Disturbances*. *1*, 511–523.

Urquiza-Haas, T., Dolman, P. M., & Peres, C. A. (2007). Regional scale variation in forest structure and biomass in the Yucatan Peninsula, Mexico: Effects of forest disturbance. *Forest Ecology and Management*, *247*(1–3), 80–90. https://doi.org/10.1016/j.foreco.2007.04.015

USAID. (2006). *Vulnérabilité Environnementale en Haïti: Conclusions et Recommandations*.

Vijith, H., Seling, L. W., & Dodge-Wan, D. (2018). Estimation of soil loss and identification of erosion risk zones in a forested region in Sarawak, Malaysia, Northern Borneo. *Environment, Development and Sustainability*, *20*(3), 1365–1384. https://doi.org/10.1007/s10668-017-9946-4

Villa, P. M., Martins, S. V., de Oliveira Neto, S. N., Rodrigues, A. C., Martorano, L. G., Monsanto, L. D., Cancio, N. M., & Gastauer, M. (2018). Intensification of shifting cultivation reduces forest resilience in the northern Amazon. *Forest Ecology and Management*, *430*, 312–320. https://doi.org/10.1016/j.foreco.2018.08.014

Wilson, J. B., & Agnew, A. D. Q. (1992). Positive-feedback Switches in Plant Communities. *Advances in Ecological Research*, *23*(C), 263–336. https://doi.org/10.1016/S0065-2504(08)60149-X

Woods, C. A., & Ottenwalder, J. A. (1992). *The Natural History of Southern Haiti*. Florida Museum of Natural History.

4 CONCLUSÃO GERAL

Apesar de estar sendo impactados pela intensificação da agricultura itinerante e a exploração madeireira, as florestas tropicais na região do PNM se expandiram em detrimento das terras agrícolas de 1985 a 2021. Esse resultado aponta para uma possível transição florestal em curso na região, promovida por mudanças nas leis e políticas ambientais decorrente da criação do Parque Nacional Macaya. Essas mudanças aparentemente fortaleceram a resiliência do sistema reduzindo a pressão sobre os recursos florestais por meio do fornecimento de atividades econômicas alternativas. No entanto, considerando que o sistema está em constante mudança, estudos contínuos e mais aprofundados sobre os feedbacks e as forças que conduzem a sua dinâmica, são fundamentais para garantir o manejo adequado das florestas do PNM em um cenário de mudanças globais.

A interação entre múltiplas perturbações antropogênicas e naturais podem ameaçar a resiliência por meio de feedbacks positivos. Identificamos vários mecanismos de feedbacks que podem aprisionar o PNM em um estado degradado. Por exemplo, a redução da produtividade dos cultivos decorrente da diminuição da fertilidade do solo induzida pela intensificação da agricultura itinerante, cria a necessidade de mais capital para continuar produzindo; nessa situação, alguns produtores recorrem a exploração madeireira, o que acaba reduzindo ainda mais a fertilidade do solo. Da mesma maneira, a exploração madeireira e a agricultura itinerante reduzem a cobertura de árvores, o que aumenta a erosão. A erosão, por sua vez, desacelera o crescimento das árvores reduzindo assim a regeneração da floresta e, consequentemente, do solo. Como consequência, a floresta passa mais tempo em um estado degradado com menor cobertura de árvores. Quando os furacões, que são recorrentes na região, encontram a floresta nesse estado, eles amplificam a degradação prévia reduzindo ainda mais a cobertura de árvores e aumentando a erosão do solo. Portanto, esses importantes feedbacks devem ser manejados adequadamente para aumentar a resiliência do sistema e garantir o fornecimento futuro de serviços ecossistêmicos frente as mudanças climáticas.

Por fim, apesar de que as florestas na região do PNM aumentaram enquanto as terras cultivadas reduziram nas últimas décadas, alguns mecanismos de feedbacks precisam ser monitorados de maneira ininterrupta e devidamente manejados para assegurar a continuação dessa possível transição florestal em curso na região. Mobilizar uma equipe interdisciplinar de cientistas de maneira permanente e disponibilizar recursos necessários para o pleno desenvolvimento das suas atividades, são algumas medidas que podem facilitar o alcance desses objetivos.

REFERÊNCIAS

Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J. C., Keller, M., C Silva, J. N. (2005). Ecology: Selective logging in the Brazilian Amazon. *Science*, *310*(5747), 480–482. https://doi.org/10.1126/science.1118051

Asner, G. P., Rudel, T. K., Aide, T. M., Defries, R., C Emerson, R. (2009). A contemporary assessment of change in humid tropical forests. *Conservation Biology*, *23*(6), 1386– 1395. https://doi.org/10.1111/j.1523-1739.2009.01333.x

Barlow, J., França, F., Gardner, T. A., Hicks, C. C., Lennox, G. D., Berenguer, E., Castello, L., Economo, E. P., Ferreira, J., Guénard, B., Gontijo Leal, C., Isaac, V., Lees, A. C., Parr, C. L., Wilson, S. K., Young, P. J., C Graham, N. A. J. (2018). The future of hyperdiverse tropical ecosystems. *Nature*, *55S*(7715), 517–526. https://doi.org/10.1038/s41586-018-0301-1

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., BurnSilver, S. B., Cundill, G., Dakos, V., Daw, T., Evans, L., Kotschy, K., Leitch, A., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M., Schoon, M., Schultz, L., C West, P. (2012). Toward Principles for Enhancing the Resilience of Ecosystem Services. *Ssrn*. https://doi.org/10.1146/annurev-environ-051211-123836

Cazzolla Gatti, R., Castaldi, S., Lindsell, J. A., Coomes, D. A., Marchetti, M., Maesano, M., Di Paola, A., Paparella, F., C Valentini, R. (2015). The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. *Ecological Research*, *30*(1), 119–132. https://doi.org/10.1007/s11284-014-1217-3

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., C Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, *3c1*(6407), 1108–1111. https://doi.org/10.1126/science.aau3445

Ding, Y., Zang, R., Liu, S., He, F., C Letcher, S. G. (2012). Recovery of woody plant diversity in tropical rain forests in southern China after logging and shifting cultivation. *Biological Conservation*, *145*(1), 225–233. https://doi.org/10.1016/j.biocon.2011.11.009

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., C Rockström, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society*, *15*(4), 2018.

Hedges, S. B., Cohen, W. B., Timyan, J., C Yang, Z. (2018). Haiti’s biodiversity threatened by nearly complete loss of primary forest. *Proceedings of the National Academy of Sciences*. http://www.pnas.org/content/early/2018/10/23/1809753115.abstract

Hölscher, D., Mackensen, J., C Roberts, J. M. (2005). Forest recovery in the humid tropics: Changes in vegetation structure, nutrient pools and the hydrological cycle. In *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management* (pp. 598–621). Cambridge University Press. https://doi.org/10.1017/CBO9780511535666.031

Jakovac, C. C., Peña-Claros, M., Kuyper, T. W., C Bongers, F. (2015). Loss of secondary- forest resilience by land-use intensification in the Amazon. *Journal of Ecology*, *103*(1), 67–77. https://doi.org/10.1111/1365-2745.12298

Jakovac, C. C., Peña-Claros, M., Mesquita, R. C. G., Bongers, F., C Kuyper, T. W. (2016). Swiddens under transition: Consequences of agricultural intensification in the Amazon. *Agriculture, Ecosystems and Environment*, *218*, 116–125. https://doi.org/10.1016/j.agee.2015.11.013

Johnstone, J. F., Allen, C. D., Franklin, J. F., Frelich, L. E., Harvey, B. J., Higuera, P. E., Mack, M. C., Meentemeyer, R. K., Metz, M. R., Perry, G. L. W., Schoennagel, T., C Turner, M. G. (2016). Changing disturbance regimes, ecological memory, and forest resilience. *Frontiers in Ecology and the Environment*, *14*(7), 369–378. https://doi.org/10.1002/fee.1311

Judd, Walter. S. (1987). Floristic study of Morne La Visite and Pic Macaya National Park, Haiti. *Bull. Florida Mus. Nat. Hist., Biol. Sci.*, *32*(1), 1–136.

Kadoya, T., Takeuchi, Y., Shinoda, Y., C Nansai, K. (2022). Shifting agriculture is the dominant driver of forest disturbance in threatened forest species' ranges. *Communications Earth and Environment*, *3*(1), 1–8. https://doi.org/10.1038/s43247- 022-00434-5

Laurance, W. F., C Curran, T. J. (2008). Impacts of wind disturbance on fragmented tropical forests: A review and synthesis. *Austral Ecology*, *33*(4), 399–408. https://doi.org/10.1111/j.1442-9993.2008.01895.x

Le Moniteur. (1983). Décret du 4 Avril 1983 déclarant "Parcs Nationaux Naturels" les aires entourant le morne La Visite e le morne Macaya entourant le Pic Macaya au massif de La Hotte. *Le Moniteur*, No. 41 de 23 Juin 1983.

Lugo, A. E. (2000). Effects and outcomes of Caribbean hurricanes in a climate change scenario. *The Science of the Total Environment*, *2c2*, 243–251.

Lugo, A. E. (2008). Visible and invisible effects of hurricanes on forest ecosystems: An international review. In *Austral Ecology* (Vol. 33, Issue 4, pp. 368–398). https://doi.org/10.1111/j.1442-9993.2008.01894.x

Malhi, Y., Gardner, T. A., Goldsmith, G. R., Silman, M. R., C Zelazowski, P. (2014). Tropical forests in the anthropocene. *Annual Review of Environment and Resources*, *3S*, 125–159. https://doi.org/10.1146/annurev-environ-030713-155141

Malmer, A., Van Noordwijk, M., C Bruijnzeel, L. A. (2005). Effects of shifting cultivation and forest fire. In *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water*

Management (pp. 533– 560). Cambridge University Press. https://doi.org/10.1017/CBO9780511535666.028

Mertz, O., Padoch, C., Fox, J., Cramb, R. A., Leisz, S. J., Lam, N. T., C Vien, T. D. (2009).Swidden change in southeast Asia: Understanding causes and consequences.*Human Ecology*, *37*(3), 259–264. https://doi.org/10.1007/s10745-009-9245-2

Millenium Ecossystem Assessment. (2005a). *Ecosystems and Human Well-Being: Biodiversity Synthesis*.

Millenium Ecossystem Assessment. (2005b). Ecosystems and human well-being: synthesis. In *Ecosystems* (Vol. 5). Island Press. https://doi.org/10.1196/annals.1439.003

Ministère de L'Environnement. (2015). *Plan de Gestion Parc National Naturel Macaya*. Nikinmaa, L., Lindner, M., Cantarello, E., Jump, A. S., Seidl, R., Winkel, G., C Muys, B.(2020). Reviewing the Use of Resilience Concepts in Forest Sciences. *Current Forestry Reports*, *c*(2), 61–80. https://doi.org/10.1007/s40725-020-00110-x

Pereira Cabral Gomes, E., Sugiyama, M., Fernandes de Oliveira Junior, C. J., Medeiros Prado, H., Antunes Ribeiro Filho, A., C Adams, C. (2020). Post-agricultural succession in the fallow swiddens of Southeastern Brazil. *Forest Ecology and Management*, *475*. https://doi.org/10.1016/j.foreco.2020.118398

Pinheiro, T. F., Escada, M. I. S., Valeriano, D. M., Hostert, P., Gollnow, F., C Müller, H. (2016). Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 region in southwestern pará, Brazil. *Earth Interactions*, *20*(17). https://doi.org/10.1175/EI-D-15-0016.1

PNUD. (2014). *Rapport OMD 2013, Haïti: un nouveau regard*.

Robart, G. (1984). *Végétation de la République d'Haïti*. Université scientifique et médicale de Grénoble.

Sergile, F. (1994). *Arbres et arbustes de Macaya*. Florida Museum of Natural History.

Shenkin, A., Bolker, B., Peña-Claros, M., Licona, J. C., C Putz, F. E. (2015). Fates of trees damaged by logging in Amazonian Bolivia. *Forest Ecology and Management*, *357*, 50–59. https://doi.org/10.1016/j.foreco.2015.08.009

Silvério, D. V., Brando, P. M., Bustamante, M. M. C., Putz, F. E., Marra, D. M., Levick, S. R., C Trumbore, S. E. (2019). Fire, fragmentation, and windstorms: A recipe for tropical forest degradation. *Journal of Ecology*, *107*(2), 656–667. https://doi.org/10.1111/1365-2745.13076

Song, X. P., Hansen, M. C., Stehman, S. V., Potapov, P. V., Tyukavina, A., Vermote, E. F., C Townshend, J. R. (2018). Global land change from 1982 to 2016. *Nature*, *5c0*(7720), 639–643. https://doi.org/10.1038/s41586-018-0411-9

Stewart, S. R. (2017). *Hurricane Matthew*.

Tagliari, M. M., Levis, C., Flores, B. M., Blanco, G. D., Freitas, C. T., Bogoni, J. A., Vieilledent, G., C Peroni, N. (2021). Collaborative management as a way to enhance Araucaria Forest resilience. In *Perspectives in Ecology and Conservation* (Vol. 19, Issue 2, pp. 131–142). Elsevier. https://doi.org/10.1016/j.pecon.2021.03.002

Tarter, A., Freeman, K. K., C Sander, K. (2016). *A History of Landscape-level Land Management Efforts in Haiti: Lessons Learned from Case Studies Spanning Eight Decades*.

Uhl, C., Veríssimo, A., Mattos, M. M., Brandino, Z., C Guimarães Vieira, I. C. (1991). Social, economic, and ecological consequences of selective logging in an Amazon frontier: the case of Tailândia. *Forest Ecology and Management*, *4c*(3–4), 243–273. https://doi.org/10.1016/0378-1127(91)90235-N

Unesco. (2023). *La Hotte Biosphere Reserve, Haiti*. https://en.unesco.org/biosphere/lac/lahotte

USAID. (2006). *Vulnérabilité Environnementale en Haïti: Conclusions et Recommandations*.

van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., Adams, C., Schmidt-Vogt, D., Messerli, P., Leisz, S., Castella, J. C., Jørgensen, L., Birch-Thomsen, T., Hett, C., Bruun, T. B., Ickowitz, A., Vu, K. C., Yasuyuki, K., Fox, J., … Ziegler, A. D. (2012). Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. *Global Environmental Change*, *22*(2), 418–429. https://doi.org/10.1016/j.gloenvcha.2011.10.009