Trade-offs between land conservation and agricultural production

Case study of Spanish Lookout Area and the Belize Maya Forest reserve

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Abstract

Habitat destruction (evidenced in land use change) represents one of the biggest threats to environmental resources and biodiversity. In the tropics, this threat is maximized as deforestation frontiers have expanded into natural ecosystems at increasing rates over the last decades for agricultural cropping and livestock husbandry. Protected areas have been conventionally established against this growing threat, although their success is often not certain. Furthermore, they do not reduce nor address the drivers for agricultural expansion, thus exacerbating the conflict between the two modes of land management. This thesis will focus on the case of Spanish Lookout, an agricultural-based community located to the south of a newly-established protected area: The Belize Maya Forest. This thesis will aim to analyze the tradeoffs between agricultural production and conservation in the area of Spanish Lookout from 2000-2010 using remote sensing and statistical analysis.

Key Words: LULUCF, agriculture, deforestation frontiers, remote sensing, biodiversity

To Mauricio, Lina, Mateo, Salomé,
Magdalena, and Philippa, of course.

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Key Terms

Agrifood systems: “Encompass the entire range of actors, and their interlinked value-adding activities, engaged in the primary production of food and non-food agricultural products, as well as in storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption of all food products including those of non-agricultural origin.” (FAO, 2021, p. vii)

Agriculture: In this thesis it is defined as all cropping and livestock husbandry systems.

Sustainability: The ability to meet and maintain current needs, without compromising the ability of future generations to meet their own.

List of Abbreviations

BMF: Belize Maya Forest

CIAT: Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

CBD: Convention on Biological Diversity

CTCN: Climate Technology Centre & Network

FAO: Food and Agriculture Organization of the United Nations

FSC: Forest Stewardship Council

GEE: Google Earth Engine

GHGs: Greenhouse Gases

GoB: Government of Belize

IAASTD: The International Assessment of Agricultural Science and Technology for Development

IICA: Inter-American Institute for Cooperation on Agriculture

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IUCN: International Union for Conservation of Nature

LULUCF: Land Use, Land Use Change, and Forestry

MA: Millennium Ecosystem Assessment

MAF: Ministry of Agriculture and Fisheries of Belize

NAS: National Adaptation Strategy

NPAPSP: National Protected Areas Policy and System Plan

NPAS: National Protected Areas System

OECD: Organization for Economic Co-operation and Development

PA: Protected Area

REDD+: Reducing Emissions from Deforestation, Forest Degradation, Conservation of Forest Carbon Stocks, Sustainable Management of Forest, and Enhancement of Forest Carbon Stocks

RBMCA: Rio Bravo Management and Conservation Area

RF: Random Forest

SDGs: Sustainable Development Goals

SIB: Statistical Institute of Belize

TNC: The Nature Conservancy

UNFCCC: United Nations Framework Convention on Climate Change

1. Introduction

Natural habitat and ecosystem destruction (evidenced in land-cover change) represents the biggest threat to biodiversity, environmental resources and ecosystem services. While such land transformations occur at a local level, they accumulate to represent a global issue (Doyle *et al.*, 2021). The most evident example of this is the long-standing conflict between agricultural production and environmental conservation. Agricultural expansion is often at the expense of naturally vegetated areas (OECD, 2018), (such as forestland, grasslands, wetlands, and natural habitats). To defend this, Protected Areas (PAs) are often created to safeguard carbon stocks (through the prevention of carbon offsets caused by deforestation and securing above/below ground carbon biomass), as well as to protect biodiversity hotspots, while at the same time halting agricultural expansion—however not reducing or addressing the overall drivers for agricultural expansion. On a wider scale, this issue represents an SDG conflict, primarily due to the clash of goals related to socio-economic development (i.e. through anthropogenic land management), and environmental goals. This research will analyze the trade-offs between agricultural production and land conservation in the area of Spanish Lookout, Belize between 2000 and 2020. Deforestation frontiers represent dynamic/heterogeneous landscapes with both high environmental and socio-economic value, thereby with a high potential for conflict.

Belize is a country with under-studied increasing forest degradation and fragmentation caused by agricultural expansion (Doyle *et al.*, 2021). Land-use change has intensified in the previous 50 years due to a growing industrialized and export-oriented agriculture sector. Although numerous PAs have been established over the last century, deforestation and land-use change have continued. Furthermore, lands that are not under any form of protection are under an increasing threat of deforestation (Young, 2008). PAs, therefore, represent a crucial strategy for preserving biodiversity and environmental resources (*ibid.*). However, numerous studies have demonstrated that PAs still experience a significant effect (from logging, poaching, and deforestation) around buffer areas (Spracklen *et al.*, 2015), thus proving that a compromise between agriculture and PAs is pivotal to continuing agricultural production without an increasing threat to forestland and natural habitats.

An important aspect behind these trends is the existence of the *Selva Maya* (Maya Forest) inside the Belizean territory, which is the second-largest tropical rainforest in the Americas.

Landsat imagery has shown large areas of *Selva Maya* territory receding since the early 1980s (The Nature Conservancy, 2021). While this has occurred across different countries at varied rates, in the case of Belize it has been driven by agricultural expansion for cropping and livestock husbandry (Ellis *et al*., 2020). Spanish Lookout is an agriculture-based community located northwest of the country. Their agricultural production has progressively expanded into forestland in a large-scale, industrial, and heavily mechanized fashion in recent decades. Due to increasing concerns about forest degradation and biodiversity loss, environmental groups purchased 96,000 hectares of Maya Forest in northwestern Belize for conservation, creating the Belize Maya Forest (BMF) reserve in April 2021. The acquisition of the BMF for conservation represents a recent and very relevant example of the conflict between environmental conservation and socio-economic 'development', as communities see this decision as threatening their livelihoods[1]. This research will analyze the trade-offs between agriculture and environmental conservation in the Spanish Lookout area, primarily examining agriculture production trends, biodiversity, and land use, land-use change and forestry (LULUCF) focusing on the years 2000-2020.

a. Purpose and Aim

The purpose of this research is to answer the main research question: 'What are the trade-offs between agricultural production and land conservation in the area of Spanish Lookout, Belize between 2000 and 2020?' The analysis comprises two major pillars (spatial and statistical data analysis) and includes three major sections: LULUCF, agricultural production, and land conservation. The spatial data analysis is mainly concerned with remote sensing from landsat imagery, which will be used for classifying different land cover classes in order to visualize and represent the cumulative changes in land use/land cover over the 20-year period. The statistical analysis will include the analysis of agricultural data provided by MAF (and secondary data from reports), as well as environmental data from biodiversity studies conducted inside the BMF since 2014. The agricultural data analysis section will be primarily concerned with the 2018 agricultural census, which gathered statistical data from every registered farmer within the research area. This analysis will be primarily concerned with commodity production, yield, and area harvested. The environmental data analysis will assess the biodiversity in the area, and how changes in land cover might affect it. The LULUCF analysis will be used throughout the analysis in order to help interpret the statistical data.

[1] From talks with Mennonite community leader and farmer in Spanish Lookout in June 2021.

Statistical and spatial data will be used in conjunction due to their complementary traits. The spatial analysis will enlighten the agricultural statistical data by visualizing areas where agriculture has expanded, while the agricultural statistics will provide detailed crop/livestock production information that is not granted by the spatial analysis.

Land-cover change represents the best available tool to analyze and monitor pressures on terrestrial ecosystems and biodiversity (OECD, 2018), while examining agricultural and biodiversity data in the area will help examine the tradeoffs between the two. Analyzing the trade-offs between conservation and agriculture can provide insights into optimal land management practices and decisions that take into account the disparity of interests between local communities and natural resource management. The results will be divided into the three categories outlined above, and they will contain the findings from the statistical/spatial analysis.

2. Background

a. Agriculture and conservation: Global trends and perspectives

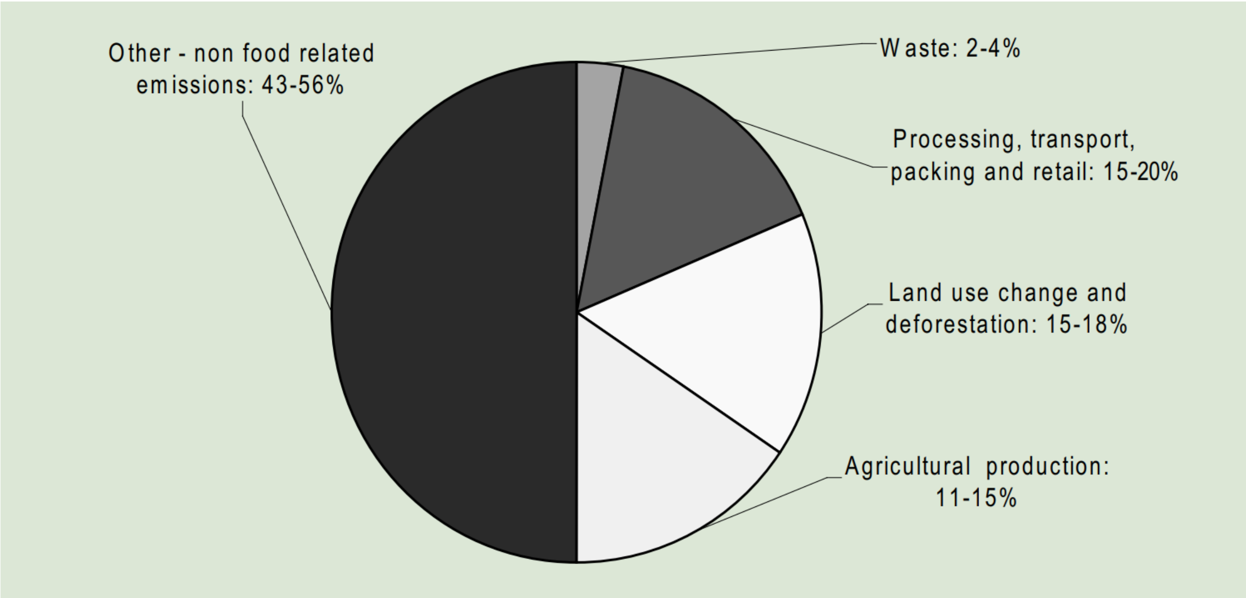
The world is at a crossroads. In the previous 50 years, the global economy has grown, diminishing global poverty and increasing food security across most countries with varying levels of development. This rapid global economic growth, however, has been accompanied by high levels of environmental degradation. While modern agriculture has increased food production, it has negatively affected the natural environment (Dasgupta, 2021), disrupting a wide range of ecosystem services such as carbon sequestration, nutrient cycling, biodiversity habitat provision and water filtration/provision, among others (OECD, 2019, p. 19), which conversely affect the current state and further development of agriculture.

Furthermore, as the food sector has become more globalized, it has also become more susceptible to increasing shocks and strains from diverse origins (FAO, 2021). These can be either socio-economic shocks (i.e. food price hikes), climate-related strains (slow: increases in temperature or short-term: extreme weather events), as well as external events, such as the COVID-19 pandemic (*ibid*.).

Agriculture (cropping and animal husbandry) currently cover half of the world's habitable land (Ritchie, 2019). Furthermore, they remain the largest driver of deforestation worldwide (FAO, 2020) and the main driver of land-use/land-cover change (IPBES, 2019). This form of landscape transformation is associated with biodiversity loss, solid degradation, increased GHG emissions, etc. The relationship between climate change and agriculture, therefore, can be defined as a zero-sum-game; since agriculture contributes to climate change in varied ways, while climate change negatively affects the current state and further development of agriculture (IAASTD, 2009). This relationship, in turn, represents a complex conflict between other large global issues (and thus the SDGs)—the effects of climate change on the agriculture system negatively affects poverty, health, economics, equity and gender relations—just as the effects of climate change is driven by agriculture, energy, unsustainable consumption, etc. (Campbell *et al*., 2018).

With current trends, the competition in land use between natural ecosystems and agricultural areas will be exacerbated by a projected increase in population, the resulting food demand increases and a transition to more carbon-intensive diets (OECD/FAO, 2016). Current estimates place agricultural emissions at around 15% of global emissions, however, this is without taking into account emissions from land-cover change, responsible for the destruction of wetlands, shrublands, forests and other natural ecosystems worldwide. Overall, the agrifood sector is responsible for approximately half of global emissions, including waste, processing, transport, packing, retail, land-use change and agricultural production (See: Figure 1). In addition to this, global meta-analyses of impacts of climate change indicate 70% of studies with a decline on crop yield by 2030 (Challinor *et al*., 2014), and thus addressing this issue will be associated with future food security along with numerous environmental and socioeconomic issues.

Figure 1: Contribution of the global food production system to global GHG emissions.



Source: UNCTAD, 2013

Between 2000-2010, the global net forest loss per year was 7 million hectares of land, while the global net gain of agricultural land was 6 million hectares per year (FAO, 2016). During this time period, most of the deforestation occurred in the tropics (ibid.) This is of high concern because tropical forests make up a third of the world's forested area and contain approximately 50% of all of the global biodiversity (FAO, 2019). Tropical forests, therefore, represent an important and threatened part of the biosphere.

b. The Maya Forest

The Maya Forest is the second-largest tropical forest in the Americas and thereby represents a large environmental resource in the Mesoamerican region. It constitutes 35 million acres of forestland stretching across three different countries, namely Mexico, Guatemala and Belize. It is home to hundreds of animal and plant species and represents one of the last regional habitats for endangered species such as the Scarlet Macaw, the Baird's Tapir, and the Puma (Bridgewater, 2012). In addition, it is a place for cultural heritage by being home to diverse Maya communities, as well as numerous archaeological sites. The primary tool practiced to protect the integrity of the Maya Forest is the creation of Biosphere reserves, and national parks, among other protected areas (Primack *et al*, 1997).

c. Belize

Belize is a small multi-ethnic country on the eastern side of Central America. Geographically, it borders Guatemala to the west and Mexico to the north. It has a land area of 22,810 km2—of which 95% is registered as being part of the mainland territory, and the remaining 5% is made up of more than 1,060 coastal islands. Although it is the second-smallest country in Central America, it has a diverse population of 430,191 (SIB, 2021) made up of Mestizos, Creoles, Garifuna, indigenous Mayan communities, and European Mennonites, among others. While Belize's geographic location lies in mainland Central America, it has economic, cultural, and historical analogues to the Caribbean due to a British colonial past. Mainly, Belize differs from its neighboring countries by its socio-political institutions (i.e. a democratic parliament) and a large English-speaking population. It is also the only country in central America that is part of the Commonwealth. In addition, while it has historically sought to establish closer socio-political ties[2] to the Caribbean, it has recently attempted to increase its relations to central America by joining numerous regional organizations[3] (Martin & Manzano, 2010).

As a small country, Belize faces numerous problems related to its low population, small land area, geography, and economic base, which make it vulnerable to exogenous shocks. For instance, while Belize's real per capita income (approximately USD$4,250) remained fairly constant over the previous decade, it decreased about 15.6% as a result of the COVID-19 pandemic, which is more than double than the average of other Latin American Countries (LAC) (World Bank, 2020). In addition to this, approximately 52% of the population lives below the poverty line—the majority of which reside in rural areas (SIB, 2021). Furthermore, its relatively low terrain makes a large part of its territory susceptible to sea level rise and flooding—which will affect a large part of coastal areas (where the majority of the population resides) and the country's ports.

Belize's economy is mainly supported by its natural resource base. The current structure of its economic system is primarily based on tourism and agriculture, accounting for 37.3% and 10.2% of the total GDP in constant prices, respectively (SIB, 2020). Both sectors are

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[2] Belize has been a member of the Caribbean Community (CARICOM) since 1974

[3] Include international bodies such as the Central American Integration System (SICA), the Central American Commission on Development and the Environment, the Council of Ministers of Tourism, the Central American Civil Aviation Agency, and the Central American Economic Integration System (SIECA) since 2013.

relatively young and emerged at different times during the second half of the 20th century. Tourism is the main foreign exchange earner and the major source of employment (38% of total employment) (*ibid*.) due to an abundant resource of natural and cultural resources. Agriculture follows behind, with a diverse pool of land management practices extending from traditional Milpa systems to large export-oriented systems. Both industries, however, are highly vulnerable to internal (price fluctuations, pests, etc.) and external shocks (macroeconomic crises, climate change, etc.) (Martin & Manzano, 2010), which can hinder their further development.

Belize's dependence on its natural resource base highlights the need for development of resilient systems within its main productive sectors. "A future increased pressure on its natural resource base [can lead to a] potential "devaluation" of its natural resources" (Riviera & Pratt 2005, p. 6).

i. History

The territory that presently comprises Belize was previously settled by Mayan communities from approximately 4000 to 1000 BP. Mayan agriculture dates back centuries, with a wide range of highly-organized and sophisticated agricultural production strategies documented by researchers (Kunen, 2001). Such strategies allowed these communities to inhabit the area for centuries through strategic management and adaptation of fragile tropical environments (*ibid*.). However, the Mayan territory in present-day Belize was largely abandoned around 1000 AD.

By the 16th century, Spanish colonizers claimed the entire central-American territory. However, as no vast reserves of resources were found in the area, unlike in other Spanish-colonized territories (e.g. the silver mines of Potosí, Bolivia and Zacatecas, Mexico), Belize was left mostly uninhabited by Spanish colonizers. This allowed the British to gradually settle along the coastline around the late 17th century. These first settlers focused on cutting logwood—a highly valued dyewood in Europe used for the expanding woolen industry (Camille, 1996). By the late 18th century, logwood was replaced as the main export by Mahogany and Timber, which were primarily used for shipbuilding and the furniture industry (Camille, 2000). While the logging industry was initially informal, a series of treaties between Britain and Spain granted official rights to English settlers to extract wood for export from certain areas in the territory (ibid.). This shortly reaffirmed Spain's sovereignty over the territory, however, Spain's defeat by the British in the battle of St. George's Cay (1798), followed by the demise of the Spanish empire halted them from asserting a claim over the territory thereafter (Dobson, 1973 in Camille, 2000). Subsequently, the logging territory expanded wider inland and along buffer areas of riverbeds. The population in the territory grew as logging proved more profitable. Slaves were increasingly imported from neighboring Caribbean colonies due to an increase in timber extraction, and in later years advancements in hauling methods for timber allowed the continuation and expansion of logging into the early 20th century. Britain formally claimed the territory of Belize (previously British Honduras) in 1862.

Britain granted British Honduras self-government in 1964 and the country's name was thereafter changed to Belize. It later gained independence in 1982. To the present day, the Belizean economy has experienced a significant level of diversification—as is evident by the large tourism sector and the expanding agricultural sector. The issue of land management and land use still persists, however, with expanding deforestation frontiers from the second half of the 20th century to the present day. Furthermore, weak institutional capacity and governmental policies hinder this relationship further (Walker & Walker, 2009).

d. Land Management in Belize

i. Land cover

Belize can be characterized by a growing agricultural sector and a high rate of deforestation. With approximately one-fourth of the Belizean GDP based on agricultural production, it is likely that the expansion of agriculture will pose a significant increased pressure on terrestrial and aquatic ecosystems (Martin and Manzano, 2010; GoB, 2008 in Patterson 2014). While 56.47% of territorial Belize is covered by forest, pressure for land is likely to increase as its population is projected to grow to over 700,000 by 2050 (SIB in Patterson, 2014). Furthermore, the conflict between agricultural production and land conservation is likely to be exacerbated due to numerous socioeconomic and environmental pressures (See: Agriculture section).

Due to limited cloud-free aerial/Landsat imagery and conflicting definitions of forest areas, it is difficult to accurately assess the forest cover extent during the early periods of industrial agricultural development (Patterson, 2016). One of the earliest land cover assessments during the time period, conducted by Wright *et al.* (1959), placed forest cover at 88.8%. Advancements in remote sensing technology and methodologies have improved since then, which have allowed for more precise and accurate classifications. Numerous regional (Chomitz & Gray, 1996; Doyle *et al.*, 2021) and nationwide (White *et al.*, 1996; Meerman & Sabido, 2001; Meerman 2005a; Meerman & Cherrington, 2005; Meerman *et al.*, 2010; Cherrington *et al.*, 2010) land cover studies have emerged since then. The study by Cherrington *et al.* (2010) represents one of the most recent and broad studies conducted, as it analyzes the time period from 1980 to 2010. Based on their analysis, it is estimated that the forest cover in Belize decreased approximately by 17.4% between 1980 to 2010, with an average annual forest decline of -0.66% (ibid.).

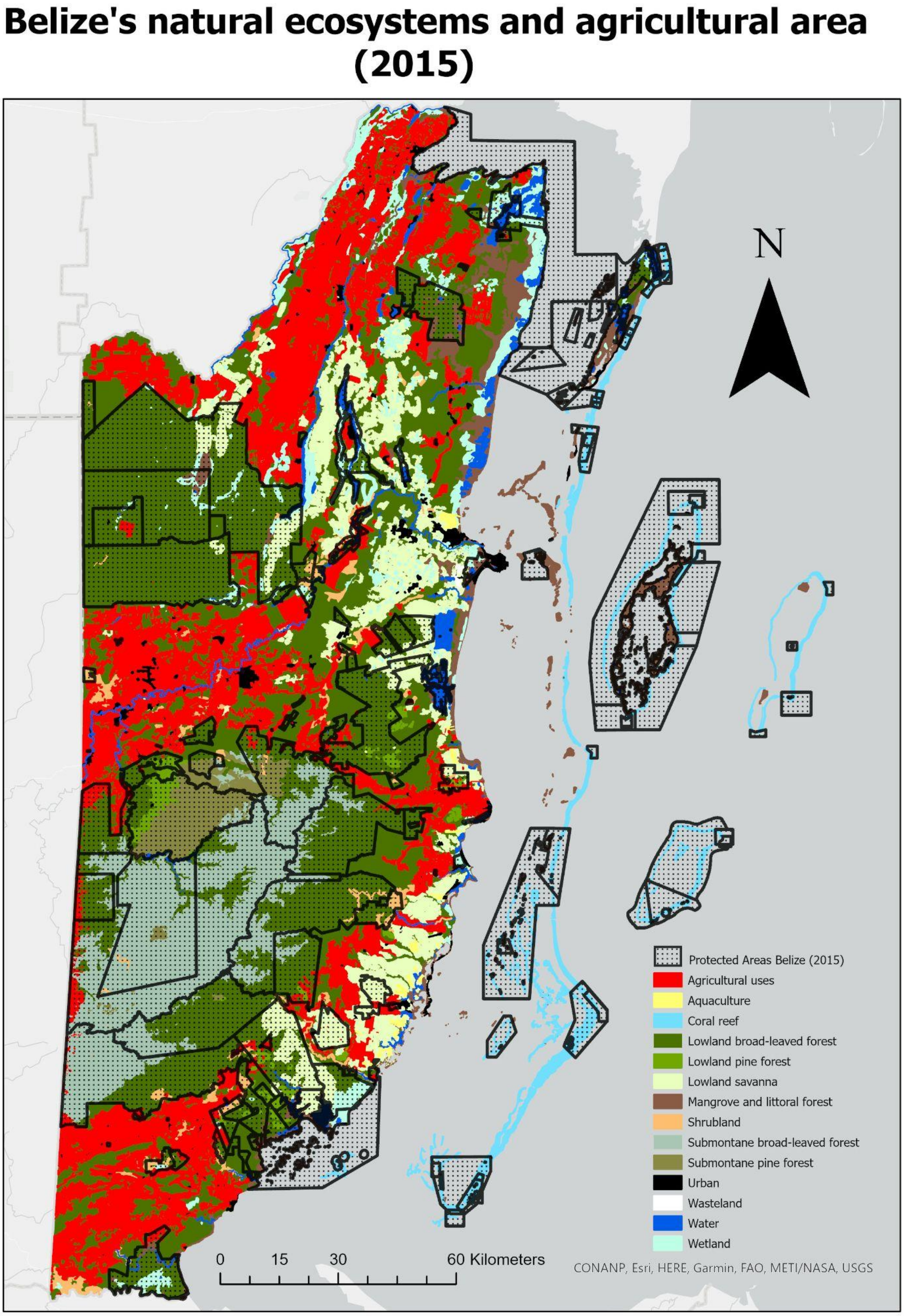
Currently, the forest cover in Belize is 56.47% (See: Table 1), and approximately 37% of terrestrial Belize (including sustainable management) is under some form of formal protection.

Table 1: Belize land cover assessment (from spatial analysis)

Broad category	Ecosystems Category	km2	%*
Forest	Lowland broad-leaved forest	10,356	46.8%
	Lowland pine forest	200	0.9%
	Submontane broad-leaved forest	2,733	12.3%
	Submontane pine forest	431	1.9%
	Mangrove and littoral forest	933	4.2%
Other wooded lands	Lowland savanna	1747	7.9%
	Shrubland	329	1.5%
Wetland	Wetland	1025	4.6%
Non-forest	Agricultural use	4433	20%**
	Urban	276	1.2%
Water	Water	89	0.4%

*Percentages are based on land area
**Generalized classification. It includes 7 subclasses (i.e. aquaculture and forest plantations). Some areas of secondary growth and short crop rotation were indiscriminately categorized as ‘agriculture’.
Source: Ecosystems map (Meerman & Clabaugh, 2017)

Figure 2: Belize ecosystems map showing agriculture extent.



ii. Conservation and biodiversity

While Belize is a leader in conservation in the region, its forest cover has decreased considerably since the 1950s—when large-scale industrial agriculture began to emerge in the territory. To a large extent, the historical dependence on forestry spared most of Belize's forests, compared to most of Central America and the Caribbean—whose (colonial) economies were grounded on agriculture (Leslie, 1996). Since early formal British claims to the Belizean territory, the establishment of structured forestry management policies became pivotal for their interests as the established economy was based on the extraction of wood. The Forest Department was formed in 1925, followed by the creation of a permanent forest estate and the formal control of timber extraction (Platt, 1998). This would prevent the overexploitation of commercial species in natural forests from logging concessions (*ibid.*). Subsequently, The Forest Ordinance (FO) was passed in 1927, which provided a legal basis for the designation of PAs, and furthermore suggested that the development of the forestry industry coexisted alongside conservation (Nicoleit and Franklin, 1995 in Platt, 1998). However, despite numerous policies, centuries of continuous logging had led to the decline (and virtual exhaustion) of mahogany, pine, and other commercial forest reserves by the 1950s (Hartshorn *et al.*, 1984). Belize's socio-economic structure, therefore, had to increasingly transform towards industries that were not conducive to forest management (Platt, 1998). By the 1960s, as large-scale agriculture replaced forestry as the backbone of the Belizean economy, investment in forestry declined dramatically thereafter, alongside the importance of the Forest Department.

After independence, the Belizean government created the National Protected Areas System Act, which provided a legal basis for the establishment of all national parks, biodiversity sanctuaries, and reserves, among others (Platt, 1998). However, with the decline in funds for the Forest Department, there was limited oversight capacity for areas that were expected to be managed by it. For instance, while logging concessions were to be regulated and administered by the Forest Department, they did not have the capacity to monitor logging operations (*ibid.*). Furthermore, a significant problem noted by the Tropical Forestry Action Plan (1989) was that "Ministers in charge of national protected lands have the ability to remove the restrictions for resource exploitation when "overriding public interest" dictated that such action was appropriate" (Platt, 1998, p. 129).

Currently, there are a total of 108 managed areas within the National Protected Areas System (NPAS) which includes an extensive network of public, private and community-based conservation initiatives (Young, 2008). However, the large majority of PAs are extractive reserves, which allow the removal of flora, fauna, and timber (Gonzalez, 2007). This reflects Belize's historical colonial economic structure, since PA's were established on an ad-hoc basis and focused primarily on the extraction of natural resources (Young & Horwich, 2007). Furthermore, the NPAS is heavily characterized by a heavy reliance on co-management and private reserves due to the aforementioned low institutional capacity and weak central governance (Mitchell *et al.*, 2017). In order to address many of the challenges faced by NPAS, the Government of Belize (GoB) commissioned the National Protected Areas Policy and System Plan (NPAPSP) in 2004. The commission highlighted a decreasing biological connectivity (biological corridors) between PAs due to continued deforestation, which can affect the viability of some large-ranging species such as the white-lipped peccary (Mitchell *et al.*, 2017). The analysis incorporated economic, ecological, social, resource conservation, and environmental variables in order to assess the multidimensional (socio-environmental) potential of various regions in Belize (Meerman, 2005b). The area of the BMF was outlined as a region with high environmental and high socioeconomic value, thus an area with conflicting forces.

Overall, Belize has a high proportion of its landmass under protection, which fulfills numerous global environmental targets, such as the IUCN's (International Union for Conservation of Nature) post-2020 biodiversity framework (aimed at protecting 30% of the territory by 2030), and the Aichi biodiversity target 11 from the Convention on Biological Diversity (CBD). However, while Belize's socioeconomic structure has transformed after the decline in the logging industry in the 1950s, its PAs legislation and governance have lagged behind—although some recent efforts have been noted. Belize's socioeconomic structure has changed and diversified over the last 50 years, but it still relies heavily on the environmental services of the Protected Areas System. The tourism industry (the principal foreign exchange earner) and the agricultural sector were identified by NPASP as high-potential sectors (Martin & Manzano, 2010), however, their heavy dependence on environmental resources and ecosystem services means that they have to establish systems that maintain balance and establish compromises between the two. Furthermore, with increasing climate variability those systems need to be highly adaptable and resilient to changes.

Table 2: Land use in Belize in 2019

BELIZE: LAND USE, 2019

	Thousands of hectares	*Percentages**
Total	2,297	
Land Area	2,281	100
Agricultural area	172	7.54
Arable Land	90	3.94
Permanent crops	32	1.4
Permanent pastures and meadows	50	2.19
Forest area	1,288.21	56.47
Inland water	16	0.70
Other lands	820.79	35.98

Source: FAOSTAT, 2019
*Percentages are based on land area

1. The Belize Maya Forest (BMF) reserve

Figure 3: BMF area showing *Selva Maya* extent

Source: The Nature Conservancy, 2021

The BMF encompasses an area of approximately 96,000 hectares of primarily broad-leaved moist forest located in northwestern Belize and constituting a significant portion of the *Selva Maya* in the Yucatan peninsula of Central America. In April 2021 it was purchased for USD$76.5 million by a consortium of environmental NGOs due to increasing threats of deforestation from the agricultural expansion of Spanish Lookout—located directly south of the reserve. Combined with the adjacent RBCMA, the BMF reserve covers 9% of Belize's territory, providing an important addition to the network of Protected Areas in Belize (The Nature Conservancy, 2021). Furthermore, it represents an important "puzzle piece" that connects important natural ecosystems and PA's in Belize to adjacent protected Maya Forest territory in Guatemala and Mexico (Wynne, 2021).

The BMF land was previously logged selectively in the 1960s, before being purchased in the 1980s by Sir Barry Bowen, a businessman and former Belizean senator (VCS, 2011). Due to his untimely death in 2010, the land went up for sale and was proposed for development and to convert it to sugarcane plantations. However, carbon credits allowed the Forestland Group (a US-based sustainable logging company) to purchase the land. They maintained the area under conservation except for low-impact timber harvesting in certain parts. FSC certification was expected to be obtained in 2015, and biodiversity studies were conducted alongside sustainable logging operations in order to study the impacts on biodiversity.

Only 8 years after this acquisition, the land went up for sale again, and it risked being purchased for agricultural development. A consortium of organizations[4] allowed the purchase of the land to take place. With this acquisition, the Belize Maya Forest Trust was founded, which will manage the BMF. In addition, the Belizean government will allow the Belize Maya Forest Trust (BMFT) to sell carbon credits to cover approximately half of the purchase costs, plus funds for the sustainable management of the reserve.

"The average tropical tree can soak up approximately 50 pounds of carbon per year. Once mature, the Belize Maya Forest will sequester more than 10 million tons of carbon. If this land were cleared for farms or ranches, much of that carbon would be released again. But thanks to the landmark deal secured between The Nature Conservancy and the Belize government, this forest will be preserved in perpetuity. Once the carbon stocks in the forest are fully assessed and validated by a third party, they can be sold as credits on the international carbon market to businesses and other organizations to offset their emissions." (The Nature Conservancy, 2021)

Overall, the area of the BMF comprises three different properties; Laguna Seca, Yalbac, and Gallon Jug. Gallon Jug is still owned by the Bowen family.

iii. Agriculture

1. Overview

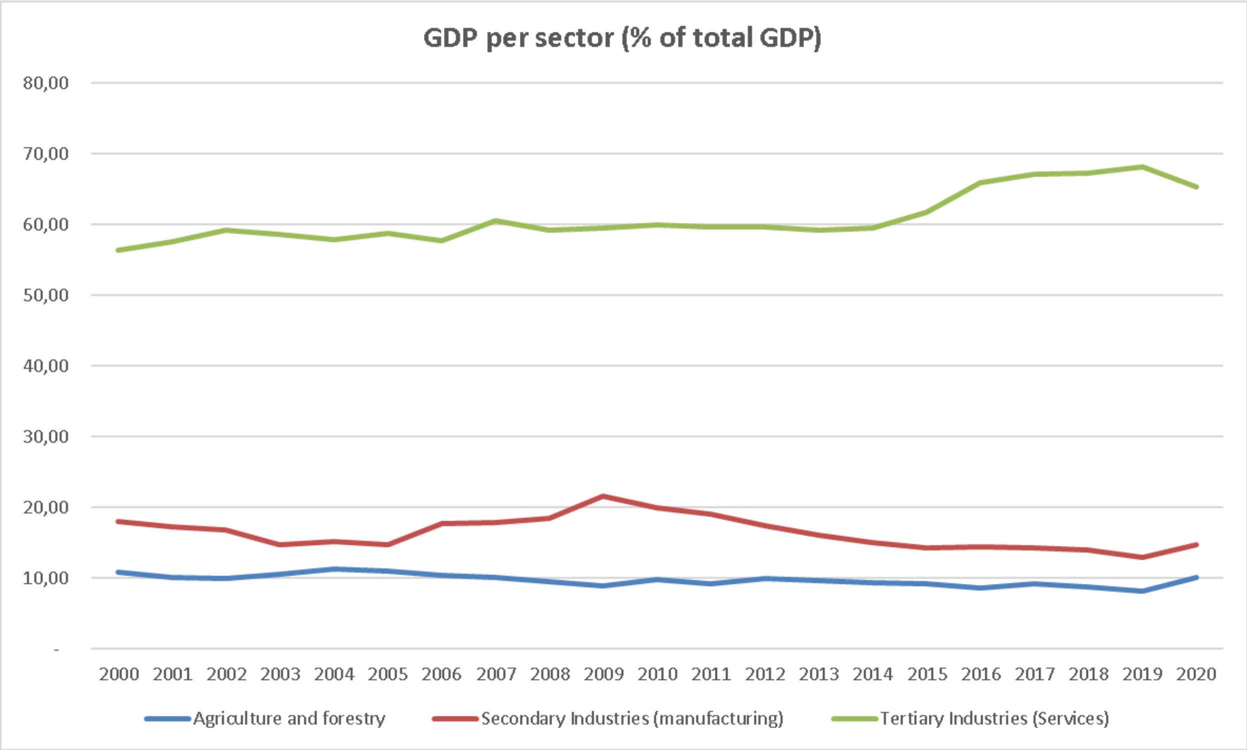
It is important to note the significance of the agricultural sector in the Belizean economy. Although it only accounts for approximately 10.2% of the total GDP (SIB, 2020), it has maintained a relatively stable position within the economy for the previous decades compared with other sectors (See: Table 4). The agriculture sector employs approximately 23,400 people (16% of the labor force) (CIAT; World Bank, 2018), although that figure would be substantially higher if part-time and informal employment was accounted for (Martin &

[4] Includes The Nature Conservancy, The Wyss Foundation, and the Rainforest Trust, among others.

Manzano, 2010). Furthermore, agricultural products account for the vast majority of exports (90% in 2019) (IDB, 2020), while agricultural imports are considerably low compared to agricultural exports—thus indicating that the non-export sector satisfies most of the Belizean food demands. The 2015 National Adaptation Strategy (NAS) to Address Climate Change in the Agriculture Sector in Belize underlined that Belize is self-sufficient in seasonal fruits and vegetables, as well as staple crops (i.e. corn, livestock, beans, among others).

Approximately 800,063 hectares of land (38% of Belize's total land area) are suitable for agricultural production, but currently, only 158,000 hectares are used for agriculture (7% of total land area) (FAOSTAT, 2019;). This figure, however, is highly controversial, as this percentage varies depending on the definition of what agricultural land entails. Spatial analysis reports (e.g. Meerman & Clabaugh, 2017) quote a much higher figure due to a broader definition (See: Table 2). Furthermore, this variability can also be attributed to a low rate of land utilization in Belize. Approximately 46% of land registered to farms is underutilized—which "can be explained mostly by the cost of developing it, including building access roads, providing potable water and electricity, constructing irrigation facilities, and in some cases clearing the land, without touching protected areas. Lack of secure markets and profitable new farming options also may be factors contributing to the apparent underutilization of the land resource" (Martin & Manzano, 2010, p. 107). In addition to this, Belize has an unequal distribution of land ownership. The International Fund for Agricultural Development (IFAD) highlighted that farms under 5 acres (2.02 ha), although making up 24% of all farms, account for only 1.4% of all the agricultural land, while 26% of the rural population is landless (IFAD, 2017).

Figure 4: Percent of GDP per sector (Belize)



Source: SIB, 2020

Additionally, it has been noted that food security and agricultural production in Belize should not be taken for granted, since the agricultural sector is often heavily affected by climate-related natural disasters, and changes in climate patterns have become more common in previous decades (CIAT; World Bank, 2018). From the years 2000 to 2016, agricultural losses from climate-related natural disasters have been estimated to have totalled over US$235 million (Ishizawa *et al.*, 2017). While macroeconomic trends (in the form of food price fluctuations, trade imbalances, viruses, pests, etc.) point out another vulnerability to the agricultural sector—and to a significant part of the Belizean economy as a whole. Most recently, prolonged dry weather conditions in 2019 and the following COVID-19 pandemic has taken a heavy toll on the sector and pushed the country into recession (IDB, 2020).

Overall, agricultural trends in Belize have increasingly been characterized as expansive, in a territory with a limited capacity to sustain it. While it has been estimated that 38% of the land is suitable for agricultural production, a large part of the territory is protected (nearly 40% of the country's landmass), while the majority of the territory is either unsuitable for production or requires substantial investment in order to generate acceptable returns (See: Table 3). The continuous expansion will be met, therefore, with PA frontiers, or marginal lands that are ill-suited for agricultural production (CIAT; World Bank, 2018). The expansion of large industrial cropping and livestock systems will likely increase land degradation, and thereby drive forward the demand for land-use change (Toensmeier, 2016). Furthermore, climate-related natural disasters and changes in precipitation and temperature will exacerbate these trends, which will increase pressure on the agricultural sector to satisfy food demands (CIAT; World Bank, 2018). This points to a major challenge in the Belizean economy, as there are increasing demands for the agricultural sector (and for rural development overall) for ensuring food security, conserving natural resources and ecosystem services, as well as reducing rural poverty.

"There is the urgent need for the GoB to develop an integrated policy framework that balances the conservation and the development agendas. This tension between them became apparent in the communities of Nago Bank and Maskall, in which small farmers who were allocated State lands for agricultural use are encroaching on the surrounding forest. In places like these, there is a clear need for environmental safeguards and/or incentives to promote sustainability (e.g., payments for environmental services) for production systems that go hand-in-hand with ecosystem conservation (e.g., agroforestry)."

(IFAD, 2017, p. 6)

Table 3: Soil categories by agricultural suitability in Belize

Grade	**Description**	**Category**
Grade 1 & 2 16%	Suitable for mechanized agriculture - Suitable for most crop and livestock production (including cash crops).	Good for cultivation
Grade 3 20%	Requires substantial investment in order to generate acceptable returns (however, suitable for smallholder development)	Sub-par quality for cultivation
Grade 4 20%	Marginal land	Cultivation discouraged - danger of increased runoff, reduced groundwater replenishment, and (rapid) land degradation
Grade 5 44%	Extremely marginal for agriculture. Mostly covered by forests.	

Adapted from Simpson, 2009.

2. Agricultural production subsectors in Belize

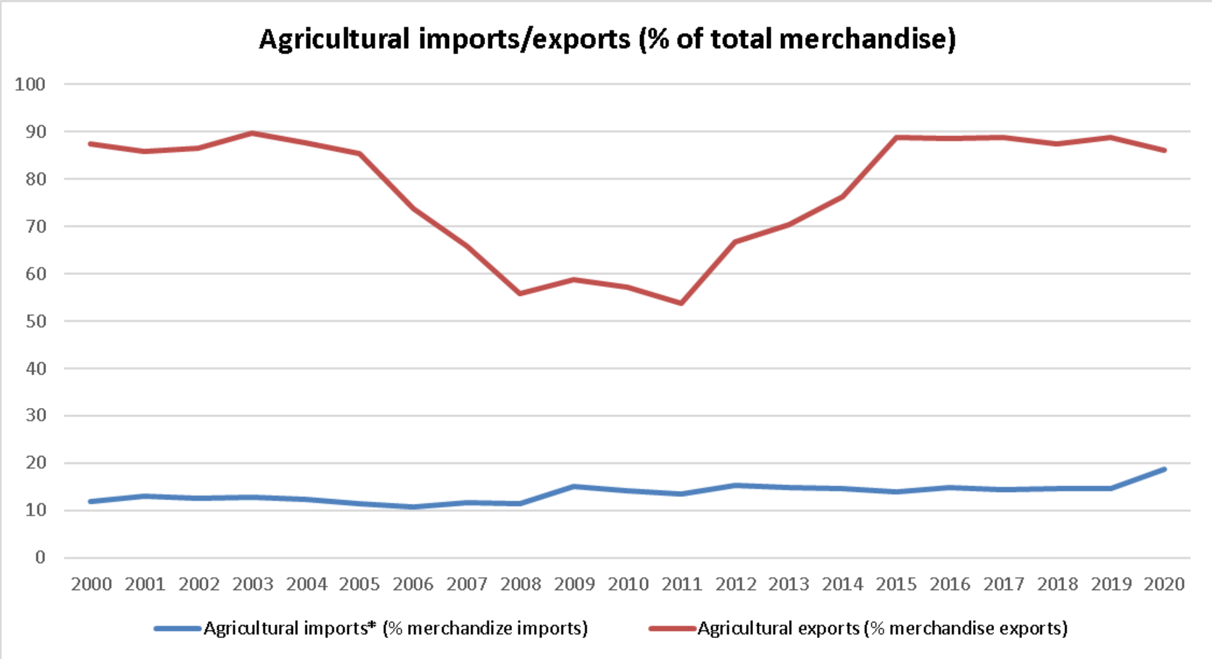
Belize's agriculture (cropping and livestock husbandry) is primarily divided into three main sub-sectors: an export sector (mainly characterized by the production of citrus, sugarcane and bananas), a small-farming sector that mainly produces for local consumption, and a well-integrated largely industrial-scale sector (e.g. The Mennonite community in Spanish Lookout) (FAO, 2011). In general, farm systems range broadly in terms of crop produced, acreage, land ownership type and inputs used. In terms of size, farms vary from small and low-input arrangements (e.g *Milpa*) to large industrial farms that can expand over several hundreds of hectares. Overall, sugarcane, bananas, citrus (export crops) make up the majority of the agricultural land use, followed by livestock pastureland, and then annual crops (Martin & Manzano, 2010). Finally, it is important to note that each subsector is not systematically exclusive—which means that there are production similarities among them. For instance, most of the export sector produces at an industrial scale, and not all small-scale farmers produce for local consumption.

a. Export

In terms of production value, the agricultural sector in Belize is highly export-oriented. 60% of the total production value consists of only four products: sugarcane, bananas, poultry, and oranges (only poultry is not exported) (Foster *et al.*, 2017). Other important food exports are from the fisheries sector (products like shrimp, lobster and conch), as well as a rapidly increasing papaya export sector (Martin & Manzano, 2010). Due to the variability of the landscape between the north and south areas, the export sector is highly localized (Cherrington *et al.*, 2010; Day, 2003)—banana plantations are primarily produced in the south of the country, citrus trees in the south-central region and sugarcane in the northern region (ibid.).

The agricultural export sector receives the majority of the agricultural credit (approximately USD$50 million per year)—allocated primarily to the banana, citrus and sugarcane sectors (Martin & Manzano, 2010). Furthermore, as a previous British colony, Belize is part of the Organization of African, Caribbean and Pacific States (OACPS), which grants it benefits from international cooperation programs and access to preferential markets in the European Union. This places Belize in a privileged position to foster cooperation, as well as trade. However, the competitiveness of the Belizean agricultural exports are highly dependent on trade preferences (i.e. The EU banana and sugar programs) (Martin & Manzano, 2010). Furthermore, from the early developments of export agriculture, there have been uncertainties about the long-term sustainability of plantations (i.e. citrus trees planted on poor-quality soil) (see: Arnold *et al.*, 1989). Diversification, and the overall sustainability of this sector will be determined by the improvement of its systems and its ability to mitigate some of long-term and short-term risks (See: Santos & Garcia, 2008; Martin & Manzano, 2010).

Figure 5: Belize agricultural imports/exports as a percentage of total merchandise



Source: SIB, 2020
*Includes agricultural inputs: fertilizer, seeds, animal feed, insecticides, herbicides, and fungicides.

b. Small-scale production

The type of smallholder or small-scale production in Belize varies. Smallholder agriculture systems can be family owned, or *Milpa* farms. Of the estimated 11,000 farmers in Belize in 2011, approximately ¾ were small farms under 10 hectares (Richardson, 2009). And while most farmers have holdings of under 20 hectares, the greatest agricultural land area is held by farmers holding above 20 hectares of land (King *et al*., 1992; MAF, 2018).

Studies (Beach *et al*., 2015; Drexler, 2020) have outlined the historical and cultural importance of traditional small-scale Mayan agriculture practices, or *Milpas* in the Mesoamerican region. In pre-Columbian times, Mayan agriculture was grounded on strategic and sustainable use of land resources to prevent soil degradation or depletion. They involve the clearing of lands (typically through slash-and-burn methods) for growing traditional crops (e.g. Maize, beans, squash, etc.) and then leaving fields untouched to regenerate while shifting production to new plots of land. "[B]y allowing areas to regenerate, creating a mosaic of forest succession stages and crop diversity, and providing major food sources and livelihoods for Maya *milpa* farmers" (Drexler, 2020, p. 86), these practices were able to be maintained for centuries.

Milpa practices have been decreasing over the previous decades, however, and some small-scale family farms (i.e. the Mennonite community in Spanish Lookout) have expanded to industrial and heavily mechanized systems to produce cash crops (i.e. livestock).

c. Industrial-scale agriculture

Industrial-scale agriculture has been increasing in Belize after the decline of the logging industry in the 1950s. There are some various types of industrial-scale agricultural production in Belize. 1) Export- oriented crops are often on extensive farms over 100 hectares (King *et al.*, 1992) (although some are produced in smaller scales). 2) The production of livestock also represents an extensive and industrial-scale type of agriculture in Belize. It has increased vastly since the 1980s (IICA, 1995), and it accounted for approximately 25% the total agricultural output by 2008 (Ramirez *et al.*, 2013). To account for this large growth in production, farmers have expanded supplemental cropland for livestock feed (Richardson, 2009). This means that livestock agricultural land is not limited to meadows for grazing animals but includes other types of crops (i.e. corn for poultry farms).

3. Agriculture in Spanish Lookout

Located to the south of the BMF reserve, it is a large agriculture-based community in the Cayo District of Belize. It was established by a group of 680 Mennonites migrating from Mexico (and previously Canada) that settled at the banks of the Belize river in the late 1950s (Roessingh & Boersma, 2011). While Mennonite communities in the continent vary in the present day (as they have established communities across many countries in the Americas), they all originate from the Anababtist movement of the Protestant reformation in Europe in the early 16th century (Everitt, 1983). Their early migrations are mainly due to religious persecution in Europe. During the early 20th century, however, migrations from Canada and Mexico were due to increasing governmental pressures of integration of their schooling system to the state's system, among other reasons—which posed a threat to their social and religious identity, since it is in the nature of Mennonite communities to remain a socially isolated group (Roessingh & Schoonderwoerd, 2005; Roessingh & Boersma, 2011). When they migrated into Belize (formerly British Honduras), the population was of about 90,000 (SIB, n.d.) and only a small fraction of them practiced subsistence agriculture (Higdon, 1997).

For the colonial government therefore, they represented a community of skilled farmers that could establish a thread of commercial agriculture in the country (Shaw, 1987).

From the early settlement period, they experienced a lot of uncertainty, with many community members returning to Mexico or even Canada (Roessingh & Boersma, 2011). In addition, they had to adapt heavily to a different environment and to planting new crops. This however, was not new, as the 'Kleine Gemeinde' community in general has evolved thoroughly from logging and subsistence agriculture operations to a highly complex economy grounded on commercial industrial-scale agriculture businesses as their primary engines for growth (Higdon, 1997).

Currently, Spanish Lookout has a population of 2,253 and represents one of the most economically successful communities in Belize (Roessingh & Boersma, 2011). It is one of 12 Mennonite settlements, and part of one of three different Mennonite church communities in the country. They are part of the 'Kleine Gemeinde' church and Evangelical Mennonite Mission Church (EMMC), which distinguishes them by being the most (technologically) progressive of other Mennonite settlements, which entails that they use electricity, automobiles and other types of heavy modern machinery to operate their farm businesses—unlike other Mennonite settlements that have bans on pneumatic tires or modern equipment altogether (*ibid*.). Furthermore, their farming and their land tenure system is based on communal property based on the membership of the 'Kleine Gemeinde' church (Roessingh & Boersma, 2011). This means that all farms within the community are part of a large cooperative.

The agriculture sector in the community in Spanish Lookout has evolved greatly over the past 70 years. "Mennonite communities that traditionally farm[ed] permanent fields of vegetables for their own use and for market have expanded into cash crops [...]" (Platt, 1998, p. 129). Their beans, dairy, and poultry sectors are dominant businesses in the country and their distribution and transport sector is highly organized and runs well beyond the borders of the community (Roessingh & Schoonderwoerd, 2005). Their poultry sector is important to highlight, as it has been noted to involve a large part of the farming community in the town from raising broilers to marketing poultry products (Roessingh & Boersma, 2011). Furthermore, its products have expanded immensely into the Belizean economy—chicken meat is currently one of the main protein sources in the country (*ibid*.).

3. Literature Review

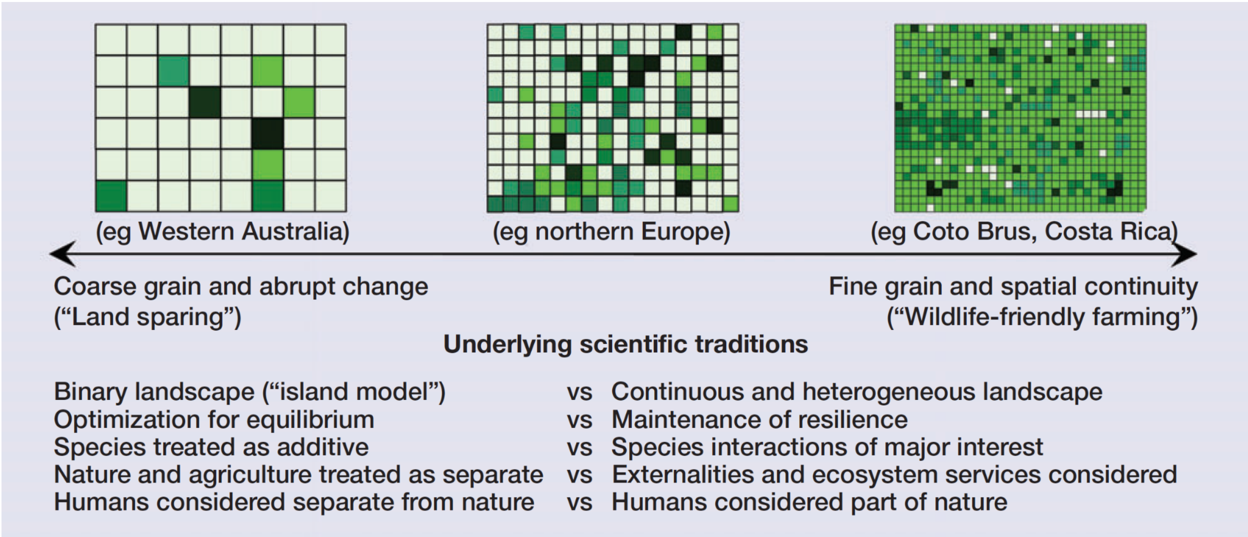
a. Global land management models

There are two ‘macro’ land management practices used globally: the ‘land-sparing’ model and the ‘land-sharing’ model (also known as wildlife-friendly farming). The land-sparing model is evidenced mostly in large industrial agriculture areas where cropland and livestock systems are managed to maximize yields by separating them from forested areas (oftentimes biodiversity hotspots). This creates largely homogeneous landscapes, where forested areas are outlined and left aside, thus creating an “island model of modified landscapes, where islands of nature are seen as separate from human activities” (See: Figure 6) (Fischer *et al*., 2008, p. 380). The ‘spared land’ allows for the preservation of biodiversity-rich areas, since intensively farmed areas support low levels of macrofauna due to its limited allocation of natural habitat.

In land-sharing models, on the other hand, yield can be considerably lower, but conservation and production objectives are interlinked in a largely-heterogeneous landscape. This model emphasizes a largely diverse land management scheme, prioritizing resilience and cross-level interactions between farmed and non-farmed areas. Furthermore, such models often require significantly less overhead costs/agricultural inputs (compared to industrial agriculture systems in land sparing models) because they generate ecosystem conditions that agriculture depends on, such as nutrient recycling, pollination, pest control, and water flow regulation (MA, 2005 in Fischer *et al.*, 2008).

The relationship between agriculture and environmental conservation represents two conflicting modes of land use evidenced in the ‘land-sparing’ model of land management. Belize is an important case study for this conflict, as it represents a country with a wide array of PAs, and a large and expanding agricultural sector. Although the agricultural sector is relatively new compared to the establishment of forest reserves and its accompanying legislation, its development (especially within export-oriented and industrial agriculture systems) have greatly transformed the national landscape. Three points of concern are (1) the expansive nature of these systems—for their continuation is prone to be met PA boundaries or non-productive land, (2) their reliance and dependence on inputs such as synthetic fertilizers, pesticides, herbicides, mechanized plowing/planting/harvesting—which makes them highly vulnerable to price fluctuations of these overhead costs, and lastly (3) their separation from natural ecosystems can make them less resilient to climate change, which can hinder their capacity to mitigate and adapt to immediate and long-term shocks.

Figure 6: Gradient of scales between conservation and agriculture can be integrated



Source: Fischer *et al.*, 2008

b. Agriculture and biodiversity trade-off analysis

The issue of how to best manage heterogeneous landscapes in agriculture-conservation frontiers remains a global challenge. Studies from El Gran Chaco (Macchi *et al.*, 2020; Law *et al.*, 2021; Piquer-Rodriguez *et al.*, 2018) (a dry subtropical dry forest in an area that stretches across 647,500 km2 along parts of Argentina, Bolivia, Paraguay, and Brazil) examine the trade-offs between agriculture and biodiversity, drivers for agricultural expansion, and biodiversity loss in large deforestation frontiers. These types of regional analyses are vital for understanding the relationship between natural ecosystems and agricultural expansion in dynamic landscapes since diverse land management practices lead to varied trade-offs between agriculture and biodiversity. Therefore, "analyzing the trade-offs between biodiversity and agriculture can provide insights into whether separating intensive agriculture and areas for biodiversity (i.e. land sparing) or integrating them (i.e. land sharing) serves more species while producing the same agricultural products" (Macchi *et al.*, 2020, p. 2). Furthermore, understanding trends in biodiversity and agriculture can help mitigate the trade-offs between them (*ibid*.).

The expansion and intensification of agricultural areas in el Gran Chaco has risen greatly since the 2000s, increasing pressure on subtropical forests that host considerable levels of biodiversity. Macchi *et al.*'s (2020) research encompasses a large study area that examines avian biodiversity in diverse agriculture-conservation contexts/gradients (which include natural woodlands, grasslands, intensified croplands, silvopasture, conventional ranching and subsistence ranching). Their results show that there is a diverse species response to landscape contexts—from increasing occupancy rates to increasing occupancy rates depending on agricultural intensity. From their bird species sample, some species benefited from agricultural intensification (evidenced by an increased occupancy rate in areas with high agricultural intensity)—known as "winner species", while others were negatively impacted by it (evidenced by a decreased occupancy rate in areas with high agricultural intensity)—known as "loser species". However, for most species in the sample, their occupancy rate relationship to agriculture was primarily based on the woodland extent within the agricultural area—known as "shifter species". This is important to note as most species' response to agricultural intensification is mandated by the gradient of woodland extent within that area, thus indicating that there is a decreased negative impact on bird species within agricultural management schemes that naturally incorporate a high level of woodland within their areas of production. Such agricultural management schemes include silvopasture systems and intensified pasture systems.

A further study to note, conducted by Delzeit *et al.* (2017), assesses food security—another crucial factor in the agriculture-biodiversity tradeoff analysis. It points out the reality and fragility of the two-sided scale. The large-scale expansion of cropland is commonly accompanied with improved food security due to a decrease in food prices and an increase in food quotas (*ibid.*). However, this comes with high costs that are often initially environmental (in the form of biodiversity loss, ecosystem service pressure, soil degradation, increased GHG emissions, etc), and later followed by a socio-economic backlash from the disruption of biophysical structures upon which agricultural systems depend. FAO (2014) has highlighted that the LAC region is amongst the world's highest expected agricultural expansion, but also amongst the regions with highest biodiversity endemism richness—which define the region as one with conflicting environmental and socio-economic targets.

This thesis, while focusing primarily on land management practices and land-use change, will include a section from biodiversity studies conducted in the BMF area in the previous decade. Something important to note is the presence of large felids within the BMF—which tend to be habitat-restricted animals, and thus require forested areas to remain intact, unlike some bird species. An important and final conclusion from Macchi *et al*. (2020) was that a binary approach (land-sparing or land-sharing) would not yield a solution for deforestation frontiers, but rather a mixed approach would allow for a better balance between biodiversity and agriculture.

c. Effectiveness of protected areas

Currently, PA's make up more than 30% of the tropical forestland (FAO, 2021). While PAs remain an important scheme for the conservation of habitat for biodiversity and carbon stocks, as well as securing numerous ecosystem services, their effectiveness is often uncertain. Global (Nelson & Chomitz, 2009; Spracklen *et al*., 2015; Joppa *et al.*, 2008; Andam *et al.*, 2008; Barber *et al.*, 2012) and regional (Soares-Filho *et al.*, 2010; Wright *et al.*, 2007) analyses of PA's effectiveness have pointed to a significant level of deforestation pressure within PAs. In moist tropical regions, approximately 73% of PAs were experiencing deforestation pressure (Spracklen *et al.*, 2015). While this varies in terms of region, country, PA management type, and the country's GDP, it is nonetheless important to account for—especially when PAs are established in areas with expanding agricultural sectors.

Another important aspect of this issue is the deforestation happening along buffer areas of PAs. Spracklen *et al.*, (2015) notes that there is a probability that the establishment of a PA might affect deforestation in non-protected areas around that reservation—known as a "spillover effect". Therefore, concluding that the usefulness of that PA is compromised if its protection is at the expense of surrounding non-protected forested areas (ibid.).

In the case of Belize, the current establishment of PA's still exacerbates the land-use conflict, and as is evidenced by remote sensing analysis—agricultural land currently surrounds most PAs in the country (See: Figure 2). Although most PAs have been successful at protecting and conserving the vast majority of natural ecosystems within their boundaries, the forests outside their confinements are under increasing threat of deforestation, logging, and other external pressures (See: Spracklen *et al.*, 2015). This points to a potential degree of 'spillover effect' from the allocation of PAs in the country. Furthermore, numerous PAs have historically been established on an ad-hoc basis for resource extraction (Young & Horwich, 2007), which means that some PAs experience some deforestation due to their respective management type. This form of allocation of PAs has reduced, but resource-extraction reserves still exist. This was the case of the area that now comprises the BMF, which was previously allocated for sustainable logging. However, initial reports from biodiversity studies conducted in forested areas where logging operations took place hint that “multi-use management of tropical rainforest is potentially compatible with conservation of wildlife” (Kelly & Rowe, 2014).

International frameworks, such as UNFCCC’s REDD+ (Reduction of Emissions from Deforestation and Degradation) are becoming increasingly important, as they highlight the importance of not only protecting forest cover and reducing deforestation, but also agendas to help implement the sustainable management of forests. Moving forward, the sustainable management of areas that lie outside of PAs is becoming increasingly important since the establishment of reserves often fails to address this issue—which can lead to an increase in deforestation rates outside PAs or it can even lead to increased pressures within PA boundaries.

4. Conceptual Framework

Due to limited existing theory in this line of research (See: Tallis *et al.*, 2009), this thesis has opted for a conceptual framework, rather than a theoretical framework.

a. Ecosystem-based Adaptation (EbA)

i. Agricultural landscapes as complex socio-ecological systems

Agricultural systems have been transformed greatly over the past century. The development of conventional/industrial agriculture has meant a transition in the *status quo* of the production of agri-food products. The most important change has come from the development of industrial agriculture systems that are based on high-yielding and input-intensive arrangements (Fischer *et al.*, 2008), and therefore no longer defined by or seen as complex socio-ecological systems. Furthermore, they have accommodated the (export-oriented) demand of a globalized world, which leads to a decrease in crop diversity production, increased waste, and increased GHG emissions (Toensmeier, 2016). In terms of crop diversity for instance, a whopping 66% of the world's crop production constitutes only 9 crops (FAO, 2019). This type of homogeneity derived from industrial monocultures are increasingly vulnerable to pests, market fluctuations and climate change events.

This thesis will use Ecosystem-based Adaptations (EbA) as a conceptual framework to develop the analysis of this socio-environmental conflict. EbA's "integrates the use of biodiversity and ecosystem services into an overall strategy to help people adapt to the adverse impacts of climate change. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to both current climate variability, and climate change. Ecosystem-based Adaptation contributes to reducing vulnerability and increasing resilience to both climate and non-climate risks and provides multiple benefits to society and the environment" (Colls, 2009, p.1). EbA strategies are not singular, but rather they accommodate a wide range of land management activities that promote cross-system synergies (CBD, 2009).

EbAs place the conflict of anthropogenic development and environmental conservation within the same interconnected system. For instance, while agriculture is an anthropogenic system, it relies on biophysical factors (i.e. rain, temperature, soil health, etc.) that must be incorporated into planning and decision-making processes. As long as the issue remains a zero-sum game, the conflict will persist—since the advancement of one system will signify negative repercussions on the other—the expansion of industrial agricultural land indicates receding forest areas, while the establishment of PAs designates boundaries where agriculture can not be established. PAs are successful in conserving numerous ecological benefits (i.e. ecosystem services) and securing the conservation of habitat for a wide range of species, but they create binary/homogeneous designations in largely heterogeneous landscapes. 'Land' in itself is largely a heterogeneous domain, as it accommodates socio-economic and environmental value. PAs, therefore, represent an ad-hoc solution to the issue of deforestation and agricultural expansion because they do not address and sometimes exacerbate deforestation rates in surrounding non-protected areas (Young & Horwich, 2007; Spracklen *et al.*, 2015). This is of concern, as a large part of the global ecosystems and biodiversity are located outside of PAs (Dasgupta, 2021). That being said, even with the most current ambitious conservation efforts, strategies that fail to account for a transformation in the agri-food sector will be in increasing conflict with the future provision of food (Leclère *et al.*, 2020). With increasing demands for the production of food, fuel and energy, the development of anthropogenic systems will have to address and resolve conflicting and opposing threats to the environmental pillars it depends on.

ii. Resilience models

Resiliency is defined as the ability of a system (i.e. farm, ecosystem) to endure social, biophysical, and economic pressures. More specifically, it can be defined as "[t]he capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity" (Folke *et al.*, 2010, p. 23). As mentioned earlier, 'shocks' or 'disturbances' can be varied (i.e. extreme-weather events, market fluctuations, temperature rise, etc.). In the case of agri-food systems, agriculture must be able to withstand these shocks/disturbances in order to remain both productive and sustainable— by providing current and future production demands as well as for maintaining environmental provisions and services. This concept is very important and relevant in the case of Belize, for the whole socio-economic structure is maintained by its large pool of environmental resources. Furthermore, a large part of the rural economy, and the state of the country's food security is directly or indirectly tied to the agriculture sector.

Milpa practices are still practiced in Belize today, but to a limited capacity (Doyle *et al.*, 2021). In the study of crop yield simulations (Santos & Garcia, 2008) it is demonstrated that the extent of the effect of climate change on agriculture in Belize will depend on the type of production systems and area studied. This, in turn, suggests that agricultural systems that do not aim for resiliency will be the most affected in the coming decades.

5. Methods and data

a. Methods

i. Statistical analysis:

The statistical analysis section of this research was primarily conducted using SPSS. This software was used to analyze the data from the 2018 Agricultural Census of Belize, District/National production datasets (acquired from MAF), as well as FAOSTAT statistics and World Bank statistics.

1. Statistics

- District/national agricultural trends (income and acreage for selected crops) (acquired from MAF).
- SIB Census data in the public domain

- The 2018 Agricultural census (acquired from MAF). Access to other agricultural censuses or Farm Registries was not granted (See: Limitations).

ii. Spatial analysis:

There were two main tools used for the spatial analysis section of this research:

A. Google Earth Engine (GEE) Python API was used for the remote sensing section of this research.
B. ArcGIS Pro was used for spatial mapping and processing. This included preliminary spatial data processing and visualization, as well as raster data analysis.

1. Spatial Data

- General land spatial data (containing forestland, watersheds, boundaries, cities and roads, etc.) and Digital Elevation Models (DEMs) is readily available from public websites, including OpenStreetMap, Esri ArcGIS Open Data, Global Forest Watch, DIVA-GIS. This type of data allowed for preliminary data processing and analysis of the Belizean territory and the research area.
- Landsat imagery: obtained from the USGS Earth Explorer database.
- Belize-specific data: Numerous sources were required to obtain spatial datasets from Belize. Meerman and Clabaugh (2017) provided useful spatial datasets from several time periods. These datasets included the PAs from Belize, Belize ecosystems map, roads, etc.

6. Methodology

a. Remote sensing:

An important aspect of this research is aimed at mapping land cover and land cover change for the entire area extent of the Spanish Lookout Zone and the BMF reserve. This research builds up on previous regional and national land cover assessments, namely Cherrington *et al.* (2010) and Doyle *et al.* (2021).

The python algorithm (a time-generalized Random Forest (RF) classifier) developed by Doyle *et al.* (2021) was used to process Landsat 5, 7, and 8 imagery in order to classify land cover for different time periods between 2000-2020 with GEE Python API. However, the algorithm created by Doyle *et al.* (2021) was used to map the land cover for three different time periods ranging from 1985 to 2016 and it was clipped to the Orange Walk district of Belize (north of the BMF reserve). Therefore, the python code had to be edited to classify land use and land cover for the time periods between 1999 and 2021 and it had to be clipped for the study area outlined for this research. Two different land use/land cover maps were created using 3-year landsat imagery composites: 1999-2001 and 2019-2001. Using landsat data for multiple years and multiple seasons (dry/wet) allows to smooth temporal variation in the image (from cloud cover or climate/atmospheric-related differences), and also enhances the ability to use a single training dataset for multiple time periods (Doyle *et al.*, 2021). The training and validation data from the research area had to be created using GEE in order to run the python code successfully with GEE Python API (See: Limitations). As the region is geographically similar to the area classified by Doyle *et al.* (2021), the random forest classifier worked similarly. Overall, this workflow comprised numerous steps, as outlined by Cherrington *et al.* (2010):

1. Pre-processing,
2. Training,
3. Image classification,
4. Post-processing, and
5. Validation assessment

The initial preprocessing step included selecting and creating training datasets in GEE within the study area to run the RF classifier. As this research is concerned with forest degradation and agricultural expansion, the land cover classes created in the training and validation datasets reflect this focus. Overall, 7 land cover classes were created, namely, urban/roads, forest, agriculture, wetland, shrubland, water, and forest degradation (defined as degraded/deforested forests not under agricultural use). The land cover classes for ‘agriculture’ and ‘forest’ were broadly generalized—instead of dividing agriculture into several production classes (i.e. cattle ranching, rice paddy, etc.) and forests into different forest classes (i.e. tropical broad-leaved moist forest from other forest types). In the land cover classification analysis, therefore, agriculture is defined as any land production type (including cattle ranching, grain crops, fruit trees, etc.), and forest is defined as any type of forested area excluding wetlands and shrublands (since they differ spectrally and geographically to agricultural land and forests). The algorithm was trained on Landsat 8 data from 2015—since it was one of the years with least cloud cover, and therefore yielded a clear image of the research area.

b. Statistical analysis

All statistical data from the Spanish Lookout Area was obtained from the 2018 Agricultural census. Agricultural data from the district of Cayo was obtained from MAF as well as secondary sources. In order to assess the agricultural production of the Spanish Lookout area, the 2018 agricultural census had to be codified in order to simplify the dataset. Temporal assessments for the Spanish Lookout area were not possible to carry out due to lacking village-specific data (see: Limitations). All temporal assessments, therefore, had to rely on Cayo district data. Furthermore, some data was missing in various databases which limited the ability to conduct certain analyses. (See: Limitations).

c. Ethical considerations

While this research will largely rely on quantitative data, it is important to take into account the ethical issues when accessing, handling, processing and publishing this data. There are numerous ethical considerations when using GIS software and statistical analysis software (SPSS), but they are often dependent on the type of analysis and data handled. For this research there are 5 main ethical considerations;

- Take into account collaborators' expectations of data privacy when handling primary and secondary data.
- Data obtained should be accurately portrayed, without distortions.
- Data should be handled appropriately with the same standards of an academic paper—sources should be cited properly.
- The work should be both valid and reliable. In that sense, the work should be repeatable with the data obtained and replicated with the processes used.
- Finally, regarding GIS, there should be a commitment from practitioners to share electronic maps with research collaborators.

Sources: (Berman *et al.*, 2018; Altaweel, 2021; Scheyvens, 2014).

7. Results

a. LULUCF

i. Land-use change

- Over the 20+ year period, 16,252 hectares was the total amount of deforested area for agriculture between 1999-2001 and 2019-2021 in the area of Spanish Lookout.
- Non-forest land (defined as the sum of all agriculture and forest degradation land cover classes) increased from 15,501.72 hectares in 1999-2001 to 31,753.68 in 2020, although there was a marginal increase in natural ecosystem cover in some areas/plots.
- Non-protected Forest (natural ecosystem) cover in the area of Spanish Lookout decreased from 33,978 hectares in 2000 to 14,675.67 hectares in 2020, representing a 56.8% decline, and constituting approximately 965.14 hectares of forest loss per year.
- Agricultural land grew by 53.29% from approximately 13,147 hectares in the 1999-2001 period to 20,154 hectares in the 2019-2021 period. If the 'forest degradation' land cover class is included, then the total amount land cleared for agriculture would amass to 16,252 hectares, and a 104.8% increase from the total amount of cleared land in the 1999-2001 period (See: Figure 9).

b. Agricultural production

1. Land distribution

- The majority of agricultural land is concentrated in the Spanish Lookout village, while the surrounding villages in the area have less than 3,000 hectares.
- The majority of land is held by large and medium-sized farms. The majority of farmers, however, own less than 10 hectares of land.
- Some villages, such as Duck Run 1 and 2, are specified in a single crop—about two-thirds of their land used for cattle production.
- After Spanish Lookout, the two villages with the largest area of agricultural land are situated in newly deforested areas, around the 10km buffer area of the BMF.
- If farms over 50 hectares (large and large-medium sized farms) were to be categorized together, they would amass almost 60% of the total agricultural land (with only 99 farms), while farms under 20 hectares amount to only 13.11% of the total agricultural land (with 347 farms).

2. Crop production assessment

- The main crops produced in the area are cattle, poultry, yellow corn, and other grains.
- Crop diversity decreases with larger farm sizes; Larger farms produce a limited number of crops (i.e. only cattle or yellow corn), while smaller farms produce more diverse/varied crops.
- The production of cattle increases with farm size—however, cattle production is often produced in combination with other crops in smaller farm sizes.

3. Temporal analysis: Cayo district agricultural production

a. Corn Case study: *Milpa* v. Industrial production

- Industrial agricultural production of corn has increased fivefold over the last two decades from 15,271,933 kg in 2000 to 76,536,755kg in 2020. Similarly, its agricultural land has increased as well by 164.53% from 4,373.533 hectares in 2020 to 11,569.41 hectares in 2020. The average yield of industrial corn production is considerably higher than Milpa production (approximately threefold), however, its yield has been highly unstable over the past two decades.

c. Land Conservation

i. BMF inner/outer buffer

- The 10km buffer of the BMF (See: Figure 19) has an area of 126,490.55 hectares (excluding the area in Guatemalan territory).
- Approximately 26% (33,704.63 hectares) are degraded/developed lands, while the remaining 74% (93,787.54 hectares) are natural ecosystems.

ii. Biodiversity

- From the numerous species in Belize, the BMF has a considerable number of them. Biodiversity studies (Kelly & Rowe, 2014; Kelly & Nipko, 2022) have evidenced the immense biodiversity richness in the area. Over 40 species of mammals and birds have been documented within the reserve, not taking into account several small mammals and herptiles that were captured in camera traps. A total of 5 species are classified as near threatened, 3 are vulnerable and 1 is endangered (See: Table 4). In addition to this, a considerable number of them are in decline (even though they are categorized by the IUCN as ‘least concern’), while a significant number of them are wide-ranging species that depend on large forested areas to survive.

- The overall impact of deforestation occurring in the previous two decades on key species within the region could not be assessed as occupancy rates from biodiversity studies have not been analyzed yet. However, the extent of deforestation shown in the remote sensing analysis implies a negative impact on wide-ranging species.

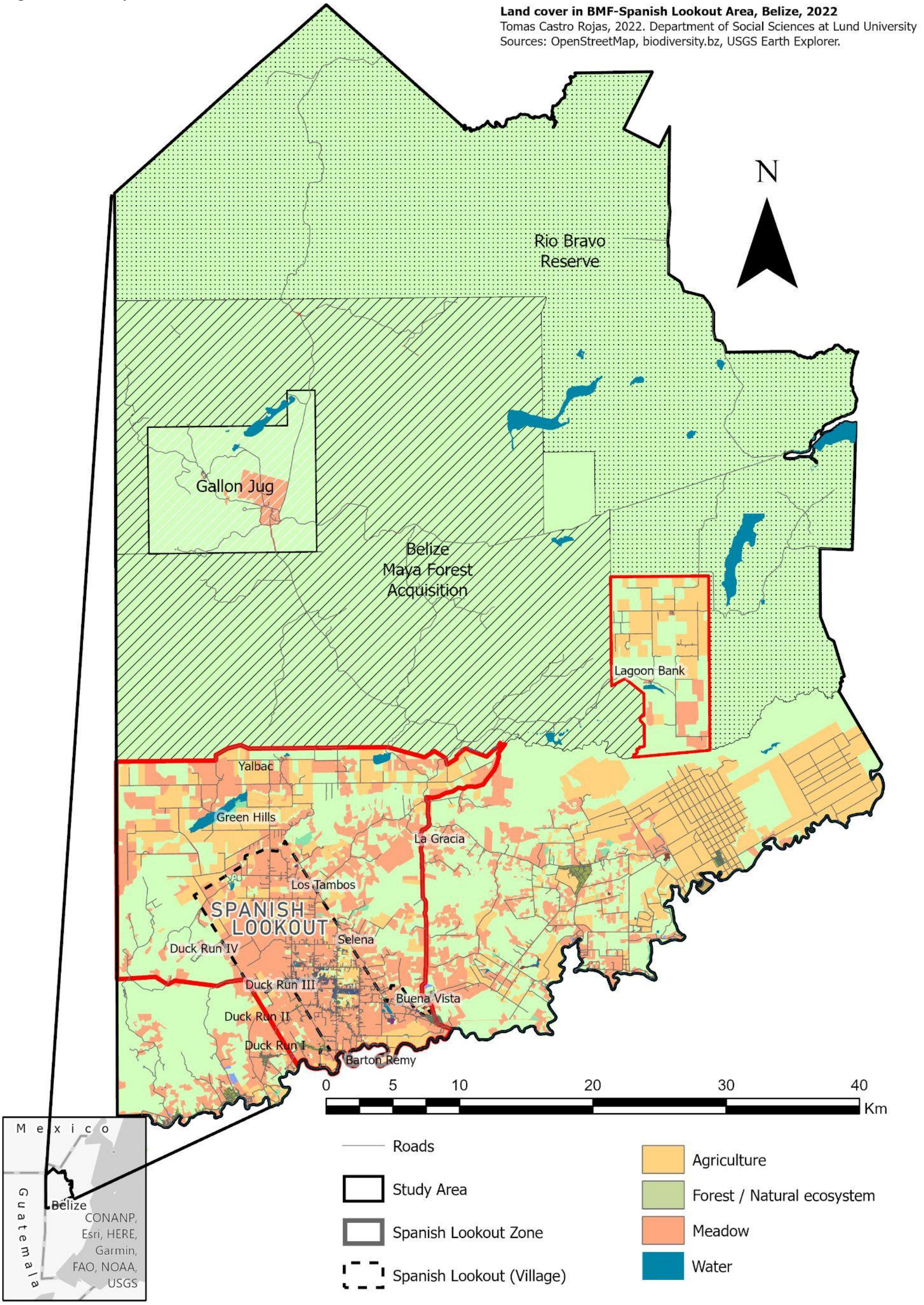
8. Analysis

a. Study Area

This research is focused on the area of Spanish Lookout and the BMF reserve in the northwestern region of Belize. The area of the BMF comprises a total of approximately 96,000 hectares, while the Spanish Lookout area comprises approximately 51,227 hectares. There are no official documents that outline the official boundaries of the Spanish Lookout area, so the outline of the area had to rely on open-source data from OpenStreetMap. The official boundaries, therefore, might differ from this outline. The boundaries of each village within the Spanish Lookout area could not be outlined for this same reason. In addition, while this analysis is focused on the area of Spanish Lookout and the BMF, the map projection below displays all the land north of the Belize river and the area surrounding the BMF reserve. The projection includes, therefore, nearby farming areas to the east of Spanish Lookout (largely owned by the Santander Sugar Group), as well the RBCMA (as it is part of the same contiguous forest area as the BMF). This was done in order to display how the extent of agricultural expansion is not limited to large agricultural-based communities like Spanish Lookout, but rather the overall trend of expanding deforestation frontiers caused by agricultural expansion is a nation-wide phenomenon.

As it is evident from the map projection, the large majority of the area within Spanish Lookout is allocated as ‘meadow’ primarily for livestock husbandry.

Figure 8: Study area



b. LULUCF

i. Land use/land cover change 2000-2020

The remote sensing analysis revealed a substantial change in the land cover scene over the 20-year period. The RF classifier was executed successfully, although the validation data indicated that there was a significant level of misclassification between the 'agriculture' and 'forest degradation' land cover classes. This was expected since degraded forests eventually become agricultural plots (also noted by Doyle *et al.*, 2021). Furthermore, from landsat imagery, some crop plantations (such as fruit trees) can visually resemble forests, and sugarcane plantations east of the Spanish Lookout area were partially classified as savannas for the same reason.

What is important to note is the expansion of agricultural land and the receding areas of tropical forest and other natural ecosystems. Land cover change has been primarily driven by agricultural land (See: Figure 9). This landscape transformation can be attributed to numerous factors, but perhaps the most influential one is the growth of industrial-scale agriculture in the area. From the Spanish Lookout area, numerous farms currently located in newly-deforested areas are farms over 50 hectares. Another contributing factor is population growth. Although rural-specific population data could not be obtained (where most of the land use/cover change is taking place), census reports (SIB, 2010) reveal that Cayo district has experienced the largest population increase in the country at 38.5%, from 54,197 in 2000 to 75,046 in 2010[5]. This increase in rural population growth combined with a low governmental oversight of PAs could have an escalated detrimental effect in PAs and surrounding areas (See: Land Conservation section).

The most visible tradeoff in the agriculture-conservation nexus from the remote sensing analysis is the zero-sum game outlined earlier—loss of natural ecosystems for gain in agricultural land. The expansion of agricultural land has been characterized mainly by an increase in cash crops/livestock production (See: Agricultural production).

ii. Agricultural expansion

Once surrounded by forest, the BMF reserve along with the adjacent RBCMA are slowly resembling an island of forest in the land-sparing mode of land management (See: Doyle *et*

[5] SIB data from the 2020 census data was not available

al., 2021). This has significantly decreased the habitat extent of wide-ranging species such as the puma and the jaguar that have been documented in the area (See: Land Conservation section). Furthermore, the increased expansion of agricultural land is starting to meet its boundaries, which will hinder the type of agriculture practiced within the Spanish Lookout community.

Overall, the remote sensing analysis suggests that the forests in BMF reserve have experienced no significant land degradation from 2000-2020. However, the PA status of the BMF is still very young and further efforts to supervise land use changes will be important moving forward, especially now that the agriculture-conservation frontier meets face-to-face. PAs often rely on high management oversight and are often vulnerable to shocks that increase drivers for agricultural expansion.

Figure 9: Land use/land cover change Spanish Lookout Area and BMF reserve (1999-2021)

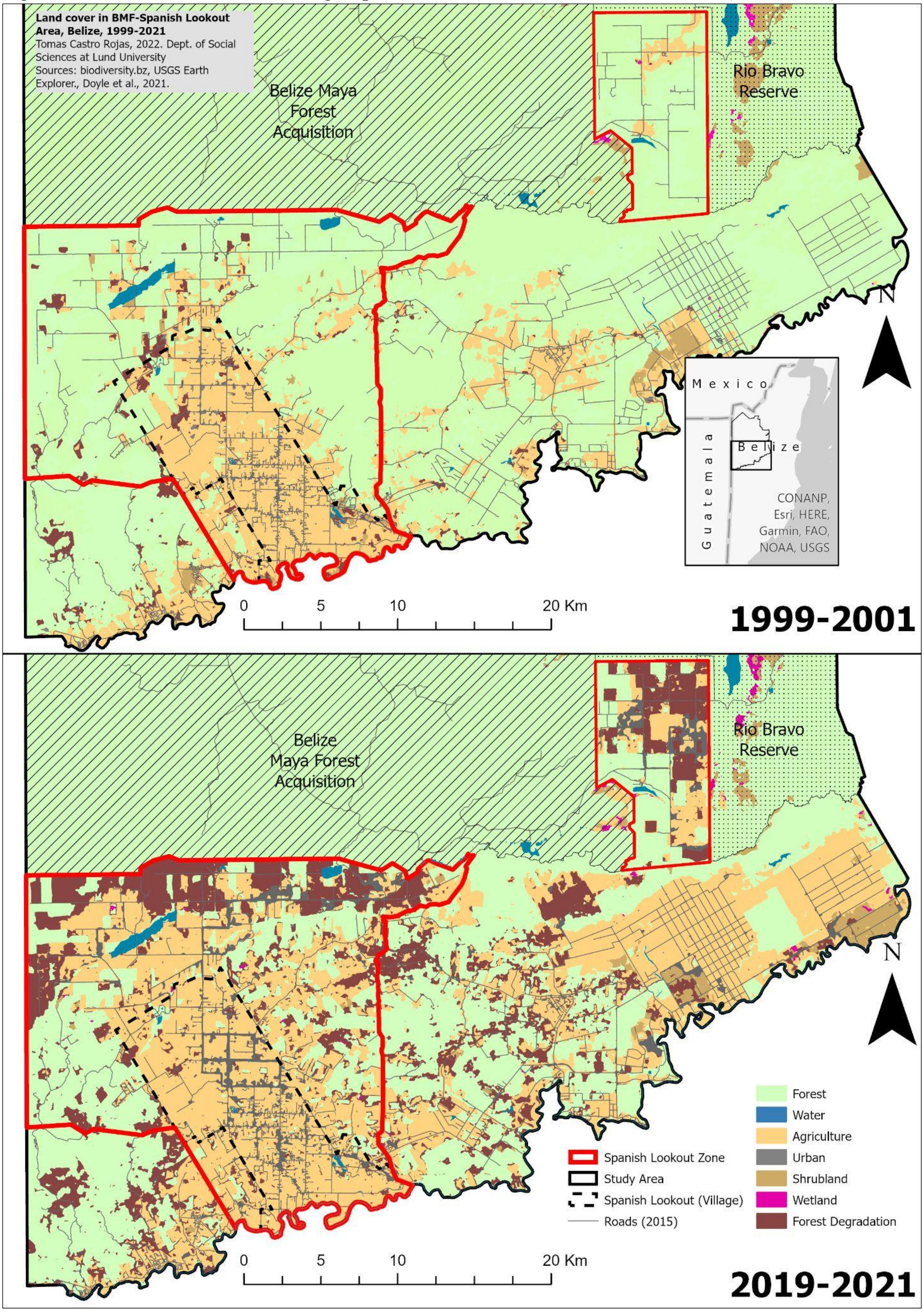
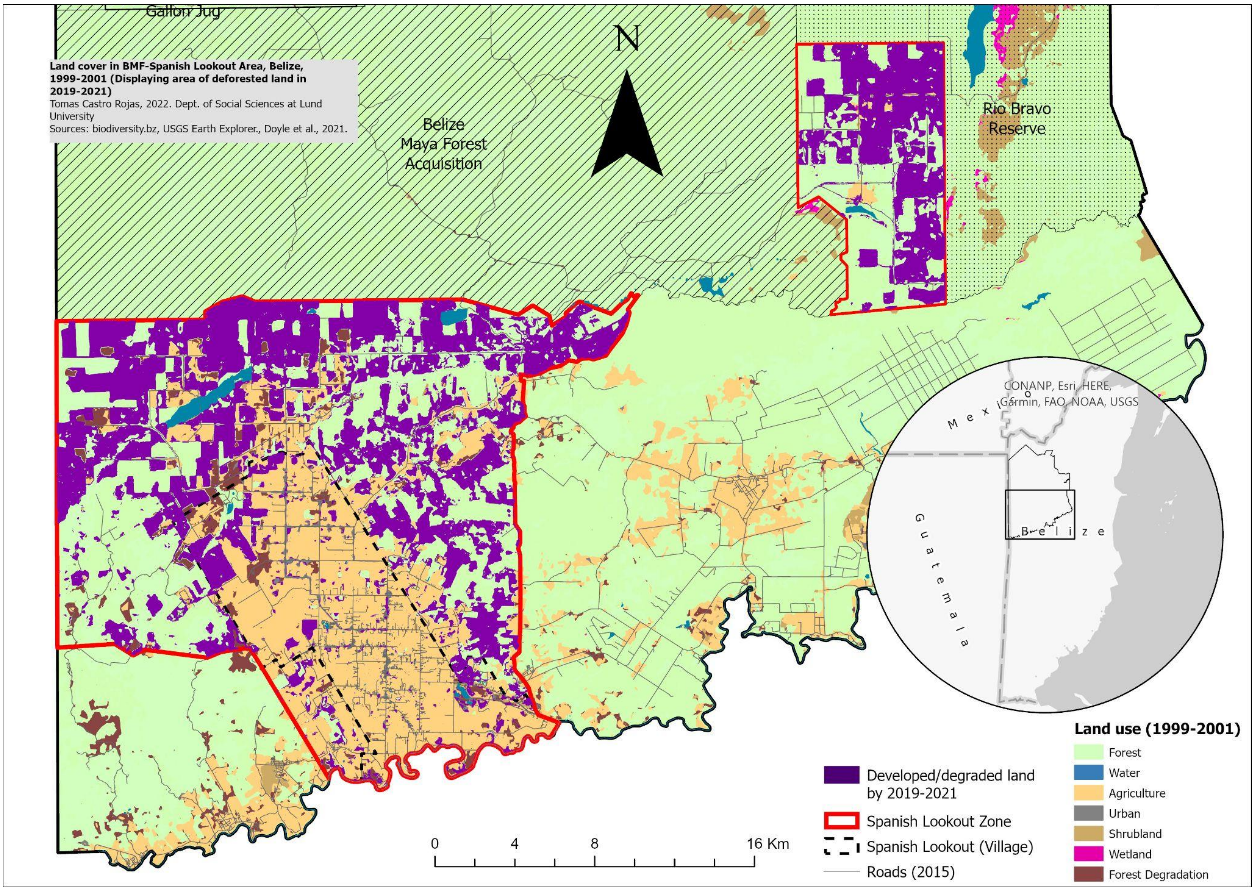


Figure 10: 1999-2001 land use map displaying deforested areas by 2019-2021 within the Spanish Lookout Zone.



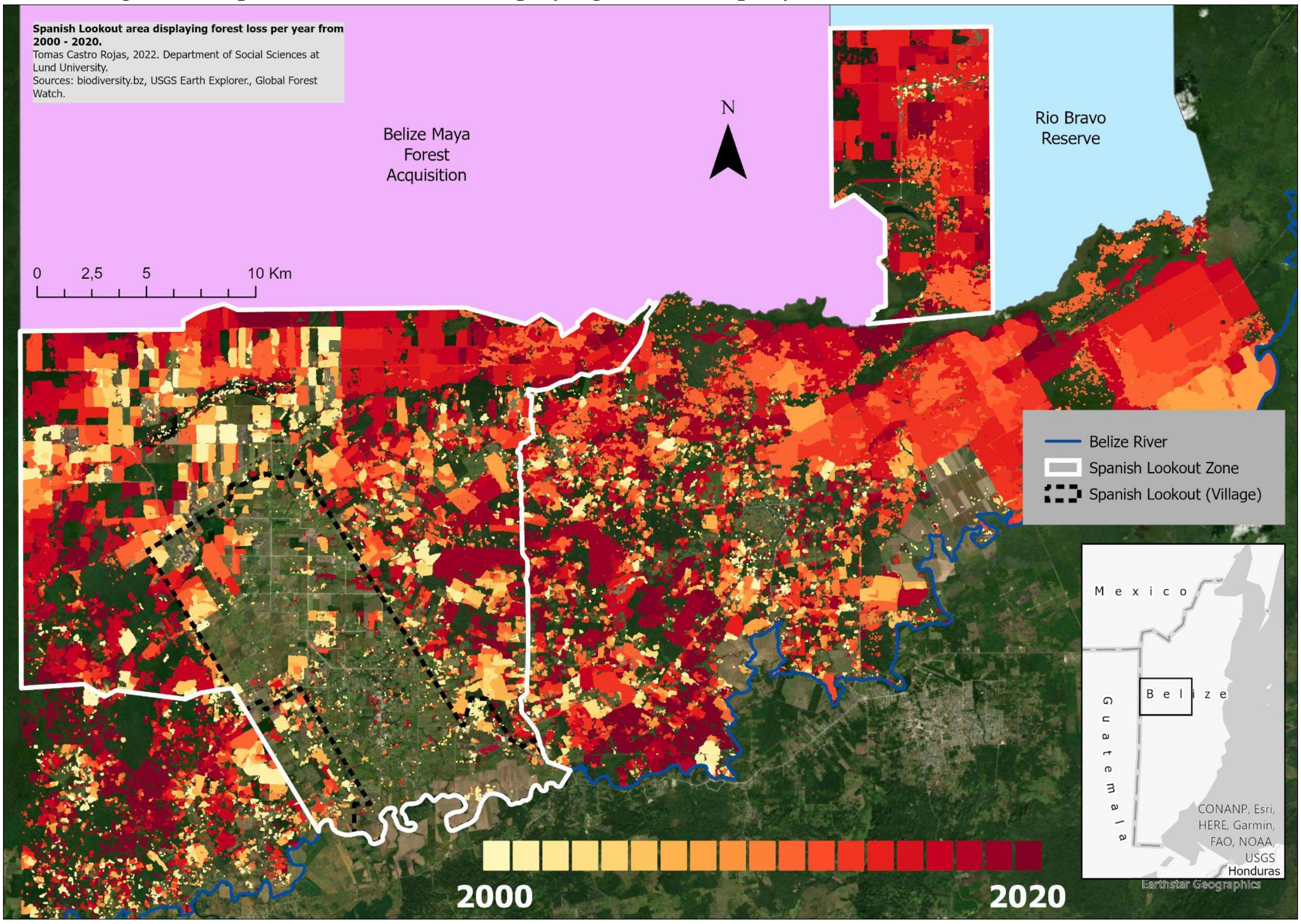
iii. Forest loss

Regional forest loss analyses such as the ones conducted by Global Forest Watch (GFW) are important to determine deforestation and forest degradation rates across large regional areas. However, they are more likely to have a larger percent error due to wider variation between different landscapes. This is evident in the high level of noise[6] contamination in the dataset, which can be due to a high cloud coverage in the landsat image (See: Figure 11). This dataset demonstrates why the use of localized training data is important for local remote sensing analyses. If the GFW dataset were to be used to quantify the local deforestation for such a small area like Spanish Lookout, it would overestimate the area.

This dataset was used to demonstrate the yearly expansion on the deforestation frontiers in the area of Spanish Lookout. As shown in Figure 11, deforestation started relatively low in the early 2000s and then intensified quickly into the BMF boundaries in recent years.

[6] Random variations in sensor output

Figure 11: Spanish Lookout area displaying forest loss per year from 2000 to 2020



Source of Dataset: Globalforestwatch.org, 2022

c. Agricultural production

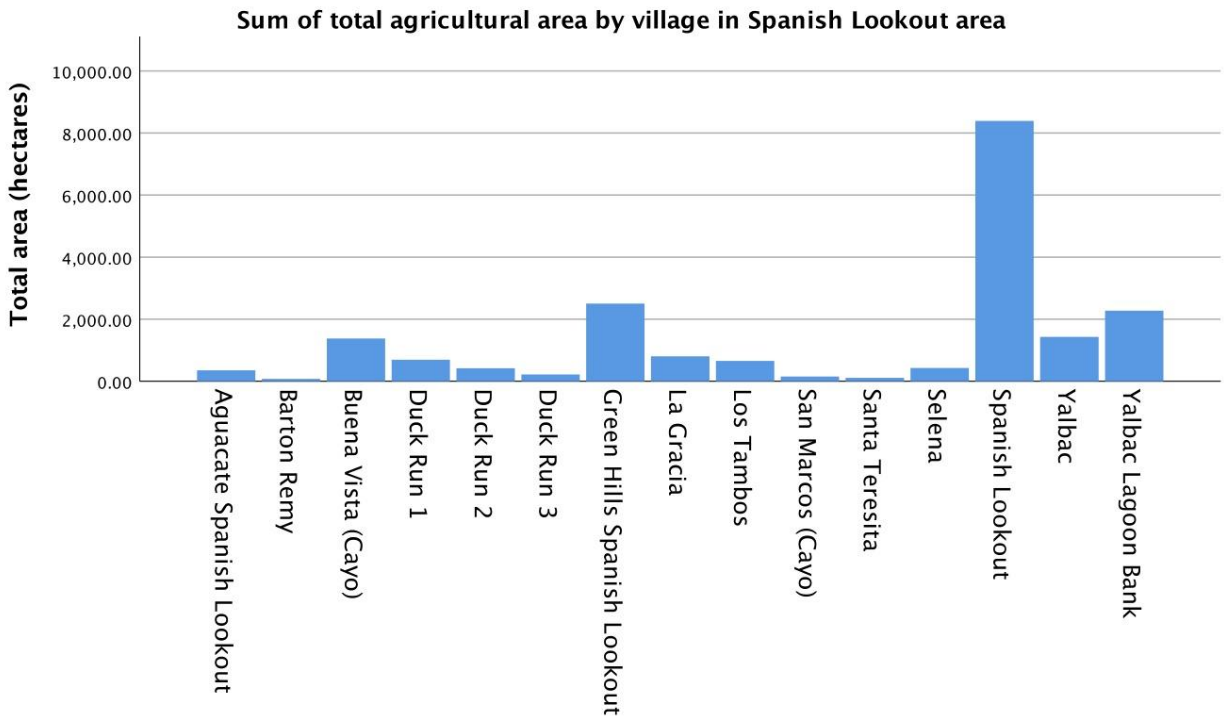
i. Land distribution

The entire area of Spanish Lookout includes 15 villages and 640 registered farms. The total amount of farmed land in 2018 was 19,878.53 hectares. Most of the agricultural land is concentrated within the Spanish Lookout village (as it is the oldest settlement in the area), while other villages[7] have appeared as agricultural land has expanded. The type of agricultural production in the area differs relatively to other areas in Belize, as production is mainly focused on livestock (mainly cattle and poultry) and grains (mainly yellow corn). The large production of corn is mainly due to the large commercial broiler operations of the Mennonite community in the Spanish Lookout. Export products, such as citrus or bananas are seldomly produced.

[7] While they are categorized as 'villages' in the agricultural census, many of them have little or no settlements.

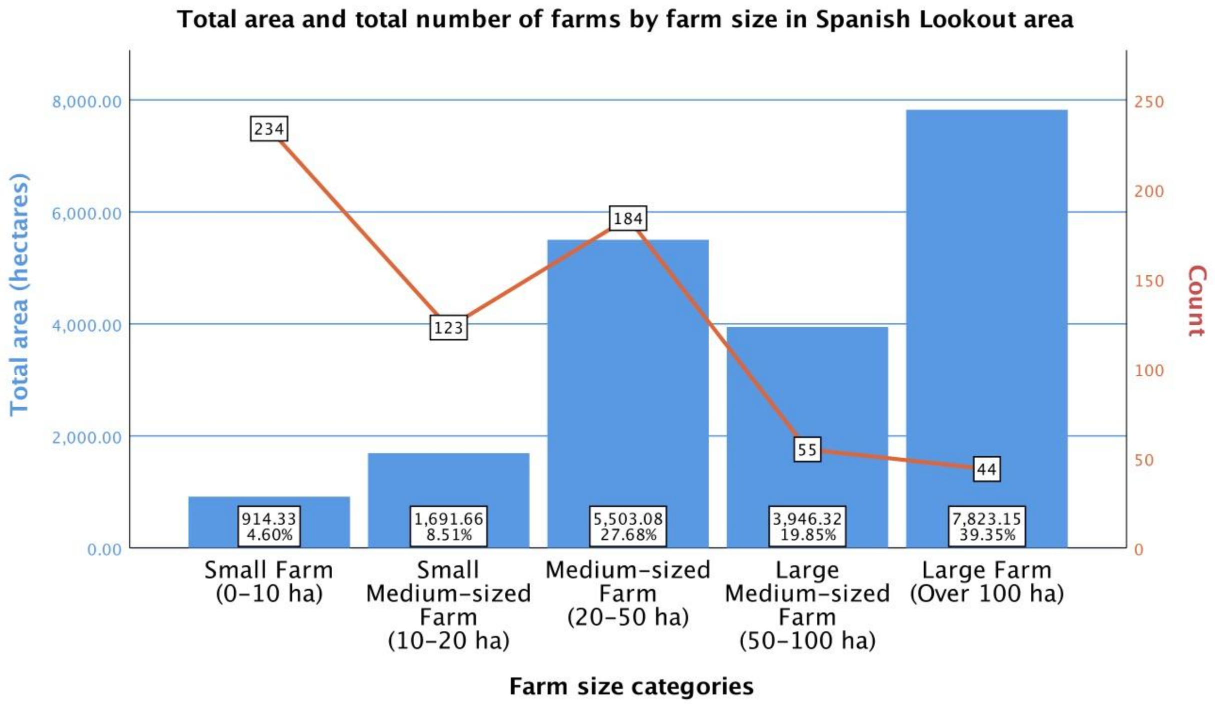
The total number of farms are seemingly evenly distributed according to farm area within each village, however, upon closer examination there is a large divide in land tenure between large and small farms. Larger farms account for the vast majority of agricultural land in the area, but they account for a small minority of farms, while small-scale farms account for the majority of farms, but amounting for the minority of agricultural land (See: Figure 13).

Figure 12: Agricultural area by village in Spanish Lookout area



Source: MAF, 2018

Figure 13: Total area and total number of farms by farm size

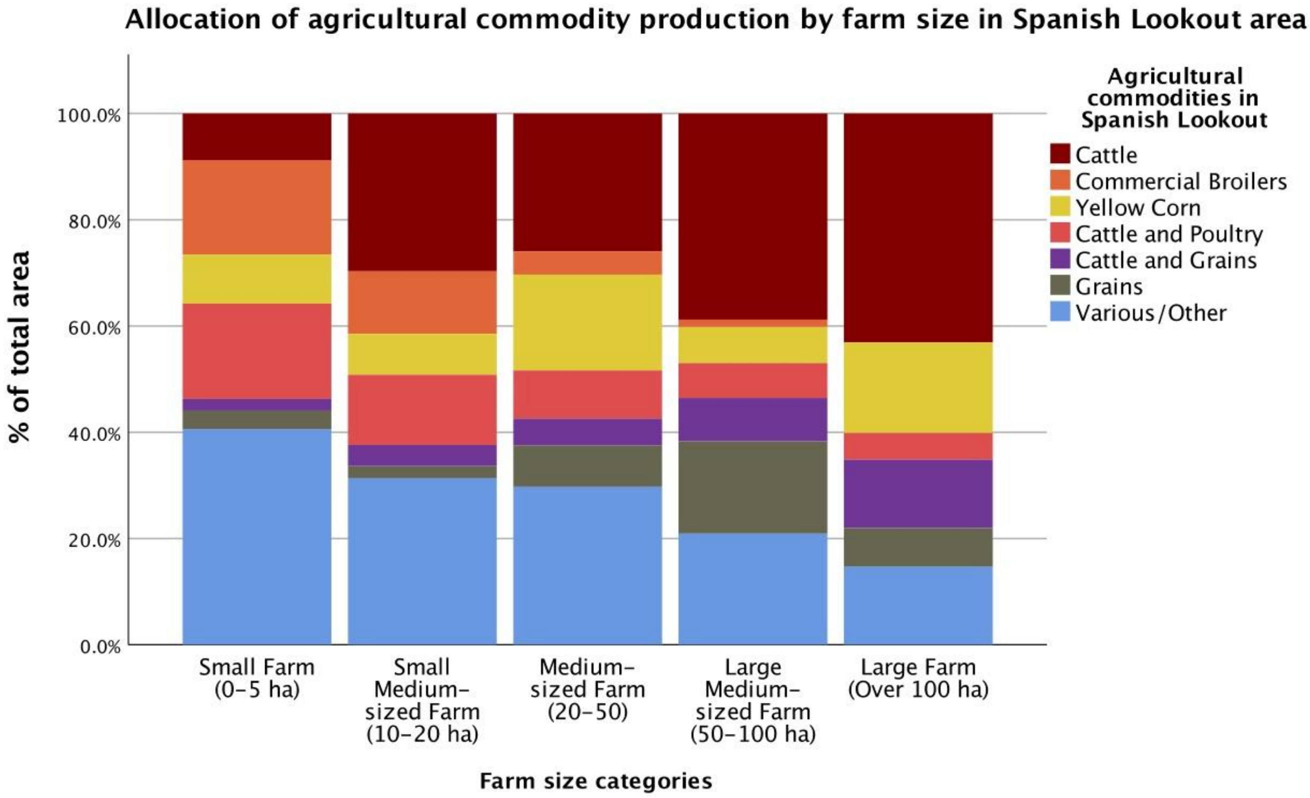


Source: MAF, 2018
Note: Count refers to number of farms

ii. Commodity production assessment

Agricultural production in the area of Spanish Lookout is highly specialized in 3 main commodities: cattle, poultry, and grains—named *cash crops* hereafter. A total of 6 categories were created for them as they are produced in different combinations or independently depending on each farm arrangement. In terms of total area, cash crops comprise 15,367.37 hectares and 77.3% of the total agricultural area in the Spanish Lookout area. The remaining 4,511.16 hectares (22.7%) comprise a combination of various traditional crops such as cantaloupe, habanero peppers, cabbage, root vegetables (e.g. cassava, potatoes, carrots etc.), among many others. These farms often produce numerous crops on their plots, and while they may also have cash crops (e.g. cattle, or poultry) on their property, it is not their sole production output. Such diversified production, such as *Milpa* systems, have been evidenced to adapt and mitigate climate fluctuations.

Figure 14: Agricultural commodity production by farm size



Source: MAF, 2018
*cattle includes dairy cattle

Approximately 40% of the agricultural land of small-scale farmers is allocated to a diverse mix of crops, while the remaining 60% is a combination of cash crops with a large focus on production of commercial broilers (poultry) independently or in combination with cattle. With an increase of a farm's area, there is a decrease in the cultivation of various/diverse crops and an increase in cash crop production—especially cattle. Cattle comprises over 40% of total agricultural land in large farms (if produced by itself) and over 60% (if produced alongside other cash crops).

Cattle, as a land-extensive commodity (under industrial production), requires large tracts of land that depend on regular expansion if production is to be increased (due to a low heads/hectare ratio). Soils in cleared tropical forests are typically of low quality (See: Table 3), and therefore can only sustain a few animals per hectare under extensive industrial agricultural systems (McAlpine *et al.*, 2009). However, the reason why expansion and deforestation for such systems continue is because lands in such tropical environments are often inexpensive and therefore can prove profitable although they are not highly productive systems (Bowman *et al.*, 2012; McAlpine *et al.*, 2009).

As noted earlier, the production of livestock has been increasing in Belize (MAF, 2021), but mainly under industrial/extensive agricultural systems, which are unproductive and can be conducive to a larger environmental impact (See: Boucher *et al.*, 2012). However, the Agricultural census of 2018 and the district-specific agricultural data from MAF did not contain any data relating to cattle stocking rates per farm. This points out to a weakness in agricultural data reporting, and limits the capacity for more in-depth analysis in this area.

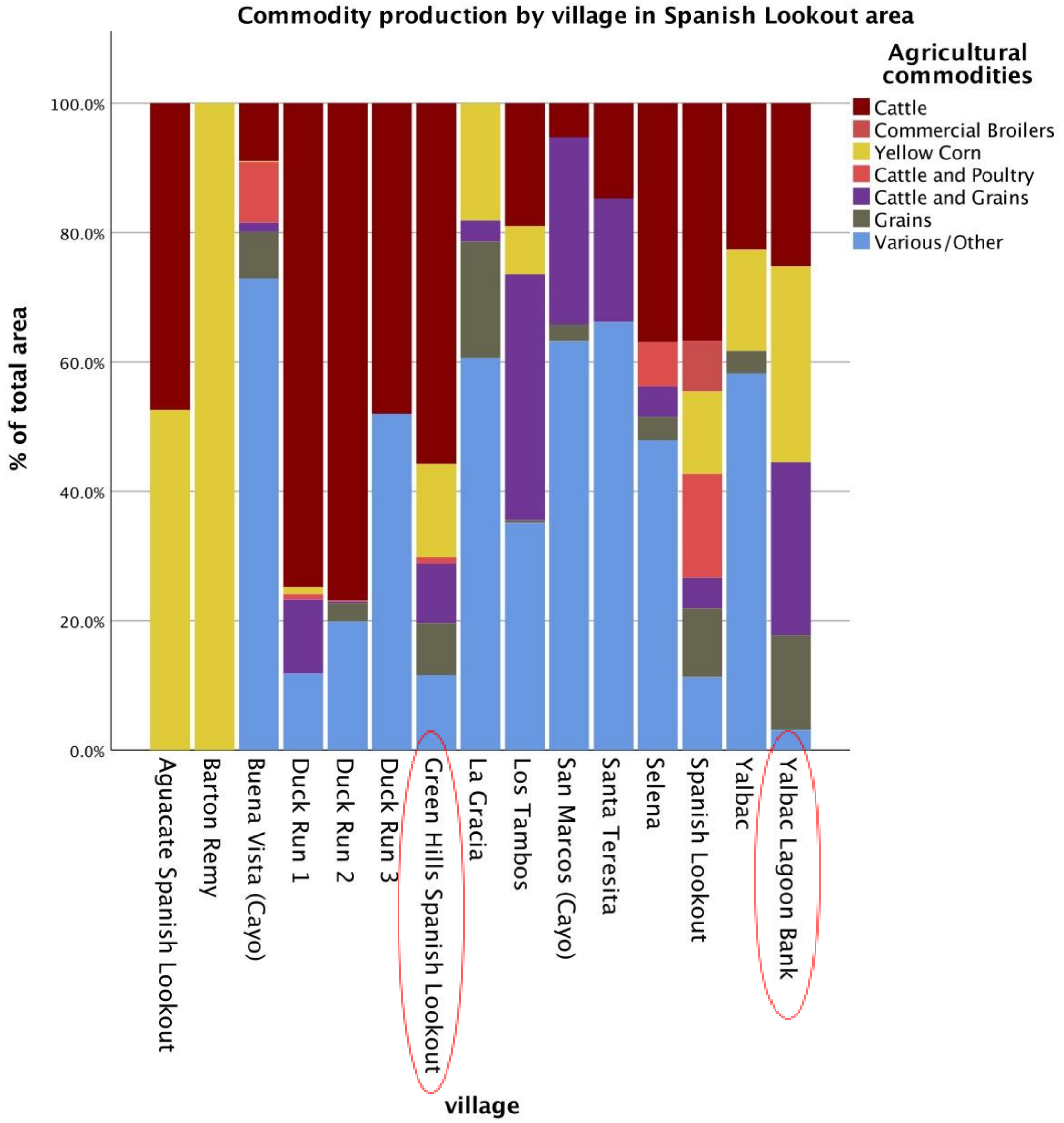
1. Village production

An important assessment from a village-specific analysis is examining which commodities are produced in each respective area. By assessing the commodity production by village, a wider image emerges. The data suggests that several villages are specialized in certain commodities. For instance, Barton Remy is a village that has 100% of its agricultural land under yellow corn production and Aguacate produces only two commodities: cattle and yellow corn. The villages of Duck Run 1 and 2 are highly cattle intensive.

The villages of Green Hills and Yalbac Lagoon Bank constitute an important case study as they represent the 'villages' that were created with the expansion of agricultural area in the last 20 years[8]. Aside from Barton Remy and Aguacate, Lagoon Bank and Green Hills are the villages with the highest percentage of cash crop production and lowest percentage for diverse/various crops. This implies that a large proportion of the land that has been cleared in the previous two decades has been to expand cash crop production (mainly by large-scale farms) rather than a diverse production of various crops. This suggests an important tradeoff within the agriculture sector in the case of Spanish Lookout: the expansion of cash crop production at the expense of diverse and varied production.

[8] Although other villages fit in this category, they are located in areas where agriculture was already taking place in the 1999-2000 period. Green Hills and Lagoon Bank represent areas that were mostly forested in the early 2000s and now have been vastly cleared for agriculture.

Figure 15: Commodity production by village in Spanish Lookout area



Source: MAF, 2018

As aforementioned, the major concerns with this type of agricultural development relate to its vulnerability to disturbances, and high environmental costs. With increased extreme-weather events, the production of industrial agriculture can disrupt production patterns (see: Temporal analysis), and with global market fluctuations (from global disturbances such as the COVID-19 pandemic), the prices of agricultural inputs (e.g. pesticides and fertilizers) have increased (Strauss, 2022)—which can heavily impact the stability on industrial farms due to their dependence on such inputs.

Important issues from the Belize agricultural sector are evident in the case of the Spanish Lookout area. An important issue is the low rate of land utilization—as noted earlier. The causes of this are varied and they range from high expense of converting the land to lack of secure markets. The Spanish Lookout area appears to follow the national trend, as the remote sensing analysis reveals a much larger amount of land cleared (non-forest) (31,753.68 ha), than the amount of land registered for farming (19,878.53 ha). A potential cause for the high level of underutilized land and a high degree of agricultural expansion can be due to a loss of productivity in farmed lands under industrial systems (See: Balogh, 2021), although an in-depth analysis for this would be required in order to support this. Studies in tropical regions, nonetheless, have indicated that input-intensive arrangements (characterized by a high use of synthetic fertilizers, pesticides, etc.) can cause a decrease in soil carbon levels over time (Ontl & Schulte, 2012), and thus necessitating consecutive land clearings in order to maintain production. Although this is in a localized context, it has been recognized that conventional/industrial agriculture will not be able to feed a growing global population (sustainably) due to its destructive capacity on its natural resource base (FAO, 2021), which hinders its own ability to progress. This is clearly evidenced in the case of Spanish Lookout, as the remote sensing analysis clearly demonstrates that the agricultural expansion will not be able to continue as it has been met with transnational boundaries (Guatemala) and legally protected boundaries (the BMF). This clearly suggests that in order for agricultural production to continue, it will have to integrate and restore degraded/underutilized lands, and find alternative ways of production that are not only resilient to climate/market shocks, but also integrate the potential of ecosystem services to stabilize and maintain production yields (See: Figure 18).

iii. Temporal analysis: Cayo district production

1. Case study: corn production

Corn was selected as a case study for it represents both a cash crop and a traditional crop in the region, and therefore it is farmed by *Milpa* farmers and industrial farmers alike. Corn production in the district has increased by 388.85% from 2000 to 2021 (MAF, 2021). It is important to note that this extensive growth in production has had positive socioeconomic implications on the Belizean economy. For one part, corn constitutes a staple crop in the region, and its consumption has been key in the regional diet for millenia (Anderson, 2017). Secondly, the growth in corn production has been propelled by the growth in the poultry sector, which has made Belize in a large part independent from expensive chicken meat exports (Roessingh & Boersma, 2011).

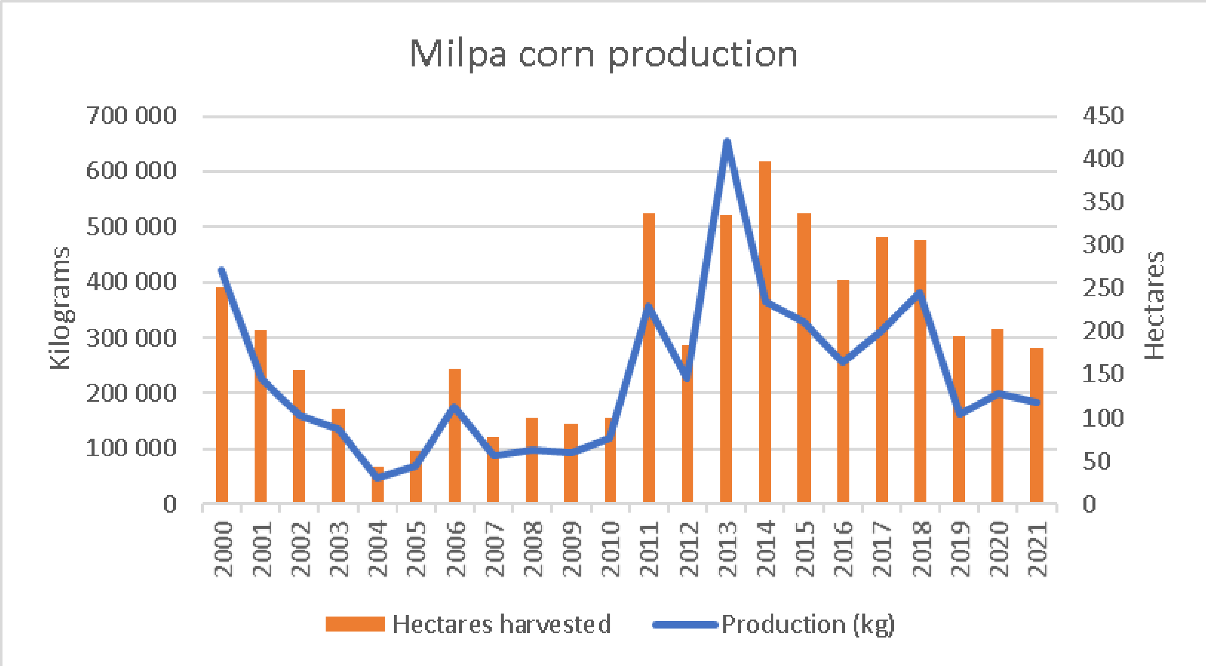
Industrial corn production has increased its output by 401.15% in the last 20 years. By doing so, however, they have also increased their land use by 164.53% expanding into 11,569 hectares of land by 2021.

On the other hand, *Milpa* corn production is largely variable in terms of output and land use. Their overall output is significantly lower than industrial production, but they produce only in a fraction of the land used by industrial farms. Their variable use in land is mainly due to their crop-rotation systems that allow fallow land to regenerate. Furthermore, they produce various and diverse crops in the same plots of land, which could explain their lower amount in production for a single crop.

An important assessment in agricultural production is yield. Comparing the yield between *Milpa* and industrial production displays a wider image about the two forms of production. While the yield is considerably lower in *Milpa* production, it is in a large part stable. Overall, it has maintained its production around 1000 kg of corn per hectare. On the other hand, industrial production—although it increased its yield over the previous two decades—it remains highly volatile. Its yield decreased by half only over the course of two years from 2014-2016, and then it followed a similar decline from 2018-2019.

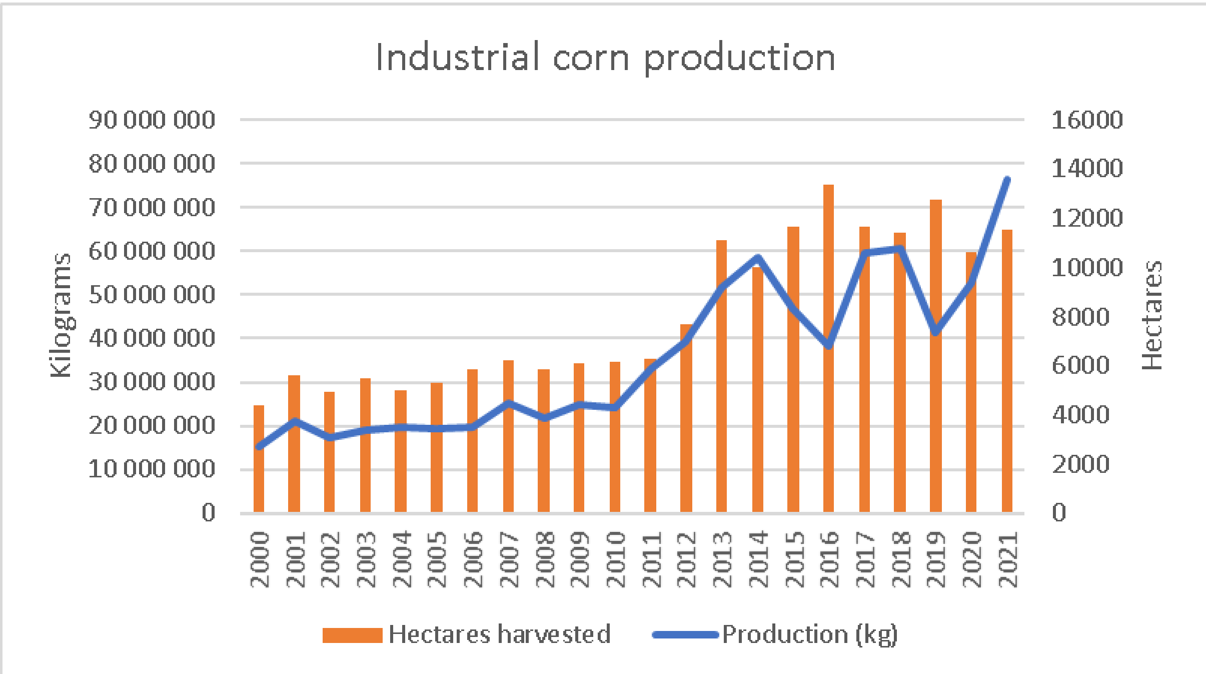
Finally, taking into account the remote sensing analysis and the agricultural production analysis in Spanish Lookout, an important question arises; Do the negative effects of agricultural expansion represent an acceptable trade-off to improve the food security prospects? This question encapsulates the issue of the tradeoffs in agriculture-conservation conflict. Agriculture has expanded greatly in Spanish Lookout, which has moved forward its economy—as well as benefited food prospects in the country (Roessingh & Boersma, 2011). However, the same trends will not be able to continue due to land-expansion constraints.

Figure 16: *Milpa* corn production statistics displaying total output per year in kilograms and total area used in hectares



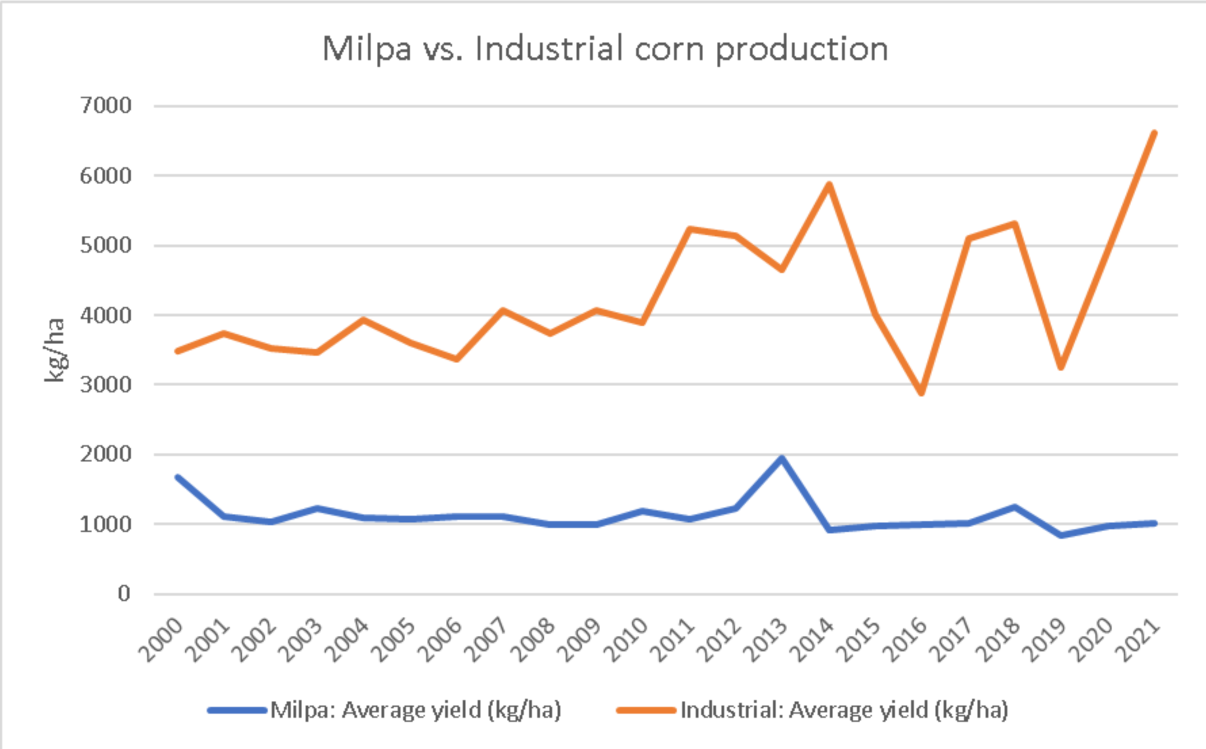
Source: MAF, 2021

Figure 17: Industrial corn production statistics displaying total output per year in kilograms and total area used in hectares



Source: MAF, 2021

Figure 18: *Milpa* vs. Industrial corn production

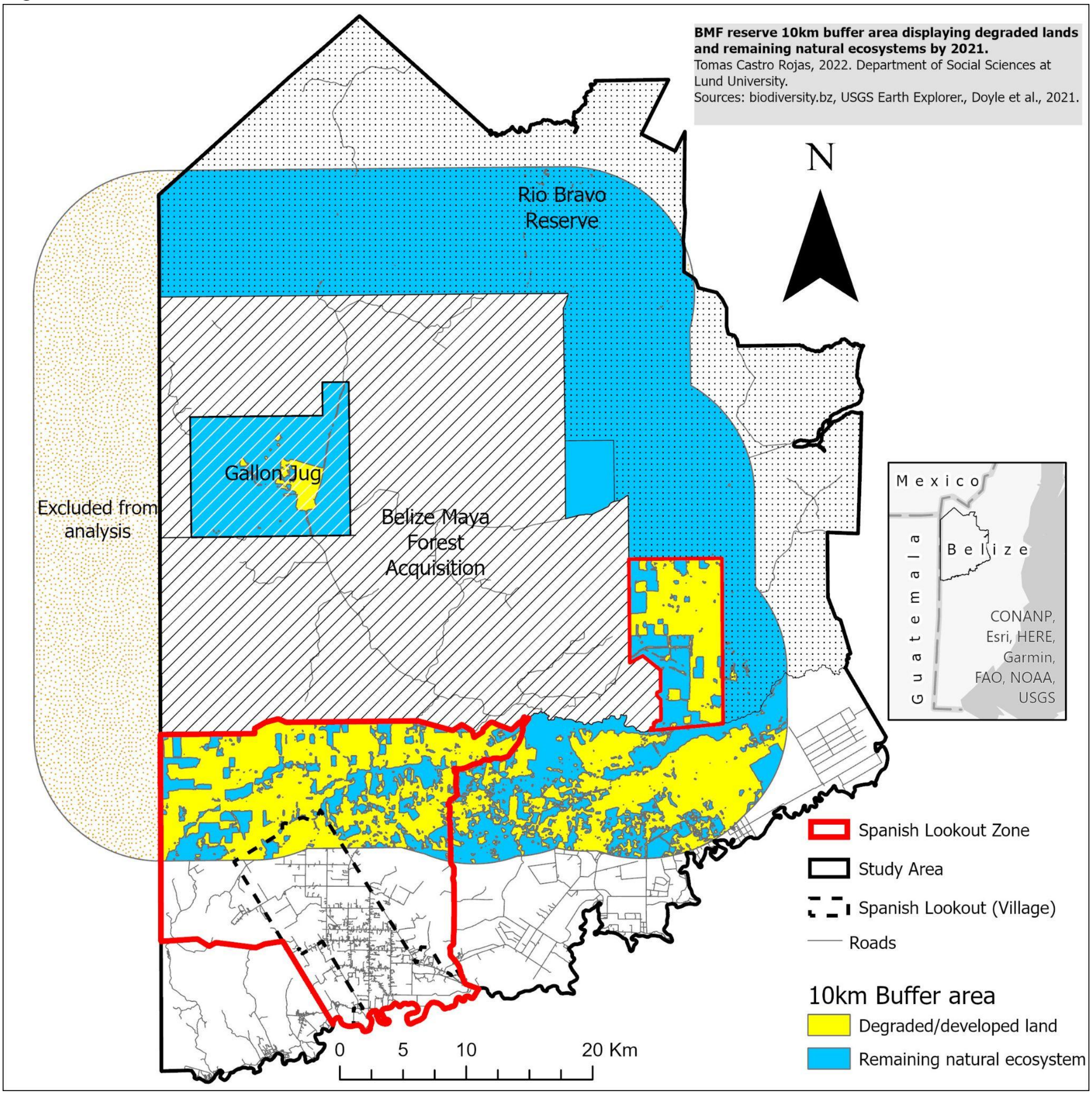


Source: MAF, 2021

d. Land conservation

i. BMF reserve buffer

Figure 19: BMF 10km buffer area



The vast majority of the forested area within the BMF reserve remains intact—aside from the impact from selective logging operations from the Forestland Group (which was not significantly captured by the remote sensing analysis).

The outer 10 km buffer area around the BMF has a variable level of impact. The northern and northeastern buffer areas have been vastly protected by the RBMCA, which acts as a protective cushion in those areas—although it is important to note that the RBMCA has also experienced deforestation along its own buffer area (See: Doyle *et al.*, 2021). The south and southeastern buffer areas represent lands without any form of formal protection and therefore vulnerable to deforestation. The buffer area to the west of the BMF was excluded from the analysis for it represents Guatemalan territory and lies outside of the study area. This type of analysis relates to the studies conducted by Spracklen *et al.* (2015), which assess the spillover effect of PAs. It is difficult to determine whether there is a degree of spillover from this case study, as an in-depth analysis of deforestation and land degradation from the entire region would be required. Furthermore, the BMF reserve lies along the border with Guatemala, which entails that deforestation rates on the other side of the border would be mandated by different socioeconomic factors and implications from Belize. For instance, there have been reports of Guatemalan migrants encroaching into Belizean PAs for illegal logging and poaching (Ramirez *et al.*, 2013), which differs from the effect of agricultural expansion from Spanish Lookout.

ii. Case study: Biodiversity studies (See: Appendix)

The biodiversity studies conducted in the area have been crucial for documenting biodiversity richness within the BMF (as well as the RBCMA).

From previous studies in the region, it has been noted that anthropogenic activities are manifested to have an effect on biodiversity within PAs (Whitacre, 1998). This has been inferred from a recent report, which documented an increase in jaguar in the Gallon Jug farm in 2019 (Kelly & Nipko, 2022). It is suggested that this trend could be due to the increased land-clearings to the south of the BMF (ibid.)—although this is not yet certain. Above all, predators are key determinants for the adequacy of conservation efforts, for they are often the first species to disappear when landscape alterations occur (Whitacre, 1998). However, occupancy rates have not yet been assessed from the biodiversity data in the BMF, which is essential data to determine whether the deforestation that has occurred in previous years have or is affecting species' ranges within the region.

Notwithstanding, while the occupancy rates were not available, the biodiversity data from the latest report (Kelly & Nipko, 2022) was used to determine the extent of the biodiversity endangered status as well as to gain insights into the habitat range and vulnerability of changing landscapes for each species (See: Appendix). This data, however, can only be a preliminary analysis for what current agricultural expansion might mean for different species. Only once occupancy rates have been assessed, more in-depth statistical and spatial analysis can be integrated in order to properly analyze the impacts of deforestation and agricultural expansion on the species documented over the previous years.

9. Limitations

This research was initially planned alongside a 10-week internship with The Nature Conservancy (TNC) Belize. However, due to the COVID-19 pandemic, the internship was canceled and the research design had to adapt to a new scenario. This heavily limited access to raw data, as well as interaction with local farmers, NGOs, governmental institutions, etc.

a. Data

i. Statistics

- Many of the statistical databases are not in the public domain and could not be accessed.
- Databases acquired were dependent on (email/phone) contact to several governmental ministries (i.e. MAF), as well as experts in the field.
  - Some governmental ministries did not grant access to statistical data. For instance, SIB did not grant access to the 2022, 2010 census data.
- Data from agriculture-based communities (such as the Mennonite community in Spanish Lookout) is limited in Belize and often outdated. Agriculture statistics is a reliable source, but they are often not in the public domain. For instance, access to the 2018 agricultural census was granted by MAF, but not to previous census or farm registries, which limited the agricultural production analysis, as it made a temporal analysis virtually impossible.
- In order to get some insights into socioeconomic and demographic construction of the Spanish Lookout Area, a request for microdata access was sent to SIB, but access to the dataset was not granted.
- There is missing data within the district/national agricultural production dataset from MAF.

- The 2018 Agricultural census does not specify the amount of land allocated for each crop on each farm registered (on farms that produce more than one crop). For instance, while the dataset shows that a farmer grows yellow corn, Red Kidney beans, and watermelon in 2 hectares of land, there is no data showing the distribution of land for each of the three crops produced. This can lead to wrong assumptions and projections about crop productions in the area.
- Occupancy rates for several species captured within the BMF reserve were not yet assessed from the biodiversity data from 2014-2019. This data can be vital to conduct more in-depth biodiversity analyses in the area.

ii. Spatial Data

- As aforementioned, readily-accessible spatial data in Belize is limited and what is accessible is often out of date or incomplete.
- There is no comprehensible map for the Spanish Lookout zone, therefore reliant on external sources for a manual outline of the area and villages.
- No comprehensible database for LULUC of the research area—dependent on supervised land use classification with ArcGIS Pro from Landsat 4,5,7,8 data from the USGS Earth Explorer database.

10. Discussion

The issue of how to best manage heterogeneous landscapes remains a global challenge (Macchi *et al*., 2020). These are exemplified by agricultural deforestation frontiers across South America, Central America and the Caribbean that represent a current challenge for the environmental conservation of tropical forests and preservation of local agriculture-based communities. Various schemes, such as the establishment of PAs are beneficial for environmental resources, but they often fail to address important socioeconomic implications for local communities. Thus, data analyses of these conflicts are pivotal in the establishment of socio-environmental compromises.

While Belize has succeeded in protecting large tracts of land within its national territory, the socioeconomic transformations in the last 70 years (from the logging period) has changed not only the structure of its economy, but the drivers for land and resource management—thus necessitating a change in the way that land resources are protected and managed. With changing landscapes, tradeoff analyses become increasingly important—especially in tropical deforestation frontiers, since they harbor biodiversity and many vital ecosystem services, as well as socioeconomic value for agricultural development. From this analysis it is revealed that agricultural development in Belize poses a serious threat to non-protected areas and more importantly an increased pressure on areas that are established as forest reserves, such as the BMF. Furthermore, the remote sensing analysis along with the agricultural statistical data suggests that the expansion of agriculture in the area of Spanish Lookout is mainly caused by the growth of industrial-scale farming in the area. Farms located in newly deforested areas are mainly over 50 hectares, and produce mainly cash crops.

In addition, underutilized farmland remains a national challenge, as revealed by a large increase in degraded lands in the remote sensing analysis in the area of Spanish Lookout. But to understand this issue further, as well as the drivers for agricultural expansion, the Belizean agricultural census has to improve (Martin & Manzano, 2010). This can greatly aid the development of further research and practices within the science-policy nexus (Leclère *et al.*, 2020). Furthermore, with increased climate variability causing damaged crops and global shocks (such the COVID pandemic) causing increased prices in agricultural inputs, the agricultural sector will have to accommodate and mitigate these increased risks in order to maintain its structure. Recent studies highlight that the impacts of climate change pose a significant threat to the Belizean agriculture sector (Richardson, 2009) and "will impact the production, infrastructure, ways of life, health and safety of the population, and will also weaken the environment's capacity to provide vital resources and services (Ordaz Dias *et al.*, 2013, p. 5).

In light of these trends, "governments are faced with multiple and overlapping challenges, including improving livelihoods, tackling climate change, mitigating biodiversity loss and addressing food insecurity, shortages and waste" (OECD, 2020, p. 18). The issue of agricultural expansion and land conservation is a prime example of this complex issue, as they represent intertwined (and often conflicting) social, environmental and economic implications. Overall, land-cover change and land management are directly related to several SDGs, such as ending hunger, clean water, clean energy, climate action, and life on land (*ibid.*)—not to mention other interrelated SDGs, as well as meeting climate goals set by international agreements, such as the UNFCCC's Paris Agreement, and the CBD.

The good news is that EbAs in agriculture have been proven to reduce tradeoffs by minimizing impacts on the environment, its resources and on people, while maintaining productivity (Colls *et al*., 2009). These production systems are also more resilient to harsh climate events, making produce and local communities less vulnerable while regenerating the resources needed to support agriculture (Pharo *et al.*, 2019; Leclère *et al.*, 2020). These integrated conservation and agricultural production solutions, therefore, can mitigate their conflict. An issue moving forward is scaling them through right policies, market access, technology, finance, and capacity. The GoB can lead the way in scaling up the right agricultural systems that reduce tradeoffs, protect biodiversity and maintain agricultural productivity.

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Appendix

Table 4: Species documented in camera traps inside the BMF reserve (includes Gallon Jug, Laguna Seca and Yalbac*) between 2013-2019.

Species	**Scientific name**	**IUCN Classification**	**Habitat range**
Baird's tapir	*Tapirus bairdii*	EN↓	Wide range of forested habitat, but also successional vegetation
Central American agouti	*Dasyprocta punctata*	LC–	Occurs in mature forests and secondary forests/plantations/gardens
Collared peccary	*Pecari tajacu*	LC–	Wide range of habitats and high adaptable
Brown four-eyed opossum	*Metachirus nudicaudatus*	LC–	Mature forests and occasionally in secondary forests
Common opossum	*Didelphis marsupialis*	LC–	Tolerates a wide variety of habitats. Can withstand human settlements—feeding on garbage.
Coyote	*Canis latrans*	LC↑	Almost all available habitats “The ability of coyotes to exploit human resources allows them to occupy urban areas; their recent expansion in eastern Panama has been attributed to their using deforested areas and areas of cattle ranching” (Méndez-Carvajal and Moreno 2014 in IUCN, 2022)
Crested guan	*Penelope purpurascens*	NT↓	Occupies mainly forests
Gray Four-eyed opossum	*Philander opossum*	LC–	Occupies a variety of forests and along watercourses

Gray fox	*Urocyon cinereoargenteus*	LC–	Present across the entire American continent. In Central America they occupy mainly densely forested areas and thick brush habitats
Great curassow	*Crax rubra*	VU↓	Restricted to undisturbed humid evergreen forest.
Great tinamou	*Tinamus major*	LC↓	Occurs in dense rainforest, although recorded in secondary forests as well
Jaguar	*Panthera onca*	NT↓	Wide range of habitat—from rainforest to pampas grasslands, etc., although mainly in dense forest cover. Depend on sufficient prey base and sources of water
Jaguarundi	*Puma yagouaroundi*	LC↓	Broad range of open and closed habitats
Long-tailed weasel	*Mustela frenata*	LC–	Found in a wide variety of habitats. Tolerant of close proximity to humans
Margay	*Leopardus wiedii*	NT↓	Associated with forest habitat, although occasionally reported outside of them Adapted to live in trees Less tolerant to altered landscapes
Morelet's crocodile	*Crocodylus moreletii*	LC–	Wide range of freshwater areas
Mexican Porcupine	*Sphiggurus mexicanus*	LC ?	All forest types at distinct elevations Tolerant to altered landscapes
Neotropical river otter	*Lontra longicaudis*	NT↓	Wide variety of habitats (mainly aquatic)

Nine-banded armadillo	*Dasypus novemcinctus*	LC–	Wide variety of habitats and highly adaptable
Northern raccoon	*Procyon lotor*	LC↑	Highly adaptable and found in wide variety of environments
Northern tamandua	*Tamandua mexicana*	LC?	Found in a wide variety of habitats. Can survive in secondary forests
Ocellated turkey	*Meleagris ocellata*	NT↓	Occupies mature forests Documented in a matrix of forested and agricultural habitat
Ocelot	*Leopardus pardalis*	LC↓	Wide variety of habitats—however with mainly good vegetation cover
Paca	*Cuniculus paca*	LC–	Wide range of forest types
Plain chachalaca	*Ortalis vetula*	LC–	Wide range of forest types. Can withstand altered landscapes
Puma	*Puma concolor*	LC↓	Broad range of habitats and forest types. Can withstand low vegetation cover
Red brocket deer	*Mazama americana*	DD	Prefer large forests with extensive vegetation
Spotted Skunk	*Spilogale putorius*	VU↓	Variable habitat preference, but with dense vegetation cover
Striped hog-nosed skunk	*Conepatus semistriatus*	LC?	Occurs at the edges of forests Can be adaptable to a degree of anthropogenic disturbance
Tayra	*Eira barbara*	LC↓	Large home range Occurs in dense tropical forests as well as modified landscapes (can withstand a degree of anthropogenic disturbance)

Virginia Opossum	*Didelphis virginiana*	LC↑	Variety of habitat, from woodlands to areas of habitat fragmentation
White-lipped peccary	*Tayassu pecari*	VU↓	Wide range of habitats Important role as prey to felines and ecosystem engineers
White-nosed coati	*Nasua narica*	LC↓	Highly adaptable but mainly occurs in tropical woodland/open forest
White-tailed deer	*Odocoileus virginianus*	LC–	Wide range of habitats and extremely adaptable

Source: Kelly & Nipko, 2022; IUCN, 2022 (Adapted)
IUCN Classification: DD=Data Deficient LC=Least Concern, NT=Near Threatened, VU=Vulnerable, EN=Endangered, CR=Critically Endangered.
↑=Increasing population, ↓=Decreasing population, – =Stable population, ?=Unknown
Note: This table does not include humans, domesticated animals (i.e. dogs, cats, cows), unidentified species, or other small animals (i.e. mice, rats, squirrels), small birds, and reptiles that were photographed.
*Camera traps were established one year later: From 2014-2019
See: Kelly & Nipko, 2022 for detailed camera capture rates of each species.