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Transformative Change in the Calakmul Biosphere Reserve: using nature as a foundation for sustainable livelihoods

by

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Abstract

TRANSFORMATIVE CHANGE IN THE CALAKMUL BIOSPHERE RESERVE: USING NATURE AS FOUNDATION FOR SUSTAINABLE LIVELIHOODS

Ecosystems and their associated biodiversity are declining globally, endangering the very foundations for quality of life and security in food, water, and energy needs, particularly in the world's poorest regions that are also the most vulnerable to global climate change impacts. Neotropical forests encompass some of the world's poorest regions that are projected to experience the worst impacts from global changes in climate, biodiversity, ecosystem functions and associated degradation in nature's contributions to people (IPBES, 2019). Yet sustainable development goals can still be achieved through transformative changes from local to global scales, if we start to leverage collaborative interventions now. The main aim of this PhD project is to understand how rural communities living in Neotropical forests perceive wellbeing, what factors shape and determine their relationship with nature, and what pathways they envisage to achieving economic and food security for their descendants. To this end, the Calakmul Biosphere Reserve (CBR) of Mexico, was selected as a case study to understand the links between biodiversity and human wellbeing, and the opportunities for transformative change to sustainable and resilient futures.

Chapter 1 introduces the general context and background to the issue, along with the analytical framework and methodological strategy of the research. *Chapter 2* provides a detailed assessment of hunting practices and patterns in the area, along with the socio-economic, cultural, and geographical drivers and their implications for the long-term sustainability of hunting in the CBR. Quantitative and qualitative data obtained through interviews in 124 households in communities with different ethnic backgrounds, vegetation types and distance to the main urban centre, showed that subsistence hunting is practiced intensively in the tropical forests of Southern Mexico, particularly in isolated communities surrounded by forest. Climate change has affected this practiced by reducing the availability of game species, and in some cases, hunters have modified their hunting strategies in response to scarcer game. Socio-economic, cultural, and geographical factors coinciding at a local scale, shape the hunting practices and patterns in the CBR. However, environmental factors, such as increasing droughts and unpredictable rainfall patterns, are increasingly playing a determinant role in hunting and game consumption in these villages. Impacts of global issues such as climate change can severely threaten the food security and wellbeing of rural people in the CBR, despite these communities having contributed little to the anthropogenic drivers. Context-relevant and well-informed measures at a community scale can support transformative changes towards more sustainable practices. *Chapter 3* analyses the vulnerability to climate change of rural livelihoods based on arable farming and hunting. It uses qualitative interviews with 105 villagers, and focus group discussions with 35 participants, to assess the wellbeing of rural communities in relation to food security under climate change. Villagers in the CBR perceived droughts, changing rainfall patterns, and increasing temperatures as the main hazards impacting water availability, soil fertility, crop pests, and the distribution of wild mammals in the area, affecting their crop yields, economies, labour, traditional practices, diets, and human-wildlife conflicts. Villagers perceived increasing risks to their food security and wider wellbeing, with implications for their traditional knowledge and autonomy. Based on this, villagers designed adaptation strategies to enhance the resilience of their livelihoods. Opportunities for nature-based solutions to climate change and other societal challenges can foster transformative changes to reduce climate risks in tropical forest communities. *Chapter 4* evaluates the costs and benefits of livestock ranching versus honey production to assess the potential for apiculture to enrich nature's contributions to people through its forest resources. Through structured interviews, focus-group discussions, and scenario planning, it assessed the views, perspectives and desired development pathways of rural communities. Results showed that cattle ranching requires a higher initial investment and higher annual maintenance of both cattle and land, than honey production. The average annual production of organic honey from 20 beehives is estimated at 1,200 kg, which yields a revenue of MXN $60,000 (GBP £2,222) in the first

year. This is much higher than the annual revenues obtained from 10 cattle in 10 ha, of MXN $16,800, which are only sold in times of need and therefore represent a capital investment. Focus-groups discussions showed ranchers' willingness and potential for developing of honey production as an alternative sustainable livelihood. The uptake of honey production can benefit local and regional economies, the conservation and management of the reserve, and the wellbeing of these communities.

To measure the long-term sustainability of forest livelihoods beyond the period of this PhD, I am monitoring the distribution of jaguars (*Panthera onca*) by systematic camera trapping in three sites with and without human activities in the CBR. This top predator makes a useful indicator of ecosystem health, because it thrives only in biodiverse forest containing abundant mammals that are also game to human hunters. I am building a picture of these predators confined to ever-more fragmented forest and increasingly competing with humans for food security, resulting in attacks on livestock that only bring hardship to ranchers. The local communities fully understand these issues and are proud to host the culturally significant jaguar in their forests, suggesting that this species could function well as an indicator of social-ecological health under transformative change to sustainable pathways.

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Research Thesis: Declaration of Authorship

Print name: Cristina Argudin Violante

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I declare that this thesis and the work presented in it is my own and has been generated by me as the result of my own original research. I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;

2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;

3. Where I have consulted the published work of others, this is always clearly attributed;

4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

5. I have acknowledged all main sources of help;

6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

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Chapter 1: General Introduction

All of humanity is facing the dual crisis of biodiversity loss and climate change. The human impact on biodiversity and the climate system has drastically increased since the 1970s, driven by the demands of a growing population with rising average per capita income, which have paralleled technological advances, and supported better living standards for many. Nature is now supplying more resources than ever before, but this has come at the expense of unprecedented global declines in the extent and integrity of ecosystems, distinctness of local ecological communities, and abundance and number of wild species (Diaz et al., 2019b).

These changes reduce the quality and quantity of benefits that people obtain from nature and threaten the wellbeing of present and future generations. The benefits of an expanding economy and the costs of reducing nature's benefits are distributed unequally. The world's poorest regions are already experiencing the most severe changes in biodiversity, climate, and nature's contributions to people (IPBES, 2019). Despite the severity of the threats, opportunities exist to achieve sustainable futures through transformative changes that address the root socio-economic and technological causes of nature's decline.

Sustainable societies rely on healthy ecosystems in a stable climate. This thesis concerns fundamental dependencies between nature and human communities living in tropical forests. Particularly, this thesis aims to understand how communities that rely directly on forest resources perceive wellbeing in face of climate change and other large-scale social-ecological drivers. In doing so, it aims to foster transformative changes that lead to sustainable and resilient communities living in healthy forests. This thesis finally aims to contribute to expand the scientific knowledge about the links between humans and nature and the factors that can lead to transformative changes towards more sustainable societies In this introductory chapter, I review our current understanding on the links between biodiversity and human wellbeing, the drivers of biodiversity loss with a focus on climate change, the current efforts to achieve sustainable development by integrating with nature, particularly in tropical forests, in relation to transformative changes. I then present the aim and objectives of this thesis, along with the analytical framework and methodological strategy. Lastly, I describe how global threats to biodiversity and human wellbeing take place in the Calakmul Biosphere Reserve, the case study selected for this study, as it is place highly vulnerable to climate change where rural and indigenous peoples depend directly on the tropical forest and its biodiversities and, equally, the forest depends on people.

1.1 Biodiversity is declining globally due to human activities

Biodiversity is declining globally at an unprecedented rate due to the ongoing and increasing anthropogenic impacts on the environment. Over the last 150 years, human activities have altered ecosystems for social and economic development, more rapidly and extensively than in any period of human history (Steffen et al., 2004; Foley et al., 2005). Land and sea use change, exploitation of wildlife, climate change, pollution, and invasive non-native species are recognized as the main anthropogenic drivers of biodiversity loss (IPBES, 2019).

In the past 500 years, humans have caused the loss of billions of populations of plants and animals, at rates faster than any other period of human history (Dirzo et al., 2014). Recent studies have provided evidence of the current biodiversity crisis for different taxa. For plant populations, an estimate of 50% decline in the biomass of terrestrial vegetation has been estimated since the start of agriculture (Erb et al., 2018), with a loss of approximately 20% of its original biodiversity (Diaz et al., 2018).

Animal taxa are subject to similar trends, as defaunation has occurred in terrestrial and marine systems (Dirzo et al., 2014; McCauley et al., 2015). Like plants, around 11,000 years ago, vertebrate biomass comprised 300 million tons, of which only a small proportion corresponded to a human population of near 4 million (Smil, 2013). By 2015, total vertebrate biomass increased dramatically to 1,850 million tons, largely dominated by domesticated animals that occupied 76%, followed by humans at 23% of the total, with a population of 7.3 billion humans. In contrast, wildlife was reduced to 1%, without considering amphibians and birds (Dirzo et al., 2022). Despite this dramatic loss, a less than 700 vertebrate species have been recorded as extinct or extinct in the wild over the last 520 years (Ceballos et al., 2015a, Ceballos et al., 2015b), without considering small-sized, understudied groups such as invertebrates that might have gone unrecorded (Tedesco et al., 2014).

These and other studies (Ehrlich & Daily, 1993) showed that the main concern in the biodiversity crisis is the loss of populations and nature's contributions to people (NCP), as populations decline has profound consequences on ecosystem function, provision of NCP, and human wellbeing, even when a species is not considered as extinct (Dirzo et al., 2022). The consequences of populations loss on ecological and social systems, are projected to increase under current climate change (IPCC, 2022).

1.2. Climate change drives biodiversity loss and enhances its impacts

The interdependence of climate, biodiversity, and human societies is now widely recognized (IPCC, 2022). Widespread and fast changes in the atmosphere, ocean, cryosphere, and biosphere are affecting many weather and climate extremes throughout the planet. This has led to extensive negative impacts and related losses and damages to nature and people (IPCC, 2023). The planet is currently warmer by 1.07°C since pre-industrial times due to anthropogenic climate change. If temperatures are not limited to 1.5°C in the coming decades, impacts to biodiversity and human societies are expected to increase dramatically (IPCC, 2018).

Climate change is affecting biodiversity globally. It threatens the health of ecosystems due to disruptions in the natural feedback loops and loss of habitat for diverse wildlife species. Biological responses, including changes in physiology, growth, abundance, geographic placement and shifting seasonal timing, are often not sufficient to cope with recent climate changes. To date, climate change has caused local species losses, increases in disease, and mass mortality events of plants and animals, changes in populations size, and ecosystem restructuring (IPCC, 2022). These climate impacts on ecosystems and biodiversity affect their capacity to provide NCP, thereby harming human lives and livelihoods, with profound consequences for human health and security in food, water, and energy needs (IPCC, 2022; IPBES, 2019).

Biodiversity loss and climate change share many of the same drivers, and at the same time, each destabilises the other. Land use change, overexploitation of resources, pollution, and invasive species often exacerbate climate change impacts, and vice versa, leading to the loss of biodiversity. Climate and non-climate threats interact resulting in accumulated impacts that alter ecosystem structure and resilience, with cascading effects on human wellbeing (Pörtner et al., 2021; Knoth, 2014). There is evidence that range shifts reduce biodiversity in the warmest regions as adaptation limits are exceeded. Simultaneously, these shifts homogenise biodiversity in regions receiving climate-migrant species, alter food webs, and eliminate the distinctiveness of communities. Invasive species can reduce or replace native species and alter ecosystem characteristics if they fare better than endemic species in new climate-altered ecological niches, particularly in geographically constrained areas (Finch et al, 2021). Human societies are facing more severe consequences from the combined impacts of changes in biodiversity and climate (Pörtner et al, 2021). As biodiversity represents the foundation for human wellbeing, biodiversity loss has profound negative implications for humanity (Davies et al., 2023).

Climate change and biodiversity loss directly affect human wellbeing. These phenomena are recognised not only as environmental, but also as economic, development, security, social, moral, and ethical issues. These have already caused measurable economic and livelihood losses, transformed social and cultural practices, and affected the health, food, water, and energy needs of millions of people in urban and rural context worldwide (IPCC, 2023; IPBES, 2019). However, the world's poorest regions are currently suffering the worst impacts from climate change.

It is estimated that at least 70% of the world's poor live in tropical rural areas (Aguilar & Sumner, 2020). Most of these people depend directly on agriculture and natural resources for their livelihoods (Woodhill et al., 2022). Thus, climate change and biodiversity loss threaten the food security of rural people living in tropical forests through negative impacts on their livelihoods and income and on nature (IPCC, 2018).

1.2.1. Tropical forest biodiversity is biodiversity loss and climate change impacts

Tropical forests contain nearly half of Earth's terrestrial biodiversity and are an important influence on the climate system (Lewis et al., 2015). They are considered amongst the most diverse ecosystems on Earth and fulfil various roles in climate regulation, carbon sequestration, net primary production, and global hydrologic cycles and biogeochemistry (Daily et al., 2000; Vitousek et al., 1997), whilst providing of food and timber for hundreds of millions of people and protection against extreme poverty (Steur et al., 2020). Yet these forests are increasingly threatened by human activities and climate change.

The health of tropical forests has been affected by increasing human influence globally. Tropical forest vegetation has been removed mainly for agricultural purpose and livestock development (deforestation is 1.2%/year; Hoang & Kanemoto, 2021). Furthermore, the expansion of agriculture has fragmented the remaining forests. In many tropical biomes of Borneo and Papua New Guinea, and in the Brazilian Atlantic Forest, most forests are within 1 km of an edge, reducing the landscape connectivity and thus the persistence of wildlife, particularly in the face of climate change (Haddad et al., 2021).

Additionally, overexploitation of wildlife and other natural resources has resulted in severe population declines of many large vertebrates, resulting in empty tropical forests throughout the world, even in protected areas (Harrison et al., 2011). Subsistence and commercial hunting of wildlife in tropical developing countries is rapidly driving many species to extinction at local and global scales (Wilkie et al., 2011; Ripple et al., 2016). Among vertebrates, mammal populations are predicted to be partially defaunated (declining 10%–100%) in around 50% of the pantropical forest area of 14 million km^2, with the largest declines (>70%) in West Africa (Benítez-López et al., 2019). Furthermore, it has been projected that hunting itself can affect mammal populations in 20% of tropical protected areas, with greatest impacts in West and Central Africa and Southeast Asia (Benítez-López et al., 2019).

Climate change is an additional threat for tropical forest ecosystems. Climate change-induced drying and warming increase the risk of drought-driven mortality of emergent trees (Fajardo et al., 2019), biotic attrition (Colwell et al., 2008), and fires (Brando et al., 2020). Moreover, climate change exacerbates the impacts of agriculture, hunting, industrial logging, urbanisation, and fragmentation in tropical forests, damaging ecosystem functions and the provision of nature's contributions to people, endangering the very foundations for quality of life, livelihoods, and food security of people living in these regions (Lewis et al., 2015; IPBES, 2019).

Tropical forests uphold the highest levels of human populations (Hoekstra et al., 2005), where around 1.6 billion people directly depend on this ecosystem for their livelihoods. Of these, 60 million indigenous peoples are almost wholly dependent on forests resources, while 350 million people who live within or adjacent to dense forests depend on them to a high degree for subsistence and income (World Bank, 2004; McMullin et al., 2015; IPBES, 2022). Thus, biodiversity loss and climate change threaten the food security of millions of people living in these areas.

The severity of the threats, the complexity of the underlying social drivers of change, along with their high biological and cultural diversity (Barlow et al., 2018), make the remaining tropical forests increasingly valuable for both biodiversity and NCP. Thus, this thesis adopts a particular focus in tropical forests as places where maintaining biodiversity plays a crucial role for human wellbeing, particularly in face of climate change.

1.3. Biodiversity underpins human wellbeing

The links between biodiversity and human wellbeing are well established. Civilization depends on biodiversity, which itself depends on proper global ecosystem functioning (Dirzo et al., 2022; Kemp et al., 2022; Diaz et al., 2015). Thus, understanding Different frameworks exist for understanding the links between nature and people (see Tapio & Willamo, 2008 and Naeem et al., 2016). In this thesis, the Intergovernmental Platform for Biodiversity and Ecosystem Services' (IPBES) framework is used to understand these links and the associated interacting factors (Fig 1.1). In this context, a definition of biodiversity and human wellbeing is provided in the next section.

1.3.1 Biodiversity is key for the provision of NCP

Biodiversity is defined as the variability among living organisms from all sources including taxonomic, phylogenetic, and functional diversity and the ecological complexes of which they are part (CBD, 2009). Every ecosystem features key functions, including primary productivity, the biogeochemical cycles, and the network species interactions that compose the food chains, which give rise to NCP. NCP constitute the fabric of life and directly sustain and improve human wellbeing (Diaz et al., 2019a), representing the most direct link between biodiversity and human wellbeing.

NCP are all the contributions of biodiversity to people on which economies, livelihoods, and human wellbeing rely. These contributions can be tangible (e.g., food, wood, and natural gas) or intangible (e.g., ecosystem processes like pollination, flood control, carbon regulation, photosynthesis, nutrient cycling, recreation, spirituality, etc). These can also be positive or negative depending on the context. Positive contributions include examples such as food provision, water purification, and artistic inspiration, while negative contributions include disease transmission and predation that damage humans or their assets. NCP may be perceived as positive or negative depending on the cultural, socioeconomic, temporal, or spatial context (Diaz et al., 2018).

This thesis adopts the concept of NCP as an analytical tool, since it is a transdisciplinary, action-oriented, inclusive, and pluralistic way of understanding the benefits and detriments that different peoples derive from their relationships with the rest of nature (Hill et al., 2021). This concept builds on the definition of ecosystem services (Millennium Ecosystem Assessment, 2005), allowing a more comprehensive and inclusive understanding on the goods and services provided by nature. Additionally, it contributes to emphasizing the importance of cultural context as a cross-cutting factor shaping human perception of nature and good quality of life. This context-specific perspective highlights how diversely ecosystem services are framed across different communities and knowledge systems around the world (Peterson et al., 2018). Moreover, the concept of NCP works as an effective way to conceptualise of the most direct link between biodiversity and human wellbeing.

1.3.2 Human wellbeing relies on nature and additional factors

Like biodiversity, human wellbeing is a multidimensional construct. It includes both subjective and objective measures (Agarwala et al., 2014) and has numerous interpretations and definitions (Brown & Westaway, 2011). However, at a broad level, there is agreement on the two main dimensions of wellbeing: objective and subjective. Objective dimensions encompass material and social attributes, relevant for fostering wellbeing, that contribute or detract from individual or community wellbeing. These include many basic human needs, economic needs, and environmental needs, factors deemed important for society's welfare (Parris & Kates 2003; Talberth et al. 2006). Examples of these include wealth, education, health, and infrastructure. In contrast, subjective dimensions comprise individuals' assessment of their own circumstances, considering what they think and feel. Thus, wellbeing is an abstract concept that refers to the state of a person's life (Clark & McGillivray, 2007).

In this thesis, human wellbeing is defined as the state in which human needs are met, without compromising the ability of future generations to meet their own (Brundtland, 1987), where there is opportunity for satisfying social relationships, where people can act meaningfully to pursue their own goals, enjoying a satisfactory quality of life. This definition encompasses the four primary elements of wellbeing: basic human needs (physiological and safety needs); economic needs (e.g., education, wealth, earning capacity, household infrastructure, and certain socially oriented needs like community wealth, productivity, public infrastructure, economic diversity, and trade); environmental needs (e.g., access to clean air, water availability, and maintaining acceptable distances from critical ecological thresholds); and subjective happiness (e.g., identity, community cohesion, nature access, leisure, cultural and spiritual beliefs, and aesthetics; Summers et al., 2012; Maslow, 1954). These four elements of wellbeing are sustained, at different degrees, by nature through NCP. In this thesis it is also recognised that wellbeing is a subjective concept, and that it can adopt different meanings for different peoples (Ereaut & Whiting, 2008). Thus, to preserve nature, a better understanding of how human communities perceive wellbeing and how they envision sustainable societies is needed (IPBES, 2019).

However, human wellbeing does not depend exclusively on nature. Other factors additionally affect, positively and negatively, human quality of life (Diaz et al., 2015). These include anthropogenic assets (e.g., education, health, technology, and finance); direct drivers of change impacting nature (both non-human and anthropogenic, e.g., climate change), institutions and governance, and other indirect drivers of change affecting nature, NCP, and human wellbeing either directly or indirectly (e.g., the system of social rules and norms, and socioeconomic, cultural, and demographic factors; Figure 1.1).

Climate change is considered one of the main direct drivers of change linked to biodiversity, NCP, and human wellbeing. As described in Section 1.2, climate change directly impacts biodiversity, causing population declines of different taxa and habitat loss, The decline in biodiversity reduces the overall stability and functioning of ecosystems, compromising their capacity to provide NCP. As NCP and/or their quality decline due to climate-induced biodiversity loss, human societies face risks related to food security, water availability, and overall NCP, underscoring the intricate link between a stable environment and human wellbeing in the face of climate change.

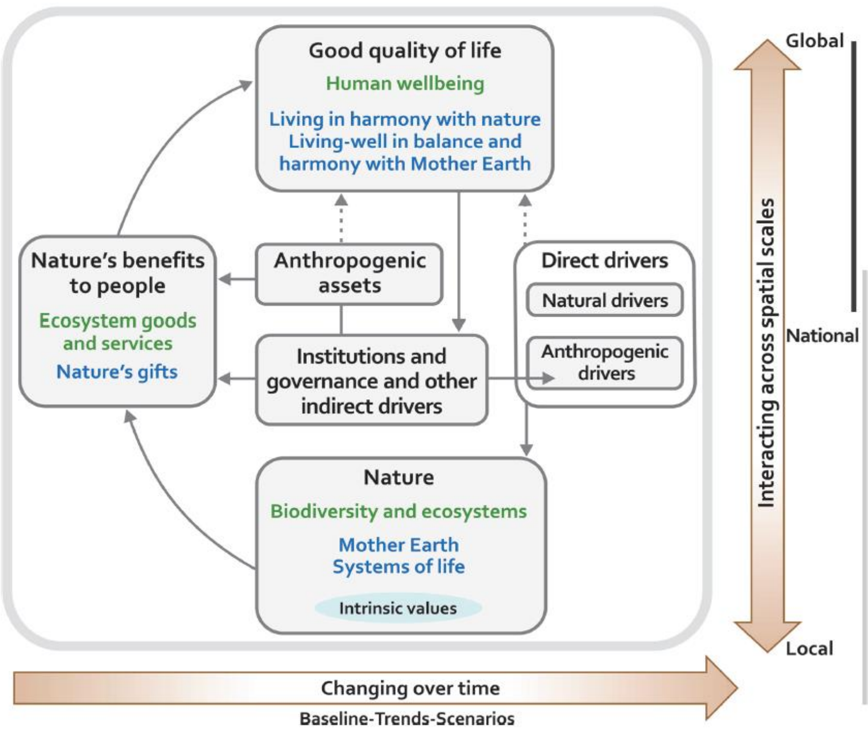


Figure 1.1 IPBES Conceptual Framework. Taken from (Díaz et al, 2015). The IPBES framework provides a model to understand human wellbeing and its link with nature. The grey boxes and arrows indicate the relationship and influence between elements of nature and society, considering western science and other knowledge systems. All the boxes target human wellbeing, which is the centre of the framework. Nature and the benefits that it provides to people lead to wellbeing but interact with different drivers, directly (straight lines) and indirectly (dotted lines), at different special scales.

1.3.3 NCP and human wellbeing in decision making

The crucial role of NCP for economic and social wellbeing is widely recognized. However, approaches for integrating them into policy and management practices are still in development (Kabisch, 2015). During the last two decades, ecosystem service assessments have been used as a tool to provide decision-makers with an evidence base about the state and value of NCP at a specific spatial scale (Dunford et al., 2018). An ecosystem service assessment is a comprehensive evaluation that aims to inform about the state and trend of NCP and its links to human wellbeing. This can include qualitative, quantitative, and monetary valuation of NCP to make the benefits people derive from nature explicit and can be used to evaluate trade-offs in impacts and changes resulting from land use decisions (Posner et al., 2016).

In this context, the adoption of monetary valuation has been advocated as a key strategy for incorporating the economic value of ecosystems into decision-making processes. Valuation of nature, in general, is the process of documenting the existence and strengths of different values, using methods and approaches that elicit and articulate values of nature (Termansen et al., 2022). Characterising which and whose values are important allows making them visible and it increases the probability of their inclusion in decision-making. The monetary valuation of nature has gained relevance in recent decades (Baveye et al., 2013). For example, the Economics of Ecosystems and Biodiversity (TEEB), states that the best way to mainstream the contributions humans obtains from nature is by making the previously invisible changes in nature's flows into the economy visible through economic valuation. This involves communicating the value of nature using the language of the dominant worldwide economic and political model (ten Brink, 2011, xxix). Assigning monetary value to various ecosystem functions and components has emerged as one of the extensively researched topics in the literature on NCP (de Groot et al., 2012).

However, the monetary valuation of NCP is subject of academic debate (Tinch, 2019). Different authors have described that valuing NCP in monetary terms can contribute to highlight, measure, and value the degree of interdependence between people and the rest of nature (Costanza et al., 2014; Ouyang et al., 2020). It is also argued that it represents a useful tool to raise awareness and convey the relative importance of biodiversity and NCP to different audiences for different purposes, including policymakers (Costanza et al., 2014; de Groot et al., 2010; Daily et al., 2009; Costanza, 2020). Information on monetary values of NCP can also provide a framework for conducting cost-benefit analysis of environmental projects, allowing decision-makers to compare the economic benefits of conservation initiatives with the costs involved, enabling a more efficient use of limited funds in areas where the conservation of nature provides the greatest economic and social benefits (Georgiou & Turner, 2012). Furthermore, the measurement of NCP flows in monetary units can improve incentives, generate expenditures needed for their conservation and sustainable use, and calculate insurance costs against ecological damages (Farley & Costanza, 2010; Kallis et al., 2013).

Yet, monetary valuation of nature faces criticism for its potential to undermine environmental protection and open the door to the commodification of nature where natural resources are treated as tradable goods (Costanza, 2006). It is argued that attempting to quantify the economic value of complex and interconnected ecosystems can undermine the importance of the wide diversity of NCP, particularly those related to cultural and intrinsic values or those with without immediate economic benefit (Chaisson, 2002; Acharya et al., 2019). Critics also caution that assigning monetary value may oversimplify citizen values, incorporating normative beliefs, principles, and collective meanings into mere consumer preferences (Vatn, 2009). Furthermore, they highlight that monetary valuation can generate uneven distribution of benefits, creating or enhancing social and environmental justice issues, particularly for marginalized populations (Matulis, 2014).

Beyond this debate, the main purpose of NCP valuation is to provide estimates of how nature contributes to the generation of income and wellbeing. Thus, it can work as a useful tool for decision making and other purposes if environmental protection, equality, and inclusivity are fully taken in consideration (Kallis et al., 2013).

1.4. Recognizing the value of biodiversity can lead to transformative changes for sustainable and resilient societies

As increasing biodiversity loss and climate change are having reinforcing impacts on social-ecological systems, there is global call for transformative changes towards more sustainable pathways recognising the value of nature (Díaz et al. 2019a). Recently, major global reports have given accounts of the current state of the biosphere and climate. It is evident that biodiversity is declining globally at unprecedented rates (IPBES, 2019; WWF, 2020) and that climate change continues to accelerate (IPCC, 2018, 2022), increasing poverty and inequality and undermining the development gains of the 20th Century (IPBES, 2019; WFF, 2020). As these challenges are interlinked, there is recognition that they need to be addressed together (IPCC, 2019; Turney et al., 2020, Seddon et al., 2020). As the Earth's systems reach tipping points (Rockström et al., 2009; IPCC, 2018; Armstrong McKay et al., 2022), transformative changes are needed to tackle these challenges, towards sustainable and resilient societies (Diaz et al., 2019b).

Transformative change refers to fundamental and profound alterations in social-ecological interactions in a way that the Earth's biophysical systems and human needs are sustained (Feola, 2015). This change requires actions across technological, economic, and social factors, containing paradigms, goals, and values (IPBES, 2019). International focus on transformation is increasing because it characterizes the most severe impacts of the current climate crisis (Blythe et al., 2018). According to the IPBES and the Intergovernmental Panel on Climate Change (IPCC), transformative change is necessary to achieve different international goals such as the Paris Agreement, the post-2020 biodiversity targets, and the Sustainable Development Goals (SDG; Diaz et al., 2019b; IPCC, 2018).Transformative changes are understood as fundamental, system-wide reorganisation Research on transformative change has grown in the last decade (Kohler et al., 2019) dealing with three broad perspectives, the socio-technical, the socio-institutional, and the social-ecological (Geels, 2010; Otto et al., 2020; Olsson et al., 2014). Yet, few studies have empirically evaluated the processes that lead to transformative change and associated sustainability and resilience outcomes (Palomo et al., 2021). This thesis concerns social-ecological transformative changes, which require reframing social-ecological relationships (Palomo et al, 2021) for sustainable and resilient social-ecological systems. It is important to highlight that transformative change is the process that will lead to sustainability, not a goal itself. Thus, this process involves reshaping and integration of different views and taking action at different levels, in ways that reshape individuals and societies, and the way humans relate to, value, and use nature.

Sustainable societies can be understood as communities living in a state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs (Brundtland, 1987; Millennium Ecosystem Assessment, 2005; United Nations, 2015). An important notion around sustainable societies is the sustainable use of the components of biodiversity and other natural resources in ways and at rates that do not lead to the long-term decline of biodiversity, therefore maintaining the potential of NCP to meet the needs and aspirations of current and future generations (CBD, 1992).

Resilience is a key feature of sustainable societies. In the context of social-ecological systems, this is defined as the capacity of a system to deal with change and continue to develop, as well as the capacity for adaptation to emerging circumstances (Adger, 2006). Loss of resilience can result in reversible (smooth) change or tipping points into irreversible (abrupt) regime shift (Dearing et al., 2014). Resilience depends on factors such as ecological dynamics as well as the organizational and institutional capacity to understand, manage and respond to these dynamics (Curtin & Parker, 2014). Further discussion on these concepts is elaborated in Section 1.6. Here I consider how transformative changes can be fostered for the wellbeing of nature and people and for addressing climate change and its impacts, and what factors play a key role in transforming people's relationship with nature.

Nature-based Solutions (NbS) have been recognized for their potential to foster transformative changes to sustainability and resilience in the face of climate change. Due to their contributions to nature conservation, climate change adaptation, human livelihoods, and wellbeing, NbS can bring long-term transformations since they contribute to profound and fundamental changes in social-ecological interactions in a way that sustains the Earth's biophysical systems, while meeting human needs (Seddon et al., 2020; Palomo et al., 2021).

NbS are defined as actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature (Cohen-Shacham et al., 2016). NbS address societal challenges through the protection, sustainable management, and restoration of ecosystems, benefiting biodiversity and human wellbeing. They mainly target challenges like climate change, disaster risk reduction, food and water security, biodiversity loss, and human health (Seddon et al., 2020; 2021). The concept is grounded in the knowledge that healthy ecosystems produce a diverse range of NCP on which human wellbeing depends.

The term 'NbS' is used as an umbrella for diverse nature-based approaches, such as ecological restoration, agroecology, ecosystem-based adaptation, ecosystem-based disaster risk reduction, among others. Due to the growing interest in the topic, efforts have been made to provide a clear definition, to identify its principles, and to develop guidelines for successfully implementing, assessing, and upscaling NbS interventions globally (Seddon et al., 2020; 2021; Sowińska- Świerkosza et al., 2021; Cohen-Shacham et al., 2019; IUCN, 2020; Welden et al., 2021). A relevant example is the International Union for the Conservation of Nature's NbS Global Standards that provide a framework to support their verification and design (IUCN, 2020).

NbS resulted from a major paradigmatic shift that occurred in the 2000s. Instead of just protecting nature for its own sake, the focus shifted to conserving nature for the benefit of people. This also meant seeing people as active protectors and restorers of nature, not just passive beneficiaries (Mace, 2014). Furthermore, it has been argued that NbS can also enable a new and more profound paradigmatic shift that transitions from our current global economic model centred on GDP and never-ending growth to a new model where a healthy economy is defined by the social-ecological wellbeing it brings (Seddon et al., 2020).

Eight core principles have been proposed for the design and implementation of NbS (Cohen-Shacham et al., 2019). These state that NbS: 1) Embrace nature conservation norms and principles, and not substitute for nature conservation. In some cases, they address biodiversity conservation priorities, but not invariably. 2) Can be implemented alone or in an integrated way with other solutions to societal challenges including technological and engineering solutions. 3) Are determined by site-specific natural and cultural contexts, considering different types of knowledge. 4) Produce societal benefits in a fair and equitable way and promote participation. 5) Maintain biological and cultural diversity and the ability of ecosystems to evolve in the long term. 6) Are applied at a landscape scale, considering the wider landscape-scale context and consequences, aiming at upscaling where appropriate.7) Acknowledge and address the trade-offs between the production of a few immediate economic benefits for development, and future options to produce diverse NCP. 8) Are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

However, for NbS to support paradigm shifts and other transformative changes towards resilience and sustainability, they require careful consideration and planning considering the principles above and other factors. They must be explicitly designed to protect or enhance biodiversity for preserving healthy ecosystems able to deliver long-term benefits to people. Additionally, NbS require involving and engaging a diverse group of stakeholders, fostering dialogue, and considering a range of perspectives, especially those of indigenous and local communities, in their design, implementation, management, monitoring, and evaluation to deliver legitimate and equitable outcomes (Seddon et al., 2020). At the same time, these factors (stakeholder engagement, dialogue, consideration of different perspectives and worldviews) have been recognized as catalysers of transformative change (Palomo et al., 2021).

Transformative change for sustainability and resilience through NbS and other pathways can occur at different levels. It has been proposed that transformational change to address climate change happens in three interacting spheres: the personal, which includes knowledge, values, and worldviews; the political, which considers rules, economic and legal instruments, and governance; and the practical sphere, that includes behaviours, management, and technical responses in which transformation processes are based (O'Brien & Sygna, 2013). This thesis concerns the personal sphere, as understanding the knowledge, views, and perceptions of indigenous and rural communities, as main stakeholders, is crucial for fostering transformative change.

It is recognized that stakeholder engagement and fostering ownership and wellbeing of the local stewards of the land in which NbS occur are crucial factors for their success and for transformative change. Indigenous and local communities pose valuable knowledge on local ecosystems and management practices gained through adaptive learning and experiences (Das et al., 2022). This knowledge, rooted in their specific environmental, socio-economic, and political context, is essential for effective land management. Furthermore, NbS require alignment with local norms, relational and moral values, and beliefs, while building social capital, for their long-term success (da Rocha et al., 2017). Lack of alignment with local perspectives can deter active participation of local communities and compromise the success of NbS, while constraining local adaptive capacity (Woroniecki et al., 2020). Thus, more attention should be given to stakeholders' perceptions and preferences in designing and implementing NbS (Raymond et al., 2017). Understanding stakeholders' perceptions is considered crucial particularly in the context of NbS to climate change. It is recognized that adopting a more comprehensive and reflective approach in climate-risk assessments can facilitate a broader pluralistic engagement on multiple dimensions of risk and the connections between risks and values and norms, particularly regarding attitudes to nature (Adger et al. 2018; Ford & Norgaard, 2020).

1.5. Aim and objectives

The global environmental crisis demands transformative approaches toward sustainability (IPBES, 2019). This PhD project aligns with a vision for resilient communities living in healthy forests. The project studies how indigenous and rural communities in tropical forests perceive wellbeing and what pathways they envisage for achieving long-term economic and food security in the face of climate change and to foster transformative changes for the wellbeing of people and nature. Understanding people's perception of wellbeing in relation to the environment is a crucial first step for transformative change (Palomo et al., 2021).

The main aim of this work is to evaluate the perceptions of rural communities about their livelihoods in relation to food security, biodiversity, and other aspects of wellbeing, in Neotropical forests under climate change, as exemplified by the Calakmul Biosphere Reserve (CBR). To this end, three thesis data chapters address the following specific objectives (Figure 1.2):

1) Understand how the characteristics of different communities influence their hunting practices and its implications for sustainability under climate change.
2) Examine the role of communities' preferences and values in shaping their perceptions to climate-risks on their livelihoods.
3) Assess the economic and ecologic costs and benefits of different forest livelihoods in relation to farmers' values.

ISSUE	**Climate change is generating and enhancing social and ecological vulnerabilities of indigenous and rural communities living in tropical forests**		
VISION	**Resilient and sustainable communities living in healthy forests**		
AIM	**Understand how forest communities perceive wellbeing and what pathways they envisage for achieving economic and food security for their descendants, to initiate a processes that facilitates transformative changes towards sustainability and resilience**		
OBJECTIVES	**Understand how the characteristics of different communities influence their hunting practices and its implications for sustainability under climate change**	**Examine the role of communities' preferences and values in shaping their perceptions to climate-risks**	**Asses the economic and ecologic sustainability of forest livelihoods in relation to farmers' values**
OUTPUTS	**Frequency of hunting and game consumption**	**Communities' preferences and values on livelihoods and food security**	**Cost-benefit analysis of livestock ranching and honey production**
	Preferred game, hunting areas, and methods	**Current responses to climate hazards**	**Perceptions towards alternative livelihoods and willingness for uptake**
	Villagers' motivations for hunting and current challenges	**Community-based adaptation actions to reduce climate risks**	**13 farmers and 10 women trained in honey production and aware of ranching impacts**
OUTCOME	**Contribute nature-based improvements to the wellbeing of rural communities in tropical forests**		
MONITORING	**Long-term wildlife surveys and monitoring of resources across human modified landscapes**		

Figure 1.2. Logical framework of the PhD project. The figure summarizes the main issue, vision, aim, objective, subobjectives (data chapters), outputs, outcome, and long-term monitoring of the project.

1.6. Analytical framework

Understanding the complex relations between nature, human wellbeing and the factors affecting these, requires an encompassing analysis. Therefore, this study incorporates different frameworks for analysing human wellbeing and their social and ecological relationships in face of climate change.

In the larger scale, this study is based on the social-ecological systems (SES) approach, which emphasizes that people, including communities, economies, societies, and cultures, are embedded in the biosphere and shape it from local to global scales (Fig. 1.3; Ostrom, 2009; Leslie et al. 2015). At the same time, people are shaped by, depend on, and evolve with the biosphere (Folke et al., 2011). Thus, people not only interact with, but are inhabitants of the biosphere along with all other species, shaping its resilience, consciously or unconsciously. Using the SES approach in the generation of knowledge and the formulation of sustainable solutions to social-ecological challenges is crucial, as it explicitly recognizes the connections and feedbacks linking the human and natural systems (Leslie et al. 2015). This interconnectedness is still poorly understood, yet, what is clear is that loss and degradation of ecosystem function has complex consequences on SES, disrupting the flow of NCP, which humans rely for livelihoods and wellbeing (Folke, 2006).

Under the SES approach, the concepts of sustainability and resilience become essential for analysing the links between humans and nature. In this thesis, sustainability is understood as the state where the present needs of a population are met, ensuring the wellbeing of humans and nature in a SES, and without compromising the ability of future generations to meet their own needs. Sustainability encompasses economic viability, social equity, ecological integrity, and resilience (Clark & McGillivray 2007; Matson et al., 2016).

Resilience constitutes another fundamental element within the SES framework and for the analyses presented in this thesis. Resilience is defined as the system's ability to adapt or transform in the face of change, particularly unexpected change, in ways that continue to support human wellbeing (Biggs et al., 2015). Consequently, resilience is not limited to the capacity to absorb or adapt to change; it also includes the ability to transform with change. Transformability is understood as the capability to create an entirely new system when prevailing ecological, economic, or social structures render the existing system unsustainable (Folke et al., 2010). In essence, resilience not only involves adaptive measures but also embraces the capacity for transformative responses to maintain overall system functionality.

The IPBES framework (Diaz et al., 2015) is used specifically to analyse the links between biodiversity and human wellbeing in the context of SES. This framework allows the analysis of direct NCPs as the main link between biodiversity and human wellbeing. At the same time, it considers and integrates other relevant factors that influence human wellbeing, such as anthropogenic assets and institutions and governance, and the links of all these elements with anthropogenic drivers of change and links with NCP. In this study, land-use change (conversion of forest to pasture), overexploitation of wildlife (hunting), and climate change are the main drivers of interest, as these are the main factors affecting tropical forests' people and biodiversity globally.

Biodiversity underpins human existence and wellbeing (Diaz et al, 2019a). Therefore, if sustainably managed, ecosystems can benefit forest communities' quality of life. This project aims to understand how nature supports and can potentially improve human wellbeing in tropical forests. NCP, such wild game and honeybees, can improve the food security and income of tropical rural villages, if sustainably managed. These can provide an alternative to global drivers of ecosystem change, such as cattle ranching and overexploitation of wild game. Strengthening the governance of rural communities in the management and conservation of natural resources is key for transformative changes, from individuals to institutions, for the long-term sustainability. To this end, wildlife monitoring tools such as camera traps and acoustic recorders, can support long-term community-led assessments of the state of natural resources (Figure 1.3).

As described in Section 1.3.2, human wellbeing is a multidimensional, dynamic, person-specific, and culture-specific concept. In this thesis, the concept of wellbeing recognises and highlights the linkages between quality of life and NCP, focusing on the four primary elements of wellbeing: basic human needs; economic needs; environmental needs; and subjective happiness (Summers et al., 2012; Maslow, 1954) in relation to nature and its contributions. These four dimensions were selected to reduce the ambiguity of the concept and to provide a secure epistemological and empirical basis (McGregor, 2004; King et al., 2014).

Simultaneously, biodiversity and human wellbeing are threatened by climate change. Increased temperatures and changes in rainfall patterns are affecting tropical forest biodiversity globally. This endangers the provision of NCP, forest livelihoods, and wider wellbeing of rural people in these areas. Therefore, the IPCC framework on climate risks (IPCC, 2014) is used to analyse how climate change impacts the livelihoods and wellbeing of human communities living in tropical forests (Fig 1.3). This framework allows the identification and analysis of climate hazards, exposure, and vulnerabilities to design adaptation actions that can increase social-ecological resilience. At the same time, elements of the IPBES framework such as strong institutions and governance and high biodiversity, are key to reduce social-ecological vulnerabilities. In the context, nature-based adaptations are key for the long-term sustainability and resilience of tropical forests.

Additionally, the framework on transformative change proposed by Palomo et al (2021) is used to support the general discussion of this thesis. The framework considers three spheres of transformation: the personal (encompassing knowledge, values, and worldviews), the political (involving rules, economic and legal instruments, governance), and practical (behaviours, management, and technical responses) upon which transformation processes are founded. These dimensions align with the concept of leverage points, asserting that transformations rooted in the personal sphere yield more extensive systemic impacts than those originating from other dimensions. The framework also considers the six indicators of transformative adaptation (restructuring, path-shifting, multi-scale, innovative, systemwide, and persistent). This framework will support the overall identification of levels and areas where transformative change can occur within the study area, based on the findings and analysis of this thesis.

These frameworks allow a comprehensive understanding of the links between people, nature, and the impacts of climate change on both, along with the identification of potential solutions that integrate the long-term wellbeing of humans and nature and the potential for transformative changes from individual to community level.

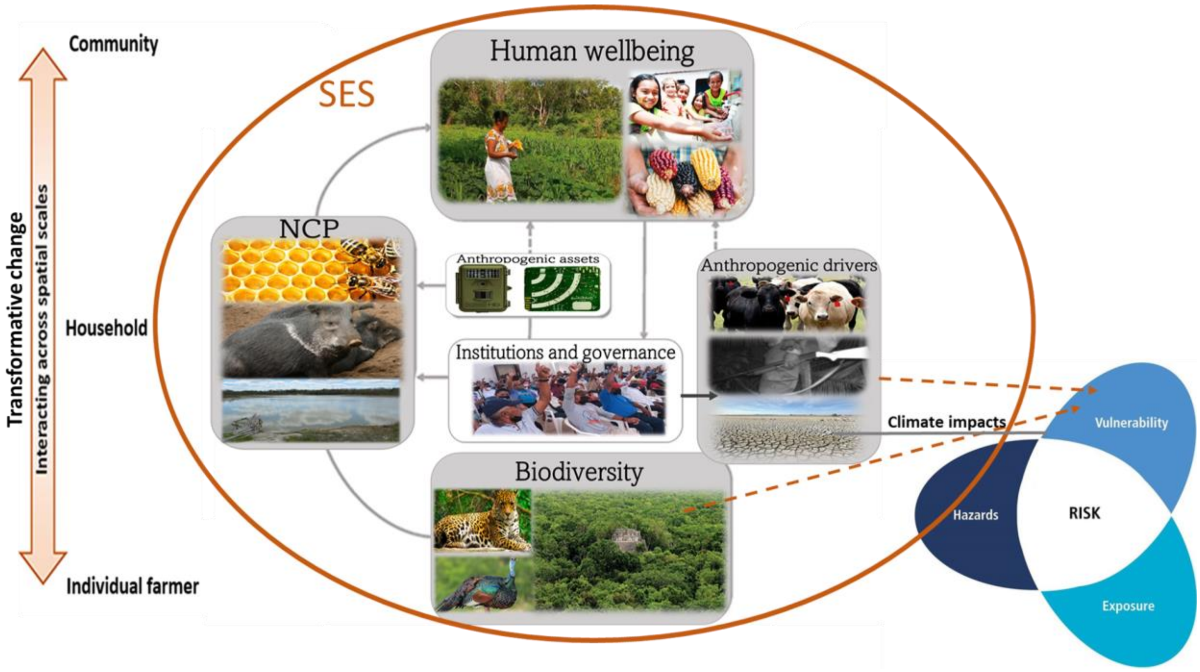


Figure 1.3. Analytical framework for the PhD thesis. Incorporating the SES approach (Ostrom, 2009), the IPBES conceptual framework on biodiversity and human wellbeing (Diaz et al., 2015), and the IPCC climate-risks framework (IPCC, 2014). The analysis will identify potential for transformative changes at different scales based on Palomo et al. (2021), towards sustainable and resilient communities living in healthy forests.

The analytical framework of this thesis is based linked to the methodological strategy presented in the following section.

1.7. Methodological strategy

This section outlines the methodological strategy of the present PhD project. To understand how human communities in tropical forests perceive wellbeing and what pathways they envisage for achieving long-term economic and food security in face of climate change, this project was designed to assess both social and ecological components of a social-ecological system. Integrating both components will build a robust picture of the sustainability and resilience of forest livelihoods in face of climate change. For this both qualitative and quantitative methods were used (Figure 1.4).

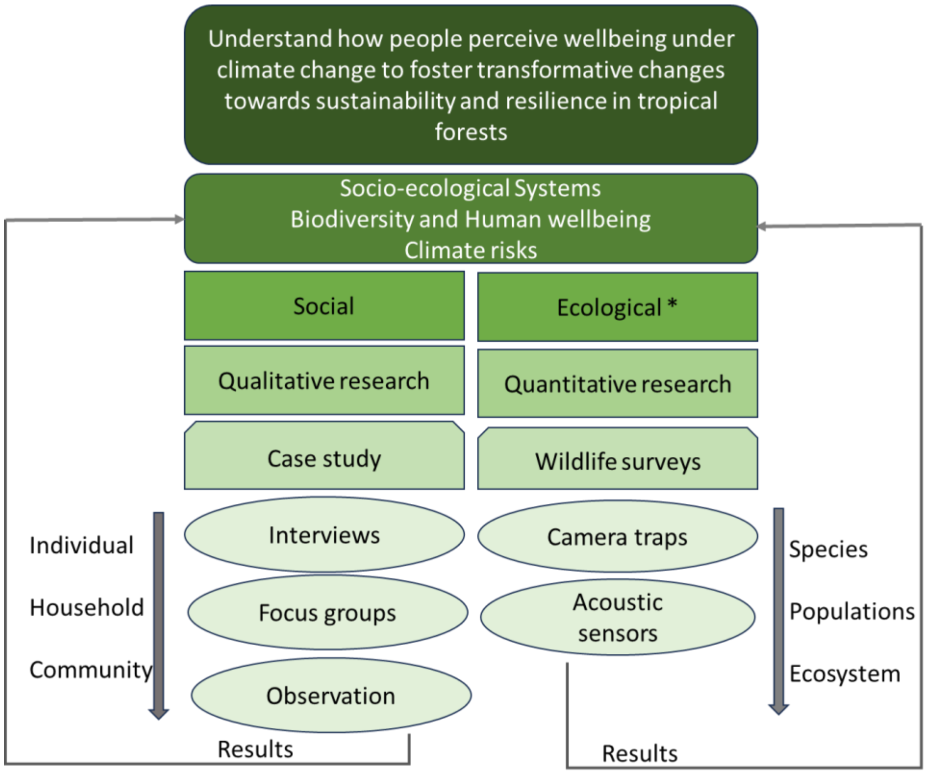


Figure 1.4. Methodological strategy of the PhD project, describing from top to bottom, the PhD main aim and analytical frameworks (round-cornered rectangles), areas of study and associated types of research (rectangles), research design (hexagon), and data-collection methods used (ovals) to gather information at different scales (grey thick arrows). Results obtained were analysed through the lens of the proposed frameworks (grey lines connecting to round-cornered rectangle). The ecological research (asterisked) was not included in the thesis as a data chapter, due to the ongoing nature of wildlife surveys.

Different tools exist to assess human wellbeing in the context of SES. Socio-cultural and economic valuation measures that reflect and translate the impact of NCP on human wellbeing have been used in this context (García-Llorente et al., 2015). The later can be done through the analysis of the perceptions and preferences of locals and different stakeholders on the NCP obtained in a given landscape (Martín-López et al., 2012; García-Llorente et al., 2020). This type of assessment can be used to identify benefits in terms of contributions to human wellbeing or the diverse values local communities place on the use of natural resources (Quintas-Soriano et al., 2018).

Perceptions, encompassing cognitive, affective, and conative components, are key to shaping individuals' relationships with nature (Walmsley & Lewis, 2014). Stakeholders' attitudes and behaviours are influenced by their perceptions, emphasizing the importance of considering these factors in decision-making (Hami & Tarashkar, 2018). People's values, beliefs, and norms further shape their interpretations and actions concerning the utilization of nature and the management of climate change risks and are closely tied to the specific context (Moser & Ekstrom, 2010). Recognizing the diverse socio-cultural contexts influencing perceptions, particularly in indigenous communities, is crucial, as these groups often possess distinct values and norms rooted in their traditions (Ahmed et al., 2019). Acknowledging the need for inclusive perspectives, this project adopts a qualitative research approach, aligning with the growing consensus on integrating the views of vulnerable groups, indigenous peoples, and traditional knowledge in climate change adaptation and resource management actions (IPBES, 2019; IPCC, 2019).

Qualitative data collection allows the researcher to understand everyday human experience in all its complexity and in its natural settings (Wu & Volker, 2009). This type of research aligns with the understanding that reality is socially constructed and acknowledges that the research process is inevitably influenced by values and subjectivity (Denzin & Lincoln, 2011). The socially constructed nature of reality assumes that reality is not directly measurable; instead, it exists as perceived by both individuals and observers. This implies that reality is subjective and diverse, shaped by socially constructed interpretations (Carson et al., 2001). Qualitative research is dedicated to exploring how the social world is interpreted, comprehended, experienced, or constructed. Thus, this approach will allow a meaningful and deep understanding on how rural communities in tropical forests perceive wellbeing in relation to nature, which is a crucial first step for transformative change (Palomo et al., 2021).

Within the scope of qualitative research, this project was designed as a case study. Case study involves empirical inquiry that investigates a phenomenon within its real-life context; it has value particularly when the boundaries between phenomenon and context are not evident, and when multiple sources of evidence are used (Harrison et al., 2017). Its main goal is to conduct an in-depth analysis of an issue, understanding it within its context and from the perspective of participants (Merriam, 2009). As for other forms of qualitative study, the researcher seeks to get close to the participants whilst retaining an objective distance in their natural setting to better understand their perspectives (Creswell, 2013). Case studies require interaction between the researcher and participants for generating data, which is an indication of the researcher's level of connection to and being immersed in the field.

Mexico’s Calakmul Biosphere Reserve (CBR) was chosen as a case study to understand the complex relations between people and nature in tropical forests, and how nature relates to human wellbeing. The indigenous and rural communities inhabiting this highly biodiverse area, have contributed less to global threats such as biodiversity loss and climate change, yet they are suffering disproportionate negative impacts of these challenges. Yet, opportunities exist for transformative changes toward resilience and wellbeing through the sustainable use of forest resources. More details of the area, and its natural and social environment, are provided in the following section (Section 1.8).

To understand how communities perceive wellbeing in the SES context, the four elements of wellbeing (basic human needs; economic needs; environmental needs; and subjective happiness) are studied in the chapters of this thesis. The research used different techniques such as interviews, focus groups, and observations to obtain information at individual, household, and community level. Interviews were tailored to each objective and to the context of the study (hunting practices, climate risk perceptions, and cost-benefits of ranching and honey production, in the context of human wellbeing and NCP) and communities. Having focus groups further allows the understanding of local institutions (ejidos), governance and communities wellbeing. King et al. (2014) suggest that research on human wellbeing with SES context should include participatory methods (e.g., focus groups) with local stakeholders to identify critical NCP for livelihood sustainability, drivers of change, and threats to wellbeing. A detailed description of the methods used for addressing the projects objectives is given in each chapter of this thesis.

Chapter 2 explores wellbeing mainly through understanding how NCP provide basic human needs. The chapter provides a detailed assessment of the hunting practices and patterns in Neotropical forests, along with the socioeconomic, cultural, and geographical drivers and their implications for the long-term sustainability of hunting and provision of wild game for food security. Evidence was based on analysis of quantitative and qualitative data obtained through interviews in three communities with different ethnic backgrounds, vegetation types and distance to the main urban centre. This chapter explores the social-ecological factors shaping this practice and its prospects for long-term sustainability. This chapter also considers elements of subjective happiness in relation to hunting.

Chapter 3 relates to the four dimensions of wellbeing and analyses the vulnerability to climate change of hunting and arable farming, as the main livelihoods for food security the studied tropical forest. It uses qualitative interviews and focus group discussions to assess the meaning of wellbeing in two rural communities, and how climate change is affecting it. Through its use of participatory methods, it supports the development of sustainable and resilient practices to improve the food security of these communities.

Chapter 4 concerns economic wellbeing and evaluates the costs and benefits of livestock ranching versus honey production to assess the potential for apiculture to enrich NCP through its forest resources. Through structured interviews, focus-group discussions, and scenario planning, it assesses the views, perspectives, and desired development pathways of rural communities. These discussions stimulated ranchers from two communities to attend an apiculture training workshop that I organised in collaboration with the honey producers, which focused on capacity building, community engagement, networking, and sustainability.

Chapter 5 delivers a synthesis of general outcomes from the study. The activities developed during this project and their results have initiated first steps towards supporting the uptake of sustainable livelihoods, towards a vision for the long-term wellbeing of rural communities and ecosystems.

An additional component of the wider project involves collection of ecological data to assess the ecosystem health and the sustainability of forest livelihoods (Fig. 1.4). For this purpose, wildlife surveys were and still being conducted to monitor large felids, including jaguars (*Panthera onca*), pumas (*Puma concolor*), and ocelots (*Leopardus pardalis*), and their prey. These species were used as indicators of ecosystem integrity since they play an important role in regulating ecosystems (Ripple et al., 2014), and thrive only in biodiverse forest containing abundant mammals that are also game to human hunters (Harmsen et al., 2011). In early 2019, I started monitoring wildlife in the area using camera traps and acoustic sensors. However, the surveys originally planned for this PhD project were severely affected by nationwide lockdowns in response to COVID-19 pandemic. Despite this interruption, I was able to resume the surveys from 2022 to Autumn 2023. Preliminary results on the wildlife monitoring surveys, including the calculation of the population density of jaguars and ocelots and the assessment their activity patterns, are presented as annexes of this thesis. Research on the densities of jaguar and ocelots in the CBR, is presented in Annex 1, whilst the manuscript of a scientific paper on the activity patterns of felids and their potential prey in the same area, now published in the journal *Biotropica*, is presented in Annex 2. The wildlife surveys monitoring aspect of this study is crucial for the long-term success of the project vision, and the integrity of this ecosystem under ever-rising anthropogenic pressures.

Although the ecological monitoring of the project is not presented as a thesis chapter, it was considered in the design of the project, acknowledging the need for obtaining and integrating both ecological and social data to better understand the links between people, nature, and drivers of change in SES. Additionally, having ecological indicators of ecosystem health was necessary to assess the sustainability of rural livelihoods. Having a more robust understanding of these two aspects, would also allow for evidence base and context-relevant solutions to current societal challenges. Overall, the chapters of this thesis provide a better understanding of the links between nature and the wellbeing of indigenous and rural communities living, and the potential for transformative changes to sustainability and resilience in tropical forests of the CBR.

1.8. The Calakmul Biosphere Reserve as case study of the links between nature and people

The CBR is an exemplar of a social-ecological system under a complex of anthropogenic pressures that sustains indigenous and rural communities that directly depend on forest resources. As in other tropical forests, people's wellbeing depends directly on the benefits they obtain from the tropical forests that they own and manage collectively. At the same time, new environmental and socio-economic dynamics are shaping the long-term viability of the whole. As in many tropical regions, the CBR faces acute challenges in preserving the forest and biodiversity whilst sustainably using these for economic benefit, and ensuring human wellbeing, now and in the future. However, unlike in most of the tropical forest of the world, the rural communities living in the CBR own and have stewardship of one of the most biodiverse tropical forests in the American continent, bringing opportunities on the management of resources.

The CBR is the largest forested and protected area in the Mexico's Yucatan Peninsula. It covers around one-third of the southern Yucatan (> 723,000 ha) and it is located specifically in the state of Campeche (Figure 1.5). The CBR is part of the Selva Maya that extends over Southern Mexico, Guatemala, and Belize, forming the largest region of tropical forest in the American continent after the Amazon. At a local level, CBR comprises the greater Calakmul region with two adjacent state reserves - Balam Kú y Balam-kin - covering a total of 1,243,375 ha of continuous forest in Campeche. This region is considered an important biodiversity hotspot and provides various nature's contributions to the many human populations throughout the region, including those most vulnerable in Campeche, which is the bottom third of Mexican states for Human Development Index (Global Data Lab, 2023).

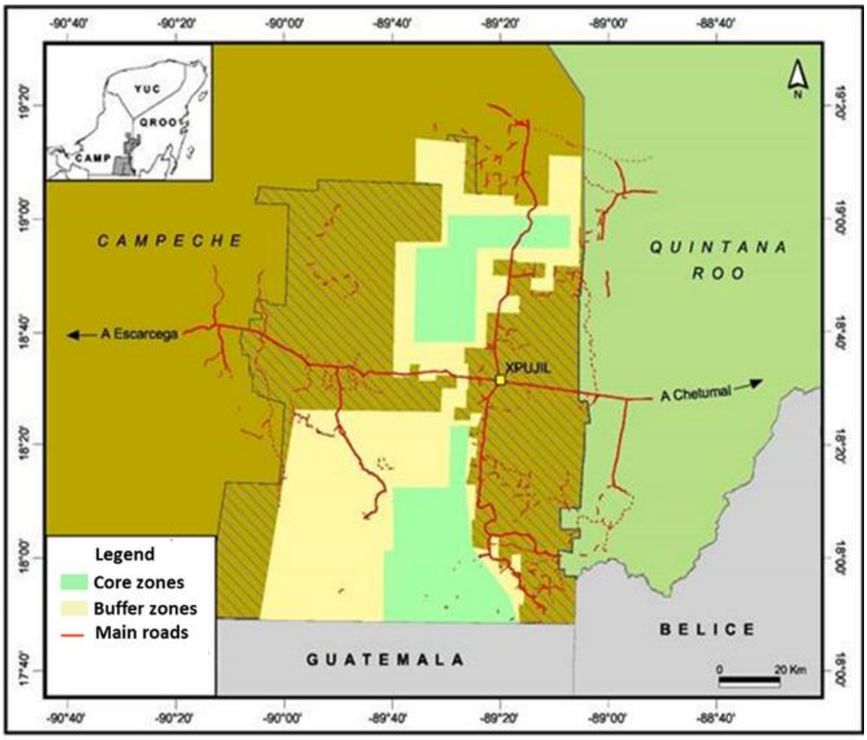


Figure 1.5. Map of the Calakmul Biosphere Reserve in the Yucatan Peninsula and its core and buffer zones (taken from Molina-Rosales, 2010).

1.8.1. Environmental and biological characteristics

The CBR holds exceptional richness in biological and cultural diversity both for Mexico and on a global scale: sufficient to warrant the UNESCO denomination of Biosphere Reserve. These protected areas are meant to support the sustainable development through environmentally friendly livelihoods, linking cultural and biological diversity for the benefit of nature and people (UNESCO, 2021; Van Cuong et al., 2017). The tropical forests of the region comprise a mosaic of different vegetation types. Forest vegetation includes five principal categories, based on tree height, humidity and drainage ability of the soils, and human perturbation: 1) tall perennial forest, 2) subperennial forest, 3) low-subperennial-flooded forest, 4) low semidecidious forest, and 5) secondary forest. Tall perennial forest is characterized by trees up to 30 m tall. This type of forest is found in the southern area near the border with Guatemala occupying only 5% of the reserve area (less than 10,000 ha). Subperennial forests occupy around 50% of the area, with trees between 15 and 25 m high. The low-subperennial-flooded forest covers around 25% of the area. Tree heights are 10-15 m and these forests are seasonally inundated. The low semidecidious forest, occur on hillside slopes with trees about 15 m high, in rocky and dry soil. Secondary vegetation is found near population centres and is formed on abandoned lands cleared for slash and burn agriculture (Martínez & Galindo-Leal, 2002; Reyna-Hurtado & Tanner, 2007).

Calakmul has a warm and sub-humid climate, presenting a mean annual temperature of 24.6°C. Seasonal rain occurs from May to October; with a mean annual precipitation of 750 mm. Rainfall in Calakmul fluctuates between 1,100 mm per year in the northwest region to 1,500 mm per year in the southeast region (INEGI, 2015). The rainfall pattern changes regularly due to the erratic occurrence of El Niño-Southern Oscillation (ENSO) that causes the incidence of hurricanes and periods of drought (Mardero et al., 2012). Besides the temporal rainfall variability, extreme climatic conditions in the region have been identified, with a decrease in the average annual rainfall from 1,100 mm to 938 mm from the mid-1980s to the late 2000s and an increase in the occurrence of periods of drought (Mardero et al., 2012) detected both. Rainfall declines have been attributed to regional deforestation processes that might have caused a decline in the evapotranspiration rate (Gueye, 2018).

The entire Yucatán region has flat topography, with karstic soils on elevations less than 400 m above the sea level. There are no permanent river systems or water bodies in the area. Water derives from precipitation, which mostly infiltrates through the limestone and drains over the surface into ponds, locally known as *aguadas*. These water bodies are formed in depressions on the land which have filled with fine-textured sediments that retain water (Martínez-Kú et al., 2008). *Aguadas* are extremely relevant for wildlife and humans in the region, since they are the only water source during the dry season that extends from November to April (Vidal-Zepeda, 2005; Garcia-Gil et al., 2002).

The CBR is a stronghold for populations of threatened and endangered mammals. More than 80 species of mammals have been identified within the reserve, representing 1.4% of Earth's mammalian species richness within 0.0014% of Earth's surface area. These include five of the six species of felids in Mexico - the jaguar (*Panthera onca*), puma (*Puma concolor*), ocelot (*Leopardus pardalis*), margay (*Leopardus wiedii*), and jaguarondi (*Herpaolurus yagouaroundi*) – and threatened species such as the anteater (*Tamandua mexicana*), the white-lipped peccary (*Tajassu pecari*), and the tapir (*Tapirus bairdii*). The area has around 400 species of birds, representing 4.0% of Earth's bird species richness. More than 60 of these birds are migratory, two species are endemic to the Yucatan Peninsula, and 32 are threatened with extinction. There are 75 species of reptiles and 18 species of amphibians, representing 70% of the amphibians found in the Yucatan Peninsula (Pozo & Galindo-Leal, 1998). Floral diversity includes over 1,500 species, of which 10% are endemic (SEMARNAP, 2000).

Water availability determines the presence, abundance, distribution and survival of local flora and fauna (Carrillo-Reyna et al., 2015; Garza-López et al., 2018; Pérez-Cortéz et al., 2012). This factor also constrains the movements of several species, such as white-lipped peccaries (Reyna-Hurtado et al., 2009), tapirs, and jaguars (O'Farrill et al., 2006). The spatio-temporal variation of the aguadas has an important effect on the activities and habits of many species (Chávez, 2010; Naranjo & Bodmer, 2002). If precipitation during the wet season does not replenish the aguadas, animals may broaden their migratory ranges to survive the dry season, increasing the risk of hunting and/or conflicts with the rural communities in the buffer zone of the CBR.

1.8.2. Human populations rely on forest resources

The tropical forests of the Calakmul region are occupied by human inhabitants that live in and depend on the forest for their livelihoods. Today, more than 32,200 inhabitants occupy the buffer zone and surrounding areas of the CBR. These are organized in 158 *ejidos*, (communal forests: Figure 1.6) of which only one is an urban area with a large population of almost 4000 inhabitants, compared to the others that have between 250-2500 inhabitants (INEGI, 2019). Around 45% of the municipality identifies as indigenous (INEGI, 2019).

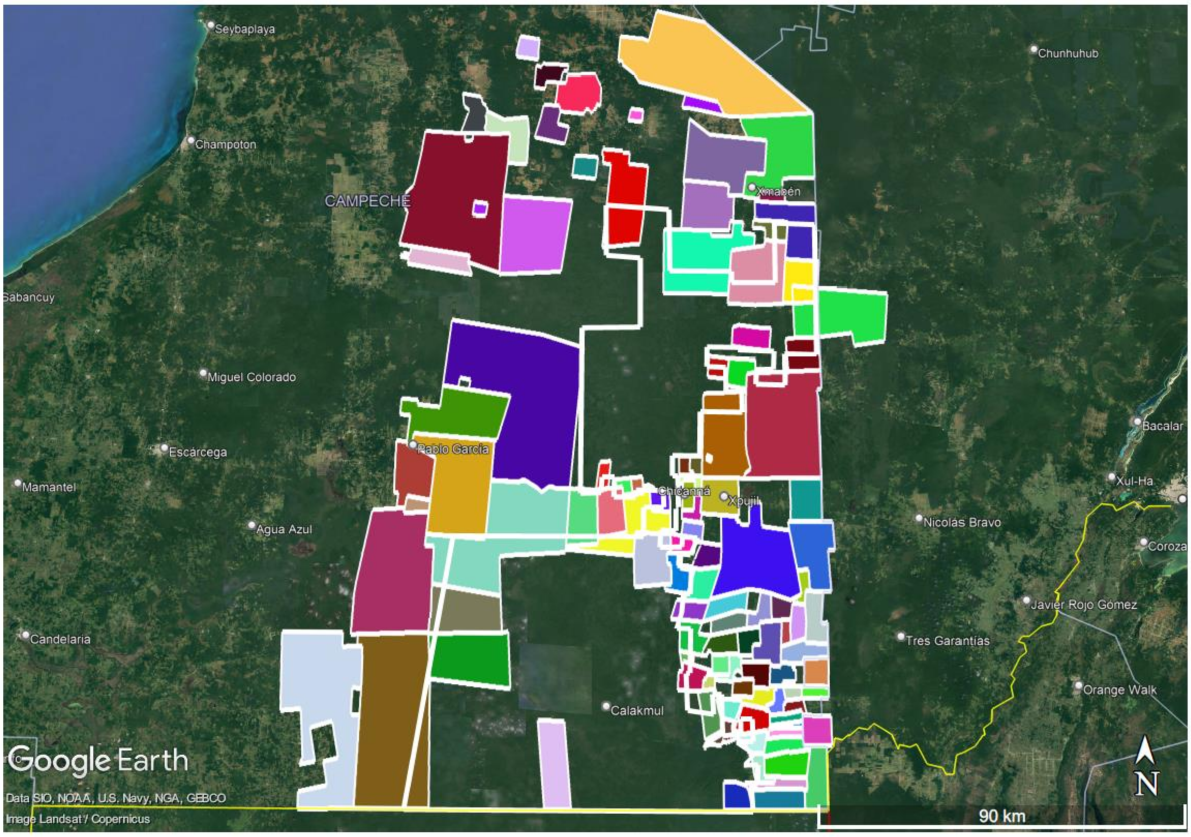


Figure 1.6. Ejidos in the buffer zone and surroundings of the CBR. Each coloured shape demarks an area of land that is collectively owned and managed by its local community.

The Calakmul region has a long history of human occupation despite its hash environmental and economic conditions. Previously inhabited by ancient Mayan civilizations, this region remained largely uninhabited during the last millennium until the 1930s (Tec-Poot & Bocara, 1980). By 1970, the Calakmul municipality had less than 4,000 residents, mostly indigenous Mayan descendants and temporary workers from lumber companies that rapidly depleted valuable timber species from the forests (Klepeis, 2004; Turner II et al., 2004). Between the 1970's and 1990's, large groups of indigenous and rural peasants from other parts of the country colonized the region. The newcomers soon realized that the area offered little opportunities for economic and social development. They were unable to use timber species - due to previous levels of overexploitation and due to the decree of the biosphere reserve in 1998. Due to water scarcity and infertile soils, these people also faced a challenging environment to farm, relying on swidden agriculture for subsistence (Dobler-Morales et al., 2020). Swidden, known as milpa in Mesoamerica, is a technique of rotational farming that involves the slash and burning of forests for cultivating maize, intercropped with squash, beans, and other plants, then left to regenerate after five to ten years (Klepeis & Chowdhury, 2004). Furthermore, the geographic location of these lands, kept the peasants isolated and far from urban areas with limited highways and communication. Despite the harsh conditions, colonization was motivated by the Federal government who granted lands known as *ejidos* to this people (García-Gil & Pat-Fernández, 2000).

1.8.3 Land tenure and ejidos in the CBR: communal agrarian tenure

An *ejido* is a type of social land ownership unit managed by peasant cooperatives, for the main purpose of agricultural development. After the 1910 Mexican Peasant Revolution, the newly instated government pledged to amend the land-tenure inequality caused by the Spanish Conquest (Perramond, 2008), by granting customary rights to landless farmers. The land and water remain property of the nation with usufruct rights held in perpetuity by the community (Ley Agraria, 1992). The agrarian reform programme was completed in 1992, after having allocated land to 4 million peasants through *ejidos*.

This communal land regime aimed to enhance the quality of life and rights for the most vulnerable people. The purpose of the ejido was to provide a subsistence base for peasant families, mainly through agriculture (Garcia-Barrios et al., 2009). As they were not to become an economic commodity, ejidos were inalienable and indivisible. Ejidatarios, mostly males, must work the land with their own hands, live within the ejido village, and participate in internal assemblies, to keep their land rights. These rights are passed down the generations by inheritance; they cannot be bought or sold. An ejidatorio can only transfer their rights to one of their male descendants; only in special circumstances, can they be passed on to women (Ley Agraria, 1992).

Ejidos are organized and commonly managed according to their land-use area. There are three forms of land-use area: 1) human settlement, meant for the development of community life; 2) parcels or plots of land, comprising fractioned fields to be exploited individually, mainly for agriculture; and 3) communal land, usually forest used for economic development of the community (Figure 1.6). Communal land is commonly owned and managed by ejidatarios.

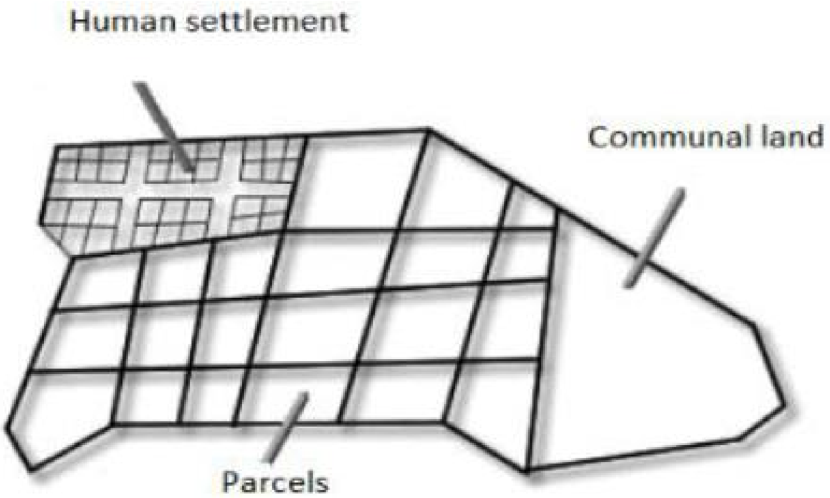


Figure 1.6. Spatial organisation of an ejido in Mexico (Taken from INEGI, 2015).

Each ejidos has its own governing board and customary laws. The use and management of the land and its resources, social norms, community activities, and investments are usually established by a community council. All ejidatarios are part of the community council and are obliged to take part in the decision-making processes and activities for the benefit of the community (Ley Agraria,1992)

Ejidos play an important role in shaping environmental, social, and cultural dynamics in Mexico. By 2017, more than 30,000 ejidos occupied more than half of the country (51% with over 100 million ha; INEGI, 2019). Ejidos have gained an important political role at local to national levels. These institutions have control over virtually all areas of community life in the countryside, including agricultural production and credit, access to land and natural resources, provision of NCP, and political participation in regional and national fora (Warman, 2001).

Ejidos can be an asset for the long-term maintenance of nature and for human wellbeing at a local scale. Currently, more than 70% of the Mexican forests fall within the common property of ejidos. Therefore, they play a key role in maintaining natural areas in public ownership (Torres-Mazuera, 2019). They represent the basic geographic unit for decision making related to the use of natural resources where decisions are generally based on local knowledge and on a feeling of common wellbeing. This form of communal land ownership is not unique to Mexico as it has similarities with the Wildlife Conservancies of Kenya, the Communal Areas of Zimbabwe, and the Communal Lands of Papua New Guinea.

While land tenure in the CBR is under shared ownership, the Federal government owns the two core zones, occupying 51% of the reserve. These are managed by the Mexican Commission of Protected Areas (CONANP for its initials in Spanish). Core Zone I is located at the south and comprises 147,915 ha and Core Zone II occupies 100,345 ha at the north of the reserve. These two areas are surrounded by buffer zones occupying 474,924 ha (SEMARNAP, 2000; Figure 3). Most of the buffer zone is mainly owned and managed by ejidos. Private property has only 2% in the north core zone (García-Gil & Pat-Fernández, 2000).

Socioeconomic conditions

The biophysical and social contexts of the region, along with the presence of the CBR which brought non-coordinated institutional actions, exacerbated existing vulnerabilities of the population living in the area. The Calakmul municipality is ranked as one of the most marginalized and deprived municipalities in Mexico, with high poverty levels (86% of the municipality) sparse population (1.9 people/km^2), and highly isolated from markets (CONEVAL 2022; Araujo Monroy, 2014). Most of its population lacks social services and basic services in their households. Many houses are not built with quality materials, making the population vulnerable to diverse hazards. In addition, most of the population has no access to electricity, potable water, or gas for cooking (CONEVAL, 2022; Table 1.1).

Table 1.1 Socioeconomic indicators and poverty ranking in the Calakmul municipality in 2022 (CONEVAL, 2022).

Indicator	Percentage of the population	Description
Educational Gap	20.0%	Population 15 years old (or older) that does not have reading or writing skills and that has not started or finished primary or secondary education.
Lack of health services	22.5%	People registered to a National Health Provider
Lack of social security	86.3%	Mechanisms to ensure economic means of individuals and families in case of accidents, illnesses, old age, or pregnancy.
Poor quality and space in household	20.0%	Houses that don't meet the four of the next requirements are considered as houses with poor quality and space: 1) flat, concrete, or wooden floor, 2) wooden, concrete, clay, palm or tile roof, 3) partition, block, rock, concrete or wooden walls,

		and 4) more than 3 persons per room (excepting kitchen and halls).
Lack of basic services in household	70.3%	Basic services include 1) drainage, 2) potable water, 3) fuel for cooking (gas, electricity, coal or wood fire and 4) electricity.
Lack of food security	35.2%	People in this category are those who: 1) feed constantly on a low variety of food, 2) think they eat less than they should 3) have ran out of food or 4) passed one day without eating or lacked one or more of the three meals taken each day.

The location of an ejido is an important factor determining its degree of deprivation. In general, deprivation rises in ejidos closer to international borders and located further away from the main urban area, Xpujil, or the Escarcega-Chetumal highway (Araujo-Monroy, 2014). These ejidos have reduced access to roads and transportation, thus being isolated from the main government and market centres. This hampers their ability to efficiently distribute their crops and products, acquire household and farm supplies, get medical attention in case of emergency, or do paperwork to access subsidies and government support. In contrast, these ejidos tend to occupy the most densely forested areas, which provides opportunities for subsistence and development (Araujo-Monroy, 2014).

Subsidies contribute substantially to farmers' economic security. The political and economic marginalization of the area has made it hard to improve local socioeconomic conditions and to promote sustainable resource use (Turner et al., 2016). Although the presence of the CBR limited the range of economic activities, it has attracted governmental support, bringing subsides and programmes that currently work as a source of income for local communities (Villaseñor et al., 2018). These include, Payment for Environmental Services, subsidies for cropping and livestock farming, and temporary employment programmes in the CBR, among others.

Rural communities in poor countries are highly dependent on the NCP provided by the natural landscapes they inhabit. These contributions offer consumable goods (e.g., wild meat, medicinal plants and timber), and capital goods that can be expected to generate consumables in the future (e.g., forested areas that can be used for ecotourism; Dasgupta, 2002). When natural systems and contributions to people are lost, people that depend directly on the forests - usually the economically weakest - tend to suffer the most. Rural communities in developing countries depend on governmental subsidies to develop their livelihoods or to sustain the economic means for subsistence, which makes them more vulnerable to both ecosystem loss and political and economic processes (Dasgupta, 2002). These rural communities can become trapped in a cycle of dependency when political and economic processes result in subsidies for types of land use that damage NCP.

Agriculture

In Calakmul, people engage in a range of natural resource-based activities, constrained by the environmental and socioeconomic conditions. Agriculture is the main subsistence and economic activity in the region. Like other tropical developing regions, agriculture is practiced by smallholder farmers in the CBR (Harvey et al., 2014). Smallholders are farmers who have low asset bases and who operate on less than 2 ha of cropland (World Bank, 2004). Agriculture and its income is complemented by the products and or profits obtained from hunting, livestock ranching, honey production, and logging. (SEMARNAP, 2000). Additionally, off-farm employment, government subsidies, and remittances from men migrating to the United States, have tended to bring additional support to household economies (Radel et al, 2017).

Subsistence and commercial agriculture are the most important activities in the CBR. All farmers and their families in the area rely mainly and foremost in swidden agriculture for food security. This small-scale, rain fed subsistence practice is widespread in the region due to its low input requirements and the ability to thrive in the challenging environments (Schmook et al, 2013). Through slash-and-burn schemes farmers cultivate maize (*Zea mayz*), intercropped with squash (*Cucurbita sp.*), and beans (*Phaseolus vulgaris*). Additionally, jalapeno chilli peppers (*Capsicum annus*) and squash (*Cucurbita sp.)* are grown in almost all the ejidos for commercial purposes (Schmook et al, 2013). These along with livestock ranching represent the most important cash crop activities in the region (Radel et al, 2017).

Livestock ranching can function as a capital asset to support households in times of need. Historically, ranching was not a common activity in the CBR since purchasing livestock is expensive and the long periods of drought make the production of pasture very challenging. However, government subsidies for production of cattle, sheep, and goats, encouraged this activity among the CBR smallholders. Farmers in the CBR incorporate cattle as a long-term source of income, but also as a relatively liquid asset in case of an emergency (Schmook & Radel, 2008; Radel et al, 2017). Cattle ranching is solely practiced for commercial purposes, while sheep and goats are sporadically consumed (Schmook et al., 2013).

Deforestation in the area has increased since human settlement began in the 1970s. By 2000, there was a slight net increase in open lands in both the core and buffer zones, with figures of 0.12% and 0.49%, respectively (Vester et al., 2007). Initially, traditional agriculture was the primary driver of deforestation, but over the past two decades, ranching and conventional agriculture have become more prevalent due to government policies promoting agricultural intensification (Spiric et al., 2022). Recent studies highlight the importance of better understanding the region's productive activities in relation to forest sustainability and suggest that to ensure resilient and inclusive growth in the CBR, it is essential to financially support sustainable agricultural practices, beekeeping, and reduced-impact logging that cover the transaction costs of unsustainable livestock breeding and industrial agriculture. (Spiric et al., 2022; Dobler-Morales, 2021).

1.8.4. Natural resource exploitation

Hunting is commonly practiced in the CBR. Wild game represents the main source of protein for many people in Calakmul (Escamilla et al., 2000; Santos-Fita el al., 2012). The extent of reliance on wildmeat for protein intake varies amongst communities and households and is influenced by game availability and cultural preferences (Escamilla et al., 2000). Despite this, wild game is an imponent of the farmer-hunters diet, even in households that keep domestic animals, such as chickens, turkeys, and pigs (Escamilla et al., 2000). Although subsistence is the main purpose of this activity in the CBR, it provides occasional income when game meat is sold locally (Escamilla et al., 2000).

Hunting choice is influenced by several factors, such as game availability, food needs, and cultural preferences (Escamilla et al., 2000). However, there is evidence that this activity, along with the synergic effect of sport hunting, has had profound consequences on biodiversity, with the almost complete elimination of groups of white-lipped peccary in some communal forests surrounding the CBR (Reyna-Hurtado et al., 2010). To date, little is known about hunting practices and patterns in relation to social, economic, and environmental features, the motivations of hunters, or the impacts of this activity in the area. Only a few studies have been developed in the CBR to investigate this matter. Most such research has focused on assessing the ecological impacts of hunting on game populations, by comparing game abundance in areas with different hunting pressures (Reyna Hurtado, 2010 and Briceño-Mendez et al., 2014 for white-lipped peccaries; Briceño-Mendez et al., 2016 for two peccary species; Reyna-Hurtado & Tanner, 2005 and Reyna-Hurtado, 2007 for six ungulate species). Results from these studies show that hunting affects the ungulate species differently. Brocket deer, white-tailed deer, and collared peccary are more resistant to hunting pressures than the white-lipped peccary.

Two previous studies have made a deeper assessment of hunting in the CBR (Escamilla et al., 2000; Santos-Fita et al., 2012). Escamilla et al. (2000) described hunting patterns, trends, and preferences, analysing a wide array of associated ecological, social, and economic factors in three communities of the CBR. The authors studied the hunting preferences and the relative abundance of game species by counting tracks and collecting hunting data through an under-covered key informant in each community. They found that ten species of birds and mammals, including great curassow, ocellated turkey, agouti (*Dasyprocta punctata*), armadillo (*Dasypus novemcinctus*), coati, paca, brocket deer, collared peccary, white-lipped peccary, white-tailed deer, accounted for 97% of the hunting records in these communities. They found that the purpose and frequency of hunting activities depend on the local context of cultural traditions, household income, game availability, and need for dietary protein.

Santos-Fita et al. (2012) studied the uses of wildlife in different communities of the Yucatan Peninsula, including a couple in the CBR. They found that wildlife in the region was widely used as a food resource, with the great curassow, ocellated turkey, paca, white-tailed deer, and collared peccary being the top harvested species. They also found that the numbers of hunted individuals and biomass obtained declined as hunting distances increased from villages. This issue will be addressed in more detail in Chapter 2.

Honey production is an increasingly important economic activity for smallholders in the CBR. Campeche is the second largest state of Mexico for honey production after Yucatan and contributes to position Mexico as the third largest honey exporting country, after China and Argentina (Ricalde, 2017). This activity is gaining attention in the CBR as it provides both economic and conservation benefits (Rodriguez-Solorzano, 2014). This matter will be further revised in Chapter 4.

1.8.5. The climate change-biodiversity nexus at local scale

Although the CBR remains one of most isolated and least populated regions in Mexico, the human communities and the tropical forests in the area are facing severe threats that risk the ecosystems' health and people's wellbeing. Climate change has significantly impacted and continues to impact the Calakmul region (Mardero et al., 2020), affecting both biophysical as and social processes, whilst exacerbating already-existing vulnerabilities.

Studies suggest that climate is becoming more extreme in the Yucatan Peninsula, Campeche, and the Calakmul regions. Andrade-Velázquez et al. (2021) found positive historical temperature trends (0.1 mm/year) and positive precipitation anomalies (~0.01 ◦C/year and ~0.1 mm/year) for southeast Mexico's Yucatan Peninsula from 1960 to 2016. Projections under three Representative Concentration Pathways (4.5, 6.0, 8.5), showed the same trend of temperature increase as the historical record for the region. Regional climate projections additionally suggest the occurrence of more extreme droughts (IPCC, 2014; Orellana et al., 2009), supporting local and state-level observations. In Campeche, average temperatures are projected to increase from 32°C to 33.4°C in the near future (2015-2039) and to 35.2°C in the distant future (2075-2099; PECC, 2014). Decrease in average precipitation have been recorded for Campeche. Overall, there is a loss of 0.65 mm/day or 237.25 mm/year between the historical period and the distant future. This pattern is expected to persist over time, with the southern zone experiencing a more pronounced decline in precipitation (PECC, 2014).

In Calakmul, rainfall patterns have shown increasing interannual variability and more pronounced anomalies, both positive and negative from 1982 to 2016, with more marked changes during 2004 to 2016 (Mardero, et al., 2019). Additionally, drought frequencies have increased for the last 50 years (Mardero et al., 2012). These changes in climate have negatively impacted the livelihoods of already deprived communities in the Yucatan Peninsula and Calakmul (Metcalfe et al., 2020).

Water scarcity is impacting wildlife and human populations in the CBR. Water available for wildlife and human consumption is stored in natural ponds (aguadas), artificial waterholes (locally known as jagueyes). These sources usually dry up during the dry season (November to April; however, the artificial water waterholes might keep water throughout the year (García-Gil et al., 2002). In the wake of severe droughts, aguadas have remained dry for long enough periods to lose their water-retention capability (Sánchez-Méndez, 2020). Water scarcity is forcing large mammals to search for food and water in places where people store water and carry out productive activities, increasing human-wildlife conflicts (Pérez-Flores et al., 2021).

Additionally, human pressures on wildlife increase the risk of biodiversity loss with implications for the food security of ejidos. Intensifying human activities in the communities, such as livestock ranching, are changing the landscape through habitat loss, fragmentation, land-use change, and habitat degradation, contributing to increasing threats to wildlife populations (Pérez-Flores et al. 2021). Hunting is actively and openly practiced in the communal forests of the CBR, where villagers rely on wild meat for protein intake (Escamilla et al., 2000). Reductions in game populations may further risk the food security and wellbeing of the rural communities in the area.

With no surface rivers or irrigation, agricultural activities in Calakmul are highly dependent on the timing of the onset of the rainy season and prediction of the intensity and distribution of seasonal precipitation (García-Gil et al. 2002). Agriculture, particularly swidden, has already been drastically affected by climatic stresses. Increasingly frequent crop failures and pests within the last two decades years, caused by unpredictable droughts, have affected the food security, income, and practices of farmer-hunters in the CBR (Alayón-Gamboa & Ku-Vera, 2011; Mardero et al., 2020). Reduced crop yields along with increasing economic demands for fertilizers and pesticides, have forced increasing numbers of communities to supplement their incomes with government-incentivised livestock ranching. The subsequent conversion of forest to pasture further exacerbates regional precipitation extremes, and depletes wild game in the forest that supplement the diet of these communities. These game populations are already vulnerable, because the presence, abundance, distribution, and the survival of many animal and plant species living in the CBR is determined by water availability (Carrillo-Reyna et al, 2015; Martínez-Kú et al, 2008) and therefore prone to increasingly erratic seasonality of rainfall (Reyna-Hurtado et al., 2019).

Arable farming in the deprived ejidos of Calakmul is highly vulnerable to climate change. Studies have shown that climate change is negatively affecting both traditional and commercial crops cultivated in the area for subsistence and income, affecting smallholders who usually have limited capacities to respond to these changes (Alayón-Gamboa & Ku-Vera, 2011; Rodriguez-Solórzano, 2014; Green et al., 2020; Metcalfe et al, 2020). Despite a growing number of studies, evidence is needed from locally grounded data sources (Thornton et al., 2014).

In contrast, little is known about climate change impacts of hunting practices in the Calakmul region and globally, despite it representing an important source of food for human groups living in tropical forests (León & Montiel, 2008; Santos-Fita et al., 2012). In Calakmul, water scarcity, fires, and increased animal movements in search of food and water have been reported as influences of droughts on wildlife populations (Pérez-Cortez et al., 2012; O’Farrill et al., 2014; Sánchez-Pinzón et al., 2020; Reyna-Hurtado et al., 2022).

A growing number of individuals are finding economic security, through alternative livelihoods such as honey production from apiaries within the forest. This activity has benefits for societies and ecosystems in the CBR. These benefits will be explored in Chapter 4. Honey producers in the area see benefits to forest biodiversity in raising the quality of their honey, and strength in numbers through increasing the size of their honey-producer community. It has also allowed farmers to cultivate smaller fields, thus reducing their vulnerability to climate and economic constraints (Rodriguez-Solórzano, 2014).

Despite these potential benefits, the impacts of honey production and other rural livelihoods on the societies, economies, and the ecosystems of the CBR are unknown. This information is particularly relevant today, when climate change is already impacting the region (Mardero et al., 2020). Data on climate change impacts on the subsistence agricultural practices of ejidos of the CBR is available (Alayón-Gamboa & Ku-Vera, 2011; Green et al., 2020), but no data is available for other livelihoods.

Chapter 2 – Hunting patterns in the CBR and their implications for long-term sustainability

Contributions

This chapter was envisioned and led by me in collaboration with my supervisor Prof Patrick Doncaster and PhD candidate Julio Carrillo Gonzalez from the School of Education, UoS. I initiated the idea for the study and developed its aims and objectives based on previous observation and work done in the CBR during 2018. Julio Carrillo and Patrick Doncaster provided support to develop the methods, design the questionnaire, and managed the evaluation of ethics in accordance with UoS policy. I performed the surveys, analysed the results, and wrote the chapter. Dr Cuauhtémoc Chávez from Mexico's Universidad Autonoma Metropolitana and Patricio Canul Chuc from the local NGO Pronatura Península de Yucatán A. C., provided links to key informants and interviewees. Julio Carrillo provided support during fieldwork, by conducting meetings with community authorities to inform them about the project and acting as a gatekeeper during the interviews. Additionally, they assisted me with the interviews. Prof Patrick Doncaster provided comments on drafts of the questionnaire and the chapter. Prof Marion Demossier from the Faculty of Arts and Humanities, UoS, provided valuable suggestions for writing the chapter. Fieldwork was conducted with resources obtained with my CONACyT studentship (472259) and a Rufford Small Grant (31803-2). This chapter is in preparation for two scientific papers. The first will contain information on hunters' practices, motivations, and identities, and will be submitted to the Journal of Ethnobiology. The second will integrate data on hunting and game consumption frequencies presented in this chapter, calibrated with data on game species' abundance and gunshot frequencies that will be available after summer 2023. This second paper will be submitted to the journal of Applied Ecology or Methods in Ecology. Collaborators mentioned above will be included as co-authors of both papers.

2.1. Abstract

Mexican tropical forests are amongst of the world's hotspots of hunting-induced defaunation. Mexican rural villages practice hunting to obtain wild meat for protein intake. However, this activity has profound implications for biodiversity, ecosystem function, and human livelihoods. In the Calakmul Biosphere Reserve (CBR), hunting functions as a supplementary livelihood. This area currently lacks objective measures of hunting frequencies with which to calibrate social-environmental impacts of hunting on cultural identity and food security under climate change. Sensible regulations for sustainable hunting must be informed by a full understanding of the drivers of wellbeing for rural communities that hunt, as well as the drivers of faunal health in the forest. A structured questionnaire survey of 124 households was conducted to evaluate hunting practices and frequencies in three rural communities of the CBR. Semi-structured interviews and participant observation were conducted in the same communities to evaluate the motivations for hunting, and hunting methods, and regulations relating to this activity in each ejido. Interviews indicated that subsistence hunting is a common practice in Calakmul. Adult males in 95 households (77%) hunted daily, weekly, or monthly. Even more households regularly consumed wild meat (n = 119, 96%). Hunting frequencies and meat consumption were highest in isolated communities surrounded by forest. Local inhabitants in the three communities had observed changes in species availability during the last 10 years, and hunters had modified their hunting strategies in response to scarcer game. Socio-economic, cultural, and geographical factors coinciding at a local scale, shape the hunting practices and patterns in the CBR. However, environmental factors, such as increasing droughts and unpredictable rainfall patters, are increasingly playing a determinant role in hunting and game consumption in these villages. Impacts of global issues such as climate change can severely threaten the food security and wellbeing of rural people in the CBR, despite these communities having contributed little to the anthropogenic drivers. Context-relevant and well-informed measures at a community scale can support ejidos to sustainably self-manage their resources.

2.2. Introduction

Ecosystems and their biodiversity are declining globally, endangering the foundations for quality of life, and security in food, water, and energy needs. The world's poorest regions experience the worst impacts from changes in climate, biodiversity, and degradation in NCP. Overexploitation of species is one of the strongest yet overlooked drivers of biodiversity loss worldwide (Diaz et al., 2019a; Benítez-López et al., 2019).

Tropical forests and the wellbeing of people inhabiting them are under severe threat from human activities. Urbanization, agriculture, and logging have severely affected the world's tropical forests, with merely 20% of the remaining area considered intact (Potapov et al., 2017). However, this estimate does not consider other subtler but widespread forms of degradation, such as the loss of wild animals from hunting (Benitez-Lopez et al., 2017). Humans have hunted for food and income during millennia, yet current hunting rates are unsustainably high in the tropics due to the high demand of growing human populations, a surge in the commercialization of wild meat, and higher accessibility to remote areas (Bennett, 2002; Robinson & Redford, 1991; Fa et al., 2002). Consequently, forests in developing countries are becoming "empty" (Redford, 1992), affecting biodiversity and the wellbeing of its human populations (Ripple et al., 2016; IPBES, 2019).

Climate change is simultaneously affecting tropical forests' biodiversity and livelihoods. Changes in temperature and precipitation have changed the distribution and phenology of tropical plant and animal species (Saatchi et al. 2008, Gopalakrishnan et al. 2011; Gunarathne & Perera 2014; Abrahms et al., 2022), contributing directly and indirectly to reductions in mammal populations, with implications for rural livelihoods (Sheldon, 2019; Bodmer et al., 2020; Nunez et al., 2019). Impacts of climate change on tropical forest livelihoods, such as agriculture and tourism, have been described (van Vliet et al., 2012; Ofori et al., 2021; Prideaux et al., 2017), yet little is known about the direct impacts of this phenomenon on hunting and its links with biodiversity loss. Only a study in Ghana showed dramatic declines in bushmeat productivity associated to climate change-related fires, affecting bushmeat intake and the income of traders for more than five years (McNamara, 2013).

Human wellbeing directly relies on biodiversity. More than 70% of people living in tropical rural areas depend directly on wild species for subsistence and income, mainly exploited by hunting. However, many of these wild game species are declining rapidly due to unsustainable practices. Globally, hunting is threatening more than 1,300 wild mammal species, including 669 species already classified as threatened by the IUCN Red List (IPBES, 2022; Maxwell et al., 2016). Addressing the causes of unsustainable use, and reversing current trends, will result in gains for wildlife and rural communities in the tropics, where environmental degradation, resource depletion, and climate change threaten the livelihoods, food security, and wellbeing of the poorest peoples relying on wild species (IPBES, 2022; Cawthorn & Hoffman, 2015).

Hunting is an important source of protein and culture for humans in the tropics. Rural and indigenous people in Africa, America, Asia, and Australia rely on hunting for protein intake. It is estimated that more than 5 million tons of meat feed millions of people living in the Amazon and in the Congo Basin forests each year (0.15 million Tons and 4.9 million tons respectively; Fa & Peres 2001; Fa et al., 2002). Yet, the connections of people with wildlife run deeper than just food security, touching on fundamental questions of identity, spirituality, and health (Descola, 1998; Fausto, 2007).

Hunting can be classified according to its purpose. Generally, this practice is considered a subsistence activity when its main purpose is to satisfy the basic needs of the hunter, his family, and occasionally the community (Jorgenson, 1995; Ojasti, 2000). However, it is important to highlight that basic needs are not only material, but also cultural and religious. Therefore, the role of subsistence hunting role is not only as a simple material practice, but rather a complex way of obtaining resources from nature lying on a wide social, symbolic, and ritual construction of reality (Dehouve, 2008). Moreover, while its main motivation is usually the need for self-consumption, subsistence hunters may sell the surplus of game as a source of income. As the proportions of meat being sold varies according to the place and context, it is difficult to establish a clear boundary between subsistence and commercial hunting (Van Vliet et al., 2019; Santos-Fita el al., 2018). Hunting is considered a commercial activity when the hunter's principal motivation is to obtain financial profit in exchange of their game (Montiel et al., 1999).

In the world's tropical areas, wild vertebrates have been an important element in human evolutionary history and culture and still represent an important NCP. In these areas, a large proportion of human residents continue to use diverse wild species as sources of protein, fat, medicine, clothes, tools, adornments, ritual objects, and income (Redford & Robinson, 1991; Milner-Gulland et al., 2003; Bodmer et al., 2004).

Inextricably linked to its value in providing food resources, hunting has important recreational and cultural values. Reductions in wild populations risk compromising not only food security but also the cultural identity of diverse human groups (IPBES, 2019; 2022). Examples of these can be found around the Americas. It is estimated that indigenous people from Bolivia would need from $60 to $120 USD per family per month if they had to replace the protein otherwise contributed by nature through hunting (Copa & Townsend, 2004; Townsend & Gomez, 2010). A study in Santa Cruz, Bolivia estimated that the monetary value of this NCP in the state at around $3-$24 million a year (Gobierno Departamental Autonomo de Santa Cruz, 2009).

In tropical America, wild game plays an important role in the daily lives of indigenous and rural communities. The Mayan people deliberately use their milpas - a private land plot where farmers cultivate maize, intercropped with squash and beans usually with slash and burn regimes - to attract game and increase their hunting success. These communities typically have no access to extensive hunting territories; thus, they rely primarily on their agricultural production (Santos–Fita et al., 2012). Although wildlife has become mainly a supplement to their household's nutrition, they maintain an important cultural and spiritual relationship with wildlife (García del Valle et al., 2015). Moreover, local communities throughout the Americas relate hunting to leadership training, territorial control, and cultural stories (Townsend & Macuritofe-Ramírez, 1995; Urbani & Cormier, 2015), and to art (Salinas, 2010) and rituals (Baleé, 1985, Santos-Fita et al., 2015; Sirén, 2012). Wild meat is also considered a festival food (León & Montiel 2008; Sirén 2012; van Vliet et al. 2015b). This is understood as a food choice that is related to identifying with certain ethnic backgrounds (Huambachano, 2019) or as a comfort food, consumed in positive social contexts resulting in a positive association between the food and emotional wellbeing.

Hunting can fulfil its diverse functions only when done sustainably, as unsustainable hunting has profound implications for biodiversity, ecosystem function, and human livelihoods. Reductions in hunted populations have cascading effects in impoverishing the compositions and distributions of wildlife species (Trolliet et al., 2017) disrupting food webs, decreasing ecosystem resilience to climate shocks, and risking the health and food security of human communities (Wilkie et al., 2016). High hunting pressure on large mammals that disperse seeds of many Neotropical trees can lead to important losses in aboveground biomass (Peres et al., 2016). Defaunation thus has the potential to reduce carbon storage, even when only a small proportion of large-seeded trees are extirpated (Bello et al., 2015). Therefore, the conservation of large frugivorous vertebrates is important to reducing emissions from deforestation and forest degradation. High hunting pressures on game species may also lead to severe decreases in game population sizes, potentially leading to local extinctions, especially in areas with habitat loss, degradation, and fragmentation (Peres, 2001).

Subsistence hunting, in its role of providing hunters' basic needs, is perceived as having lower risks for wildlife populations compared to commercial hunting, which tends to be more intensive and extractive (Fa & Peres, 2001). Subsistence hunting can nevertheless increase pressures on hunted species, particularly the large and medium-sized vertebrates (Wright, 2003). Subsistence hunting rarely occurs in isolation from commercial influences. In a world of increased interconnectedness, rural communities that depend on protein from wild animals are now exposed to trade networks, improved transportation, and external demand for forest products. Additionally, the influence of external activities such as mining and tourism tends to introduce local people into systems of cash economy that profoundly alter their relationship with their environment. These changes often result in increased rates of wildlife hunting to supply regional markets (Suárez et al., 2009), larger hunting areas (Espinosa et al., 2014), and removal of cultural taboos and practices that previously limited the impacts of hunting among certain traditional groups (Golden & Comaroff, 2015).

The character of sustainable hunting depends on its social, economic, and ecological context. Sustainable hunting, when it is indeed sustainable, removes no more individuals than are added to the population through natural population growth. It is generally agreed that there is not a single 'sustainable' size at which populations can produce a particular sustainable level of off take; rather, a trade-off to be made between population size and off take levels (Milner-Gulland et al., 2009; Wilkie et al., 2019). Additionally, other factors such as habitat degradation and fragmentation, climate change, population growth, governance and management, and multiple stressors and mismatch between hunting territories and management scales, determine the impacts of this practice on social-ecological systems (Ostrom 2007; van Vliet et al. 2015b).

The ecological impacts of hunting are determined by the configuration, quality, and extent of the landscape in which this activity is developed. The presence of large tracts of habitat that function as reproduction grounds can sustain local populations of game species, even at relatively high hunting pressure (Mockrin & Redford, 2011; Naranjo & Bodmer, 2007; Ohl-Schacherer et al., 2007). However, habitat degradation and fragmentation are a major problem in the tropics. Hunting is thus currently practiced mostly in fragmented landscapes with potential for constrained reproduction, survival, and movement of animals across forest patches. Subsistence hunting is an additional source of mortality that can increase the probability of species extinctions in small forest patches. In this context, subsistence hunting of most medium and large size vertebrates might be feasible only in areas that are still connected to large patches of relatively undisturbed forest, a setting that will become increasingly exceptional as human population growth, large scale agriculture, and cattle raising encroaches in Neotropical landscapes (Cincotta et al., 2000; Williams, 2013).

2.2.1. Hunting is widespread in Neotropical forests

Neotropical forests are amongst of the world's hotspots of hunting-induced defaunation (Benitez-Lopez et al., 2019). The relatively small human groups that hunted in large and mostly undisturbed forests using traditional weapons, have been replaced by a growing population using fragmented habitats and modern hunting methods (Suarez & Zapata-Ríos, 2019), severely impacting Neotropical forests. Population declines and local extinctions as a result of direct human exploitation have been reported in the Neotropical countries, including Bolivia (Kosydar et al., 2014), Brazilian Amazonia (Peres & Palacios, 2007; Andrade-Melo et al., 2015; Romero-Muñoz et al., 2020), Guyana (Hallett et al., 2019), and Venezuela (Urbani 2006). The reduction of wild populations further risks the food security and cultural practices of many indigenous groups.

Indigenous communities living in Neotropical forests rely on hunting to obtain protein-rich food essential for their diets, especially where agriculture may be limited or unreliable (Suarez & Zapata-Ríos, 2019). Hunting allows the use of a variety of preferred species abundant in tropical forests in the American continent, such as deer, peccaries, tapirs, large birds and rodents, providing a diverse and nutritious diet (Benitez-Lopez et al., 2017). Furthermore, hunting rituals and traditions are deeply ingrained within the cultural fabric of many communities, reinforcing social cohesion and identity (de Araujo Lima Constantino et al., 2021; Petriello & Stronza, 2020). Thus, subsistence hunting not only fulfils immediate nutritional needs but also sustains cultural values in the tropical forests of the American continent.

2.2.2. Subsistence hunting in Mexico's tropical forests

Hunting is widely practiced in Mexico's tropical forests, particularly in the Southeast region of the country (Santos-Fita et al., 2012; Piña-Covarrubias et al., 2022a; Herrera-Flores, 2016; Tejeda-Cruz et al., 2014; Bolaños, 2004). Here, wildlife remains an important food resource for the subsistence of rural people, particularly those living in small, isolated, and impoverished communities near extensive forested areas (Leon & Montiel, 2008; Herrera-Flores, 2016).

More than 60 species of wild mammals, birds and reptiles have been reported as game of indigenous and mestizo villages in Southern Mexico (Naranjo et al., 2010). Recent socioeconomic development has caused large-scale land–use changes including deforestation and habitat fragmentation (Cespedes–Flores & Moreno–Sánchez, 2010), that has resulted in increased hunting of wild species and human-wildlife conflicts (Naranjo et al., 2010; Piña-Covarrubias, 2022a). Conflicts are particularly intense between humans and large felids, such as jaguars (*Panthera onca*) and pumas (*Puma concolor*), which are perceived as competitors for many of the game species hunted by people (Piña-Covarrubias, 2022b). Additionally, these large cats have pelts and teeth with commercial value (Felbab-Brown, 2022). All these threats together can intensify the loss of wild species in the area.

Different types of hunters and hunting practices have been described in Southern Mexico. The scientific literature on the Yucatan Peninsula recognises two main types of hunters: *dedicated* and *sporadic* (Santos-Fita et al., 2012; Bolaños, 2014; León & Montiel, 2008). These types practice four different categories of hunting: 1) batida – highly organized and hierarchical events where hunters accompanied by dogs form separate groups to search and catch game during the day in forested areas (Rodríguez et al., 2012); 2) nocturnal hunting – individual or group night hunts using lamps to find and shoot game in forested areas (Mandujano & Rico-Gray, 1991); 3) stalking – a hunting style that relies on knowledge of the species' biology and habits to track and wait for game by searching for its traces and scats; and 4) opportunistic hunting – practiced by farmers who go to their milpas and find game (Pinkus-Rendón & Rodríguez-Balam, 2020).

Dedicated hunters often find their game in a selective way, and they target highly regarded species such as deer, peccaries, and large birds. They may practice several of the hunting categories. These hunters can manage habitat types for prey and are able to attract game and increase their hunting success by holding back a portion of their harvest for wildlife consumption. In contrast, sporadic hunters frequently take game when available, while traveling to or in their croplands and grazing areas with very little or no strategies of game management (Jorgenson, 1995; Naranjo et al., 2004: Ramírez-Barajas & Naranjo, 2007). Garden hunting (or milpa hunting) is a productive activity that is complementary to broader cultural and economic patterns, and that simultaneously protects crops from animal predation (Smith, 2005; León & Montiel, 2008; Santos-Fita et al., 2012). In most cases, subsistence hunting has the double purpose of harvesting wild meat and preventing or mitigating crop damage by game species (Emslie, 1981; Naranjo et al., 2010). Thus, a high proportion of subsistence hunting is focused on relatively abundant and generalist species, such as doves, armadillos, coatis (*Nasua narica*), collared peccaries (*Pecari tajacu*), and white-tailed deer (*Odocoileus virginianus*), in managed habitat types such as agricultural lands, surrounding fallows, and forest patches. However, large and threatened game species, such as ocellated turkey (*Meleagris ocellata*), curassows (*Crax rubra*), white-lipped peccaries (*Tayassu* *pecari*), brocket deer (*Mazama sp.*), and tapirs (*Tapirus bairdii*), which are often preferred over smaller game, are mostly hunted by dedicated hunters deeper into mature forests, frequently without restrictions other than the hunter's skills, weapons, and time available (Naranjo & Bodmer, 2007; Bolaños, 2014).

Hunting for subsistence is widely tolerated by authorities administering indigenous and/or rural communities, despite being an illegal activity. Hunting for any purpose, subsistence, commercial, and sport without an official permit is illegal in Mexico (SEMARNAP, 2000). In recognition of peoples' reliance on wildlife, Mexico's General Law for Wildlife (Ley General de Vida Silvestre; LGVS, 2000), contains a basic framework for the legal inclusion of wildlife use for subsistence purposes under governmental regulation. Subsistence uses considers the use of specimens, their parts, or resources derived from wildlife for direct consumption or sale, for the complete or partial satisfaction of basic needs directly related to diet, shelter, or health, as well as those of economically dependent subjects (Article 106 in LGVS Regulations [SEMARNAT 2014 (2006)]). Additionally, a distinction for uses in rituals and traditional ceremonies is included in the law. However, authorization from the Ministry of the Environment (SEMARNAT) is required for wildlife usage. However, hunting inside protected areas and hunting of endangered species listed in the Mexican law NOM-059-SEMARNAT-2010, is strictly prohibited by Mexican regulations, and less tolerated compared to hunting outside protected areas (SEMARNAT, 2010; SEMARNAP, 2000).

Despite this, hunting in the ejidos of the buffer zones of protected areas is widely overlooked by Mexican authorities (see the General Introduction for a description of the Mexican 'ejido'). This is because there is no, or little, law enforcement in this matter and because ejidos, can establish their own norms and regulations on social and cultural practices and have their own customary rights (Ley Agraria, 1992). Despite this, the forests owned and managed by ejidos in Southern Mexico are subject to diverse global and local environmental and economic pressures. Thus, unsustainable hunting in these forests further affects ecosystem integrity and community food security. These impacts will be enhanced by climate change.

Studies suggest that climate is becoming more extreme in the Southern Mexico. Andrade-Velázquez et al. (2021) found positive historical temperature trends (0.1 mm/year) and positive precipitation anomalies (~0.01 ◦C/year and ~0.1 mm/year) for southeast Mexico's Yucatan Peninsula from 1960 to 2016. Projections under three Representative Concentration Pathways (4.5, 6.0, 8.5), showed the same trend of temperature increase as the historical record for the region. Regional climate projections additionally suggest the occurrence of more extreme droughts (IPCC, 2013; Orellana et al., 2009), supporting local and state-level observations. In Campeche, average temperatures are projected to increase from 32°C to 33.4°C in the near future (2015-2039) and to 35.2°C in the distant future (2075-2099; PECC, 2014). Decrease in average precipitation have been recorded in the region. Overall, there is a loss of 0.65 mm/day or 237.25 mm/year between the historical period and the distant future. This pattern is expected to persist over time, with the southern zone experiencing a more pronounced decline in precipitation (PECC, 2014).

The scientific literature lacks objective measures of hunting frequencies in Mexico with which to calibrate social-environmental impacts on cultural identity and food security under climate change. However, studies in the Southeast Mexico suggest that hunting practices in the area are diverse in form and purpose and vary in magnitude (Escamilla et al., 2010; Santos-Fita et al., 2012; Leon & Montiel, 2008; Naranjo et al., 2004). Such differences manifest in extraction rate, hunting modalities, game species and size, seasonality of use, exploited habitats, community ethnic origin, and social demands. This highlights the relevance of local social-ecological approaches for evaluating the use of wild animals in specific regional contexts, particularly in protected areas.

Furthermore, studies on the effects of climate change on the hunting practices and patterns of peoples living in the world's tropical forests are scare (McNamara, 2013), despite the importance of this practice for the food security and culture. In contrast, wider attention has been given to Inuit hunters in the Artic (Ford et al., 2008; Laidler et al., 2009; Pearce et al., 2015; Hillemann et al., 2023). It is urgent to understand how climate change is affecting the practices and livelihoods of rural and indigenous groups in the tropics.

2.2.3 Aim and objectives

The aim of this chapter is to assess how social and environmental characteristics influence the hunting practices in Neotropical forests under climate change, as exemplified by the Calakmul Biosphere Reserve (CBR). The main goal is to establish the dependencies between the environmental, social, and economic features that shape this activity in rural communities living in tropical forests through the following objectives:

- Assess the frequency of hunting and game consumption in three communities with different landscape, socioeconomic, and ethnic characteristics within the CBR.
- Describe the hunting practices in these communities.
- Identify the composition of hunted species and preferred hunting areas.
- Describe hunters' preferences and drivers for hunting.
- Identify effects of climate change in hunting practices.
- Identify communities' perceptions about regulations on hunting.

2.3. Methods

2.3.1. Focal population

Three rural communities (or ejidos) in the buffer zone of the CBR were sampled by interviewing residents. These communities differ in vegetation type, ethnic composition, and distance to the main urban centre. All three belong to the Calakmul municipality (ca. 28, 500 inhabitants) in Campeche and are located around the southern buffer zone. To ensure the anonymity of these ejidos, their names are not provided here. An approximate location for the purpose of illustrating the distance to main urban centre and their position across the vegetation gradient is shown in Figure 2.1.

The nearest urban centre to these communities is Xpujil. This town acts as the municipal seat and is located on the trunk road connecting to Chetumal city in Quintana Roo. The town has around 5,600 inhabitants (INEGI, 2021) and although it has more services than the other communities, it is not considered a city.

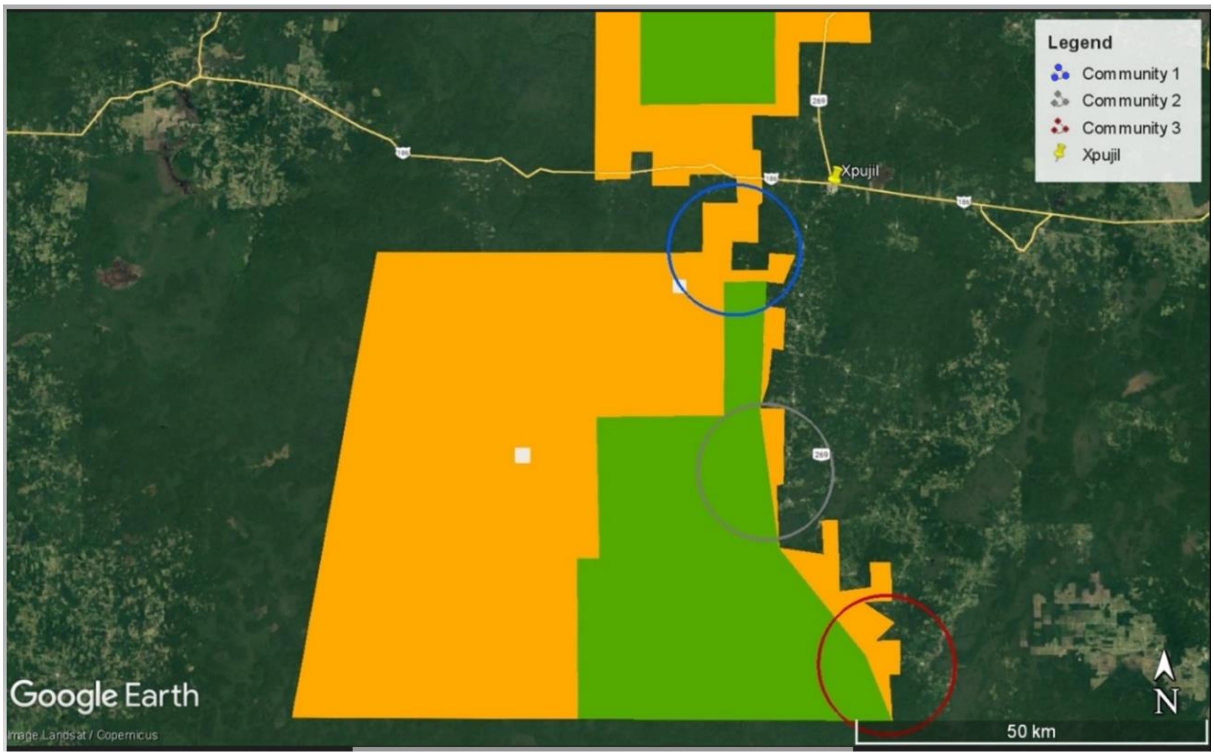


Figure 2.1. Approximate location of the surveyed community: communities 1 (blue), 2 (grey), and 3 (red) surrounding the core and buffer zones of the CBR (green and orange respectively). Xpujil, the only urban centre in the area, is also shown in the map.

Community #1 (henceforth 'C1') is the closet of the three communities to Xpujil, and the least deprived of the studied communities (Figure 2.1). It has an area of 2,603 ha, of which 1,096 ha are designated for community conservation. The village has a flat topography with highest elevations of 210 m.a.s.l. Low-subperennial-flooded forest is the main type of vegetation, with tree heights of 10-15 m in seasonally inundated forests (SEMARNAP, 2000). By 2020, the ejido had a population of 226 individuals (113 women and 113 men), with mixed composition in terms of ethnicity (INEGI, 2021). Nearly 70% of the population identifies as indigenous and the remaining population as mestizo (i.e., of mixed European and Indigenous American ancestry). More than 25% of the inhabitants are illiterate. There are 47 households in this community and most of them had access to main basic services, such as electricity, a toilet in their household, television, and a fridge. However, most lacks running water, car, and mobile phone. No one in the community has a landline telephone or private internet access (Figure 2.2, INEGI, 2021). These are common indicators of development used by the Mexican Institute of Statistics and Geography. The main livelihoods are arable farming (mainly milpa and jalapeno chilli), off-farm labour (mainly in Xpujil), small-scale honey production, ecotourism, and agroforestry. Only ten households have sheep, and in low proportions (< 8 animals). There are 28 ejidatarios in the community, holding 40 ha of land each. Around 70 % of the inhabitants were economically active by 2020 (INEGI, 2021).

C2 is in the middle of the south buffer zone, halfway between Xpujil and the border with Guatemala and has a highly deprived population (Figure 2.1). The ejido covers 3,958 ha, from which 1,250 ha are set as a community conservation area. This is also a flat area with highest elevations of 230 m. Subperennial forest is the main vegetation type, with trees between 15 and 25 m high. The southwest border of the ejido is adjacent to the south core zone of the CBR. It is one of the most populated communities in the municipality with 424 inhabitants (women = 216 and men = 2018) by 2020, mostly composed by mestizos (INEGI, 2021). Only 7% of the population identifies as indigenous, and 13 % are illiterate (INEGI, 2021). There are 58 households. Most of the population has access to main basic services such as electricity, toilet, television, and fridge; most lack a mobile phone and car, and nobody has access to piped water in their household, private internet access, or a landline telephone (Figure 2.2). The main livelihoods are arable farming (milpa and jalapeno chilli), honey production, and cattle and livestock ranching in small proportion. There are 31 ejidatarios, owning 90 ha of land each. Only 63% of the inhabitants were economically active in 2019 (INEGI, 2021).

C3 is a small village located in the southernmost part of the Calakmul Municipality, further from Xpujil than the other communities and with a highly deprived and isolated population (Figure 2.1). The vegetation is composed by tall perennial forest, with trees reaching up to 30 m tall. This community has hilly terrains reaching elevations of approximately 400 m.a.s.l., with steep slopes. Humidity levels here are much higher than in any other area (Garcia-Gil et al., 2002). Its eastern boundary is adjacent to the south core zone of the CBR. C3 occupies a total area of 2,582 ha, of which almost 1, 000 ha are designated for community conservation. The population was 309 inhabitants (women = 168 and men = 141) by 2020, comprised by indigenous people (98% of the population; INEGI, 2021). More than half (57%) are illiterate. There are 52 households in the community, most lacking basic services except for electricity (Figure 2.2). The main livelihoods are arable farming (mostly milpa and small-scale chilli crops) and livestock and cattle ranching. There are 42 recognized ejidatarios, each having a plot of 40 ha for exploitation. Of the inhabitants, 64% are economically active (INEGI, 2021).

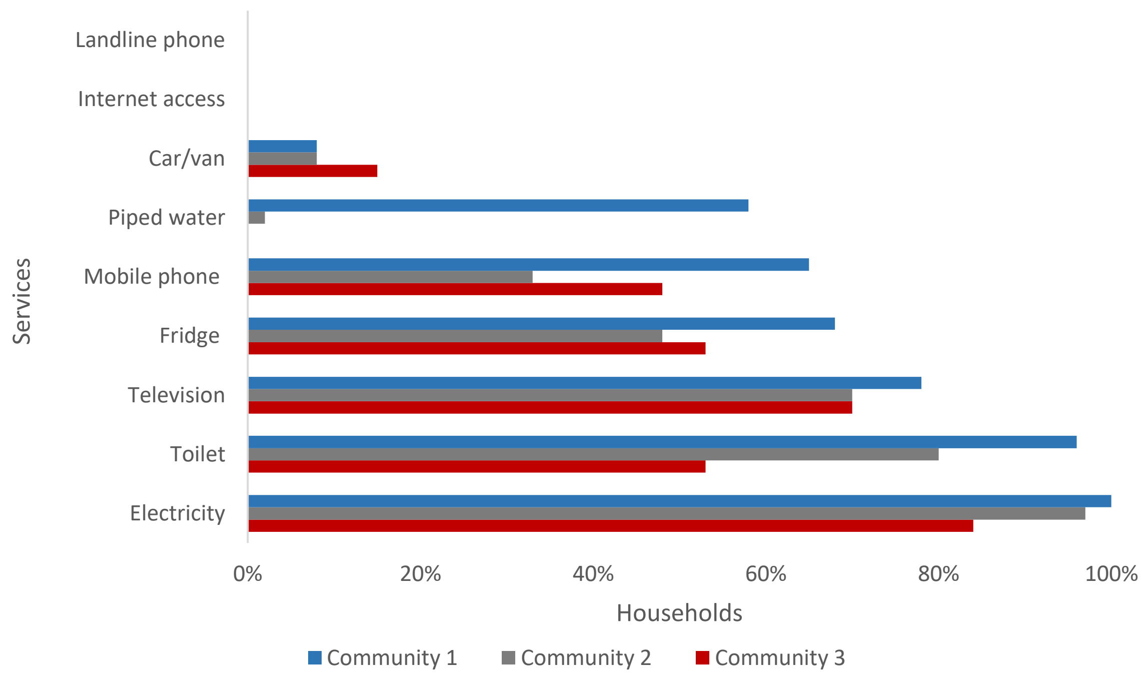


Figure 2.2. Percentage of households with the main basic services in the three surveyed communities in Calakmul. Data for community 1 (C1) is shown in red, community 2 (C2) in black, and community 3 (C3) in yellow). Mobile phones lack mobile data and Wi-Fi access inside the communities. (Source: INEGI, 2021).

2.3.2. Structured questionnaires

Adult men and women (>18 years old) were interviewed, each with a group-specific questionnaire (‘Questionnaire on hunting practices in the CBR, Mexico’, ERGO ID number: 55051) from June to August 2019. The first group comprised both regular and sporadic male hunters in the CBR; whilst the second comprised women in the same area. Although woman do not take part in hunting, they cook the animals retrieved by hunters. At least one individual per household was interviewed. Both men and women from the same household were interviewed separately, when possible, to corroborate the information obtained from each and to enhance data accuracy, in anticipation of interviewees not providing entirely truthful answers about their hunting practices (e.g., due to perceived sensitivities around legality). Additionally, participant observation was used as a tool to ensure data accuracy (DeWalt & DeWalt, 2011).

The structured questionnaires were developed from questionnaires and findings published by Escamilla et al. (2000), Quijano-Hernández & Calmé (2002), and Santos-Fita et al. (2012). Interviews were done face-to-face, involving 20 questions for men and 12 questions for women, lasting no longer than 30 minutes (Appendix 1). The order of questions was determined by recommendations in Fink (2009) and Bryman (2012) on design and organisation of surveys. The conceptual basis of the interviews was based on the IPBES framework (Diaz et al., 2015). The purpose was to obtain information on the following aspects: 1) how the hunting practices and patterns (anthropogenic drivers) affect wild game species (biodiversity), 2) how wild game provide different NCP to farmer-hunters, women, and villagers (food, protection of crops, cultural contributions, among others), 3) how these NCP affect the wellbeing of the studied villages, 4) how local institutions and governance (hunting norms at ejido level, cultural practices/values, traditional knowledge) affect NCP and hunting (as an anthropogenic driver) in relation to human wellbeing.

Local community leaders and staff from the local NGO Pronatura Peninsula de Yucatan helped to identify potential interviewees for this study. Potential participants were approached by the researcher in their households. The researcher introduced herself and gave her affiliation. Participants were asked for consent to take part in the study. Their decision was informed by a description of the aim of the study and the benefits they could gain from the interview. Interviews were performed by the researcher with a fellow researcher from the UoS and/or an individual from the community acting as a gatekeeper, facilitating access and trust in the process (Singh & Wassenaar, 2016).

Questionnaire surveys were conducted in rural communities, where many participants lack basic reading and writing skills. Before beginning each questionnaire, a Participant Information Sheet (Appendix 2) was read out to the interviewee, explaining the aim of the study, the types of questions they would be asked, the confidentiality of their responses, and their right to decline to answer any questions or to end the interview at any point. Due the sensitive nature of questions related to hunting, and due to the necessity of guaranteeing identity protection, interviewees were not required to sign an Informed Consent form. Instead, each interviewee was asked to express verbal consent to participate in the study.

Only in the event of their agreement to participate could the questionnaire begin. The questionnaire was performed in private with the participant verbally answering questions, and the researcher filling out a paper-based questionnaire.

After the questionnaire was conducted, the interviewee was asked to suggest potential participants. This 'snowball' technique amplifies a study sample through referrals made amongst people who share or know of others who possess characteristics that are of research interest. It is particularly applicable to this study, with its focus on a sensitive issue, requiring the knowledge of insiders to locate suitable people (Biernacki & Waldorf, 1981). This process resulted in 133 interviews within the three communities (42-47 per community).

Before the study took place, the researcher resided amongst, and interacted with, the residents of the three surveyed villages for practical purposes beyond the defined remit of this study (May-August 2018). This residency was key to establishing the trust and confidence of the people living in the villages, that helped to build trust with potential participants. In 2019, the researcher stayed in each community for seven days before conducting the questionnaires to strengthen bonds and trust, on the bases that familiarity has been identified as an important influence on the collection of reliable data (Singh & Wassenaar, 2016).

2.3.3. Analysis of questionnaires

The information from the questionnaire was transcribed to an anonymised electronic format and all questionnaire sheets were destroyed. A code book was constructed to organise and code the data extracted from the survey questionnaires in a database suitable for analysis. A content analysis was performed prior to the construction of the codebook for all open-ended questions, to identify common ideas and to classify them into categories based solely on the data without the use of pre-established themes (Fink, 2009; Bryman, 2012). Descriptive statistics were used to illustrate proportions and overall patterns in the raw data.

2.3.4. Semi-structured interviews

After the questionnaire surveys, key informants (n = 17 households) were approached, using semi-structured interviews to obtain in-depth information about the hunters' motivations and perceptions towards this activity. Potential informants were identified during the questionnaire surveys. People that showed knowledge and interest in the topic, and who built trust with the researcher to speak about this matter, were selected for the semi-structured interviews. Focal populations included dedicated hunters (n = 8), community authorities (n = 3), opportunistic hunters (n = 3), and people who are not actively involved in hunting (n = 3). Additionally, participant observation was carried out to interact with dedicated hunters and their families. The researcher participated overtly in the daily lives of people who accepted this intrusion, for periods of 15 days in each community, observing what occurred daily in different households and the communities, listening to what people said, and asking relevant questions related to hunting in each community. The researcher took field notes on daily facts on hunting and game consumption.

Semi-structured interviews were transcribed and reviewed using the content analysis technique. The answers were categorized into a) types of hunters and their identities: dedicated and opportunistic farmer-hunters, b) types of hunting and associated methods, c) motivations for hunting, and d) hunting regulations and awareness towards regulations. These categories were identified based solely on the data obtained. In accordance with guidelines for qualitative approaches (Rodriguez et al., 1999; Taylor & Bogdan, 1996), these three categories of information from the interviews were examined for patterns and interpreted with reference to the field notes from participant observation.

2.4. Results

Individuals from 124 households (82% of the total households in the three villages, n = 152) were interviewed. In C1, 44 individuals (female = 30, male = 14) from 42 households were interviewed. In C2, 47 individuals (female = 15, male = 32) from 42 households were interviewed, while in C3, 42 individuals (female = 16, male = 26) from 40 households were interviewed. A similar proportion between female and male interviewees was obtained. Most interviewees were young and middle-aged (Figure 2.3). No discrepancies were found between the two genders when interviewed separately throughout the study.

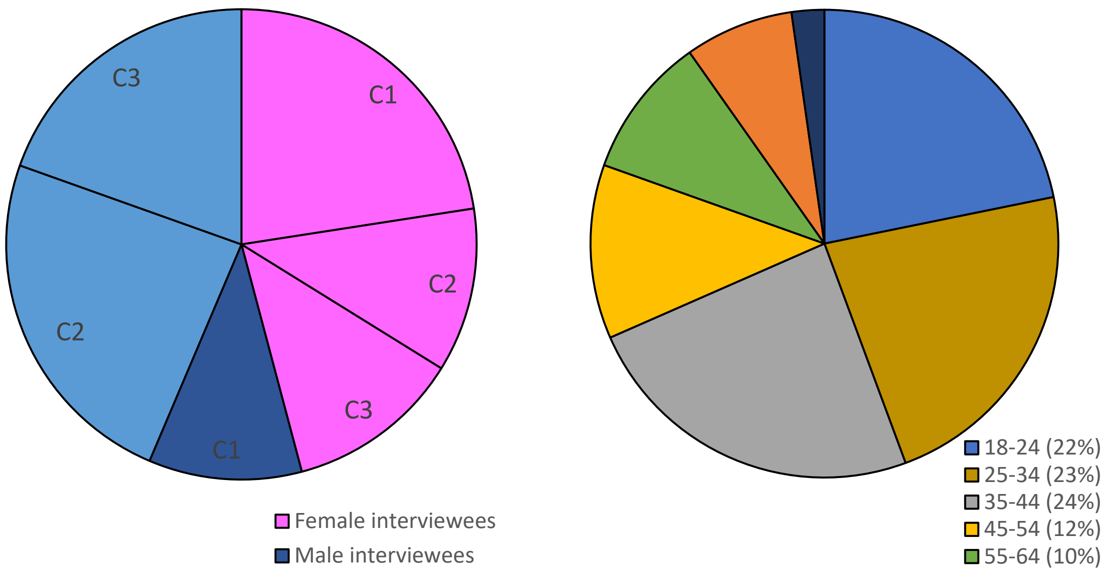


Figure 2.3. Sex and age of individuals interviewed with structured questionnaires in three communities of the CBR. The annotated lists show segments clockwise from the top.

Additionally, 15 male individuals in the CBR were interviewed with semi-structured interviews (n = 17 households). These included three non-hunters (n = 3), three opportunistic hunters (n = 3) and three community authorities (n = 3), one individual belonging to each group in every surveyed community. Five dedicated hunters were interviewed, in C1 (n = 2), C2 (n = 3) and C3 (n = 3).   Age range varied between young, middle, and old-aged men (Figure 2.4).

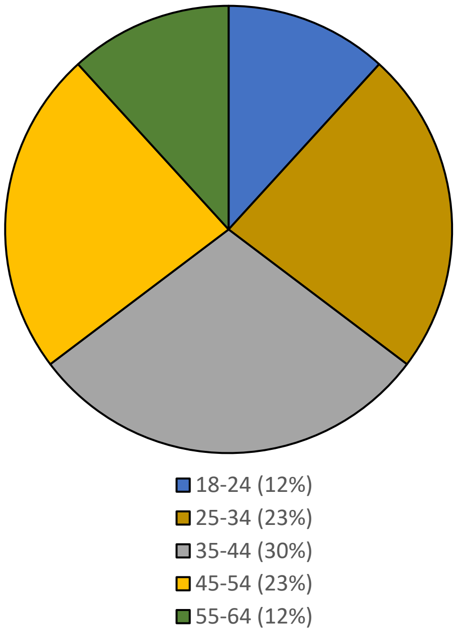


Figure 2.4. Age of men individuals interviewed with semi-structured interviews in three communities of the CBR. The annotated lists show segments clockwise from the top.

For all the sampled households in these communities, arable farming represented the main livelihood (100% of households, *n* = 124). Less than 50% of the households (44%, *n* = 55) supplemented their income with alternative activities such as livestock and cattle ranching, mainly in C3. In C1 and C2, apiculture resulted an alternative livelihood (17%, *n* = 21). However, in C1, 43% of the household male individuals (*n* = 18) were also engaged in wage labour mainly in Xpujil, military and/or local police service and/or local tourism, to supplement their income for subsistence. In contrast, no reports for this kind of activities were obtained in C2 and C3.

Individuals from all 124 sampled households in three communities reported that hunting was a common practice in the area. All the respondents (100%) reported that hunting occurred inside their communities and surrounding areas, either inside the core zone of the CBR or in other ejidos. Interviewees reported that hunting in their community was done by residents of these communities, by residents of surrounding ejidos, or by visitors only when invited by a local resident. Interviewees in C2 (*n* = 6) mentioned a recent demand for highly valued wildlife products, such as jaguar (*Panthera onca*) parts and offspring of white-lipped peccaries for harvesting, from people external to the CBR. All the participants denied participating in poaching-related activities, which are regarded as illegal in the area. In contrast, in C3 many male interviewees (*n* =15) reported that they continuously catched parrots, including the endangered northern mealy (*Amazona guatemalae*) and the yellow-headed parrot (*A. oratrix*; SEMARNAT, 2010) for personal pets or local trade. No further questions were conducted on these matters, to maintain the trust of the interviewees and the focus of the study.

In the study area, only men hunted. In the study site, 77% of the sampled households (*n* = 95) reported having at least one male adult individual in their household who hunts. C3 had the most households with hunters (*n* =37 households, 93%), followed by C2 (*n* = 37 households, 88%) and C1 (*n* = 21 households, 50%). A reduced number of households in the study site (*n*= 10, 8% of study sample) reported hunting only in the past, and now stopped mainly because of their old age or lack of a gun, or time. Other households (*n* = 20, 16%) reported not hunting at all. Most of these reports belonged to C1 (*n* = 16, 13%).

2.4.1. Hunting and game consumption frequencies

Hunting resulted a continuous and frequent practice in Calakmul. Hunters reported highly varied hunting frequencies, ranging from a minimum of five days per year to a maximum of 6 days per week hunting, with an average of 83 days per year and a median of 73 days per year. Hunting frequencies varied considerably between communities, between 102 days per year for C2, 83 for C3 and 49 days for C1 (Figure 2.5).

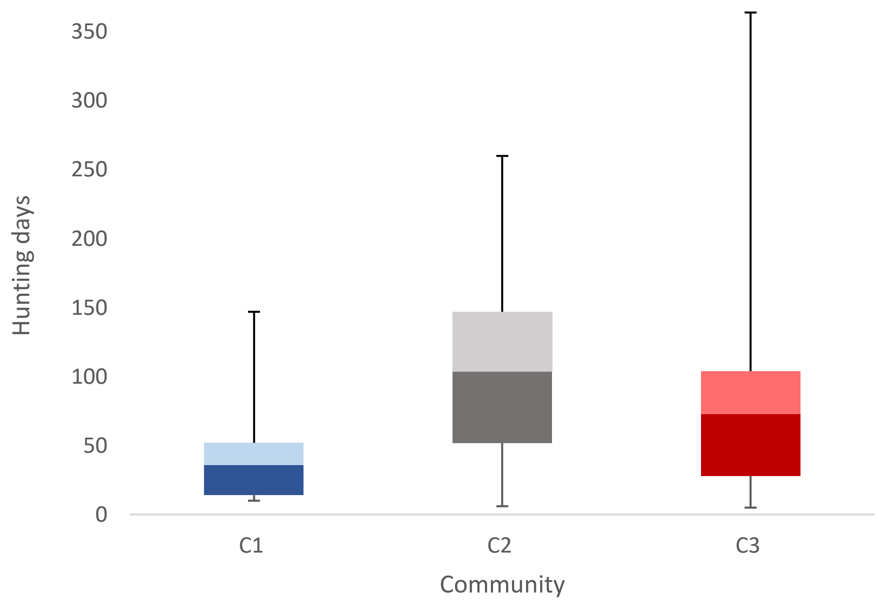


Figure 2.5. Hunting days per year in three communities of the CBR, averaged across households.

People in the study site reported increasing their hunting activities during the rainy season. The overall frequency of hunting in the study site increased by 25% during the rainy season. During the dry season, 25% of the households (*n* = 24) reported very low hunting frequencies (0-12 days per season), 13% (*n* = 12) low frequencies (13-25 days per season), 27% (*n* = 26) moderate frequencies (26-47 days per season), 24% (*n* = 23) high frequencies (48-63 days per season) and only 11% (*n* =10) very high hunting frequencies (>64 days per season). In contrast, the percentage of households that reported moderate and high hunting frequencies decreased to 13% (*n* = 15) and 9% (*n* = 9) respectively, while the number of households that reported hunting at a very high frequency increased to 39% (*n* = 37; Figure 2.6) during the rainy season.

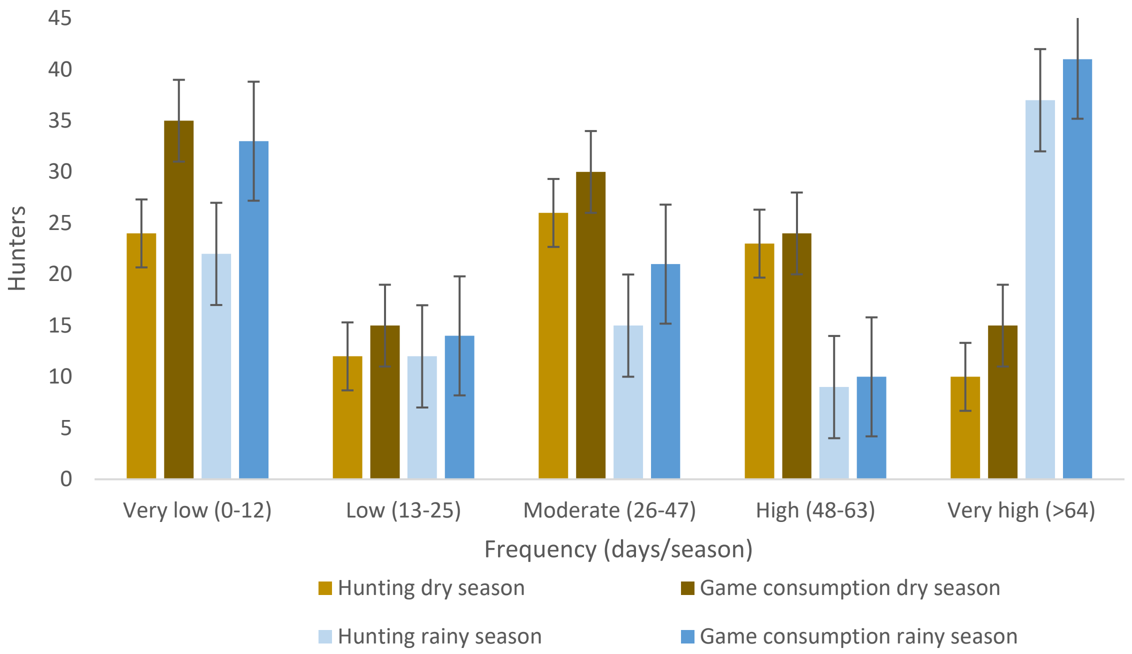


Figure 2.6. Hunting and meat consumption frequencies during dry and rainy season in the CBR. Frequencies are expressed in days per season. Black bars represent standard errors for the mean of each sample. Both seasons account for the same numbers of days (182 days), considering the mid-summer drought period as part of the dry season.

An increase in hunting activities during the rainy season was observed in each community. Average hunting frequencies in C1 increased 52%, in C2 increased 30% and in C3 increased 15% during rainy season (Figure 2.7).

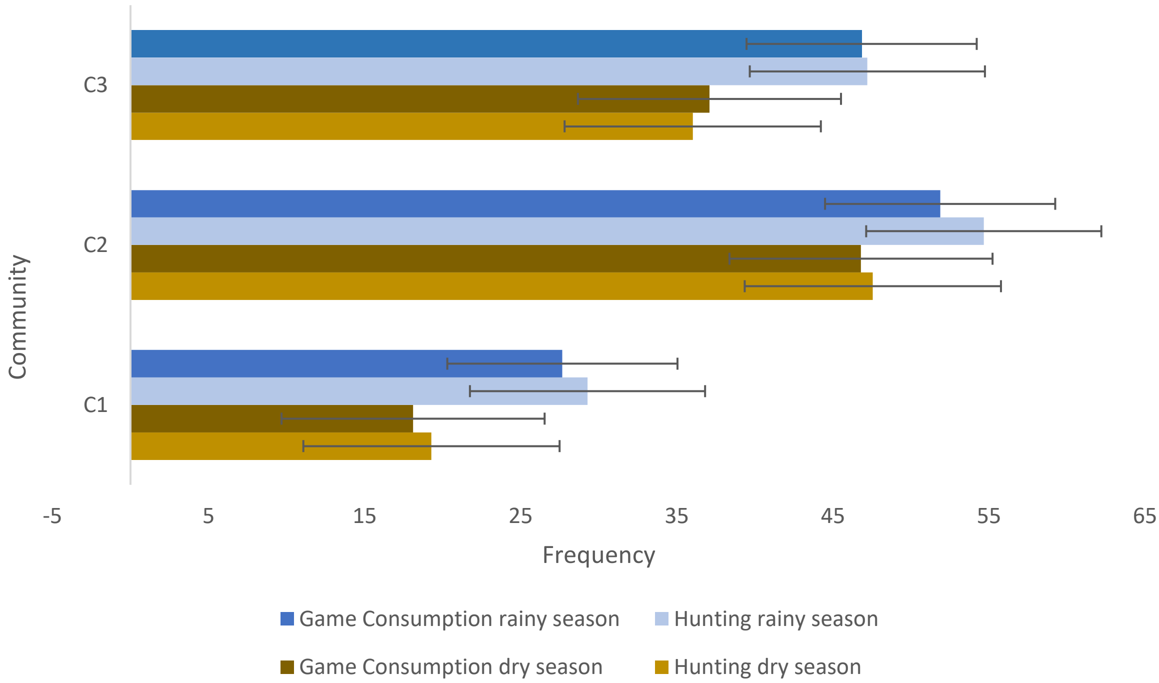


Figure 2.7. Hunting and game consumption frequencies (days per season, averaged across households) during dry and rainy seasons in three communities of the CBR. Black bars show the standard error for the mean of each sample. Both seasons account for the same numbers of days, considering the mid-summer drought period as part of the dry season.

Wild meat was commonly consumed in the study site. A high number of households reported eating meat in a constant manner (*n* = 119 households, 97%), with C3 and C2 the communities where all households consume wild meat, and C1 where 88% (*n* = 37) of the households consumed wild meat throughout the year.

The lowest frequency of meat consumption for any sampled household was 2 days per year, while the highest was 5 days per week (estimated at 260 days per year) Frequency of game consumption also varied between communities and seasons. In the CBR, households consumed meat on an average of 77 days per year and a median of 52 days per year. Consumption frequencies varied between communities, with households in C2 and C3 reporting 99 and 84 days/year respectively, and C1 reporting 46 days/year (Figure 2.8).

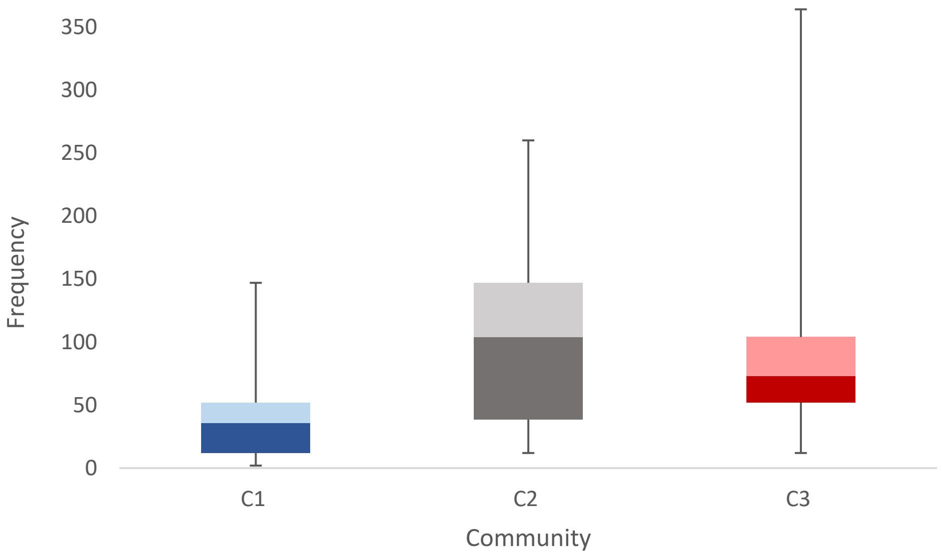


Figure 2.8. Frequency of wild game consumption in three communities of the CBR (days per year, averaged across householders).

Game consumption frequencies varied during dry and rainy season. In each community, the frequency of meat consumption increased during the rainy season, when the hunting frequencies also resulted higher (Figure 2.6). In C1 consumption frequency increased by 55%, in C3 by 27%, and in C2 by 11% during rainy season (Figure 2.7). In households with no hunters or with low hunting rates, interviewees reported obtaining wild meat from 1) family and friends and 2) local wild eat vendors in each community.

2.4.2. Types of hunters

Two types of hunters were identified in Calakmul: opportunistic and dedicated hunters, based on their purpose and motivation for hunting. Opportunistic hunters reported mainly catching game in their milpas which they visited daily for agricultural practices. Catching wild meat was not perceived as their main purpose, but as an added value to their work in the milpa. In contrast, dedicated hunters had the only purpose of catching wild meat for consumption or commerce. More details are provided in the following sections.

2.4.2.1. Opportunistic hunters

Most farmers in the studied communities hunted opportunistically whilst working in their agricultural lands (milpas). Farmer-hunters described that the crops grown in their milpas attracted wild animals, particularly during harvest times. When sighted in their plots, farmer-hunters killed animals for food or for crop protection. Interviewees described that species such as white-tailed deer, collared peccary, coati, agouti, great curassow, and ocellated turkey were commonly found in their milpas, providing an easy catch. Additionally, opportunistic hunters reported occasionally catching game while travelling to their milpas, which are located within a mosaic of agricultural plots, fallow fields, and forest patches where wild mammals can be easily found.

In the CBR, these farmer-hunters self-identified either as 'opportunistic hunters' or not as hunters. An opportunistic hunter from C1 (aged 27) stated: "I am not a hunter; I only catch animals in my milpa. That does not make me a hunter". An opportunistic hunter from C3 (aged 31) said: "I am not hunting; I just catch animals when I see them inside my plot. I must protect my crops from being eaten by these animals, and I take the opportunity to get some meat". Most opportunistic hunters in the CBR communities did not self-identify as hunters despite catching wild game. The meaning of hunting, as understood by the communities, has common elements across the three surveyed communities, with context dependencies that are described in the following section.

2.4.2.2. Dedicated hunters

In contrast to opportunistic, common elements shared by dedicated hunters across the communities included: 1) purpose, 2) knowledge of the forest and species interactions within the ecosystem, 3) preparation, management, and organisation of hunts, 4) time dedicated to this activity, and 5) access to forested areas. All dedicated hunters identified themselves as hunters.

In the CBR, dedicated hunters described going out with the main and only purpose of catching wild meat. Hunters showed certain degree of knowledge regarding 1) the behaviour of the target species, 2) the ecosystem – e.g., the best places and times to find the target species, relevant landmarks for hunting -, 3) navigation skills, 4) the effort needed to hunt depending on the species – e.g., individual or group hunting -, and 5) ways to retrieve the meat to reduce transport efforts. All interviewed hunters of this type described common features of preparing for, organising, and managing their hunting practices. They usually knew *a priori* which species they were going to target, what method they were using – mainly shotguns with different gauges, what equipment they would need – head lights, dogs, and food, how much time they would spend in hunting, and an estimate of walking distance.

Hunting in the CBR was commonly practiced after sunset, usually lasting until the next day. Hunting at other times also occurred, depending on the biology of the target species and on the hunter's preference. Dedicated hunters could spend an average of 10 hours on a hunting trip to surrounding forested areas. These were usually protected areas, located 7 -16 km away from the villages. This type of hunters always went prepared with sufficient food and drink (usually *pozol*, a traditional drink made with maize and sugar) to sustain themselves for long periods while hunting. Dedicated hunters did not use milpas during hunting trips, although they reported getting game from these areas occasionally during daytime.

2.4.3. Hunters' identities

Although all dedicated hunters self-identified as hunters in the CBR, the concept of hunter varied between the communities. In C1, only two hunters identified themselves as hunters (*n* = 2). Opportunistic hunters did not self-identify as hunters and perceived and referred to hunters in a negative way. An interviewee not dedicated to hunting (aged 23) said: "Those *cabrones* (a derogative Spanish term used to refer to someone whose actions are considered wrong or offensive) don't understand that they are not supposed to hunt, but they cannot stop killing animals". Many males in this community nevertheless hunted opportunistically and most households consumed wild meat (Figure 2.8). Two self-identified hunters, both older members of their communities (>55 years-old), reported having knowledge of the practice and to have hunted all their lives. A hunter (aged 57) in C1 said: "I don't understand why people think hunting is wrong. I have hunted all my life, my dad used to hunt before coming to Calakmul. We provide for our family, and we have knowledge of the activity. It is not only about going out with a gun… you must know what you are doing, not like those youngsters… I think people are just hypocrites because they all hunt (meaning in an opportunistic way). Now you cannot hunt inside protected areas, before they were not protected and there are still animals…" Another hunter in the same community (aged 61) said: "I love hunting and I won't stop, no matter what the authorities say. Now I eat pigs and chicken, but I love to eat the meat that I caught with my own hands".

In contrast, most people in C2 did not perceive hunting in a negative way. In this village, hunting was an open and recognized practice. Most opportunistic and all dedicated hunters identified themselves as hunters. Most hunters openly talked about theirs' and other hunters' stories and experiences. In this community, all dedicated hunters were known as *tiradores*, a Spanish term used to refer to a person who shoots with a degree of skill (Real Academia Espanola, 2020; equivalent to *shooters* in English). In this community, most *tiradores* possess deep knowledge of hunting practices and have a detailed knowledge of the forest and the water sources surrounding their community. A hunter (aged 49) said: "Being a hunter is like being a detective. You must know the space and your game…then patiently wait for the moment to shoot." Another hunter (aged 53) reported: "Before the reserve was here (2000) there was real hunting, the gringos [a term used to refer to foreigners, particularly those from the United States] came to hunt jaguars, pumas, and all animals. We helped them in exchange for money. Now we only hunt to eat. There are many animals and there will always be, you only need to know when to hunt them and which animals to get (male or females) to not affect the populations. Young people they do not care about that. They just want to go out and get animals to feel proud of themselves." In contrast, a young hunter (aged 21) said: "It makes me feel good about myself to catch animals. I taught myself how to hunt, no one taught me although my father is a recognized hunter, it is in my blood." Selling game inside the village was a common practice of both types of hunters in C2.

In C3, most hunters (*n*= 2 opportunistic and 2 dedicated)) identified themselves as hunters. Hunting was an open practice and people talked freely about it. In this village, both opportunistic and dedicated hunters self-identified simply as hunters. Selling the surplus of game was also a common practice for hunters in this village. In this village, perceptions on hunting were positive, except when hunters sold meat outside the ejido.

2.4.4. Hunting categories and associated methods

The three main hunting categories found in the CBR: nocturnal, stalking, and opportunistic, which were practiced individually or collectively, using different tools, equipment, and strategies. These varied according to the context, place of hunting, and species preference. A summary of the types of hunters, categories of hunting, and methods identified in the CBR is given in Table 2.1, and more details are provided in the following section.

Table 2.1. Hunting types and methods used by opportunistic and dedicated hunters for catching different species in different places in the CBR.

Types of hunters	**Characteristics**			
Dedicated	Visit forest areas with the main purpose of catching wild game. They rely on different hunting strategies and pose vast ecological knowledge			
Opportunistic	Catch game in their milpas when possible, depending on game, knowledge, and methods available			
Hunting categories				
Stalking	Practiced individually during the day by dedicated hunters, searching for game in the forest using tracks and knowledge.			
Nocturnal	Practiced solo or in groups during the night by dedicated hunters, using flashlights to spot nocturnal species			
Opportunistic	Catching game when encountered in milpas or forested areas. It can be practiced by both dedicated and opportunistic hunters			
Hunting methods				
Equipment	**Context**	**Hunter types**	**Place**	**Species**
• Slingshots	Used occasionally	Opportunistic	Milpa and forests	Birds
• Sticks	Less frequent	Opportunistic	Milpa	Armadillo and turtle
• Dogs	Commonly used by farmer-hunters	Opportunistic and dedicated	Milpa and forest	Mammals
• Shotguns	Usually, calibre .16 or .28	Opportunistic and dedicated	Milpa and forest	Calibre .16 for small mammals and large birds Calibre .28 for large mammals
• Rifles	Calibre .22	Dedicated	Milpa and forest	Larger mammals
• Flashlight	Used in night trips to flash species	Dedicated	Forest	Paca and collared peccary
• Machete	Used to kill small game and to build structures in forests to spy on game	Opportunistic and dedicated	Forest and milpa	Mammals

2.4.4.1. Hunting categories and methods used by opportunistic hunters

Opportunistic hunting occurred when opportunistic hunters shot animals sighted at their milpas. Farmers described using shotguns, calibre .16 or .28, which they carried to their milpas with the dual purpose of protecting themselves and protecting their crops from wild animals. Due to economic constrains and the expensive price of shotguns (MXN $20 000, GBP £705) many hunters reported building their own firearms using metal water pipes and rudimentary equipment, which are cheaper than commercial shotguns (MXN $6000, GBP £210). Opportunistic hunters also reported having .22-calibre rifles, instead of shotguns. In C2 and C3, local shops where cartridges or projectiles were sold, were easy to identify. In C1, the researcher could not identify any place selling these items.

In lack of firearms, interviewees described using rustic equipment. Slingshots and sticks were commonly reported for catching birds (e.g., doves, chachalaca, curassows, ocellated turkeys) and armadillos respectively, with the help of dogs occasionally. Machetes, a common tool for farmers, were also reported as means to kill small animals. A farmer, self-identifying as a non-hunter, from C1 (aged 23) reported: "I don't hunt, my dogs get the animals (paca or coati) for me in my milpa and consequently eat them". We found no evidence on the use of snares in the CBR.

Opportunistic hunters described strategies to increase their hunting success. Farmers made use of crop and water to bait for animals during rainy and dry season respectively. An opportunistic hunter in C2 (aged 29) reported: "I know that animals will come to my plot in time of harvest. I do not need to go to the forest to hunt. Recently, extended droughts have helped me to hunt much more than in the rainy season. I leave water containers in my father's milpa, animals come to drink water and then is when I get them... It always works". Opportunistic hunters who did not own a plot of land reported openly hunting in family's or friends' milpas, regardless of the community's regulations (see section on Hunting regulations).

Opportunistic hunters relied, to a certain degree, on ecological knowledge and hunting strategies. They had knowledge of the biology the species that visit their garden plots. Mostly, they were aware of the activity patterns of species at the milpa, their reproduction times, and their eating preferences. In contrast, other opportunistic hunters described having no interest in this topic. As an example, a farmer-hunter in C1 (aged 23) said: "It doesn't matter where animals live or what they do; what matters is to catch them when they are in your milpa for whatever reason".

2.4.4.2. Hunting categories and methods used by dedicated hunters

Dedicated hunters relied on more sophisticated methods, strategies, and ecological knowledge for hunting than the opportunistic hunters. All dedicated hunters used shotguns, rifles, and trained dogs for hunting. These hunters practiced stalking and nocturnal hunting, the latter either individually or in groups.

Stalking was practiced individually. When stalking, sole hunters walked silently in the forests using mostly old and thin trails, looking for tracks and scats of potential game. Hunters followed these signs until game was found. Stalking trips were described to be simultaneously used for hunting and for scouting future hunting trips. Hunters commonly marked the areas where animal tracks were found, as landmarks for future trips. This was done by marking trees with their machetes or arranging logs to function as landmarks. Hunters reported trying to be discrete when doing this to avoid other hunters from taking advantage of their findings. When stalking game during daytime, hunters usually spent between eight and ten hours in the forest. Sole hunting was the most common practice amongst dedicated hunters. Individual hunting usually relied on the hunter's knowledge of the place or the target species and allowed the hunter to have independence in decision-making and strategies used.

Dedicated hunters usually used various strategies to improve their hunting success when stalking game. These involved knowledge of the landscape, vegetation structure, and the target species' behaviour. A hunter from C3 (aged 37) reported targeting and baiting his game in the areas where *ramon* trees (*Brosimum alicastrum*) are found only when this tree has fruit. Hunters cut fruits from the tree to intentionally leave them on the forest floor as bait for frugivorous mammals during the rainy season. Other hunters reported specifically targeting aguadas to find more game during dry season. A hunter from C2 (aged 49) said: "If I want to hunt when it is dry, I have to go to the aguadas located deep in the forest; there is where I am able to get all kinds of animals with less effort". A hunter from C3 (aged 43) said:

"Nowadays I must change my hunting sites; I must go either deeper into the forest or south where the larger aguadas are found. I know that I will find game in those sites".

Another common practice among dedicated hunters was nocturnal hunting, practiced individually or collectively. When hunting solo at night, hunters visited aguadas or previously identified trails with fruits to search and wait for game, using flashlights. Hunters from C2 and C3 (aged 49 and 43, respectively) reported that flashlights were key to successful hunting, particularly when hunting pacas. Hunters usually built off-ground wooden frames to wait for game at a particular site during the night. Evidence of wooden structures and hunting equipment is presented in Figure 2.9. Hunters reported avoiding hunting during full moon because it reduces their hunting success. A hunter from C3 (aged 43) reported: "I go hunting almost every day, except when there is full moon. Sometimes I still go, but it is not good for catching game." A low number of dedicated hunters (*n* = 3) reported that although they strive to hunt regularly, up to 6 times a week, they do not necessarily succeed in catching game every time.

Figure 2.9. Examples of hunting strategies and equipment used in the three studied communities; a) aboveground wooden structure for spotting wildlife in C2, b) wooden structure used to cook during hunting trips in C2, c) shotgun and machete carried by hunter in C2, and d) cartridge shell (calibre 12)) found in the forest in C1.

Individual hunting posed advantages and disadvantages for hunters. Advantages included having independence for choosing hunting sites and modifying hunting plans. The reported disadvantages included higher risks for the hunter's safety and targeting smaller game due to the effort required to retrieve the animals. A hunter in C3 (aged 35) reported: "I hunt alone. I can go anywhere I want. If you hunt with friends, there is too much noise… However, I must be careful about the snakes if I want to come back home safely". Potentially deadly snakes included venomous *Bothrops asper*, … and constrictor *Boa imperator* …

Collective hunting at night was also reported in the three communities of the CBR. A group of two to six people, usually family or friends, came together to catch game, mostly during the rainy season. Hunters described starting this practice at dusk, leaving the community around 19:00, using their motorbikes to reduce the walking distance to forested areas. Hunters reported leaving their vehicles inside the community area, as they cannot penetrate the forest due to the vegetation structure and the reduced width of hunting trails. The use of flashlights was an important technique in the CBR, used also when hunting collectively. Group hunters spent up to 12 hours hunting. Evidence of this kind of hunting found in C3 is shown in Figure 2.10.

Figure 2.10. Evidence of collective hunting in C3. Hunters returned from night hunting trip (a), unpacked the lowland paca caught (b & d) for females to cook it (c).

Collective hunting implied benefits for hunters. Hunters perceived that this practice improved their hunting success by enabling different hunting techniques where (e.g., building off ground structures out of local wood to spot wildlife and spend the night safely and opening trails based on species movements with their machetes). It also facilitated the job, as hunters were able to shift active times and improve their knowledge of different species. Other described advantages included targeting and retrieving larger game (e.g., deer or white-lipped peccaries), or more small vertebrates (e.g., up to five paca), fewer risks to hunters' safety, and strengthening social relationships and kinship. A hunter (aged 49) from C2 said: "I prefer to hunt with my brothers-in-law; we can go deep in the forest and catch way more meat…We can build structures and stay for a long time in the forest catching animals. We spend all the night talking and having fun…sometimes we eat some game there. I also enjoy hunting alone, but it is not the same...You must put a huge effort to carry the game back home by yourself".

Disadvantages included having less independence while hunting and dedicating a higher number of resources and time in planning and hunting. After group hunting trips, all hunters involved divided the meat fairly.

2.4.5. Hunting sites

Four different hunting sites were identified: 1) hunters' own milpas or garden plots, 2) others' milpas, 3) protected areas (the core zone of the CBR and ejidos' conservation areas) and 4) other communities (ejidos). Almost half of the hunters in the three communities (n= 44, 46%) reported hunting in only a single site, of which the most common was their own milpa (n=42, 44%). More than half of the hunters (54%, *n* =) reported hunting in two or more sites. Of these, 56% (*n* = 53) hunted in their own and others garden plots, 13% (*n* = 12) in their own garden plots and inside protected areas, 43% (*n* = 41) of hunters and 16% (*n* = 15) reported hunting in all of these hunting sites. Reports of hunting inside protected areas accounted for 43% (*n* = 41) of the reports and hunting in other ejidos constituted 31% of the reports (*n* = 30). Hunters (*n* = 5) from C1 reported not hunting in other people's milpas, conservation areas and/or other communities, because it is forbidden and there are fines if caught hunting in these areas. One hunter in this community reported hunting five years ago in his own garden plot, but currently switching his hunting sites to protected areas due to the lack of animals.

2.4.6. Hunting motivations

Four main motivations for hunting were identified in the study site. In order of frequency, these were: 1) food, 2), crop protection, 3) commerce, and 4) recreation. A limited number of households (n=5, 6%) referred to a single motivation. The majority of hunters (n=71, 74%) reported that their main purpose when hunting was to obtain wild meat to eat. Of these, 96% (*n* = 68) reported crop protection and 5% (*n* = 5) reported commerce as an additional motivation besides eating wild meat. Only 1% (*n* = 1) of these hunters reported recreation as a complementary purpose to eating wild meat. Crop protection was the main motivation for a reduced number of hunters (n=16, 15%). Regardless of purpose, all hunters consumed the meat of the animals they catch. A lower proportion of hunters reported commerce as their main motivation. Although nobody in the study area hunted with the sole purpose of selling wild meat, 13% (*n* = 12) of the interviewed hunters reported commerce as a primary motivation, with secondary motivations of eating the meat (n=10, 11%), or recreation or crop protection (each n=1, 2%). Only one hunter reported recreation as their main motivation for hunting. However, when hunting they also consume and/or sell the meat. A higher percentage of hunters (n=17, 18%) sell wild meat in their communities. Of these, 10 reports for commerce were obtained in C2 and seven in C3. No reports of hunters selling wild meat were obtained in C1.

Nuanced and varied motivations existed between the two main hunter types. These reflect different values associated with the activity, such as the importance of continuity through generations, valuing the skills involved in hunting, sense of self-worth from hunting and the relevance of wild meat as a social bonding agent.

When asked about their motivations, opportunistic hunters reported crop protection, food, and recreation as main motives. An opportunistic hunter (aged 27) in C1 mentioned: "I don't want animals eating my crops, it takes a lot of work to harvest the maize and squash… I also enjoy shooting and eating meat, but I am too lazy to go to the forest and I don't like bugs…Why do people want to go to the forest when animals come to the plots naturally?" Another male in C2 (aged 29) said: "*Puerco de monte* (a local Spanish term referring to the collared peccary) cooked in banana leaves and curassow broth are my preferred meals; I have eaten these since I was a kid. If I see one of those animals in my milpa I will kill them so my wife can cook them." Another opportunistic hunter in C3 (aged 31) reported: "I usually carry a slingshot in case I find big birds. It is fun to catch them; it is like a hobby for me."

In contrast, dedicated hunters specifically reported other motivations, including 1) cultural and/or emotional drivers, 2) habit, and 4) profit. A dedicated hunter from C2 (aged 53) reported: "I have always hunted. Before we used to walk our way to El Mirador ruins (in Guatemala), just to hunt… now we don't do that because there is more work in the milpa, but there are still good places to hunt. We still have vast forest so we can open trails and spend hours finding game. The rewards are good." Another hunter from C2 (aged 49) said: "Not everyone knows how to hunt successfully, you must observe and know your environment. Not even droughts can stop a real hunter, there is always food. It makes me feel very happy to come back home with a good catch". A hunter from C3 (aged 43) said: "I am smart, I know my forest and I know how to hunt. I also make more money selling the meat…everyone loves to eat wild meat, but not everyone is good at hunting. They hunt but that does not mean they are good. Other people get jealous because I make a profit of hunting and they discredit my work. However, they are buying my game". A hunter (aged 61) from C1 reported: "I have always hunted. I hunted with my father, now I hunt with my kids, and I would like to hunt with my grandchildren".

When asked if they were willing to stop hunting and supplementing wild meat with domestic meat, all hunters replied that they would not stop hunting. A hunter in C2 (aged 21) reported: "Even if we had a butchery here selling all kinds of meat, I will still go out into the forest. Hunting is what I know how to do best." Another hunter from C1 (aged 57) said: We do have domestic meat, that is not the problem. The thing is that wild turkey is healthier and tastier than chicken". A hunter in C3 (aged 35) reported: "Some people have chickens, but wild meat is better. Having a butchery won't be feasible; we are far away from the cities".

Non-hunters in the three communities reported that they enjoyed eating wild game and their willingness to continue consuming it, even though they do not hunt. A non-hunter from C2 (aged 41) said: "I enjoy when my wife cooks wild meat, I love to eat paca, curassow, and *jabalin* [white-lipped peccary]. I don't shoot because I don't have a gun, but I constantly buy wild meat". Another non-hunter from C3 (aged 28) reported: "I eat wild meat once a week. Wild meat is so good. I have chicken and goats. We do not eat the goats, but we do eat the chicken sometimes… Many people sell meat here, it is good to have it available". A non-hunter from C1 (aged 23) said: "I don't like to hunt because I do not like to shoot animals and because I spend much time in Xpujil…Still it is good to come home when my grandma cooks curassow".

A total of 16 species from three groups (reptiles, birds, and mammals) were identified as game species in the three communities (Table 2.2). Most game species were reported in the three sites except for the tapir and the furrowed wood turtle which were only hunted in a single community. Of the hunted species, only three: great curassow, white-lipped peccary, and tapir, are under the International Union for the Conservation of Nature's (IUCN) global risk categories, and five: furrowed wood turtle, crested guan and the three species listed previously, are under a risk category from the Mexican law NOM-059-SEMARNAT (2010).

Table 2.2. Species and conservation status of game in three communities of the CBR. Global conservation status (IUCN, 2020), Mexican conservation status (NOM-059-SEMARNAT, 2010).

Order	Family	Common name	Scientific name	Global Conservation Status	In-country Conservation Status
CLASS REPTILIA					
Testudines	Geoemydidae	Furrowed wood turtle	*Rhinoclemmys areolata*	Near threatened	Threatened
CLASS AVES					
Collumbiformes	Collumbidae	Mourning dove	*Zenaida macroura*	Least concern	Na
Galliformes	Cracidae	Great curassow	*Crax rubra*	Vulnerable	Threatened
		Crested guan	*Penelope purpurascens*	Least concern	Threatened
		Plain chachalaca	*Ortalis vetula*	Least concern	Na
	Phasianidae	Ocellated turkey	*Meleagris ocellata*	Near threatened	Na
CLASS MAMMALIA					
Cingulata	Dasipodidae	Armadillo	*Dasypus novemcinctus*	Least concern	Na
Rodentia	Cuniculidae	Lowland paca	*Cuniculus paca*	Least concern	Na
	Dasyproctidae	Agouti	*Dasyprocta punctata*	Least concern	Na
Carnivora	Procyonidae	Coati	*Nasua narica*	Least concern	Na
		Racoon	*Procyon lotor*	Least concern	Na
Cetartiodactyla	Cervidae	Brocket deer	*Mazama sp.*	Data deficient	Na
		White-tailed deer	*Odocoileus virginianus*	Least concern	Na
	Tayassuidae	Collared peccary	*Pecari tajacu*	Least concern	Na
		White-lipped peccary	*Tayassu pecari*	Vulnerable	Endangered
Perissodactyla	Tapiridae	Tapir	*Tapirus bairdii*	Endangered	Endangered

Across the three communities, the brocket deer (*Mazama sp.*) was the preferred game species, followed by the lowland paca (*Cuniculus paca*), the collared peccary (*Pecari tajacu)*, white-tailed deer, and the great curassow (*Crax rubra*). In C1, the three preferred game species were white-tailed deer, collared peccary, and coati (*Nasua narica).* In C2 these were lowland paca, great curasaw, and collared peccary, while in C3 the prefereed game species were brocket deer, lowland paca, and white-tailed deer (Table 2.3).

Table 2.3. Preferred hunting game species in three communities of the CBR. Each coloured bar illustrates the given frequency of response as a proportion of all 124 households.

Game species	C1	C2	C3
Reptiles			
Rhinoclemmys areolata	0	**1**	**0**
Birds			
Zenaida macroura	3	*0*	2
Crax rubra	5	**36**	**25**
Penelope purpurascens	4	*7*	0
Ortalis vetula	4	*4*	5
Meleagris ocellata	16	*20*	26
Mammals			
Dasypus novemcinctus	12	*20*	7
Cuniculus paca	6	**37**	**31**
Dasyprocta punctata	11	*21*	10
Nasua narica	14	*20*	8
Procyon lotor	0	*12*	1
Mazama sp.	8	*31*	34
Odocoileus virginianus	20	*29*	27
Pecari tajacu	17	*32*	8
Tayassu pecari	3	*28*	9
Tapirus bairdii	0	*2*	0

Game availability reported by hunters varied considerably. All hunters reported finding more game during the rainy season. However, 39% of the hunters (n = 37) reported that the game species listed in Table 2.3 are always available during dry season or during the last five years of severe droughts. In contrast, 61% of the hunters (n = 58) reported that their preferred game species were not always available during the dry season. These hunters reported finding less species in their croplands, having to walk longer distances to find game or having to switch their hunting sites to find game. Species reported being less available include the white-lipped peccary, the great curassow, and the ocellated turkey. Evidence of hunted game species found in the studied villages is presented in Figure 2.11). Hunters reported different factors determining prey preference, including the hunting season, occasion, and number of people to be fed, and taste.

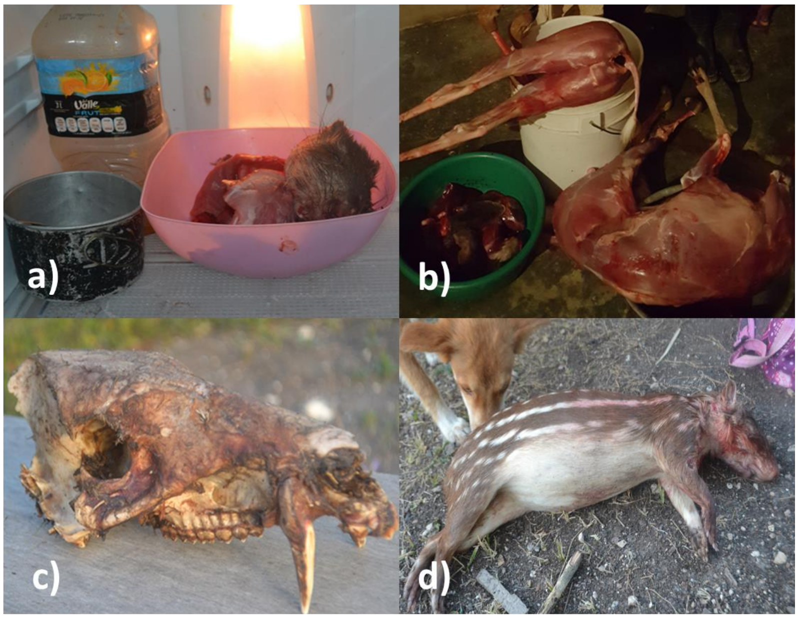


Figure 2.11. Hunted game species found in the CBR: a) & d) lowland paca in households of C2 and C3 respectively, b) two white-tailed deer individuals in a household in C3, and c) skull of endangered white-lipped peccary hunted for game in C2.

2.4.7. Perceived long-term changes in game availability

People in three communities had different perceptions regarding game availability. Of the respondents, 39% (*n* = 48) perceived that there are less species available over the last ten years, 18% (*n* = 22) perceived that there are the same number of species available than ten years ago, and 13% (*n* = 16) perceived that there are currently more species than ten years ago. Households (*n* = 39) reported that particularly they have perception of less white-lipped peccaries in C2 and C3 and less curassows and turkeys in the three communities. However, 30% of the respondents (*n* = 38, of which 24 were women) reported that they could not answer that question due to insufficient knowledge. A relationship between perception and sex was identified ($\chi^2 = 29.81$; d.f. = 3; $p = 0.00001$). Female respondents tend to have less knowledge on species availability than men do. Similarly, a relationship between perception towards species availability and age was identified ($\chi^2 = 14.69$; d.f. = 3; $p = 0.0021$). Respondents between 18 and 35 years old generally perceived more or the same number of species in the area than ten years ago (*n* = 11 and *n* = 12, respectively) or did not know (*n* = 7).

Additionally, respondents reported that in the last ten years, they have perceived other changes that relate to game availability. Respondents reported changes in climate (*n* = 43) and hunting tactics (*n* = 19) in relationship with game availability over the last ten years. Reports described perceived changes in rainfall patterns that indicated that the times of sowing and harvest have changed for farmer-hunters, affecting crop productivity and therefore the availability of game inside their plots. Reports regarding hunting tactics indicated that hunters walk longer distances (distance in km was not specified) to find game and switch preferred hunting sites, and that a smaller number of hunters persist in the community compared to ten years previously due to the lack of game. Four women reported changes in game size describing the game as smaller now than ten years ago.

2.4.8. Hunting regulations and hunters' awareness of regulations

Different hunting regulations were identified in the three communities, as decreed by each ejido authority. In C1, hunting is allowed when farmer-hunters catch game in their own milpas. Hunting is banned in 1) communal areas including community conservation site and areas designated for ecotourism activities; 2) other people's garden plots; 3) adjacent communities; and 4) the archeologic site, managed jointly by the community and the National Institute for Anthropology and History (INAH). Hunting in any of these sites is penalized with a fee of MXN $2,000 (GBP £71). Apart from the legal repercussions, interviewees reported that the activity is commonly regarded as a "bad" practice amongst inhabitants of the community. There were no reports of regulations regarding selling meat in this community. Most hunters – and non-hunters – in this community are aware of hunting regulations. Although subsistence hunting is widely tolerated in the area, local hunters ($n = 2$) in C1 reported that "their right to eat wild meat has been restricted by the environmental police (a federal authority that regulates illegal activities throughout the country)". Two hunters (aged 57 and 27) reported being intimidated and threatened by environmental police officers when caught in possession of a game. Threats included being transferred to the Municipality's police department or to be put in jail. In both cases, police officers asked to keep the game in exchange to let the hunters go home. A member of the community authority (aged 63) confirmed this information. A reduced number of interviewees ($n = 3$) also reported avoiding hunting in other people's milpas and in community conservation areas due to potential fines. However, there was no report of actual penalties in C1. Despite this, people in the area considered hunting a private matter and that one must avoid repercussion from federal authorities yet not from the ejido. An opportunistic hunter (aged 27) said: "SEDENA [the federal ministry housing the environmental police) forbids hunting in the community, so I only get animals in my milpa". A non-hunter in this area (aged 23) said: "Hunting is a private matter. There are regulations and everyone knows that because we talk about this in the community meetings, but people do not care about regulations. They hunt everywhere". Hunters ($n = 2$, aged 27 and 57) report that personnel from the local NGO Pronatura constantly visit the area and ask questions regarding hunting practices. They reported not answering Pronatura's questions to keep their people safe and to stop foreigners from limiting their livelihoods.

Hunting regulations were also identified in C2. A member of the community authority (aged 48) reported that hunting is prohibited in 1) protected areas, including the core zone of the CBR that lies within the eastern border of this community, and the community conservation area; and 2) in other people's milpas. Hunting in adjacent communities is permitted and is frequently done in this village. Hunters that do not follow these regulations can be penalized with a fee of MXN $1,000 (GBR £35). Despite regulations, hunters from this village (both dedicated and opportunistic, $n = 3$) reported that even if caught, they are not penalized for hunting in banned areas. However, awareness of hunting regulations is vague or unimportant for hunters in this community. A hunter (aged 21) reported: "I do not hunt in others garden plots because I can be fined, but if I hunt in the reserve no one will notice". Despite the absence of regulations on the communities of the CBR regarding hunting bans during certain times of the year, elder dedicated-hunters practice self-imposed hunting bans. A hunter in this community (aged 49) said: "I do not hunt paca from March to May because this time is important for its reproduction. After this time, I can freely hunt these animals". There were no reports of regulations on selling meat.

In C3, the community has also established regulations on hunting although less restrictive than in other communities. In this village, hunting is banned only in other people's garden plots. No regulations on hunting in other communities and inside protected areas were reported by the local authority, although the community is adjacent to the core zone of the CBR. Although hunting in neighbouring communities is not forbidden, there are restrictions and fines – of MXN £1,500 (GBP £53) for selling game meat outside the community. Three hunters (aged 37, 43, and 35) reported selling wild meat in C3 and in the surrounding villages and not being penalized. However, a member of the community authority (aged 42) reported repeatedly asking these hunters to stop the commerce outside of the village, to avoid conflicts with other communities. Interviews in C3 did not comment on fines or regulations.

2.5. Discussion

The results of this study revealed commonalities in hunting practices amongst three communities of the CBR, and nuanced differences in relation to local bio-geographies, socio-economies, and regulations. Community-specific hunting regulations themselves reflect the needs, priorities, values, and ideologies of the communities. Hunting is an important supplementary livelihood that provides valuable food resources to all the villages in the CBR. Nevertheless, different socioeconomic, cultural, geographic, and environmental factors, shape the hunting practices and patterns in different communities. Hunting provides a clear and direct example of the links between people and nature. Preserving the viability of wild populations and ecosystems, enhancing the sustainability of hunting are key for the long-term human wellbeing in the CBR.

The observation period of this study might not have been enough to capture the complete dynamics of the community monthly. However, this bias of data collection was mitigated by integrating different methods into the study (e.g., interviews and meetings with key informants).

2.5.1. Factors shaping the hunting and game consumption frequencies in the CBR

Hunting is a common activity among rural communities of the Neotropics, where wild species complement the diets of local villagers (Cawthorn & Hoffman, 2015; Quijano-Hernández & Calmé, 2002; Naranjo et al., 2004; Santos-Fita et al., 2012). In Calakmul, hunting is a common and widespread supplementary livelihood to agricultural practices. Most surveyed households had at least one male hunter catching game in a quotidian manner, mainly for food. Hunting and wild meat consumption were deep-rooted practices in the culture of all rural villages, regardless of their characteristics. However, differences in hunting patterns and practices were influenced by socio-economic, cultural, geographic, and environmental factors, as described in the sections below.

Our results showed that wildlife remains an important resource for people living in tropical forests, particularly in small, isolated, and impoverished forest communities (also reported by Leon & Montiel, 2008; Herrera-Flores, 2016). Although all studied communities hunted, C3, the most isolated ejido surrounded by densely forested areas, presented highest numbers of hunters, followed by C2 (, which was also isolated and surrounded by large remnants of continuous forest. A similar pattern occurs in sub-Saharan Africa, where poor households, isolated from markets and with limited access to protein from domesticated animals, hunted more than those less deprived and with access to markets and other meat sources (Wilkie et al., 2016). In contrast, the lowest number of hunters and reports of this practice were obtained in C1, where socioeconomic factors played an important role in shaping hunting practices.

Livelihood diversification affects subsistence hunting practices. The diversified activities C1 (ecotourism and off-farm jobs) have modified the traditional practices and income in the village's households. The presence of tourists (influenced by local NGOs) and an archaeological site inside the ejido (managed by the INAH), limit the hunting activities in forested communal areas. Additionally, young men in C1 were increasingly getting off-farm jobs in the near urban centre and thus dedicate less time to agriculture. This provided more income, but reduced the time spent in the milpas, thus changing traditional practices and associated eating preferences. Similarly, Gray et al. (2015) found that wealth, livelihood diversification, and participation in conservation programs, were factors influencing the decline in the use of wild resources in indigenous communities of the Ecuadorian Amazon. In Southeast Asia, livelihood diversification resulting from globalisation and urban expansion has changed the hunting practices of different forest communities (Rubiyanto & Hirota, 2021). In Mexico, current national development programs are causing profound changes in the lifestyle of rural people; particularly affecting traditional practices and reducing the dependency of people on wild resources (Navarro-Benítez, 2019). However, young men reported that even if not hunting very frequently, they enjoy and value consuming wild game. The number of hunters in this community is likely to be higher than reported in this study, since people in C1 were reluctant to speak of the topic. This was not the case for the other surveyed villages.

The same pattern was observed for hunting and game consumption frequencies. However, environmental factors such as seasonality and water availability played a key role influencing the frequency of these activities. Most households in the study site reported increasing their hunting frequencies and meat consumption during the rainy season. This overall increase can be related to a higher presence and dispersal of wildlife when water and food are available. Dedicated hunters obtaining game in forested areas benefitted from the fruits of many tree species, such as *ramón* and *nance* (*Byrsonima crassifolia*), available during rainy season, which many mammals eat. Additionally, the water available during rainy season in the aguadas plays a key role for successful hunting. It a common practice for hunters in the Yucatan Peninsula to visit these and other water bodies (Santos-Fita et al., 2012; Quijano-Hernández & Calmé, 2002).

Climate change is affecting the distribution of game with implications for hunting. Although large and medium mammals are found in and near the CBR aguadas all year round, higher abundances have been reported during the dry season as this is when aguadas are their only source of water (Martínez-Kú et al., 2008; Reyna-Hurtado et al., 2022). Due to severe droughts over the last ten years, most aguadas do not replenish enough to hold water during dry season (Revollo & Rios, 2023), making it harder to find animals during this time. Although the rainy season is the easiest time to find game, dedicated hunters who know the landscape can access remoter and larger aguadas with water during the dry season to catch game.

In contrast, opportunistic hunters also benefit from water availability through their harvest. In the CBR, agriculture is the most important activity for all farmer-hunters. During the rainy season, the crop harvest attracts game searching for food in the milpas. Therefore, the overall increase in hunting and game consumption frequencies during rainy season can be related to water availability, harvest, and associate increased hunting success in the CBR. This appears particularly relevant for C1 where these variables considerably increased during the rainy season, compared to C2 and C3. In C1, hunting mostly occurred in an opportunistic way at the milpas, where wild animals constantly searched for food, specially corn and squash that are about to be harvested. Similarly, Santos-Fita et al. (2012) found that hunting activities substantially increased in agricultural landscapes during the rainy season, due to the constant presence of animals such as collared peccaries and white-tailed deer searching for different plants found in agricultural areas.

Lower hunting and consumption frequencies in C1 during the dry season might have socioeconomic explanations as described above, but this community also has easy access to food goods and services due to its location close to Xpujil. Different households reported sporadically buying meat in Xpujil or from meat sellers that visit C1 once a week selling pork chicken, and beef which inhabitants can usually afford with money obtained from off-farm jobs. The lower hunting and consumption frequencies in C2 and C3 in dry season do not mean that farmers hunt less, only that they hunt in a more constant way throughout the year with a slight increase in the rainy season. This slight rise in both villages can also be explained by the presence of harvest crops in milpas and their effect on hunting success. However, in C3, the hunting frequencies remain high in dry and rainy seasons. This can be related to the environmental conditions of C3, which is in the Southeast extreme of the CBR with wetter and more humid conditions. There have been reports of high numbers of mammals that represent wild game to hunters year-round and of more water sources in this humid area covered by tall perennial forest (Reyna-Hurtado et al., 2011; Reyna-Hurtado & Sima-Panti, 2019). Studies on the abundance of large mammal populations in relation to hunting frequencies and game extraction rates are scarce in the CBR. This data can be valuable to inform strategies that contribute to the long-term viability of wild populations and the food security of these communities.

2.5.2. Types of hunters and hunting practices

Opportunistic and dedicated hunters were common throughout the study site. These types of hunters are also common to the wider Yucatan Peninsula (Santos-Fita et al., 2012). The strategies used by each, are largely determined by the environment and the landscape they visit, and the targeted species. Hunters' identities, however, are additionally shaped by their social, cultural, and ideological affinities. Even though most men in the community hunted, and all villagers consumed or have consumed wild meat, hunting was disdained by farmer-hunters and inhabitants in the CBR. Various opportunistic hunters in C1 denied being hunters, as it can be perceived as an illegal activity or one that deeply damages wildlife. Here, dedicated hunters are mostly disregarded by villagers, especially when hunting in protected communal forests. Perceptions on hunting have been largely influenced by the presence of external organisations (such as the INAH, NGOs, and the CBR managers) and by internal ejido regulations. In contrast, people in C2 and C3 were more open and tolerant towards hunters. Here, experienced hunters, were referred as wise people whose local ecological knowledge can be valuable for the community. However, profiting from hunting was much derided, despite the sale of surplus game meat after fulfilling a hunter's family needs being an integral part of subsistence strategies (Van Vliet et al., 2019). Perceptions towards dedicated hunters might be influenced by the fact that they obtained individual profit (in food and/or income) from shared resources at communal forests or illegally at protected areas (Knoop et al., 2020), unlike opportunistic hunters, who mainly obtained food from their privately owned land.

Ecological knowledge was a feature of perceived importance to both types of hunters. Dedicated hunters possessed vast empirical knowledge of the landscape, species biologies, and ecosystem dynamics and cycles. Opportunistic hunters shared this knowledge, but usually with a narrower scope, limited to the dynamics of species present in their milpas. Studies in Mayan communities in the Yucatan Peninsula, have found long-lasting traditional expertise in the management and harvesting of wild game in the milpas by opportunistic hunters (Barrera-Bassols & Toledo, 2005; Jorgenson, 1995). Similarly, studies in Nicaragua and wider Latin America have showed that campesinos (peasants) pose vast traditional knowledge on hunting, which remains relevant for current practices even when hunting in agricultural landscapes (Petriello & Stronza, 2020; 2021). Our study focused on the overall hunting practices and patterns in the CBR, with a larger focus on dedicated hunters' strategies to understand the use of the forest and landscape. However, targeted interviews with opportunistic hunters and observations in their milpas, can reveal more details on the strategies and knowledge of this hunters. This information has the potential to complement scientific knowledge and enhance sustainable initiatives in the area (Zhang et al., 2020).

The hunting types, methods, strategies and species preferences found in this study were similar to those described in previous research in Calakmul (Escamilla et al., 2000) and the wider Yucatan Peninsula (Jorgenson, 1995; Delfín & Chablé, 2004; León & Montiel, 2008; Santos-Fita et al., 2012; Piña-Covarrubias et al., 2022a). Firearms were the most common method used among dedicated and opportunistic hunters (cf much of Asia where snares are more common than guns). This is a common method in Mexico as ejidos are allowed to own firearms (shotguns and rifles) to protect their croplands and territories as part of their customary laws (SEDENA, 2019).

Hunting types in the CBR were usually related to the biological characteristics of the target game species. Nocturnal hunting and the use of flashlights were mostly reported for paca, which is a nocturnal and solitary animal (Argudin-Violante et al., 2023). As found by Escamilla et al. (2000) and Santos-Fita et al. (2012), there were no reports of batida practice in our studied communities. This traditional Mayan technique for catching large-game, consists of two-highly organised groups of hunters that support each other to maximize hunting success. This practice is widespread in areas of the Yucatan Peninsula with fragmented forests and high human densities (Delfín & Chablé, 2004; Hernández-Betancourt & Segovia, 2010; Rodríguez et al., 2012), and rare in small communities embedded in extensive forests (Santos-Fita et al., 2012). Further studies comparing the practices of Mayan communities in the CBR might provide more insights into the wider hunting practices present in the area.

2.5.3. Game species, game availability, and implications for sustainability

Of the 16 game species found in the three study sites, only the great curassow is listed under a protection category by the IUCN and the Mexican legislation (IUCN, 2020; NOM-059-SEMARNAT, 2010). Deer species and collared peccary are widely distributed and abundant in different habitat types across the CBR, despite hunting pressures (Weber, 2000; Reyna-Hurtado & Tanner, 2005). These mostly large-sized species might be preferred over smaller species due to its ability to feed more people. There is no ecological information on curassows and lowland paca in the study area.

Game preferences in the CBR were similar to those previously described for the Yucatan Peninsula (Leon & Montiel, 2008; Santos-Fita et al., 2012; Ramírez & Naranjo, 2007; Rodríguez et al., 2012; Piña-Covarrubias et al., 2022a) and other tropical forests in the American continent (Petriello & Stronza, 2020). Unlike other studies (Redford & Robinson, 1987; Naranjo et al., 2004), mestizos in the CBR hunted a wider array of species than indigenous groups. Ideological drivers, rater than ethnic or traditional ones, were found to affect species preferences in the CBR.

In C3, most hunters and women reported restraining from eating peccaries (both species) as eating pigs was forbiden by their religon (Adventist Church, a relgion adopted around 15 years ago by families in C3 and that is rapidly gainig popularity). Two interviewees from C1, mentioned that armadillos should not be consumed as the Bible (of the common Catholic Church) forbids eating creeping creatures. In contrast, the mestizo population of C2 did not mention any preferences related to religious or other kind of ideology, despite a strong presence and influence of the Catholic Church in the area. Hunting preferences impose a heavy mortality on certain species (Piña-Covarrubias et al., 2022a). Understanding social-ecological drivers of game preferences can conribute to building context-relevant strategies to preserve heavily hunted wild game species for the benefit of the ecosystem and people, particularly in the face of global and regional environmental pressures.

Perceptions of historical game availability varied considerably amongst hunters. Most hunters reported a lower availability of game during the last five years, particularly during dry seasons. This can be related to different environmental pressures, such as habitat fragmentation, overexploitation, and climate change in the CBR. Although the forests in the region remain largely preserved and continuous, large areas have been fragmented due to land-use change derived from recent agricultural intensification policies (Špirić et al., 2022). Combined with this, overexploitation of game species can be affecting the abundance and distribution of certain groups. Reyna-Hurtado & Tanner (2005) identified reductions in ungulate populations, particularly the white-lipped peccary in the CBR, and secondary effects of hunting on animal behaviour and decisions about habitat use. There is no recent information available of the impacts of hunting in this group or on other game populations. Evidence from African and Asian tropical forests suggest that anthropogenic pressures have severe impacts on the viability of wild game populations (Kamgaing et al., 2019; Hema et al., 2019; Pullella et al., 2021). Farmer-hunters perceived long-term changes in wildlife related specifically to climate change. Perceived changes in climate and their impacts on wildlife were in line with scientific observations and evidence on these topics. Mardero et al. (2019) reported the most pronounced anomalies in rainfall from 2004 to 2016, whilst interviewees reported extreme changes in rainfall patterns over the last ten years. Additionally, Mardero et al. (2021) reported increased drought frequencies over the last 50 years (Mardero et al., 2012). In contrast, villagers mostly recalled extreme droughts during the last 10-15 years. Regional climate projections for the Yucatan Peninsula suggest the occurrence of more extreme droughts (IPCC, 2014; Orellana et al., 2009), supporting local observations.

Climate change-related impacts on wildlife identified included reduced availability of species in their milpas due to increasing crop failures and reduced availability of game in the forest that force dedicated hunters to switch hunting sites or walk longer distances. Farmer-hunter perceptions can be explained by the reduced availability of water in aguadas located near the villages during dry seasons, affecting wildlife distribution (Revollo & Rios, 2023; Reyna-Hurtado et al., 2019). The most impacted species according to hunters' perceptions were the white-lipped peccary, the great curassow, and the ocellated turkey. A recent study (Sánchez-

Pinzón et al., 2020) found that white-lipped peccary populations in the CBR have been decreasing due to the lack of water in aguadas, increasing the risk of extinction of local populations. Additionally, my own wildlife survey with camera-traps set from Apr-Aug 2022 in the studied communities, showed records of white-lipped peccaries only in C2. This can explain hunters' perceptions of the availability of this species. Additionally, farmer-hunter perception on increasing changing rainfall patterns and severe drought during the last 10-15 years are in line with observations in the scientific literature (IPCC, 2014; Orellana et al., 2009). In contrast, there are no studies available on the impacts of hunting or climate change on large bird species to corroborate hunters' perceptions. An in-depth understanding of the relationship between forest use, climate change, and their combined impacts on game populations in the CBR is necessary for the development of forest and wildlife conservation strategies in and surrounding ejidos.

In Calakmul, hunting is practiced mainly for subsistence purposes, as wild meat constitutes an important part of villagers' diets. Similarly, food remains the main purpose of hunting for other human communities in the tropical forests of Mexico (Pina-Covarrubias et al., 2022a; Bolaños, 2004), Africa (Braga-Pereira et al., 2022; Groom et al., 2023; Lhoest et al., 2019), America (Petriello & Stronza, 2020; de Paula et al., 2022;), and Asia (Corlett, 2007; Harrison et al., 2016), even when domesticated meat is available. Villagers in the three study sites of the CBR, preferred wild game over domesticated animals as it was usually perceived as healthier and tastier. The preference of wild game over domesticated animals has also been described for hunters living in protected areas of Malawi (van Velden et al., 2020), where, as in the present study, motivations for hunting were multi-facetted and are not only related to economic factors.

Crop protection was an additional purpose of hunting described in the CBR. Although crop protection is a common reason for hunting in Southern Mexico (Leon & Montiel, 2008; Santos-Fita et al., 2012; Piña-Covarrubias et al., 2022a), farmers in the CBR are increasingly hunting to protect their crops from raiding in response to unpredictable rainfall patterns and droughts that increase vulnerability to crop failures and pests. Under increasing resource scarcity, farmers are unable to afford more losses and consequently are particularly vigilant on their milpas for animals' intent on raiding their vulnerable crops. Climate change is considered a critical yet underappreciated amplifier of human–wildlife conflicts worldwide (Abrahms et al., 2023). Thus, a better understanding of the current interactions between people and wildlife in the CBR is needed for developing more sustainable practices.

Although commercial hunting was reported, it was not a common practice in the surveyed communities. Hunters from C2 and C3 sold wild game inside their village and in surrounding communities. The isolated location of these villages along with the high demand of time and effort, might be constraining hunters in C2 and C3 to sell game in wider markets. A study in the northeast region of Papua New Guinea (Pangau-Adam et al., 2012) showed that local hunters' purpose shifted from subsistence to commercial and that hunting became more intense with an urban and infrastructure development and the introduction of a cash market economy.

There is growing evidence of illegal wildlife trade in the region (Felbab-Brown, 2022). Reports from key informants during the time of this study revealed that there is a growing regional market for wild game and wildlife in Xpujil. Additionally, hunters from the Southern villages reported a recent and increasing demand for wildlife and wildlife products from "people from the city" and from "the Chinese". Examples include, jaguar pelts and teeth, white-lipped peccary offspring, toucans, primates, and highly valued timber trees. The CBR's location in the border with Guatemala and Belize makes it vulnerable to illegal trade and other activities (Nijman, 2010). Although illegal trade was not in the scope of this study, urgent attention to this issue is needed in the Calakmul area.

Subsistence hunting and other traditional practices continue in Mexican ejidos. Traditional forms of using wild animals, which remain mostly misunderstood and unappreciated by urban societies, have resulted in social contradictions and taboos (Retana-Guiascón, 2006). Hunting without a permit in Mexico, particularly in protected areas, is illegal. However, customary rights allow ejidos to establish and apply their own regulations regarding land and resource management and social norms (Santos-Fita, 2018).

In the studied communities, Mexican legislation on hunting was widely ignored. In contrast, local norms at ejido level were widely known and mostly followed by local farmer-hunters, particularly the prohibition to hunt in other people's croplands. Ejido hunting regulations identified in this study seemed to be adopted for the purpose of avoiding conflict, inside and outside the ejido, rather than ensuring the long-term sustainability of this practice. In the face of current societal challenges in the area, context-relevant regulations designed by and for each ejido, along with strategies for monitoring their forests, can help rural communities to manage their resources.

Communities in the CBR can have their own regulations on hunting activities through community and customary governance. These are set by the community leaders once approved by ejidatarios through a voting system. Regulations vary between communities and are in line with communities' management strategies and needs, priorities, values, and ideologies. In Calakmul, there are communities that have agreed to regulate this activity (e.g., by establishing authorized hunting sites and setting fines when breaking the rules), whilst there are others where the community leaders have decided to have no regulations at all.

In the context of legal pluralism and land-tenure, community-led monitoring of wild game species can contribute to transformative changes in the area. Knowledge on the status of wildlife can provide evidence to influence farmer-hunters views and values of wildlife (personal sphere of transformation) and to inform ejido regulations on hunting (political sphere). The later can trigger restructuring transformations towards more sustainable hunting practices.

None of the studied communities had a Mayan background. Furthermore, even the Mayan communities currently living in Calakmul arrived from other parts of the Yucatan Peninsula (the region where the original Mayan communities have resided for centuries). The Mayans living there arrived in the 1970s and 1980's as part of the government's programme to colonize the area. For these two reasons, the period of analysis starts in the 1970's, as no communities lived in the area before.

The results of this study show that wild game still represents an important NCP for indigenous and rural communities living in tropical forests. However, the maintenance of this contribution is at risk due the high intensity of hunting and wild game consumption and climate change impacts. At the same time, hunting practices and patterns are changing because of reduced wild game availability and changes in species distribution resulting from climate change, affecting traditional practices and local ecological knowledge. Considering projected changes in climate, climate change-related impacts on wild game will only exacerbate in the coming years (Pérez-Flores et al., 2021). Thus, hunting will not be sustainable in the near future under current hunting and consumption frequencies, climate trajectories, and wider social and economic dynamics. A better understanding and awareness of the impacts of hunting on wildlife and its implications for food security by farmer-hunters along with the implementation of ejido regulations on hunting can provide transformative changes towards more sustainable practices.

Preliminary results from my wildlife surveys in 2019, suggest that the population of jaguars in the CBR decreased during the last decade. A population density of 2.37±1.38 individuals/100 km^2 was calculated in 2021 (Annex 1), whilst 3.3±6.6 individuals/100 km^2 were calculated in 2010 by Chávez (2010). Although further monitoring and analysis are needed for a reliable evaluation on the status of felids and their prey, these results might be indicative of the increasing human and environmental pressures on wildlife in the CBR. This reinforces the results obtained through the surveys with farmer-hunters that indicate that current hunting patterns are not sustainable in the region. However, evidence is needed from ecological indicators to further assess this. Adoption sustainable practices to reduce pressures on game populations is critical for ensuring their long-term viability and the food security of the CBR communities.

Overexploitation and climate change are recognized as two of the biggest drivers of biodiversity loss (IPBES, 2019). Both drivers can have profound consequences on the CBR's ecosystems and their function. High hunting frequencies arguably have worse and broader, ecosystem- and biome-level implications than the community-level implications of not hunting. However, neither extreme represents a solution for the CBR villages, given the potential for regulated and sustainable hunting that can be enabled by rigorous monitoring and self-policing. Examples from the Amazon, show that community-based regulations on hunting can sustain the use of wild species for food (Campos-Silva et al., 2017). In the CBR, training was provided to farmer-hunters in the use of camera-traps and wildlife monitoring. However, financial, and technical resources are still needed to achieve a long-term systematic community-based monitoring.

2.6. Conclusion

Biodiversity provides important material and non-material NCP to rural and indigenous forest communities. Subsistence hunting is a socially and culturally rooted livelihood for the indigenous and mestizo communities living in Neotropical forests. In the CBR, wild game is a major component of the diets of rural villagers living close to the core zone of the reserve. Currently, the high frequencies of hunting and game consumption found in this study, facilitated by poorly defined and administered regulations, suggest that mammal populations are, overall, abundant in the CBR even in human-modified landscapes. The low human population densities in the large continuous forests of the CBR have facilitated the conservation of wildlife populations despite their exploitation, contrary to other densely populated regions around the world where hunting has contributed to local extinctions (Bodmer & Robinson, 2004; Bodmer et al., 1997). However, in the event of increasing human populations, economic development, ecosystem fragmentation and degradation, climate change impacts, and losses of traditional practices in the CBR, its forests have the potential to become empty (Redford, 1992). This will profoundly affect the subsistence and culture of rural villages. This study provides essential information on the ways in which subsistence hunting practices are changing in the face of climate change and other challenges at a local scale.

This study expands our understanding of how hunting practices are shaped in the context of global environmental and socioeconomic change (e.g., climate change, globalisation, biodiversity loss, etc). There is a lack of scientific studies of Neotropical forests that explore the impacts of climate change on hunting practices, despite this being a widespread and relevant livelihood for the food security of forest people. The study also contributes to a better understanding of the different factors shaping hunting from the perspectives of farmer-hunters, providing evidence that rural and indigenous communities possess valuable knowledge of nature and the environment relevant for sustainable use of natural resources, which, however, is at risk as younger farmer-hunters are losing their relationship with nature due to diverse socioeconomic factors. Most importantly, the study helped to identify potential transformative changes, in the personal and political spheres, towards more sustainable hunting practices, that support the wellbeing of people and nature under a changing climate.

This research also contributes to a better understanding of the links between biodiversity, NCP, and human wellbeing, in relation to anthropogenic drivers and institutions and governance at a local scale. . The interlinked and complex relationships between nature and the people that live and directly depend on it are mostly ignored or misunderstood in societies of the Global North that promote and lead sustainable development and wildlife conservation initiatives in the Global South. Proposed 'development' models in the tropics relate industrialization and market dynamics with progress, without considering the cultural, social, and environmental particularities of rural societies (Wicander & Coad, 2018). Hunting and wild-game consumption represent clear example of these issues. With global biodiversity loss now a reality that cannot be ignored, hunting and wild game consumption are often stigmatized as backwards and environmentally destructive by development advocates. Raising cattle and livestock and integrating (and thus depending) on a larger and more destructive meat industry (Kraham, 2017), are often proposed by Western conservation and development organizations, as strategies for reducing hunting pressures in the rural tropics. Hunting can be more conservative of nature and more appropriate in areas disconnected to larger market and distribution dynamics (Zhou et al., 2022).

Critiques of hunting practices need to recognize the social and cultural dynamics of hunting and other livelihoods embedded in natural systems, and their links to food habits and wider social and cultural practices, along with the context-dependent needs and values of villagers. Most importantly, the cultural and social aspects of hunting and the views and needs of rural communities need to be considered and respected. This is particularly relevant in the CBR, where people are directly linked to nature. Thus, uninformed and out of-context 'solutions' can potentially and simultaneously affect the wellbeing of these communities, their relationship with nature, and the vitality of the forests.

This study contributed to expanding the knowledge of hunting patterns and practices in Neotropical forests and to understand the role of wild game as NCP that supports the basic human needs element of wellbeing. At an individual level, it will help to identify and foster transformative changes in the knowledge and values (personal sphere of transformation) of farmer-hunters in the studied communities towards adopting a more informed perspective and awareness of the impacts of hunting on wildlife. At an ejido level, this study represents the first step for acknowledging the need to develop regulations for hunting in each ejidos (political sphere of transformation).

Chapter 3: Perceptions by rural communities of climate threats to livelihoods, their adaptation measures, and implications for food security

Contributions

I initiated the original idea for this chapter, led the related research activities, and led applications for funding, in collaboration with my supervisor Prof Patrick Doncaster and PhD candidate Julio Carrillo Gonzalez from the School of Education, UoS. I developed the chapter aims and objectives based on my previous observation and work done in the CBR during 2018 and 2019. Julio Carrillo and Patrick Doncaster provided support to develop the methods, design the questionnaire, and manage the evaluation of ethics in accordance with UoS policy. I performed the surveys, analysed the results, and wrote the chapter. Julio Carrillo provided support during fieldwork, in logistics and development of the meetings for group discussions, where he also supported as a facilitator. Prof Doncaster provided comments on drafts of the chapter. Dr Lon Grassman from Texas A&M University and Dr Francisco Botello form the National University of Mexico (UNAM) provided support during fieldwork to set camera-traps and acoustic devices in the target communities to survey mammals and gunshot frequencies, for long-term monitoring of forest health. That information will later build on the information presented in this chapter. Fieldwork was conducted with resources obtained with my 2nd Rufford Small Grant (31803-2), my Idea Wild grant, and my Frederick Soddy Postgraduate Award from the Royal Geographical Society (FSPA 08.22). This chapter is in preparation for the International Journal of Environment and Climate Change. Additionally, a report presenting the results of this chapter will be prepared for the ejido authorities, local government (CBR and municipal authorities), and for the German Agency for Development (GIZ), working in climate change matters in the area.

3.1. Abstract

Climate change threatens livelihoods vital to food security for indigenous and rural communities in the world's poorest regions. I aimed to examine the role of communities' preferences and values in shaping their perceptions to climate-risks on their livelihoods.
, as a first step to enhance the resilience, food security, and wider wellbeing of the rural communities. For this, I assess villagers perceived climate risks on arable farming and hunting, using semi-structured questionnaires applied to105 farmer-hunters and women in two villages of the CBR (C1 and C2). Later, in focus groups with a total of 35 participants, we discussed climate impacts on their livelihoods, how they perceived food security and wellbeing, and co-produced adaptation measures to increase their resilience to climate change and food security. Villagers in the CBR perceived that drought, changing rainfall patterns, and increasing temperatures increasingly affected water availability, soil fertility, pests in crops, and the distribution of wild mammals the area, affecting their crop yields, economies, labour, traditional practices, diets, and human-wildlife conflicts. Villagers perceived increasing risks on their food security and wider wellbeing, with implications on their traditional knowledge and autonomy. Based on this, villagers in C1 and C2 proposed two and five adaptation strategies to enhance the resilience of their livelihoods. Villagers viewed that adaptation strategies might be insufficient for coping with increasing changes in climate and with deprivation levels. Opportunities for nature-based solutions to climate change and other societal challenges exist in the CBR if transformative changes occur from local to regional scales.

3.2 Introduction

Climate change and biodiversity loss are affecting food security and human wellbeing in the world's poorest regions. Increasing and interacting human-induced changes in the atmosphere, biosphere, and other Earth systems have affected weather patterns and climate extremes globally. This has led to widespread negative impacts and related losses and damages to people and nature, downgrading food security globally. Rural communities that depend on local ecosystems and contributions for their own food production and intake are amongst the most vulnerable populations to climate impacts (Mbow et al., 2019; IPBES, 2019; IPCC, 2023).

3.2.1 Climate change threatens food security

Food security is defined as a state in which everyone has access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life, at all times (FAO, 2018; Ford, 2009). It follows that every individual in a community must be able to rely on having sufficient (1) available food to feed themselves and their community, (2) access to diverse and quality food resources from healthy sources, (3) usage of food resources with nutritional and cultural value, and (4) stability in continuous provision of resources. These are considered the four pillars of food security (Mbow et al., 2019).

Risk is defined as the potential for adverse consequences in human and/or ecological systems, recognising the variety of values and objectives linked to these systems (Reisinger et al., 2020). Climate-related risk to food security arises from different interacting drivers that involve both climate change impacts and responses to these and other stressors. In the context of climate change impacts, the multiple drivers of risk include: 1) climate hazards such as drought, temperature extremes, and humidity; 2) indirect climate-related impacts such as pest outbreaks triggered by ecosystem responses to weather patterns; 3) exposure of people and livelihoods, for example people depending on a specific crop; and 4) vulnerability or adaptability for example, how able are affected people to substitute alternative sources of food, which may be related to financial access, markets, and culture. In the context of climate change responses, the drivers of risk include: 1) the demand for land from climate change responses, 2) the role of markets, 3) governance, and 4) human behaviour, for example dietary preferences.

This study concerns the adverse consequences that climate change and other stressors are generating and/or exacerbating for the livelihoods of rural communities that depend directly on food resources obtained from the local forests and from traditional subsistence agricultural systems, embedded and thus affected by ecological dynamics. In this context, the IPCC risk framework was used to support this study (Figure 3.1), integrated in SES, thus considering synergies between the socioeconomic and ecological systems (Seddon et al., 2019).

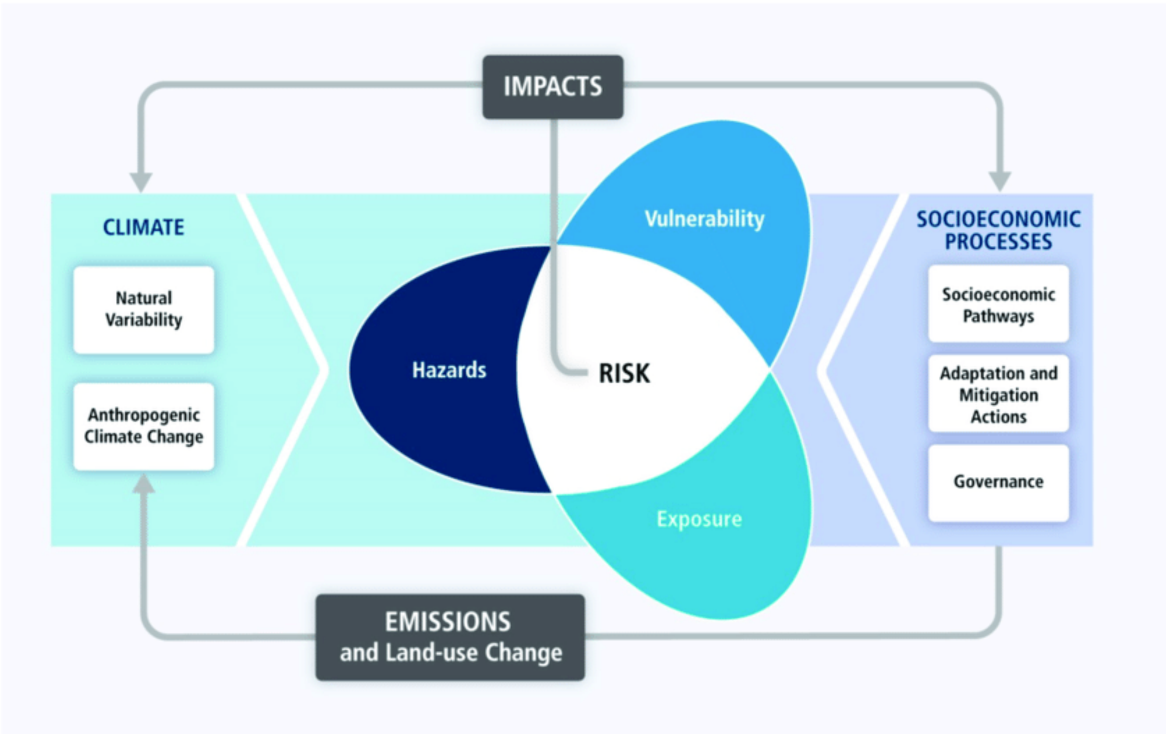


Figure 3.1. The fundamental concept of climate-change risk and vulnerability (IPCC, 2014).

In SES, safeguarding and strengthening nature is key to securing a liveable future (IPCC, 2022). Nature-based human development can protect and enhance natural resources while protecting people from shocks, promoting economic and food security. Such investments are especially relevant at the local level, to address the need for investing in governance that is connected to people on the ground, that builds bridges among policy and institutional silos, and that ensures all voices are heard. At the same time, investments are needed in global public goods, to tackle the planetary and societal challenges of the Anthropocene (UNDP, 2022).

Ecosystems and their biodiversities directly and indirectly support food security and human wellbeing (Diaz et al., 2018). Tropical forests contribute positively to food and nutrition security through the direct provision of forest foods and by the indirect effects from forest-based NCP on surrounding agriculture in integrated nutrition-sensitive landscapes (Olesen et al., 2022; Powell et al., 2015). Communities living in or near tropical forests usually have access to substantial resources, such as vegetables, fruits, and game meat, obtained freely from nature (Borelli et al., 2020; Bennett, 2002), allowing more varied diets than those reliant only on commercial food sources and markets (van Vliet et al., 2015). Additionally, tropical forest communities frequently rely on small-scale agriculture for food provision and income. However, interacting impacts of climate change and biodiversity loss can threaten the pillars of food security particularly in the world's rural and most impoverished regions (Muluneh, 2021, IPBES, 2019). Thus, sustainable use of natural resources must confront the globally accelerating loss of biodiversity (IPBES, 2022).

Marginalized rural communities living in tropical forests are often disproportionately affected by climate change (Stern et al. 2006). Climate vulnerability and exposure are largely determined by socioeconomic and societal conditions, whilst sensitivity to climate change depends on the diversity of local landscapes and systems (Thomas et al., 2007). Usually, the most vulnerable communities are those that are both most exposed to hazards and have least adaptive capacity, resulting from a lack of financial resources, human and social capital, or access to adaptation technologies (Turner et al. 2003; Schröter et al. 2005; Vogel and O'Brien 2006). This includes, for instance, sectors of the population that depend heavily on subsistence activities involving extraction of natural resources which are themselves vulnerable to climate shocks (Bohle et al., 1994).

Within vulnerable communities, smallholder farmers in tropical developing countries are particularly at risk of climate change impacts (Harvey et al., 2014) Research suggest that that individuals, small groups, or households manage more than 90% of the 570 million farms in the world (Lowder et al., 2016). Approximately 2.5 billion out of the total 3 billion rural inhabitants rely primarily on farming for their livelihoods (FAO, 2018), with smallholders constituting 84% of this demographic (Lowder et al., 2016). The impacts of climate change pose significant threat for smallholders, as their limited resources hinder their ability to adapt to climate-related shocks (Harvey et al., 2014), further exacerbating their vulnerability (Jarvis et al., 2011).

Opportunities for adaptation are available for smallholder farmers living in rural communities, through nature-based solutions and other transformative changes that reinforce positive synergies between social and natural systems for human wellbeing (IPCC, 2022; 2023).

3.2.2. NbS for climate change adaptation

Extreme weather events and the failure to adapt to climate change are among the greatest risks to human wellbeing, both in terms of severity of impact and likelihood of occurrence (World Economic Forum, 2020). Although extreme weather events and other climate change risks have been mainly addressed through engineered interventions (e.g., sea walls, irrigation infrastructure; Jones et al., 2012), evidence show that NbS can act either as an alternative or complement to this approach (Global Commission on Adaptation, 2019) in some contexts, such as SES.

NbS are actions that involve working with and enhancing nature to help address societal challenges (Seddon et al., 2020; see Chapter 1 for more information on NbS). In the context of SES, NbS can play a major role for adapting to climate impacts. In SES the vulnerability of ecosystems and of socioeconomic systems are integrated. In each system, climate change vulnerability is determined by the exposure, sensitivity, and adaptive capacity. Exposure refers to the extent to which an ecosystem, resource, or community is impacted by climate change; the sensitivity refers to the degree to which a system is affected by, or responsive to, those effects; lastly, the adaptive capacity is the ability to adjust or innovate in response to changes (IPCC, 2014). NbS act at the interface of the socioeconomic and ecological systems to reduce the vulnerability of the SES. Thus, by protecting, restoring, and managing ecosystems NbS can positively shape the three dimensions of socioeconomic vulnerability (Seddon et al., 2019).

Evidence shows that nature supports human adaptation by reducing socioeconomic exposure and sensitive of SES. In terms of exposure, the protection, management, and restoration of natural forests in catchment areas has secured and regulated water supplies, reduced flood risk, and reduced exposure to soil erosion and landslides (Jiao et al., 2012; Bradshaw et al., 2007; Huang et al., 2012). NbS supported by biodiversity have also the potential to reduce the sensitivity of individuals and societies to climate change by securing the provision of NCP that sustain livelihoods and wellbeing whilst providing diverse sources of income to help communities adapt to climatic and non-climatic shocks (Seddon et al., 2019). For example, forests protection in Zimbabwe ensured honey production during times of droughts, giving a degree of food security when crops fail (Lunga & Musarurwa, 2016).

Additionally, nature can contribute to increase socioeconomic adaptive capacity of a system. NbS aiming to maintain species diversity can contribute to maintain a reservoir of wild species that can help people adapt to change; for example, breeding resilient food crop varieties to climate change and pests. Additionally, implementing NbS can bring communities together and foster learning and innovation, especially through the Ecosystem based adaptation process (Seddon et al., 2019). The implementation of community-based natural resource management in Ethiopian rural communities motivated them to develop systems for managing natural resources under climate change, whilst improving institutional governance and thereby potentially increasing their capacity to deal with future climate changes (Reid et al., 2009b). However, other factors such as financial and human resources, education, and governance, determine the adaptive capacity and influence opportunities to implement NbS (Abdul-Razak & Kruse, 2017).

NbS for climate adaptation in SES address vulnerability to climate hazards, whilst reducing risks and support human wellbeing. Studies on NbS have the potential to support the four elements of wellbeing, including basic human needs (e.g., securing water supplies and reducing flood risks; maintaining wild species reservoir for resilient food crops; Bradshaw et al., 2007; Seddon et al., 2019); economic needs (e.g., providing diverse sources of income to help communities adapt to climate change, reducing impacts on infrastructure from flooding; Mureithi et al., 2016; Sutton-Grier et al., 2018); whilst simultaneously addressing environment needs (by preserving and/or enhancing the natural environment maintaining ecosystem function and the provision of NCP) and contributing to subjective happiness (e.g., fostering relationships and learning, among others; Seddon et al., 2019).

3.1.3. Community-based adaptation can build resilience to climate impacts locally

Community-based adaptation contributes to reducing vulnerability and enhancing resilience, whilst sustaining local economies and potentially strengthening community cohesion. This bottom-up process coordinated and led by communities has strengthened adaptive capacities of rural and indigenous peoples worldwide (Reid et al., 2009a; Morecroft et al., 2019; Owen, 2020; McNamara et al., 2020). However, the decision to implement adaptation strategies depends on individual and communal perceptions, which are the strongest positive predictor of behavioural responses to hazards (Ngo et al., 2019; O'Connor et al., 1999). If individuals have a reduced risk perception, they will be unlikely to undertake adaptive actions, whilst higher risk awareness leads to enhanced preparedness, limiting potential damage (Howden et al., 2007). Adaptation planning therefore depends critically on understanding risk perceptions at individual and community levels and the factors shaping them.

Climate risk perceptions and responses occur in the context of multiple biophysical and socioeconomic factors (Battisti & Naylor, 2009), which influence individual decisions (Howden et al. 2007; Slovic, 2009). Thus, what climate change means to rural villagers is, in large degree, a product of the context in which climate change takes place. Yet, the links between perceptions and adaptation context remain insufficiently supported by empirical evidence (Safi et al., 2012). Therefore, a detailed understanding of rural inhabitants' perceptions is a needed to strengthen adaptation and disaster risk reduction in the world's poorest regions, for human wellbeing.

Shared understanding communities' perceptions on climate change, and related risks on subsistence livelihoods, can lead to more integral community-based adaptations that enhance the food security of people and the vitality of wildlife in the CBR.

3.1.4. Aim and objectives

This study aims to examine the role of preferences and values for members of two rural communities in CBR in shaping their perceptions to climate-risks. This was addressed with three objectives:

1) Assessing perceived climate risks, considering perceived hazards, vulnerabilities, and impacts on forest livelihoods and their implications for food security, in communities affected by climate change.

2) Identifying how communities perceive wellbeing and food security.

3) Identifying climate change adaptation measures that enhance the resilience and sustainability of human communities living in tropical forests and their livelihoods.

Qualitative methods of information gathering and community participation were used to achieve the objectives of this study. A descriptive approach was deemed appropriate to the aim, given the current consensus that transformative changes require embracing the knowledge, views, and needs of indigenous and rural communities affected by climate change local knowledge in adaptation planning (IPBES, 2019). The Results section includes extended quotes from farmers-hunters, selected to capture their breadth of knowledge, perceptions, and views, and thereby to form a holistic overview of current living conditions in relation to nature. This approach to reporting is commonly adopted for qualitative studies in conservation and other environmental studies, when people's perceptions, obtained though narratives, constitute the primary source of data (Eldh et al., 2020; Sutherland et al., 2021). Examples of this kind of studies include Martello (2008), Pennesi et al. (2012), and Popovici et al. (2021) for integrating indigenous views on climate change studies; and Vannelli et al. (2019), Queiros & Mearns (2019), and Davis et al. (2023), on people's perceptions on wildlife and conservation.

3.3. Methods

The study took place in two communities in the buffer zone of the CBR where previous research had been conducted (C1 and C2) in 2019. These communities were selected based on the following criteria: prior knowledge about the communities, the need to assess climate-related impacts on their livelihoods identified during previous research, links to other data chapters, and awareness of communities' willingness to accept further investigation. Additionally, the communities were selected for their differences in socioeconomic conditions, distance to the main urban centre, ethnic composition, and vegetation type. In general, C1 has less level of deprivation and reliance on forest livelihoods and resources that C2. C1 is closer to the main urban centre, has a mixed indigenous-mestizo composition and its vegetation is mostly low-subperennial-flooded forest. In contrast, C2 is highly dependent on forest livelihoods and resources as it has higher levels of deprivation and isolation, being further away from the urban centre. Its population is mostly mestizo, and the vegetation type is subperennial forest. refer to the *Methods* section in Chapter 2 for more details on the socioeconomic conditions of these communities.

In these villages, small-scale arable farming and hunting of wild game represented primary sources of food and income, until increasingly frequent crop failures within the last 10 years caused by climate change, have affected these livelihoods, crucial for the food security.

Different studies suggest that the climate in Calakmul has become more extreme over recent decades. Rainfall patterns have shown increasing interannual variability and more pronounced anomalies, both positive and negative from 1982 to 2016, with more marked changes during 2004 to 2016 (Mardero, et al., 2019). Additionally, drought frequencies have increased for the last 50 years (Mardero et al., 2012). Regional climate projections for the Yucatan Peninsula suggest the occurrence of more extreme droughts (IPCC, 2014; Orellana et al., 2009), supporting local observations.

In summer 2022, adult male farmer-hunters and women (>18 years old) from these communities were interviewed face-to-face, each with a group-specific semi-structured questionnaire ('Subsistence hunting, climate change and food security in the Calakmul Biosphere Reserve, Mexico', ERGO ID number: 71885;), with 20 questions with 40 minutes duration (Appendix 4). The questionnaire was designed to explore villagers' perceptions on climate changes and impacts, the vulnerability of their livelihoods in face of the perceived changes, and current responses to climate impacts. Villagers were also asked about their diet and the elements that compose it.

Men and women from the same household were interviewed, separately, when possible, to corroborate the information obtained from each. The semi-structured questionnaires were developed based on my previous research on hunting in the CBR (see Chapter 2) and on the components of climate change risk (IPCC 2014, Figure 3.1). Participants, identified during previous research, were approached directly in their houses by the researcher (C.A.V.) and invited to participate in the study. In case of acceptance, the researcher conducted the questionnaires in private, filling out paper-based questionnaire, after reading a Participant Information Sheet (Appendix 2). Participants were asked to express verbal consent to participate before starting the questionnaire. A total of 105 interviews were conducted in two communities. During the interviews, participants were recruited for focus group discussions. This purposive sampling technique is widely recommended as focus group discussions rely on the ability and capacity of participants to provide relevant information (Morgan, 1988).

After the interview phase, two focus groups were held in the Ejido Guildhall of each village to: 1) discuss perceptions on different components of climate risks in relation to their livelihoods, and 2) identify adaptation measures for building resilience and their long-term food security. The focus groups had 20 participants in C1 and 15 in C2. The scope of the focus group discussions was limited to the following: 1) perceived climate hazards and risks to subsistence livelihoods, 2) community responses to perceived climate impacts, 3) defining wellbeing, 4) identifying dependencies on principal elements of local diets and their importance for food security, and 5) identifying best practices for resilient livelihoods. For #1, different approaches were used to facilitate information exchange, such as building timelines (Reenberg et al., 2012) and agricultural calendars, describing their livelihood strategies in relation to perceived weather events. The purpose and rules of the activities were described to participants prior to creating the focus groups. All the activities and discussions were done in plenary, and communication occurred in Spanish. Participants were giving the choice to withdraw from the study at any point by leaving the room (none did). Pictures of the focus group discussions are presented in Appendix 5.

The motivating questions for focus group were open-ended to elicit a broad range of opinions and issues related to each topic. To moderate the discussions and to collect qualitative data whilst validating the information obtained, we used and adapted the ‘metaplan’ technique (Metaplan, 2009). This method is a card sorting technique based on a group discussion that facilitates a structured classification process, which allows for the identification and assessment of environmental issues whilst encouraging transparent, responsible, and accountable democratic decision-making processes (Campagna, 2014). The method was adapted to the study context, as most participants were illiterate or reported feeling confused when using colour cards. To mitigate these arising issues, the answers and views of participants were directly recorded by the researcher in plenary, either on flipcharts or on a whiteboard, instead of using colour cards. During the discussions an additional researcher took notes. When the discussions were finished, photographs were taken of the pinboards containing the information provided by participants. Additional notes on the topics of interest were collected by the researcher and facilitators when relevant.

During the focus group discussions, the concept of wellbeing was discussed with participants to obtain a context-relevant definition. As participants did not recall a particular definition for this concept, seven aspects of wellbeing were deconstructed by participants reflecting the main factors that provide them a good quality of life, based on the four elements of wellbeing (Summers et al., 2012; Maslow, 1954).

Data obtained was transcribed to an anonymised electronic format, after which all questionnaire sheets and notes were destroyed. A qualitative content analysis was performed, to avoid decontextualising participants narratives (Dey, 1993; Harper, 2003; Silverman, 2011) of the open-ended questions in questionnaires and group discussions, with the objective of identifying common ideas and classifying them into categories (Fink 2009; Bryman 2012). Data were analysed in accordance with guidelines for qualitative approaches (Rodriguez et al., 1999; Taylor & Bogdan, 1996). The information was organized in the following categories: (1) perceived changes in climatic conditions, hazards, associated vulnerabilities; 2) perceived effects and risks on livelihoods (arable farming and hunting); (3) responses to climate impacts; (4) food security; (5) wellbeing; (6) adaptation measures. Interview and focus group responses were catalogued with a relative value on a 4-point scale of quartiles, where Q1 corresponded to < 25% of interviewees, Q2 to 25-50%, Q3 to 50-75%, and Q4 to 75-100%. Aspects of wellbeing relevant for the communities were classified and discussed according to the four primary elements of wellbeing: basic human needs; economic needs; environmental needs; and subjective happiness, described by Summers et al. (2012) and Maslow (1954). Adaption measures were classified according to the categories proposed by O'Neill et al. (2022) presented in Table 3.3.

3.4. Results

This section described the results of the study based on different categories.

3.4.1. Perceived changes in climatic conditions, hazards, and associated vulnerabilities

Interviewees in Q4 (75-100%) perceived changes in rainfall patterns (time, frequency, intensity, and geographic distribution), intense and prolonged droughts, and increased temperatures, as having caused losses and damages in their communities. Villagers in Q4 were aware of the overall climatic conditions and were familiar with extreme weather events, recognizing in general more intense changes in climate and drier conditions during the last 10-15 years. They also perceived themselves as highly vulnerable, as they considered that the region was highly exposed to weather extremes and lacked “good” conditions for farming due to poor soils and water scarcity since the time of colonization, along with a high sensitivity due to the levels of isolation and deprivation, and lack of government support (Figure 3.2). In contrast, villagers in Q1 (< 25%) reported that they hadn’t perceived any changes in climate, as droughts and changing rainfall patterns were the “normal” characteristic of the Calakmul region since they arrived in the late 1970s.

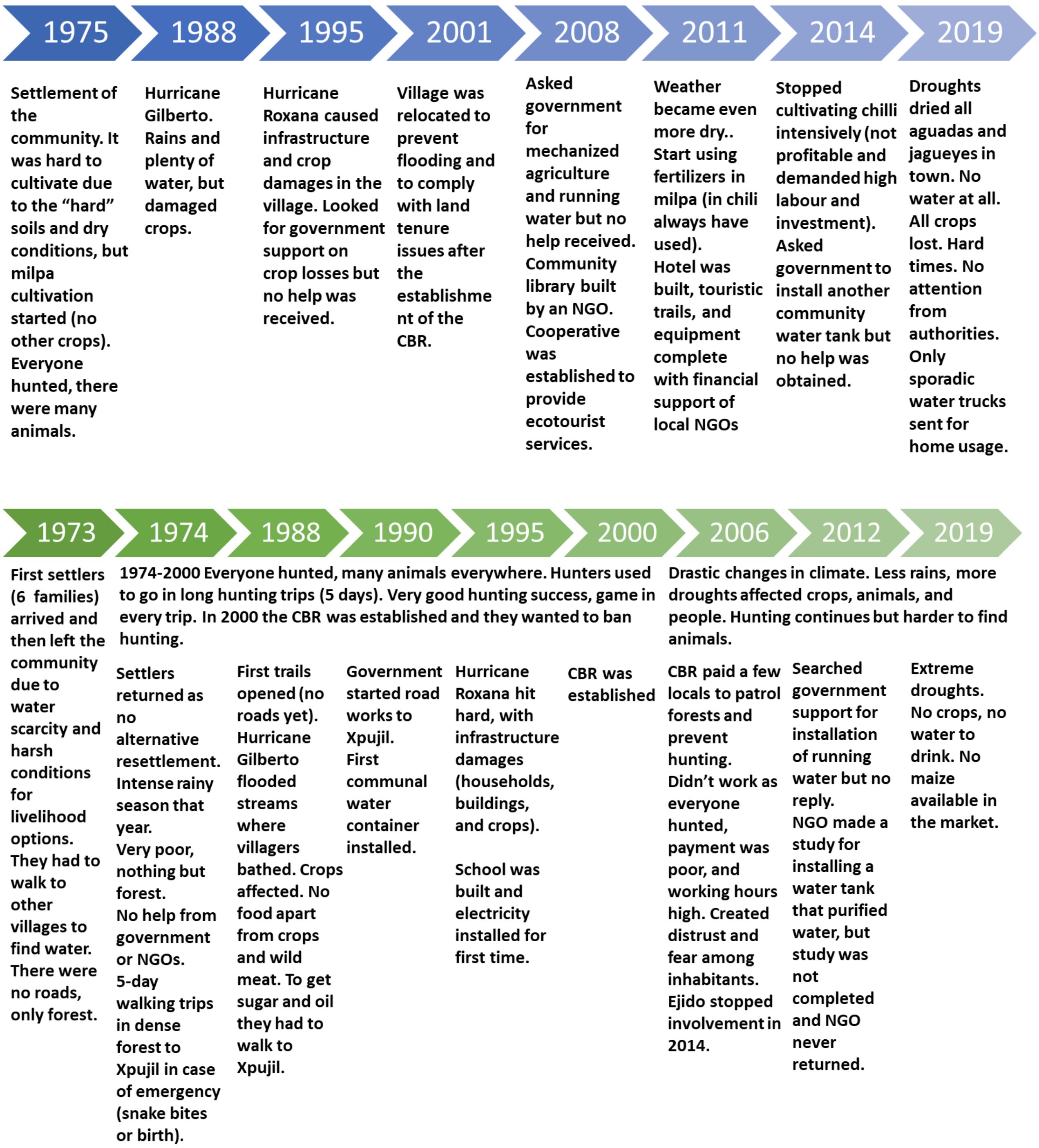


Figure 3.2. Perceived changes of villagers in Q4 on the climatic conditions and vulnerabilities since the settlement of the villages to the present date (1975-2019) in C1 (blue) and C2 (green). C2 is located approximately 45 km further than C1 to the main urban centre.

Perceived climatic changes and hazards were the same in both villages. Villagers did not link these changes directly to global climate change. Interviewees in Q4 expressed not having heard about this global phenomenon, whilst interviewees in Q1 mentioned having heard this term in the national news, therefore relating it to climate hazards such as fires and floods in other parts of the country but having no further knowledge. Yet, less than 25% of the villagers (Q1) explained the perceived changes in climate because of human modifications to the natural forest cover. A farmer-hunter (81 years-old), who was one of the first settlers in C2 said:

> “Water availability has always been an issue here in C2; therefore, we have always valued water as a precious resource. However, when I arrived at this village around 40 years ago, it used to rain more and stronger than today. The aguadas retained water, they never dried completely. We even had small streams, especially after hurricanes, which kept water for up to 5-6 years because of the heavy rains. There was a marked rainy and dry season; during the rainy, we used to get real rains. For the last 15 years or so, everything is different. Now you never know when it is going to rain, and even if it rains, it is not strong enough to support our crops. Therefore, some years we lose all the harvests [referring to milpa crops, milpa is a small field where maize, beans, squash, and other crops are grown together]. Before, hurricanes that came every 8 years or so, used to damage our crops. Today continuous droughts ruin all our harvests”.

A woman in C1 (37 years-old) described:

> “Here we feel many changes in climate; for the last 10 years, the rains have been different every year. There are some years with no rains, and others we get a few, yet less hard (intense) than before. The only constant here is the increasing heat. Before (10 years ago) in December, it got very cold. My kids used to wear jackets and blankets; I don’t use these items anymore. I think it was the rains that “washed away” the heat. Now the heat is unbearable because there are less rains. The intense heat is a threat because my kids and my animals [referring to her backyard’s chicken and domestic turkeys] get sick very often. The kids need more medicine for fever, and we don’t get to eat the animals anymore because they die”.

In contrast, a farmer-hunter from C2 (aged 45) said:

> “I think that the climate has not changed. It has always been like this. In Calakmul there is no water and there are no rains. Yes, sometimes when a hurricane comes, we get some water, yet this place has always had bad conditions”. You just need to be aware that some years you will get good harvest and other you won’t because of the weather conditions”.

Another farmer-hunter from C1(aged 53) mentioned:

> “I have seen that climate has changed a lot since around 20 years ago. Since the ejidatarios decided to cut the (communal) forest, there is more heat in the village, we have less rain, and the aguadas don’t retain water anymore. Every year it gets worse as many ejidatarios are cutting the forest in their (private) plots to claim *Sembrando Vida* (government program for agroforestry) subsidies”.

3.4.2. Perceived effects and risks for livelihoods

Villagers described the effects of the different hazards on their livelihoods (arable farming and hunting) with consequences for their economies, food security, labour, traditional knowledge, and culture. The perceived vulnerability and climate impacts on each livelihood are described below in separate sections for the purpose of organisation. However, 75-100% of the interviewees (Q4) perceived that interlinked and reinforcing effects of climate hazards with other non-climatic stressors and pre-existing vulnerabilities, represented increasing risks for their livelihoods, the environment, and their overall wellbeing (Figure 3.3).

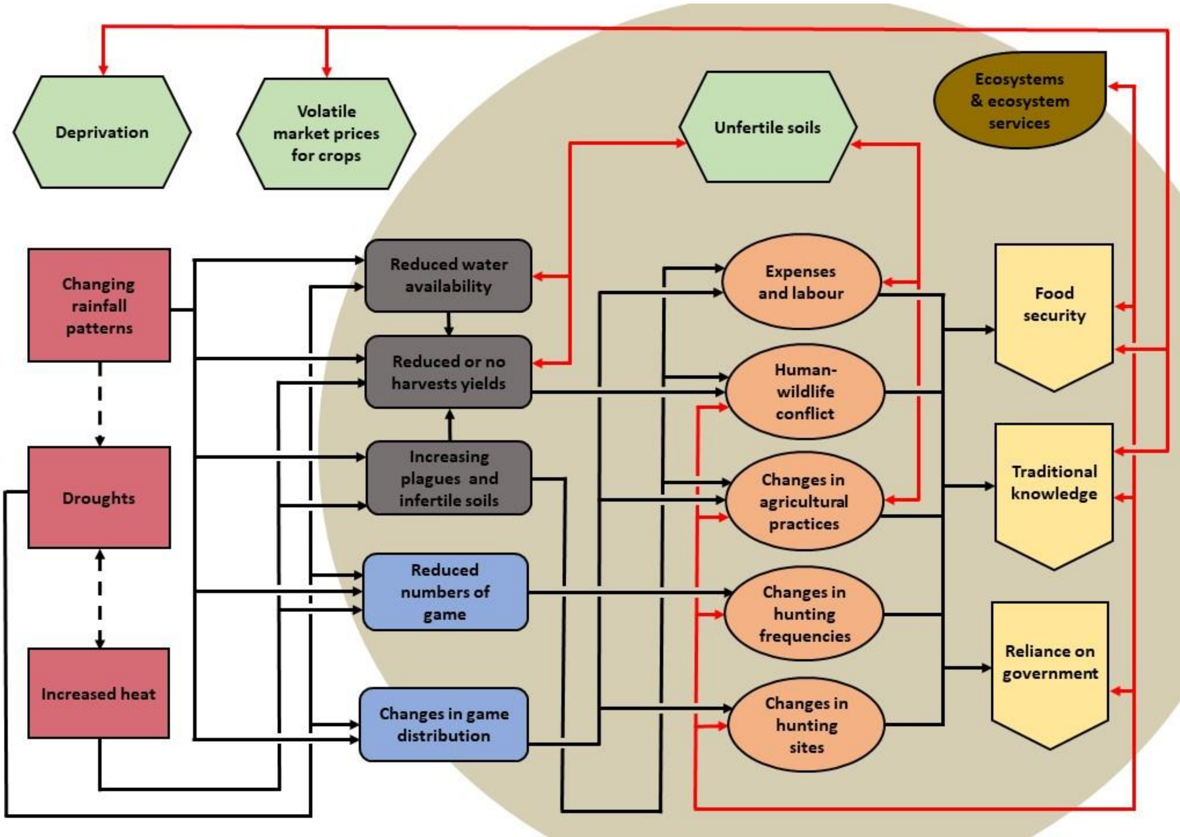


Figure 3.3. Perceived effects and interactions of climate hazard (red rectangles) and other non-climatic stressors (green hexagons) on arable farming (grey rectangles) and hunting (blue rectangles), on other environmental, socioeconomic, and cultural components of these livelihoods and also internal to the system (orange ovals and yellow pentagons). Hazards and non-climatic stressors are external to the social-ecological system (beige background). Black arrows show one-way (black) and two-way interactions (red) between elements.

3.4.2.1 Arable farming

Villagers in Q4 from both communities, perceived that their economies and food security were at risk because arable farming was extremely vulnerable to the combined effects of different climate hazards. Changing rainfall patterns were directly affecting the productivity of their already vulnerable crops during the last decade, as rain was key to the success of their rainfed agricultural practices. This hazard, along with increasing droughts and temperatures, were reported to have reduced the fertility of already unfertile soils and increased plagues in all crops, which made deprived farmers spend more money on fertilizers and pesticides year on year. At the same time, the combined effects of the three hazards made farmers spend more money on water, to water crops and avoid further losses. The most important impact reported on arable farming was the reduction of maize and chilli yields.

A farmer-hunter (49 years old) in C2 said:

> "Before (10-15 years ago) maize harvest was better than today; today we don't get yields. No matter what we do, crops fail because of the lesser rains and increased droughts. If there is no rain, there is no food. Before by May 15th, I already had planted maize as the land was wet, but not anymore. Now, whenever we get a little rain, we get some harvest; but even in "rainy" years, sometimes the corncob does not grow enough. Now, I also must carry water to my plot, and it is a lot of work and money. Buying water here is hard as it takes time and money, and then you need a vehicle to carry it. Every trip in the motorbike I can take only two water containers of 120 L each, which cost me $120 each. Every week I take more than 1000L in my bike and it is a lot of work. Then, add up that I must fertilize the crops much more than before. I have always added fertilizers because the land here is poor. However, I used lower amounts before. Now I use a lot and it doesn't even work, because the granule (of the fertilizer) needs rainwater to function. Fertilizer for maize is $850, and I need four sacks for my milpa in each harvest season. Also, the *cojollero worm* (plague) is ruining the maize crops, and every year it gets worst. Therefore, I don't plant that much maize as before, when I planted 4 ha, today only 1 or 2 ha depending on when and how intense the rainy season starts. Today, I don't sell maize as before, now I buy it! Therefore, I cannot feed my family and even the animals are hungry because there is no maize to eat".

A farmer-hunter in C1 (aged 27) described:

> "Farming is becoming impossible in Calakmul. It was already hard enough to work here and now things are getting worst. The aguadas are dry, rains are coming in different times, and are less intense…where are we supposed to get water from? Without water there is no way to harvest crops, we don't have irrigation systems here, and now we are even losing the aguadas. When the aguada dried, we lost our last chance of maintain my crops, as we [father and him] irrigated them manually with this water. We have now set large water containers in the plot, but it is expensive to fill them, and we don't always get water when we need it. Five years ago, we stopped growing chilli because it needed much more water for maintenance and fertilizers and much more work. We gave up because we lost all our yields during three continuous years, and we needed to invest money that we didn't have. Today, we only grow 1 ha of milpa. In "good years" we grow 1.5 to 2 ha, but it is not certain that we will have a good harvest. We do still get some maize and beans sometimes. I don't know what I am going to do if things keep up like this. I don't know how to work in other thing apart from farming, but all this is too much of a struggle".

Another farmer-hunter in C2 (49 years old) described the impacts of climate hazards on arable farming and its implications for farmers' lives:

> "The weather has affected our livelihoods, living us with no food and no money. Farming is everything for us, that is what we do from sunrise to sunset. But this activity is not good anymore. Before, we (farmers in the community) used to cultivate 4 ha of milpa and obtained a yield of 4 tons of maize. For the last 7-10 years, we only grow milpa in 1 ha and obtain a yield of around 500 kg in good

> years. In dry ones, we only get 250 kg. But we cannot stop cultivating, we are still there fighting to eat and have income. We know that maize is no longer an income, so we must find other ways…However, it is still our source of food, therefore we cannot stop farming our milpa”.

A famer-hunter from C1 (68 years old) said:

> “Here, we don’t have enough money to solve new problems. I have tried to cope with the rains, but I cannot afford to buy more fertilizers and pay for water anymore. Five years ago, I spent all my money in building a jaguey in my plot, but it never filled up with rainwater. I had to bring water with trucks, but it didn’t last. With the crops, you need to put in a lot of money and effort in something that is now uncertain. In other ejidos people have cows and at least that seems more profitable, but here we don’t. Luckily, my son turned out smart, and he is now working in Xpujil. He is earning a constant income and won’t rely on crops like me”.

Another farmer-hunter (aged 66) said:

> “We, Calakmul farmers, don’t need much money, and we don’t need it as it is not very useful here. There are no shopping centres, no unnecessary needs, nothing to buy. What we do need are good harvests. With crops from the milpa and wild animals once in a while, we have everything we need. With that we eat, we make our own tortillas, bread, different dishes, drinks... what else do we need? Money cannot buy that. A little money is good, though, to cover the costs of some necessary stuff like our bikes and petrol, but only that and a few more things. Without money we are still fine, but without rains, water and crops, we have nothing”.

3.4.2.2. Hunting

Villagers in Q4 from the two villages perceived different climate effects and impacts on hunting with implications for food security, traditional knowledge, and biodiversity conservation. These included less game available in the communal forests, surrounding protected area, and around in the villages as a result of droughts and related water availability in local aguadas; higher frequencies of certain species, such as coati, collared peccary, and parrots in agricultural lands, which represented a problem for farmers and they had to immediately kill them to protect their already vulnerable crops; and changes in the distribution of game species during the last 5-10 years, as large ungulates have migrated deep into the protected forests of CBR, or alternatively to their agricultural lands in search of water and food. In C2, villagers additionally attributed the reduction in number of animals to changing rainfalls and its effects on the phenology of trees that provide food for game. Perceived impacts on hunting practices included loss of traditional knowledge and traditional practices due to the reduced prey availability, changes in hunting sites, and increased effort required for hunting in forested areas, and changes in the diet due to reduced game. In C1, villagers claimed that hunting had stopped “completely” in the forested areas of the village due to the lack of game. In contrasts, more than half of the villagers (Q3), particularly from C2, perceived more game in the agricultural lands. Species included parrots, collared peccaries, and coatis.

A farmer-hunter in C2 (73 years old) mentioned:

> "There are much less animals now than before! When we arrived [1980's], we could see hundreds of turkeys and curassows that came down to the village around August. People used to shoot at them, and we could get around 16 each! Now they don't come anymore, because there aren't so many [individuals] due to the droughts and because people shoot them, and birds are smart and learn to recognize their hunter. Now in the forest it is also very hard to find animals, there are less of the big ones. Now it is very hard to find *jabalines* [white-lipped peccaries] and big deer [white-tailed deer], when before we could always see big groups of around 10-12…I haven't gone hunting in the forest in a long time [3-5 years]. Why would I go there if there are no animals? At my age I cannot afford to make more effort. But in my plot, there are many smaller animals that I can easily get".

In C1 a farmer-hunter (24 years old) said:

> "There are not many animals left in our forests because all our aguadas are dry. Animals have gone to the reserve to find water. They are smart and go other places with better conditions, not like us that must stay here. In this village we don't hunt in the forests anymore. We only catch animals when they go in our croplands, because we have to protect our crops".

In C1, more than 50% of the villagers (Q3) perceived that because of climate hazards, hunting had been dramatically reduced in forested areas, pushing families to consume more domesticated and/or commercial meat. They perceived negative implications of this on their health and cultural practices. A woman (aged 35) in this village described:

> "When I was a kid, my father used to hunt in the forest, bringing [wild] turkey, deer, and paca every week. Now there are no animals left in the forest, so my husband doesn't hunt. Sometimes when he gets to go to the milpa and sees an animal eating his crops, he brings it home, but this is rare. My kids don't get to eat [wild] meat as I did, they don't know the good meat. We mostly eat farm [commercial] chicken, sometimes the one in my backyard too, but these are not as natural and healthy as the wild ones. They put lots of chemicals into the chicken they sell in Xpujil or those sold at the village; chicken in my backyard eat all the rubbish in the floor. In the wild, animals grow healthy eating the fruits of the forest, therefore the flavour is different".

In C2, more than 50% of the villagers (Q3) perceived that game had reduced in the last decades, with implication to their traditional practices and food security. A farmer-hunter (57 years old) said:

> "When we first arrived here, wild meat was the base of our diets. Later, when we started growing the milpa, we began to eat maize and other crops. We still consume meat but not as before. It is harder to find game. You can still find it if you are a good hunter, but it is harder. You must know where to go, where to look, but as ramon [*Brosimum alicastrum*] fruits are not ripening, there are no animals where there used to be before. The kids don't want to go to the forest anymore because they see it as a lot of work. Now they don't know how to hunt,

> and they just shoot animals without knowing what they are doing. With less animals they cannot shoot like crazy because there will be no more animals, and what would we do then? In this village we have no money to buy meat, meat is very expensive…and it is not as good as the wild one".

Farmer-hunters in Q4 perceived the combined climate change effects on arable farming and hunting, enhancing their vulnerabilities for food security.

A woman in C2 (aged 56) mentioned:

> "Tell me, what we can do about the animals [asking the researcher]? We put lots of money and work on the crops and we barely get a harvest. When we finally get a few maize or squash crops, the animals come and eat them! And it's many of them, the coatis, the parrots, the other birds, the deer, and the pigs [collared peccary]. Those [peccary] are the worst because they come in groups of 15 and raid the crops! We always put *Fabuloso* [a highly scented multipurpose cleaner] in the crops to drive away the animals, we also use poisoned eggs to kill the racoon [*Procyon lotor*] and coati, but it doesn't work. We cannot share with them crops anymore, there is not enough for everyone. I rather feed my family and my own animals than the animals in the forest. So, I ask my sons to kill them all with the shotgun whenever they come close to our crops".

A farmer-hunter in C2 (36 years old) described:

> "I cannot hunt in the forest anymore as I used to. I enjoy hunting but you need time and strength for that. We must go into the reserve to find a good catch and you need at least a couple of days and be able to carry double amounts of *pozol* [traditional drink made of maize] plus the water for the dogs. Now, the milpa demands me much of my time, so I cannot go hunting...It is harder".

3.4.3. Responses to climate impacts

All interviewees in the CBR reported having responded, at least in one way, to the effects of climate hazards on their livelihoods. For impacts on arable farming, the shared responses in both communities and among all farmers included: 1) modifying the agricultural calendar (Figure 3.3), 2) reducing farming intensity for all crops, or even stopping cultivating, 3) storing water, 4) increasing their working times, 5) introducing hybrid maize varieties, and 6) changing the source of their diets. Exclusive responses in C1, included income diversification and looking for government support; whilst in C2, migration of males from the village was the only additional response to climate related impacts on arable farming.

All farmer-hunters in both villages had modified their agricultural calendar. They described that they started cleaning and burning the land as well as sowing seeds later than usual and in accordance with the rains and predictions. These were based either on direct observations of environmental variables or in ideologies. Farmer- hunters perceived that climate hazards had affected the resilience of arable farming systems, as these could not easily recover from extreme climatic events. A farmer-hunter in C2 (aged 46) said:

> "Here, the rains always started on the day of Saint Cross [May 15th]. This is our most important festivity because it coincided with the day when we started sowing

> the milpa. Now, if lucky, we can start sowing in July or as soon as the rain starts. Sometimes, even if the rain starts, the land is very dry, and it is not good for sowing. We also don't know any more when we can burn because of sporadic rains… So, we must observe the moon, if it looks smoky, that means that the rain is going to start, and then we start sowing. Some people prefer to wait until the quarter of the moon to start sowing, after the moon gets smoky. You never know if it is going to work but you need to have faith".

A farmer-hunter (aged 23) in C1 explained:

> "We have no expectation anymore on the rain timings as rain starts at a different time every year. Now you can only have an idea of the starting date when you see the bunches of ants coming out of the nests. They come out when they feel that the rain is starting so they don't die when their nests get flooded".

A farmer-hunter (aged 36) in C1 mentioned:

> "There is no rainy and dry season anymore. The raining times have changed. We used to start planting seeds on May, whilst now by late June-July I start to sow [maize], depending on the rains. Then I used to have a big harvest by September [for native maize], and then start cleaning and sowing in November again for the tornamiel [second maize harvest of the year]. Now, in some years, if the rain doesn't come, I start sowing for the first time until November for the tornamiel; without having a previous harvest. I just must wait for the rains. My cue for planting seeds is to wait for rains in the first day of each month. If rains come during the first five days, I start sowing. Sometimes it works and sometimes it doesn't, and even if it rains, the intensity of the rain is not sufficient for the crops".

A farmer in C2 (aged 34) mentioned:

"With the unpredictable rains, I must change my working pattern every year. I am not certain when to start burning and sowing anymore, as I don't know if it is going to be dry to burn or rainy for the soil to be wet and plant the seeds. Some years I cannot burn in February as we get unexpected rains that come when they are not supposed to. The timing of the rain has also changed dramatically. I don't sow in May anymore; I now must wait until later months for rain to start. However, some years the rain doesn't come at all, we only get terrible droughts. It has been extremely dry for a long time here [around 10 years], but in 2019, it was very dry, dry as it never had been before. That year I only cultivated half hectare of milpa because I was desperate and I thought that maybe I got lucky, but I lost all the harvest. I thought that the coming year was going to be better, and I prayed for rains, but the water didn't come. In 2021, it started raining again, however the soil was so dry from the previous years that the yield of the harvest was very low, despite that it was a good year [for rains]. The drought of 2019 hit this place so hard that it hasn't been the same since. Look at the aguadas, most of them are dry and some keep very little water, despite having rain for the last year. I don't know if things are going to be the same again".

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cleaning fields Harvest torna-miel	Slashing	Slashing and/or burning	Burning	Sowing milpa crops on 15th May. Rains started in early to mid-May.	Sowing	Sowing and or harvest. Harvest only for hybrid dwarf maize (2-months variety)	Harvest dwarf maize and/or maintaining fields.	Harvest of native maize (4 months). By Sept 10th harvest was ready.	Prepare land for torna-miel (second maize season; shorter than the first).	Prepare land for torna-miel	Harvest (for dwarf maize)
			Coatis available in these months. May: reproduction time of paca and turkey.		Animals found with offspring June: no deer in this time				Many curassows and peccaries are found in these months.		

Figure 3.3. Original agricultural calendar described by farmer-hunters in Calakmul and perceptions on game availability during the year. Dates of arable farming practices change according to rainfall patters.

Villagers in Q4 from both communities reported reducing the farming intensity by reducing the size of their farming plots to decrease the risk of losing crops. Working in the milpa and commercial crops demanded increasing time, labour, and financial resources, and the gain was uncertain. Farmers reported stopped cultivating crops that are sensitive to the recent climatic conditions. A farmer-hunter (43 years-old) in C1 said:

> "The droughts have change everything here. I used to grow chilli and I invested a lot of time and resources, which I lost. Every season I needed more money to get more fertilizers, to buy pesticides, and to pay more labourers because it was too much work. The chilli also needed a lot of water and care, I had to clean the land twice a week. A few years ago, I stopped growing chilli, I just couldn't have it".

Another farmer (29 years-old) in the same village said:

> "Here [in C1], we used to cultivate 4 ha of milpa and 4 ha of chilli and squash, each. Now we only cultivate milpa in 1 ha, because despite investing much more work and money on it, we still lose everything because of the drought and heat, so there is no point… Here people don't grow chilli anymore, some seasons they do but only 1 ha, before chilli cultivation was a big deal in this village. This is for the best, as it is impossible to obtain harvests in more than 1 ha currently in Calakmul".

A farmer (37 years-old) in C2 mentioned:

> "I still cultivate my crops, but I work a smaller portion of land. I divide my plot in smaller subplots of half hectare to cultivate my milpa during the first three months of the year. If it doesn't work, or even if it does, I then cultivate another half hectare during the next three months of the year. I do the same every three-month period until the end of the year. By this, I increase the chances of my harvest to succeed, at least in one of my plots according to the rains".

Storing water was also an important response shared by all villagers. Keeping large plastic containers in the croplands and houses or digging jagueyes (artificial small ponds) were the most common strategies. However, they claimed that these were not enough to meet agricultural and household needs. Although keeping water for crops was necessary for farmer-hunters, this could have have negative implications for their crops. A farmer-hunter (26) in C2 mentioned:

> "We have water containers in our land, some of 1000 or 2000 L, where I store water for applying fertilizers and pesticides on my crops, and to water them in times of drought, but I wish I had more because it is not enough for the crops. I also have some water containers at home, but I cannot carry that water to the milpa because we need it for my house, we need to drink and shower. It is hard to distinguish what is more important, having a shower or keeping the crops… I guess crops…because if there are no crops there is no food.

A woman (aged 26) in C1 described:

> "My husband installed a jaguey in his plot. It worked for a while but then during a heavy drought it got dry. Since then, it is hard to keep it full of water as rains are not so intense. My husband has brought water trucks to fill it, but it is very expensive. He must go to Xpujil to talk to the municipality, but they never have water trucks, so he sometimes had to buy it to a private company, and it was very expensive. They take advantage because we cannot risk our crop production and we are willing to do anything to sustain even a little bit of it".

A farmer-hunter in C2 (49 years-old) said:

> "Water containers make a difference in the milpa. It is hard to keep them as you need to carry water constantly in the bike to fill them because of the poor rains. Also, the big problem are the animals, all of them want a share of the water. I have tall containers in my land, but my brother-in-law had short ones and the water was consumed and contaminated by all the animals. Even with the tall ones there are problems, the *danto* [tapir] has taken out many in this village because he looks for water and because he is big, he can push the containers down and then you are ruined".

Villagers in Q4 from both sites reported increasing their working times in the milpa and commercial crops in response to climate hazards. Villagers described requiring working more time for taking and administering water to their crops, slashing and cleaning growing vegetation during abnormal times, applying increasing amounts of fertilizers and pesticides, and protecting the crops from predators. A woman (aged 55) in C2 reported:

> "My husband and sons must work in the milpa every day, sometimes even on Sundays. Here we don't rest. The days that my husband works in *Sembrando Vida* [government program requires farmers to work a certain time of hours in different agroforestry activities in the ejido], he still needs to go and check the crops, even when he is tired. Sometimes my sons go instead as someone must be there working. The problem is that one man is not enough for the job. My husband and sons some days leave very early to work and return very late, especially when they must take water in several trips [in a motorbike] to water the crops. The years we grow chilli they have to work even more. This crop always has demanded a lot of work as it needs to grow on clean plots of land and you must apply fertilizers

> constantly, but now it requires more! The native weeds grow very fast whenever there is rain, and we must clean them immediately to maintain the land and crops. Sometimes it is so bad that my husband uses *matamonte* [herbicide] to make the job easier. Also, when we grow squash, he additionally needs to apply more pesticide than before as the worm is hitting it hard".

In C1 a farmer-hunter (29 years-old) said:

> "I work in my dad's milpa most of my time and I barley can do anything else. I go in the before dawn, come back home and rest for a couple of hours in the afternoon, and then go back to check my corps so they don't get raided by animals. I must be at my lands waiting…Well, I don't lose my time whilst I am there. I get to work whilst I check, but it is more dangerous at night as there are some dangerous animals [snakes]". The next day, I must go back to the plot very early again to make sure that my crops are maintained as I cannot afford to lose them".

All villagers in C1 and C2 reported introducing hybrid maize (dwarf maize variety) as it harvests in only two months (compared to native "criollo" variety) and for being more resistant to environmental factors. However, interviewees perceived that using this corn type has implications on their identities, health, and dependency on the government. The variation of corn types, along with the direct effects of failing maize crops, resulted in changes in the diets of the farmer-hunters in both communities. A farmer-hunter (aged 64) in C1 said:

> "I try to grow only native maize because that is the maize that is ours. Farmers in Calakmul take pride in our native maize and its quality since it is the foundation of our life. The ones that the government sell come from the *gingos* [United States citizens] and they are genetically modified and therefore rubbish. Growing those is dangerous for our fields and for our culture. I still grow native but now I must grow the hybrid [dwarf] too, because this is ready in two months and gives us food quickly. The problem with this is that I cannot keep it for the next season, the seeds don't last. So, I get food and if there is a few more, I need to sell it. But that means that next season I must buy seeds from the government again…The dwarf maize is not good as the native, but it is better than other genetically modified varieties that the government wants to give us".

A woman (31 years-old) in C2 mentioned:

> "My husband grows the hybrid maize [dwarf maize] because that grows better than the native. I don't like the hybrid because its seeds are hard to grind for cooking and the tortilla and *pozol* don't taste as good as with the native. Also, the seeds get rotten very quickly, but the hybrid is still better than eating Maseca [industrially processed corn flour].

A recurrent response to climate impacts on crops was the changes in the source of the villagers' diets. In both communities, all interviewees described that the reduced yields of maize and beans pushed them to buy government and/or industrial maize and flour. Women and men in the villages described that these changes were bringing confluent changes in culture, knowledge, and traditions. A woman (aged 41) in C2 mentioned:

> "For the last 5 years I have relied on Maseca more than in our milpa's maize because of the low yields. I still make the same food but now I use the Maseca instead of maize for the tortillas and tamales. Everything is different: the work involved, the taste, the results…everything. The benefit is that cooking with Maseca is easier and faster. But the taste is different and the work too…The older girl there, she knows how to cook. She is in charge of threshing the maize, and cleaning, preparing, and grinding the grains. Then she makes very good food. But these others [pointing to two younger girls, aged 4 and 6] they will only learn how to mix Maseca. They won't be able to feed their families properly".

A farmer-hunter in C1 (64 years-old) mentioned:

> "When maize yields are low, we buy LICONSA maize to eat, but that maize is not good for eating, not even for feeding the animals…I feel angry when I lose my harvest because I invest lots of money buying inputs from the government [such as maize seeds, water, and fertilizers] to grow my crops, and then I get nothing because there is no water. On top of that I must buy low quality and genetically modified maize from the government for being able to feed my family. It's a vicious cycle and it is not fair for us the farmers. There are no rains, and the government doesn't want to bring irrigation systems, not even give us water for drinking. We are not supposed to eat that rubbish, that's not good for our kids, it is not good for everyone, but if we don't eat maize what do we eat? As farmers we are supposed to have access to high quality maize and other goods because we are the ones growing them".

In C1, income diversification was a common response amongst more than 50% of the interviewees (Q3) to climate impacts on arable farming. Farmer-hunters in this community diversified their livelihoods by working in Xpujil in different off-farm jobs. They reported that the close distance to this town allowed them to commute every day. In C2, income diversification was not directly reported. However, migration of young adult males to other parts of the country, was reported by less than 50% of its villagers (Q2). Villagers described that young individuals left C2 in search of income and to avoid working in their non-productive farming lands. In contrast, 75-100% of the villagers (Q4) in C1 reported that they did not migrate anymore to other states, as the levels of violence in these places are very high and represent great risks for the safety of their people. Villagers in C1 and C2 reported that both income diversification and migration had implications on their diets. A woman (25 years-old) in C1 said:

> "My husband is a construction worker in Xpujil. The crops were not profitable and didn't feed the family anymore. He earns good income, and we buy food and supplies in Xpujil. We eat pasta soups, beef, sometimes fish, we can even buy sweets and *Sabritas* [crisps]. I mostly make tortillas with Maseca because we don't have maize, but sometimes my mom shares with me the good tortillas. I prefer it this way because at least I know I will have food on my table…During the recent flu [COVID-19 pandemic] it was very hard and we struggled a lot because there was no income, but we made it because our families fed us. Luckily that bug [virus] has passed".

In contrast, a farmer-hunter (19 years-old) from C2 said:

> "I am thinking about going to Playa del Carmen to work. One of my uncles left the village to work there and he can help me get me a job selling handicrafts to tourists. But I am not sure yet… I don't want to work in the milpa and struggle as my dad does. It is a lot of work because of the drought for nothing. If I go to Playa, I will make some money for the house and help my family, but at the same time I won't be able to enjoy life with my siblings and I don't want to be away from them".

For climate-related impacts on hunting, interviewees of each community described different responses. In C1, more than 50% of the villagers (Q3) claimed to have drastically reduced their wild meat consumption and changing the source of protein intake of their diets during the last 10 years, as they only catch game sporadically, when protecting their crops. A farmer-hunter (aged 31) said:

> "Before [10 years ago] we ate game at least two times a week. Now, we barely eat wild meat. The animals have gone far away form the ejido to the biosphere [reserve]. For this, along with my job [military working in Xpujil], I don't hunt anymore. Furthermore, I barely visit my dad's cropland as my job consumes most of my time. I only catch animals when I join my dad at the milpa, and only if I see one and have my rifle with me, but that is not common. However, when I crave game, I buy it".

A woman (aged 24) in C1 described:

> "Eating deer or pig is currently very hard, whist before it was normal. There are some people that still hunt, even though they say they don't, but still not as much as before. Before, we didn't buy meat, we only ate game. Today I sometimes buy chicken and pork from the cars that sell meat every week in the village. I don't like it as much because the meat is hard and tastes weird, but that is what we get now. When I don't have money, I don't eat meat and that is it".

In contrast, interviewees in C2 responded by changing their hunting sites for finding prey, reducing their game consumption during recent years, and baiting game in their croplands with water. A farmer-hunter (aged 48) in C2 explained:

> "During the last few years, I had to get to know the forests again… It was like being to a new place, despite having hunted all my life here. I had to observe the trees in different season, look for fruits throughout the year, find the water sources available, look for tracks… It was a lot, but I know where to find game because I am a good hunter. Now I go further into the reserve to hunt, it takes me double the time and effort than before, but it is worth it."

Another farmer-hunter (57 years-old) in the same community said:

> "I still hunt, and the drought is good because I get more animals. I leave water containers open so they can drink when they are thirsty and I don't apply *Fabuloso* anymore around my crops [to scare crop predators], I let them come and I shoot them. I ask my sons or brothers to help, and we take turns for watching the milpa. We are there all day working anyways, but we also go during night times because we can get paca and other nocturnal animals. We take more dogs though to help, especially when the large groups of coatis come all together".

A woman (40 years-old) in C2 mentioned:

> "In this village people used to eat game every day! You could see the hunters alone or in groups with lots of animals every day passing in the roads. Today, we still eat game, but people don't get as many animals as before because of the water. Animals are going away from here. If they all go, we don't have meat and then we don't eat…Sometimes we have [domestic] pigs from our backyards or that neighbours sell in the village, but there would not be enough pigs to feed us all. Furthermore, we cannot rely on pig and chicken only. That's not healthy, we need more variety".

Inhabitants of C1, described other responses to recent climatic conditions, that villagers in C2 didn't have. These included: 1) looking for municipal government support to install wells; the petition was unsuccessful as shallow soils (80 cm) preventing digging the well, 2) splitting their plots into small quadrants and cultivating in these separately, to reduce labour and inputs, and 3) halting deforestation in the ejido to moderate climate extremes, on the understanding that in forested areas the heat is less and that if they had more forest cover, they would have more rains.

3.4.4. Food security

Villagers described the common and important elements of their diets, and the source of these elements, according to the reliance and availability of the food type, and personal preferences. In general, both communities relied on the same resources. The most important food resources according to all villagers were maize and beans, along with other smaller crops produced in their milpa. Smaller crops varied in the two villages. These resources were supplemented with other plant and vegetable products obtained from other sources, such as the surrounding forest, their backyards, or shops. Villagers perceived themselves as less dependent on these supplementary products than maize and beans, as these were either seasonal, or sporadic if obtained from shops.

Additionally, villagers reported that protein was an important part of their diets. This was obtained from game, domestic animals, and/or internal and external commerce. Villagers in C1 relied more on commercial and domestic meat, whilst inhabitants of C2 considered themselves more dependent and keener on wild game. Both communities complemented their diets with limited supplies obtained from local grocery shops, such as oil, salt, sugar, coffee, sweets, and other goods. However, in C1 there was a growing dependency on commercial products purchased in Xpujil, such as commercial meat and industrialized products (Table 3.1). All interviewees viewed the milpa as the source of their diets, for both plant and animal products. Villagers reported that the milpa was not only important for their diets but also for their wellbeing, as this provides food, work, purpose, and knowledge. Overall, both communities were still highly dependent on forest and milpa resources, as 12 of the products they described as important for their diets came from milpa, 14 from the forest and 10 form their backyards. Additionally, villagers used another 16 products including goods purchased in small local groceries and meat purchased in the village from neighbours who sell domestic or wild meat.

People in C1 additionally described five products purchased from larger commercial outlets usually in Xpujil (Table 3.1).

Table 3.1. Main components of the diets, sources, consumption frequencies, and availability in C1 and C2.

Source	Diet component	Scientific name	Used by community	Consumption	Availability
Milpa	Maize (criollo & hybrid)	*Zea mays*	C1, C2	High	All year
	Beans	*P. vulgaris, P. lunatus*	C1, C2	High	All year
	Chaya	*Cnidoscolus aconitifolius*	C1, C2	High	All year
	Chilli	*Capsicum annuum*	C1, C2	High	All year
	Squash	*C. argyrosperma,, C. pepo*	C1, C2	High	All year
	Yuca	*Manihot esculenta*	C1, C2	Moderate	All year
	Sweet potato	*Ipomoea batatas*	C1	Moderate	All year
	Banana	*Musa spp.*	C1, C2	Moderate	All year
	Watermelon	*Citrullus lanatus*	C2	Low	Seasonal
	Tamarind	*Pithecellobium dulce*	C2	Low	Seasonal
	Melon	*Cucumis melo*	C2	Low	Seasonal
	Apples	*Pyrus malus*	C1	Low	Seasonal
Forest / milpa	Nightshade (hierbamora)	*Solanum donianum*	C1	High	All year
	Nance	*Byrsonima crassifolia*	C1, C2	High	Seasonal
	Chaya	*Cnidoscolus aconitifolius*	C1	High	All year
	Curassow	*Crax rubra*	C2	High	Seasonal
	Paca	*Cuniculus paca*	C2	High	All year
	Ocellated turkey	*Meleagris ocellata*	C2	High	Seasonal
	Deer	*O. virginianus, Mazama sp.*	C2	High	All year
	Peccaries	*P. tajacu, T. pecari*	C2	High-moderate	All year
	Coati	*Nasua narica*	C2	Moderate	All year
	Armadillo	*Dascypus novemcinctus*	C2	Moderate	All year
	Agouti	*Dasyprocta punctata*	C2	Moderate	All year
	Crested guan	*Penelope purpurascens*	C2	Moderate	Seasonal
Backyard	Lemon	*Citrus limon sp*	C1, C2	High	All year
	Oranges	*Choisya dumosa*	C1, C2	Moderate	Seasonal
	Soursop	*Annona muricata*	C2	Low	Seasonal
	Leafy greens	Various	C1	Low	Seasonal
	Cucumber	*Cucumis sativus sp*	C2	Low	Seasonal
	Chicken	*Gallus domesticus*	C1, C2	Moderate	All year
	Pigs	*Sus domesticus*	C1, C2	Moderate	All year
	Turkey	*Meleagris gallopavo*	C1, C2	Low	All year
	Ducks	*Anas platyrhynchus*	C1	Low	All year
	Goats	*Capra hircus*	C1, C2	Low	All year
Local groceries or locally bought	Tomatoe	*Solanum lycopersicum*	C1, C2	High	All year
	Garlic	*Allium sativum*	C1, C2	High	All year
	Herbs	Various	C1, C2	High	All year
	Onion	*Allium cepa*	C1, C2	High	All year
	Eggs	NA	C1, C2	High	All year
	Pasta	NA	C1, C2	High	All year
	Salt	NA	C1, C2	High	All year
	Oil	NA	C1, C2	High	All year
	Sugar	NA	C1, C2	High	All year
	Coca cola	NA	C1, C2	High	All year
	Coffee	NA	C1, C2	High	All year
	Milk	NA	C1	Low	All year
	Wild game	Various species	C1, C2	Moderate-low	Sporadic
	Chicken	*Gallus domesticus*	C1, C2	Low	All year
	Pigs	*Sus domesticus*	C1, C2	Low	Sporadic
	Turkey	*Meleagris gallopavo*	C1, C2	Low	Sporadic
External commerce	Industrialized products	NA	C1	Moderate-high	All year
	Beef	NA	C1	Low	Sporadic
	Fish	NA	C1	Low	Sporadic
	Chicken	NA	C1	Low	All year

Pork	NA	C1	Low	All year

3.4.5. Wellbeing

Villagers of C1 and C2 perceived that having water, successful crops, means of transport, and access to education where key for their wellbeing. These are presented in a single table (Table 3.2), as villagers of both ejidos described mostly the same aspects of wellbeing.

Table 3.2. Elements of wellbeing according to the villagers of two communities of the CBR, from most to least frequently mentioned.

Aspects relevant for wellbeing	Description	Key comments	Primary element of wellbeing
Water	Access to water to fulfil needs at household and community levels (e.g., dinking, showering, washing clothes; successful crops; maintaining domestic animals)	Water in the form of rains to support rainfed agriculture was also imporntatn. Water in containers, water in aguadas and jagueyes, and from rain.	Environmental needs
Successful crops	Obtaining at least 4 tons of maize (native) from 4 ha of land and cultivating 2 ha of chilli and squash, each season. Successful crops meant that the yield is enough to feed the household, animals, and to sell.	Successful harvest did not require extreme labour and increasing costs. No need to use fertilizers.	Basic human needs Economic needs
Having enough food	Access to food that meets their nutritional and cultural needs, from their environment and with the income they obtain	Food from milpa and game and access to extra goods at fair prices in C2, to provide and share with family Food from milpa and healthy sources (without chemicals) in C1.	Basic human needs
Transport	Trucks for carrying equipment and tools to the farmers' croplands.	Bikes were perceived as insufficient for carrying large water containers to the lands.	Economic needs
Health	Healthy lives involved enough natural (chemical free) food, clean water, no diseases from external sources (e.g., COVID-19)	Health was perceived to come from healthy food, water, and environment. Access to hospitals or clinics was perceived irrelevant, except for emergencies (e.g. snake bites and terminal diseases)	
Education*	Access to education beyond primary school.	Villagers in C2 mentioned the lack of secondary schools and higher education in or close to the villages. *In C1, education was not perceived as part of wellbeing.	Economic needs
Drug-free youth and environments	Villages free of drug consumption	Villagers perceived that drug consumption was growing in the villages after men migrated to other states in Mexico or to the USA.	Basic human needs

3.4.6. Adaptation measures

Villagers in both communities perceived a need for various actions to adapt to climate changes and reduce climate-related risks on their livelihoods and food security. Having access to water for agricultural and household needs was considered the most important requirement and the only solution to current challenges according to 75-100% of the villagers (Q4) in both communities. This was viewed as a priority for adapting to the changing climatic conditions.

Villagers in C1, proposed two measures focused on infrastructure and capacity building for coping with climate extremes. However, they claimed that they had already responded in different ways to the climate hazards, without managing to reduce the risks. A villager in C1 (53 years-old) described:

> "Here we have tied so many things to keep our crops viable that we don't know what to do anymore. Moreover, the droughts are so strong that there is not much left to do. I cannot make rain. The only thing that would change things here is having enough water. Having rains, and having the tanks filled constantly by the government is the only way".

In contrast, villagers in C2 proposed five measures for reducing climate impacts on their food security. They perceived that improving the resilience of their crops, understanding their environment to reduce impacts on wild game populations, and strengthen the governance of the ejido was key for reducing climate risks on their food security (Table 3.3). Consensus was reached amongst villagers on proposed adaptation measures.

Table 3.3. Proposed adaptation measures and associated actions proposed by villagers in C1 and C2, along with the targeted system and category classification.

	Proposed measure	Actions	Responsible party	Target	Category
Community 1 (C1)					
1	Install water tanks in each cropland	Look for government support to obtain tanks	Ejido and municipal authorities	Crops	Infrastructure and technology but rely on Institutional adaptation at federal/local government levels
		Designate representatives in the community for these processes.	Ejido authorities		
		Use personal money from Sembrando Vida to install tanks (but won't be enough)	All villagers		
2	Improve soil fertility by changing agricultural techniques	Find training in sowing techniques by experts and NGOs in the region.	Ejido authorities, NGO, academia	Crops	Infrastructure and technology/ Behavioural and cultural/ Capacity building
		Find training in biofertilizers and ways to improve soil fertility by experts and NGOs in the region.	Ejido authorities, NGO, academia		
Community 2 (C2)					
1	Improve soil fertility	Add nutrients to the soil to increase crop resilience	All villagers	Crops	Infrastructure and technology Behavioural and cultural
		Use natural fertilizers instead of chemicals	All villagers		
		Look for capacity building on crop improvement to avoid genetically modified maize varieties	Ejidal authorities, local government, NGOs, academia		
2	Mechanise agriculture	Look for government support for mechanizing agriculture in the region	Ejidal authorities, municipal and federal governments	Crops	Infrastructure and technology but rely on Institutional adaptation at

					federal/local government levels
3	Install water tanks in each crop land or build wells	Look for government support to purchase and install tanks	Ejido and municipal authorities	Crops	Infrastructure and technology
4	Maintain wild game populations viable	Apply sanction to non-ejidatarios and villagers from other communities hunting inside the ejido	Ejido authorities	Hunting	Institutional adaptation at federal/local government levels but rely on Behavioural and cultural
		Reduce hunting of females and juveniles of all species, although sometimes hard to distinguish	All farmer-hunters		
		Reduce hunting pressures during critical times (reproduction times and droughts)	All farmer-hunters		
		Build capacities on sustainable hunting and build knowledge on game species behaviour	Ejido authorities, all farmer-hunters, NGOs, academics		
		Find alternative strategies to protect crops from predation	All farmer-hunters		
		Carry out carrying capacity studies on game populations like in villages with UMAs (environmental management units) with support of NGOs or CBR	Ejido authorities and academics		
		Self-monitor game populations and natural resources in the ejido	Ejido authorities, NGOs, CBR authorities		
5	Improve governance in the ejido	Develop communication strategies across the ejido	Ejido authorities, all villagers	Governa nce	Institutional adaptation at ejido level
		Strengthen cooperation in community projects as these sometimes are unsuccessful due to lack of organisation	All villagers		

In C1 all villagers were concern about the fact that the proposed adaptation measures would not be enough to reduce the risks on their livelihoods. In their opinion, they had already tried to cope with these changes through different unsuccessful actions. In C1, there was a sense of giving up on the land and forest resources and seeking stronger connections with the urban centre. In contrast, villagers in C2 showed potential for enhancing their adaptive capacity as they had more ideas for sustaining their integrity as a community, considering both land and forest resources, such as wild game.

3.5. Discussion

As shown in Figure 3.3, villagers of the CBR ejidos perceived that their livelihoods were subject to multiple and interacting climate change stressors. These are exacerbating the complex dynamics and risks in the rural communities of the area. Climate stressors interact with diverse environmental, socioeconomic, and institutional pressures identified in the region, enhancing the vulnerability and risks of these communities and their livelihoods. The environmental challenges of water scarcity and infertile soils (Klepeis & Chowdhury, 2004) in the region are further exacerbated by droughts and changing rainfall patterns, affecting the livelihoods and needs of rural communities and wildlife. At the same time wildlife populations are potentially further stressed by hunting pressures, likely reducing the food security of the communities. Economic constraints include the deprived and marginalized economies that are disproportionately reliant on rainfed agriculture and other climate-sensitive livelihoods (Dobler-Morales et al., 2020), which are further affected by unstable crop prices determined by national and regional markets and the dependency of farmers on unreliable intermediaries for crop distribution (Schmook et al., 2013) affecting the cash profits of local farmers (Keys & Chowdhury, 2006). Furthermore, the isolation of these villages from basic services, markets, and institutional headquarters, increase their sensitivity to climate impacts, and reduce their food availability and access. Additionally, institutional factors such as the weak social fabric in the CBR ejidos (Radel et al., 2012; 2017), their fragile governance (Haenn, 2006), along with their high dependencies on government subsidies, represent additional constraints to adaptation in the region.

Villagers, both male and female, in the studied communities were aware of changes in climate and increasing hazards in Calakmul during the last 10-15 years. In general, their views on the changing conditions are in line with local observed climatic changes in the Calakmul area, except for their perceptions on reduced amounts of rain, that have not been confirmed through instrumental records. However, Mardero et al. (2020) found that rainfall in the area is becoming more extreme, based on high interannual variability and more pronounced positive and negative rainfall anomalies from 1982-2016. Additionally, changes in the "normal" rainy and dry seasons, have been confirmed as the timing of summer rainfall and an intensification of the mid-summer drought (*canicula*) have been recorded (Mardero et al., 2020). These, combined with increasing temperatures, have led to higher evaporation and surface drying, increasing the intensity and duration of droughts (Trenberth et al., 2011) in Calakmul. Similarly, rainfall changes have been reported at a regional scale for longer periods. Mardero et al. (2012; 2015) identified decreases in annual precipitation and drier conditions in southwestern area of the Yucatan from 1957-2007 (Mardero et al., 2015). This can explain the perception of villagers who claimed that the climate in the area had always been the same. Villagers in C1 and C2, recalled hurricanes during past decades and changing rainfall patterns and droughts in recent years, particularly the one in 2019, as the most important climate hazards. Pérez-Flores et al. (2021) reported 2019 as one of the years with the lowest rainfall (626.6 mm) in the last decade.

The effects of rainfall variability on agriculture according to local farmer-hunters' perceptions had been previously identified in Calakmul and the wider Yucatan Peninsula region (Metcalfe et al., 2020; Green et al., 2020). Similar perceptions to those found in the present study included reductions in water availability, maize yields, and areas of milpa cultivation, increasing losses of crops due to high temperatures and growing pests and crop predation from wild animals, increasing the vulnerabilities of farmer-hunters through conditions (Metcalfe et al., 2020; Green et al., 2020). Other effects of climate hazards previously identified in Calakmul included the benefits and losses of crops from hurricane Isidoro in 2002 (Metcalfe et al., 2020) and its direct impacts on livestock (Green et al., 2020). The target villages of this study did not keep livestock nor recall or mention hurricane Isidoro as a relevant hazard. In the CBR and wider region, the effects of variable rainfall patterns on agricultural practices have contributed to the loss of food security of the villages, modifying rural livelihoods, and increasing deprivation in the area (Mardero et al., 2020).

Our study is the first to evaluate climate impacts on hunting practices and food security in Neotropical forests, and the topic remains understudied elsewhere. Few studies in have analysed impacts of climate change on game species in the Amazonas (Bodmer et al., 2020), in Ecuador (Torres et al., 2022), and Mexico (Briceño-Méndez et al., 2022; Monalvo et al., 2019). However, the scientific literature lacks an evaluation of climate risks on the hunting practices in relation to its socio-cultural and ecological interactions in tropical forests. The studies available on these matters have been conducted in the Arctic with Inuit populations (Ford et al., 2008; Ford, 2009; Pearce et al., 2010; Pearce et al., 2015; Hauser et al., 2021). Although no specific studies on hunting and climate impacts are available on studied area, evidence suggests that the presence and abundance of ungulates, such as tapirs, collared and white-lipped peccaries, in forested areas has been affected by droughts and the lack of water availability in the aguadas, and increased animal movements and migrations to in search of food and water (Reyna-Hurtado et al., 2009; Reyna-Hurtado et al., 2020; Sánchez-Pinzón et al., 2019; O'Farrill et al. 2014), even inside the villages and agricultural areas (Pérez-Flores et al., 2021). The results of these studies support farmer-hunters' observations in the area. However, studies on the status of game populations in the face of climate change and hunting pressures are needed to better assess the climate-change vulnerability of hunting practices in the area.

The interactions between different climatic and non-climatic stressors and their impacts have the potential to create new risks or exacerbate existing risks in coupled systems (Pörtner et al., 2022). The results of this study reinforce this idea, with the example of the interactions of climate impacts on arable farming and hunting, which create and exacerbate risk for wildlife ecosystems and human wellbeing. The changing distribution of game populations due to climatic stressors is further affected by climate impacts on arable farming and associated responses. Reduced crop yields and the presence of (artificial) water sources in farmers' croplands increase the human wildlife conflict in the region and intensify the hunting pressures, increasing the risk of food insecurity in the longer-term through reductions of game populations. In this example, of cascading risks on biodiversity conservation, climate change and human systems. Previous studies in the CBR on climate impacts have identified particular targeted impacts on a single species (Pérez-Flores et al., 2021). A wider understanding of the interacting dynamics of the social, ecological, and climate systems interacting in SES is needed to increase opportunities to strengthen resilience of these systems in the future.

In the studied communities, the milpa and its products (both plants and animals) represented the most important source and elements of villagers' diets. The milpa can ensure the food security of rural and indigenous farmer-hunters (Falkowski et al., 2019), as it has proven to be more resilient to climate hazards (Alayón-Gamboa & Ku-Vera, 2011; Drexler, 2021) than other farming systems. Additionally, it is estimated that the yields of 2 ha milpa can provide a 5-individual family with most daily nutritional requirements per capita (calories, fat, carbohydrates, fibre, sugar, protein, vitamins, etc). The deficiencies in saturated fat, cholesterol, and sodium from the milpa, are usually supplemented with foraging and hunting in surrounding forests (Falkowski et al., 2019). Despite this, farmer-hunters in Calakmul perceived increasing impacts to their milpa crop yields, with risks on their food availability, access, utilisation, and stability, even in C1 where famer-hunters have more possibilities of supplementing their diets with commercial products. Despite the different number of crops obtained in the milpa, farmer-hunters in C1 and C2, recalled only the impacts of climate on maize, and beans to a lesser degree, without mention of the other crops. This might be explained by the fact that maize is the basal element of the diets of all Mexicans (Eakin et al., 2014) and an important cultural element amongst farmers (Fitting, 2010). Authors have evidenced and suggested that the milpa system should be valued as a resilient land management system that provides food security, food sovereignty, and food self-sufficiency amongst Mesoamerican rural communities (Gurri-García, 2018; Falkowski et al., 2019).

Increasing climate-related crop risks and interacting pressures on ecosystems, have the potential to reduce the resilience of traditional milpas with consequences on human wellbeing and traditional knowledge (Ebel et al., 2018). Wellbeing is a subjective, multidimensional, dynamic, person-specific, and culture-specific concept (Brown & Westaway, 2011). Understanding the drivers of wellbeing and integrating this concept into local-scale adaptation measures is important for context-relevant sustainable and resilient strategies (Misselhorn et al., 2012). All the aspects of wellbeing mentioned by farmers (Table 3.2) were in line to the concept of objective wellbeing and related to material and social attributes that support villagers' and communities' welfare (Parris & Kates 2003; Talberth et al. 2006). Five of the seven elements that villagers considered important for their wellbeing had to do with food security either directly or indirectly (water, successful crops, food, transport working in croplands, and health). At the same time, this involves different material and regulating NCP (Diaz et al., 2018). These show that farming practices are valuable for food security in the CBR context and dependent, in different degrees, to nature (e.g., material and regulating NCP such as water provision and soil fertility were key for crops). In C2, game was considered as a key component of having "enough food", which reinforces the importance of the milpa and forested areas for food provision, and the links between biodiversity and NCP (wild game) for a good quality of life (Diaz et al., 2018).

In contrast, no mention of elements of subjective wellbeing or non-material NCP were mentioned by farmers during the focus groups. However, farmers described elements these during the interviews on hunting and rural livelihoods on Chapter 2 and Chapter 4 and will be discussed in Chapter 5. More research is recommended to understand the non-material dimensions of wellbeing in forest communities in relation to climate-risks.

This study showed that there is potential for the development of NbS for climate change adaptation in the studied area. The careful design of NbS in the region can trigger transformative changes in a personal, political, and practical spheres. Due to the magnitude of the impacts of climate change in the livelihoods of the rural communities studied, the capacity of transformation, will determine in large degree the resilience of the SES.

This study concerns climate change impacts and risks in a deprived regional economy where rural communities depend directly on rural livelihoods and natural resources for survival, as is the case with 50% of the world's rural populations (Word Economic Forum, 2020). Perceptions of climate change and related risks on livelihoods can contribute to people's actions in mitigating, adapting to, and coping with this phenomenon (Mitter et al., 2019). Villagers in the CBR have responded to climatic stressors in different ways over the last 15 years. The coping mechanisms adopted for arable farming as described in this study have also been identified among other rural villagers in the Yucatan Peninsula (Mardero et al., 2015; Blázquez, 2011; Audefroy & Sánchez, 2017).

However, despite their diverse responses to climate change, villagers still perceived themselves vulnerable to various risks and actions taken. Additionally, current responses have not been enough to reduce risks, pushing farmer-hunters to migrate from their villages. This suggest that as climate change and socioeconomic and environmental constraints intensify and accelerate in the CBR, adaptation options are being limited, as despite adaptive action, actors can no longer secure valued objectives from intolerable risks (Dow et al., 2013; Adger et al., 2009). Improved understanding of what risks are held to be tolerable or intolerable, and how climate change is pushing actors to adaptation limits, is relevant for governance processes needed to address these challenges (Dow et al., 2013).

Most of the proposed adaptation measure by villagers in both communities, have the potential to reduce risks and support both ecological and social systems of the ejido. These can be done by mitigating damages to crops, human wellbeing, and food security (e.g., water tanks installation in ejidos and croplands), strengthening the environmental conditions (e.g., improving soil fertility), reducing human pressures on nature (e.g., reduce hunting activities during critical times), strengthening governance (e.g.), and building villagers' capacities in different matters (considered in various measures). Similar actions in the same areas have enhanced the resilience of the different social-ecological system (Pörtner et al., 2022). The implementation of the proposed measures will strongly depend on institutional willingness and capacities from ejidal to municipal scales as well as funding available from different sources. Measures related to infrastructural needs are more reliant on government support (e.g., mechanizing agriculture, self-monitoring own resources, government support for building tanks) can be more challenging to implement due to financial constrains at larger scales and social contains along with the complexities of governance networks composed of multiple actors and institutions (Klein et al., 2014) in the Calakmul area.

In a protected area some of the proposed adaptation measures need careful consideration to avoid maladaptation practices and/or long-term negative impacts on the ecosystem. The idea of mechanizing agriculture in the CBR, expressed by villagers, needs further assessment. Evidence shows that this practice can bring negative impacts on the environment (Lovarelli & Bacenetti, 2017) and demands more resources (Matsuura et al., 2011). This, and other uninformed and uncontextualized measures, could potentially result in maladaptation, which from the implementation of adaptation options that increase the vulnerability of individuals, institutions, or regions (Barnett & O'Neill, 2010).

Similarly, adaptation measures at a local scale need to integrate and be in line with socio-cultural factors. For farmers in the CBR, switching completely to genetically modified maize was not a plausible adaptation measure due to the risks it poses to their cultural identity. Evidence from subsistence smallholder agriculture in Asia and Africa shows that the potential advantages of genetically modified crops, including being independent to farm size, tolerance to extreme weather conditions and poor soils, improvement of occupational health issues, and the potential of bio-fortified crops to reduce malnutrition (Azadi et al., 2015). In contrast, studies have shown some of the challenges faced by smallholder farmers for adopting genetically modified crops including high seed prices, lack of information, and negative impacts to agrobiodiversity and seed sovereignty (Azadi et al., 2015; Mueller & Flachs, 2022). The present study shows the importance of co-creating context-based adaptation measures in line with communities' values to ensure the wider wellbeing of rural communities.

Similarly, adaptation measures in SES, particularly in protected areas, need to address both ecological and socioeconomic resilience (Seddon et al., 2019). The villagers in Calakmul perceived that reducing anthropogenic pressures on the ecosystem and wild population was an important adaptation strategy. In C1, villagers had previously taken measures to reduce deforestation in the ejido to reduce climate extremes; whilst in C2 villagers considered different measures to reduce impacts on wild game populations, without explicitly relating the importance of nature for their subsistence. Nature-based solutions in rural areas cases have proven effective for addressing climate adaptation, while delivering positive ecosystem health and socioeconomic outcomes, and benefits in food security (NbS Initiative, 2023). This is particularly important in the CBR, where conservation and development goals are met (SEMARNAP, 2000). Additionally, maladaptation arises from the implementation of adaptation options that increase the vulnerability of individuals, institutions, sectors, or regions (Barnett & O'Neill, 2010).

In this context, NbS to climate change adaptation can play a key role in the area, for their potential to address both ecological and social needs (Seddon et al., 2019). Careful planning and consideration, led by rural communities is needed to design and implement NbS. Due to the magnitude of the climate change impacts on the CBR, NbS might need to be design along other technological and engineering solutions (Cohen-Shacham et al., 2019) to ensure human wellbeing in the area, particularly related to access to water and food security.

Integrating the views, perspectives, and desired development pathways of indigenous and rural communities has been recognized as an urgent need for informing regional and global scenarios (IPBES, 2019). To this end, qualitative methods and analysis were used in this study to explicitly portray the CBR's villagers' perceptions of climate risks, based on the larger context of their vulnerabilities, along with their perceived needs for adapting and building resilience. Qualitative analysis avoids decontextualising participants' narratives (Silverman, 2011) and can benefit from the mixed use of inductive, deductive, and abductive reasoning (Braun and Clark, 2006; Sappleton, 2013). In the longer term, this study would benefit from integrating with information on the ecosystem integrity and status of wild populations (see Annex 1), to build a more integral picture of resilience of both natural and human systems.

3.6. Conclusion

Half of the planet's population is projected to suffer from the increasing effects of climate change by 2050 (State of the Tropics, 2020). These impacts are expected to be felt in the environment, health, food security, and economic development. Today, climate change is already causing losses and damage to the livelihoods of the rural communities living in tropical areas.

The Calakmul municipality is ranked as the most deprived of the 12 municipalities in the state of Campeche (CONEVAL, 2022; Pérez-Canul et al., 2022), and therefore it is considered among the most vulnerable to climate change. However, this municipality also has the largest proportion of ecosystems and forest cover in the whole state. In this SES, nature plays a key role in shaping the resilience of rural communities. Thus, the rich biodiversity of the area can potentially contribute to reduce the vulnerability of the rural communities (Seddon et al., 2019). This, and other attributes, such as the land tenure of the area, the traditional knowledge of its population, and the high biodiversity of the region, offer the potential to enhance the resilience of its human and natural systems, transforming its vulnerabilities into strengths through transformative changes from individual to regional levels.

This study builds on the findings of previous studies on farmers' vulnerabilities to climate change, by developing consensus proposals for wellbeing from the shared perceptions and knowledge of farmer-hunters in the area. It also provides an integral understanding of food security forest rural communities, considering both subsistence agriculture the climate risks of subsistence agriculture and subsistence hunting, along with their implications for villagers and wildlife populations, in the context of SES. Increased efforts are needed to assess perceived climate risks to rural livelihoods and to identify the needs of villagers to adapt to them. Such information can provide valuable context for scientific understanding, evidence-based management, and policy development (Ford, 2009). Most importantly, attention is needed in the development of NbS led by the and community to enhance the resilience of these communities and reduce vulnerabilities to climate and non-climate stressors.

Chapter 4: Evaluation of the long-term sustainability of rural livelihoods

Contributions

This chapter was designed and led by me in collaboration with my supervisor Prof Patrick Doncaster, PhD candidate Julio Carrillo Gonzalez from the School of Education at the UoS, and the farmers of different associations and villages in the CBR. I developed the original idea of the study during an initial collaboration with Operation Wallacea and the CBR authorities. I designed the aims and objectives of the study. I developed the methods, designed the questionnaire, and managed the evaluation of ethics in accordance with UoS policy, with support from Julio Carrillo and Patrick Doncaster. I performed the surveys, analysed the results, and wrote the chapter. Antonio Lopez Cen and Patricio Canul Chuc from the local NGO Pronatura Península de Yucatán A. C., provided links to key informants, interviewees and supported the interview process as gatekeepers. All the interviewed farmers in the CBR shared their knowledge during interviews and discussions, which constituted the core of the study. Julio Carrillo provided support during fieldwork, in the design, organisation, and development of the training of honey production and focus group discussions. Porfirio Uribe, CEO and founder of Calakmiel, provided guidance and support for the organisation and design of the training in honey production. Jennifer Arias, Ricardo López from the Asociación de Apicultores Orgánicos de Calakmul AC, and Esteban Dominguez-Bonilla from Unión de Sociedades Apícolas Ecológicas de Calakmul, delivered the training in honey production. Patrick Doncaster provided comments on drafts of the questionnaire and the chapter. Fieldwork was conducted with resources obtained with my CONACyT studentship (472259) and two Rufford Small Grants to me (28146-1 & 31803-2). This chapter is currently in preparation for a scientific paper for the journal *Human Ecology*. The contributors mentioned above will be co-authors in the paper.

4.1. Abstract

Climate change impacts on rural livelihoods are negatively affecting rural livelihoods globally risking the wellbeing of human and nature. The Calakmul Biosphere Reserve (CBR) in southern Mexico encompasses the largest region of tropical forest on Earth outside of the Amazon. More than 150 rural communities live in its buffer zone, where a deprived regional economy leaves them depending for their livelihoods on the natural resources of these forests. Subsistence arable farming provided their primary source of income until increasingly frequent crop failures within the last decades – caused by climate change to unpredictable droughts– started to force these communities to supplement their incomes with livestock ranching. The subsequent conversion of forest to pasture further exacerbates regional precipitation extremes, and depletes wild game in the forest that supplement the diet of these communities. A growing number of individuals are finding economic security by other means, through honey production from apiaries within the forest. They see benefits to forest biodiversity in raising the quality of their honey, and strength in numbers through increasing the size of their honey-producer community. This chapter explores how these farming communities perceive wellbeing, and what pathways they envisage to achieving economic and food security for their descendants and to assess the economic and ecologic costs and benefits of forest livelihoods in relation to farmers' values. In 2018, I interviewed 36 local ranchers and 16 organic honey producers, using structured questionnaires that allowed me to compute a cost-benefit comparison of livestock farming and organic honey production in the area. Results showed that cattle ranching in the CBR requires a higher initial investment, of MXN $258,350 (GBP £10,336), and higher annual maintenance of both cattle and land, of MXN $65,180 (GP £2,414), than honey production, which requires a lower initial investment, of MXN $76,204 (GBP £3,048.7), and lower annual maintenance of beehives, of MXN $35,610 (GBP £1,425). The average annual production of organic honey from 20 beehives is estimated at 1,200 kg, which yields a revenue of MXN $60,000 (GBP £2,222) in the first year. This is much higher than the annual revenues obtained from 10 cattle in 10 ha, of MXN $16,800, which are only sold in times of need and therefore represent a capital investment. In 2019, I shared results with the participants, to facilitate informed choices about alternative uses of land, based on immediate and longer-term costs and benefits to their individual incomes and to ecosystem functioning. Together in focus groups, we examined their views, perspectives, and desired future development pathways. These discussions stimulated 24 ranchers from two communities to attend an apiculture-training workshop that I organised in collaboration with the honey producers, which focused on capacity building, community engagement, networking, and sustainability. After the training, focus groups discussions were conducted to assess perceptions on honey production vs cattle ranching, showing that there is willingness and potential for developing this activity. The uptake of honey production in the CBR can benefit local and regional economies, the conservation and management of the reserve, and the wellbeing of these communities.

4.2. Introduction

Ecosystems and their associated biodiversities are declining globally, endangering the very foundations for quality of life, and security in food, water, and energy needs. Increasing demand for natural resources, energy consumption, and transformation of land and seas are not only driving ecosystems decline, but also global changes in climate (Pörtner et al., 2021). The world's poorest regions are those projected to experience the worst impacts from global changes in biodiversity, climate, ecosystem functions, and associated degradation NCP (IPBES, 2019).

Sustainable societies, where the needs of its population can be met without compromising those of future generations (Millennium Ecosystem Assessment, 2005), require both a stabilized climate and healthy ecosystems. However, more than 70% of terrestrial biomes have been modified by human activities and global temperature is now rising by 0.2°C (±0.1°C) per decade, reaching 1°C above pre-industrial levels around 2017 (IPCC, 2018). Sustainable futures for people and nature remain possible only if rapid and transformative changes occur from individual to global scales (IPBES, 2019).

Rural households in tropical developing countries are facing weather-related risks with strong negative effects on agricultural output (Mendelsohn et al., 2007; Nepstad et al., 2008). In smallholder-dominated rural landscapes, households may derive about two thirds of their incomes directly from living resources, either cultivated or from the wild, including agriculture and livestock, and from foraging and hunting in natural forests (Angelsen et al., 2014).

Smallholder farmers represent a significant portion of the world's population, with an estimated 450–500 million smallholder farmers globally, representing 85% of the world's farms (Ricciardi et al., 2018). In tropical regions, smallholder farmers are highly vulnerable to climate change as they encounter various risks to their agricultural practices, such as pest and disease outbreaks, extreme weather conditions, and market instabilities, among others that at the same time, interact with other stressors, such as the degradation of nature and its contributions to people, infectious diseases, nutritional deficiencies, and other stressors related to socio-cultural globalization (Cohn et al., 2017).

All these frequently jeopardize household food and income security. Since smallholder farmers usually rely directly on agriculture for their livelihoods and have restricted resources and capabilities to cope with shocks, any decrease in agricultural productivity can profoundly affect their food security, nutritional intake, income, and overall wellbeing (Cohn et al., 2017). In this context, rural households in developing nations typically use assets such as savings and livestock to mitigate negative income shocks. These assets can be sold during periods of income shortfall to maintain consumption levels (Cervantes-Godoy et al., 2013).

Studies show increasing climate impacts on crops that smallholder farmers rely on. Here is evidence that moderate increases in temperatures negatively impact rice, maize and wheat, the main cereal crops of smallholder farmers (Morton, 2007; Hannah et al., 2017). These crops further suffer from pest and disease outbreaks, increasing the frequency and severity of droughts and floods, raising the likelihood of crop failures (Cohn et al., 2017). Thus, there is an urgent need to identify adaptation strategies that can assist smallholder farmers in reducing their vulnerability to climate change and coping with its adverse consequences, particularly in tropical regions (Cohn et al., 2017).

In this context, livelihood diversification represents a key strategy playing an important role in reducing vulnerability to climate change that can work as an adaptation option for adverse impacts to smallholder agriculture (Mohammed et al., 2021). In rural communities living in relatively un-disturbed continuous forest, diversification to sustainable livelihoods is key for maintaining the ecosystem function and human wellbeing. Degraded forests are known to be less resilient to climate change compared to relatively undisturbed natural, biodiversity-rich forests, impacting their capacity to provide NCP (Thompson et al., 2009). A varied array of species enables forests to thrive in a wide range of climatic conditions. Consequently, forest activities should yield relatively higher incomes, while crop production should yield relatively lower incomes in extreme climates. Moreover, in response to weather-related shocks, incomes derived from biologically diverse forests are likely to be less vulnerable than incomes from monoculture cropping systems (Thompson et al., 2016).

This chapter presents the CBR as a case study to understand how adopting sustainable livelihoods can improve the wellbeing of rural communities living in tropical forests, whose main livelihood, subsistence arable farming, is at risk of climate change. Opportunities exist for using NCP for economic wellbeing whilst preserving nature under transformative changes from local to global scales.

4.2.1. The CBR as a case study for using nature to enhance livelihood sustainability

The Calakmul Biosphere Reserve (CBR) in the Yucatan Peninsula in Southern Mexico, encompasses the largest region of continuous tropical forest on the American Continent after the Amazon. This flat karst limestone region has no surface flowing water; all its biodiversity and human inhabitants depend on seasonal rains replenishing underground aquafers and aboveground ponds, known as aguadas, which constitute the only source of water during the dry season from November to April (Vidal-Zepeda, 2005). More than 150 rural ejidos, or rural communities, totalling 32,174 inhabitants live in its buffer zone, where a deprived regional economy leaves them depending for their livelihoods on the natural resources of these forests. Since its modern colonization in the 1980's, the region has experienced slow development (Dobler-Morales, 2021). Its isolated location, and its challenging conditions in the form of poor soils and water scarcity, largely contribute to the economic marginalization of these communities, with limited livelihood options available.

Subsistence arable farming represents the primary livelihood and source of income of the communities in the CBR. Maize, beans, and herbs grown under the milpa or swidden system provide the basis for subsistence, whilst commercial crops, including squash and jalapeno chilli peppers, provide cash income to most of the villages in the CBR (Chowdhury, 2006: Schmook et al., 2013). All farmers in the CBR lack access to irrigation systems, relying only on rainfall for agriculture (Rudel et al., 2009). In general, households in the region supplement their food and income with other activities such as hunting, small-scale livestock ranching, forestry, ecotourism, and honey production (Radel et al., 2010; Schmook et al., 2013). This livelihood diversification allows a dynamic integration of land-uses. Highly integrated agricultural-forest mosaics can increase the multifunctional character of the landscape, supporting a wide range of land-based activities without necessarily degrading the natural resources of a particular social-ecological system (O'Farrell & Anderson, 2010; Dobler-Morales, 2021).

However, climate change is adding new threats and exacerbating the already vulnerable economic and environmental conditions in the CBR. Increasingly frequent crop failures during the last decades, caused by the regional climate changing to unpredictable droughts and floods (Mardero et al., 2014), started to force communities to supplement their incomes with government-incentivised livestock ranching (Busch & Vance, 2011; Schmook et al., 2013). From 2003 to 2012, the number of households with cattle increased from 10% to 50%, and pasture per household grew from 8 ha to 21 ha in the CBR ejidos (Schmook et al., 2013).

Livestock ranching has negative impacts on social and ecological systems. The subsequent conversion of forest to pasture further exacerbates regional precipitation extremes and ongoing habitat and biodiversity loss, which depletes wild game in the forest that supplement the diet of these communities. Furthermore, it increases soil erosion, water scarcity, and plague outbreaks in a region with already challenging environmental conditions (Turner II et al., 2004). Other observed impacts of ranching in the social and ecological dynamics of the CBR include an increasing dependency of rural communities on governmental support (Rodriguez-Solórzano & Fleischman, 2018) and the development of negative attitudes towards jaguars (*Panthera onca*) and pumas (*Puma concolor*), due to attacks on livestock. These top-predators play an important role in structuring ecosystems along multiple food-web pathways (Ripple et al., 2014); thus, impacts on their populations further affect ecosystem functions and nature's contributions to people.

Livestock farming continues to increase in the CBR increasing habitat loss and fragmentation (Gueye, 2018; Radel et al., 2010). This activity has particularly grown in the South-eastern region of the Calakmul municipality, which has the highest rates of deforestation (Gueye, 2018). The main causes of ranching expansion have been attributed to government subsidies, income obtained by remittances from male individuals migrating to the United States, and preference for cattle adoption among households (Busch & Geoghegan, 2010; Radel et al., 2010; Gueye, 2018). Livestock ranching fulfils a security function, in providing a source of emergency money to ranchers in the CBR, and a wealth accumulation and savings strategy (Busch & Geoghegan, 2010; Schmook & Vance, 2009). However, there is no evidence of other impacts of this activity on local people's wellbeing.

Apiculture – beekeeping for honey production, is an increasingly important livelihood in the CBR, which functions as a nature-based solution to local societal challenges. A growing number of Calakmul farmers are finding economic security through honey production from apiaries within the well-preserved forests, particularly from organic practices (Rodriguez-Solorzano & Fleischman, 2018). Farmers benefit mainly from two bee species living in the forest, *Apis mellifera* introduced in the 1910's from Europe, and *Melipona beecheii* a native stingless bee that provides relatively small quantities of high-quality honey (around 0.25–1 litre per colony per year; Echazarreta et al., 1997).

Apiculture occupies a unique economic niche because it provides secure cash income, it provides pollination services for agriculture and biodiversity preservation, and it depends on other NCP in the form of pollen and nectar resources from flowering plants (Galbraith et al, 2017). Beekeepers benefit from natural floral resources without requirement for land conversion, and without competing with other livelihood strategies or conservation efforts in the landscape (Brown & Paxton, 2009, Ingram & Njikeu, 2011).

Honey production has other social benefits beyond income generation and biodiversity preservation. It demands low labour, inputs, and time, so it can be scaled up without inducing competition with other farming systems (Bradbear, 2009; Gupta, 2014). Bee products can provide an important source of nutrition, and it has medicinal applications (Meda et al., 2005). Most importantly, this activity can offer opportunities for marginalized groups, such as women and the landless poor, to access alternative income without exacerbating environmental and land-tenure issues (Gupta, 2014; Koeniger et al., 2010; Schouten et al., 2020).

In the CBR farmers see benefits to forest biodiversity in raising the quality of their honey, and strength in numbers through increasing the size of their honey-producer community. They not only protect their forest but also advocate among their neighbours for forest conservation and the reduction of agrochemicals to protect a larger area where bees can find flowers and maintain the organic certification of their honey (Rodriguez-Solórzano & Fleischman, 2018). Calakmul has a large market for organic honey, as the State of Campeche has the second largest honey production in Mexico after Yucatan and contributes substantially to a total supply that positions Mexico as one of the largest honey exporter countries worldwide (World Bank, 2021).

Ecosystem degradation and climate change demand land system transformations that improve human wellbeing and reverse biodiversity loss through conservation (Leclère, et al., 2020). To assure resilient and inclusive growth in Calakmul, sustainable activities and nature-based solutions, such as beekeeping, should be supported with monetary resources that cover the transaction costs of unsustainable livestock breeding and industrial agriculture (Rodriguez-Solórzano & Fleischman, 2018).

4.2.2. Aim and objectives

The aim of this chapter is to assess the socioeconomic wellbeing of rural communities living in Calakmul, towards the goal of supporting the uptake of sustainable livelihoods based on their needs, perceptions, and views on wellbeing. In pursuance of this goal, a deprived an isolated ejido in the CBR was selected as a case study for quantifying economic and ecological costs and benefits of livestock farming initiating a process of change towards sustainability.

The aim of evaluating wellbeing was addressed with the following objectives:

- Identify the socioeconomic conditions linked to drivers of livestock ranching in an isolated and deprived community.
- Evaluate the economic and environmental costs and benefits of livestock ranching and honey production in the CBR.
- Identify the farmers' motivations and perceived challenges to these activities.
- Provide training in honey production for farmer-ranchers interested in this activity.
- Identify the perceptions of ranchers towards alternative livelihoods and willingness to diversify.

4.3. Methods

This study was developed in two phases: 1) Evaluation of rural livelihoods, and 2) Facilitating the uptake of sustainable livelihoods. During the first phase, developed in summer 2018, data were collected to evaluate the costs and benefits of ranching and honey production in the CBR and to identify farmers' perceived wellbeing related to these activities. Additionally, data were collected to characterize the socioeconomic and environmental dynamics and the linked drivers of livestock ranching in one highly deprived and isolated village.

The second phase of the project was developed in summer 2019. Here, the results obtained in 2018 were shared with and evaluated by villagers of the same community. A training programme in organic honey production was provided for interested farmers and ranchers of this and an additional village, as a first step for the uptake of sustainable and resilient livelihoods. In this phase we explored the perceptions of villagers towards alternative livelihoods and their willingness to adopt alternatives. During the whole study, the participation of rural inhabitants in interviews, meetings, focus group discussions, and other activities such as training, were essential for co-creating the outputs of this study. Details of the methods used in each phase of the study are described below.

4.3.1. Focal population

During phase 1, interviews to identify the livelihoods, socioeconomic dynamics, drivers, and costs-benefits of ranching were developed in a village of the CBR hereafter encoded as 'Cx'. This ejido was selected as a case study, on the basis of its location in the south-eastern extreme of the CBR, which is a hotspot of forest fragmentation (Fig 4.1., Chowdhury et al., 2004; Rueda, 2010; Ramírez-Delgado et al., 2014, Gueye, 2018), due to increasing numbers of arable farmers recently adopting ranching as a complementary livelihood (Gueye, 2018). Additional motivations included the high isolated and deprived conditions of the village as it has no centralised services, schools are not available locally beyond primary level, the nearest medical surgery is 75 km away (SEPLAN, 2021). Additionally, the CBR managers expressed the need of obtaining information on this ejido's socioeconomic conditions for management purposes.

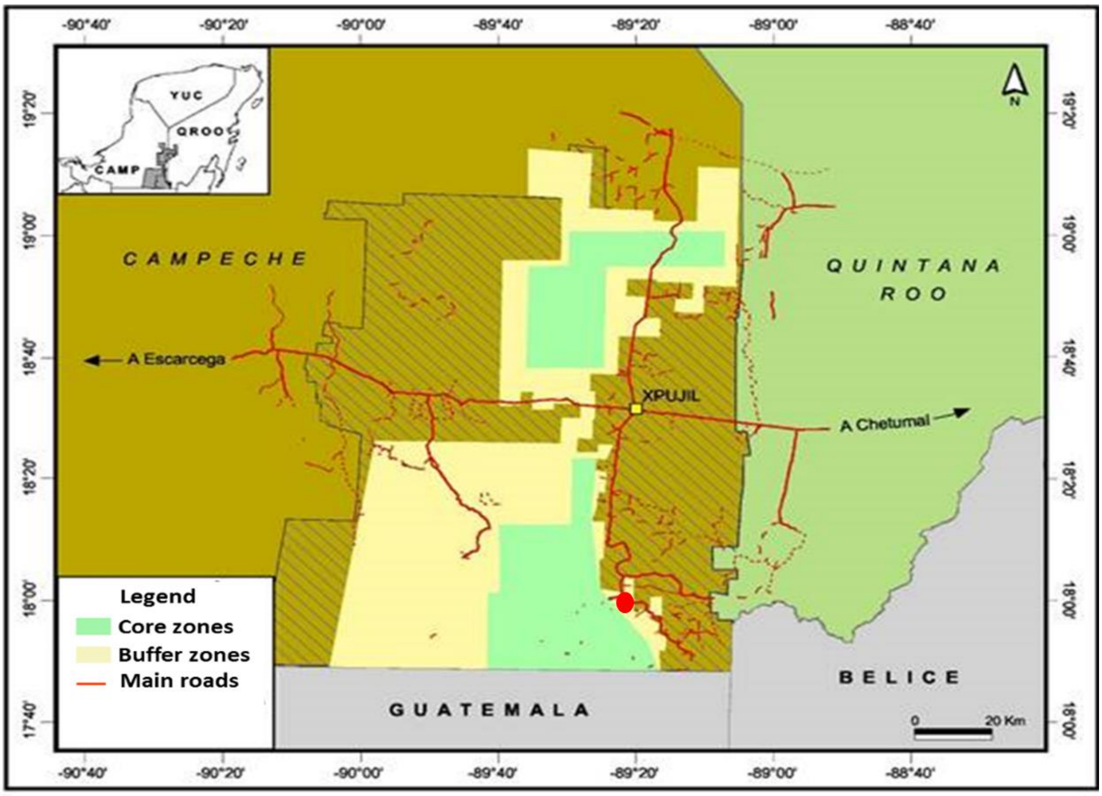


Figure 4.1. Relative location of Cx in the CBR (blue square). Areas in green correspond to the core zones and yellow areas correspond to the buffer zones of the CBR (Source: Molina-Rosales, 2010).

Cx had a small population of 309 inhabitants by 2018 (female =168, male = 141 male). The population age structure is weighted towards young adults, with 63% younger than 25 years old (Figure 4.2). Inhabitants were mostly indigenous descendants of the Ch'ol group, originally from Chiapas highlands that migrated in 1980s after the eruption of the Chichonal volcano. More than 80% of the population speak Ch'ol as their main language (Casa de Salud Cx, 2018).

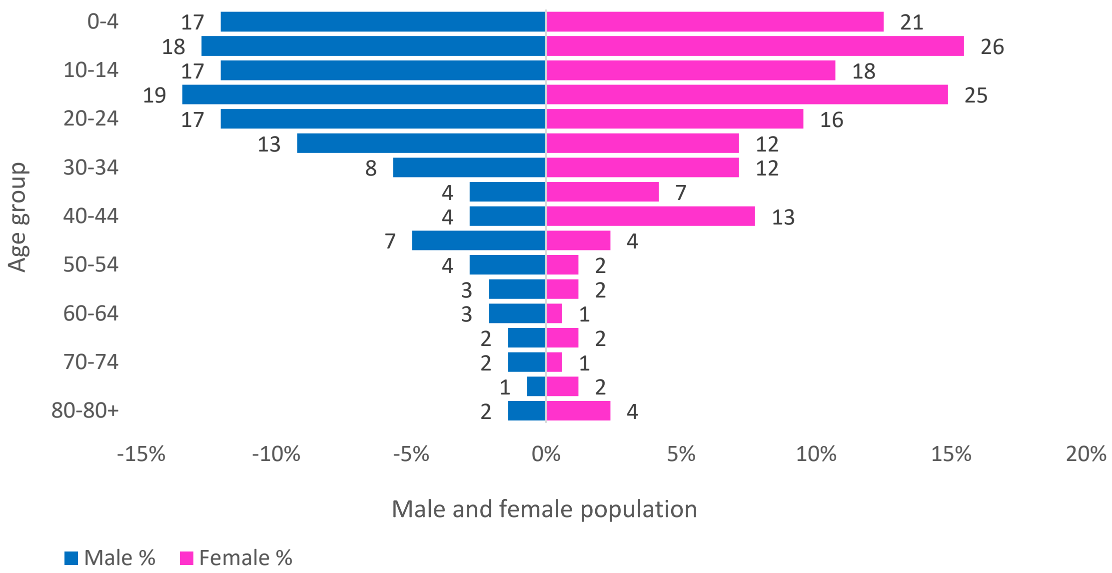


Figure 4.2. Population pyramid and number of individuals according to age group and sex in Cx in 2018 (Casa de Salud at Cx, 2018).

Additional interviews with honey producers and long-established ranchers were conducted in eight other villages in the south and centre of the CBR buffer zone. These provided valuable information on the costs and benefits of honey production in the region and enabled calibration of the information obtain by recently established ranchers. Data was pooled across villages for analysis.

Later, in phase 2, results obtained in phase 1 were shared with the villagers of Cx and a training programme in apiculture was provided to them, and to newly established honey producers from another ejido in the South of the reserve, hereafter referred as ‘Cy’.

4.3.2. Evaluation of rural livelihoods

4.3.2.1. Structured questionnaires

In summer 2018 (phase 1), adult men (>18 years old) in Cx were interviewed with a structured questionnaire to obtain information on the socioeconomic dynamics of this village. Additionally, adult men (>18 years old) from four target groups were interviewed, each with a group-specific questionnaire (‘Questionnaire survey of land-use in Calakmul, Mexico’, ERGO ID number: 41354) in different communities in the CBR. The main target group (group 1) consisted of newly establishing farmer-ranchers in Cx engaged in this activity for 1-4 years. Groups 2 and 3 consisted of long-established cattle and other livestock ranchers (sheep, goats, other) respectively, managing livestock for more than 10 years. Group 4 comprised successful apiculturists dedicated to honey production for more than 5 years (Appendix 6). The structured questionnaires were developed from findings published by Ferguson et al. (2013) and Contreras-Uc & Magaña-Magaña (2017). The order of questions was determined by recommendations in Bryman (2012) on design and organisation of surveys. Questionnaires on socioeconomic dynamics explored demographics, livelihoods, and wellbeing at a household level. All questionnaires on ranching and honey production explored the financial, human, and natural resources required by these activities; the infrastructure and management required; the motivations for dedicating to each livelihood;

and the perceived wider benefits and challenges for farmers. Women were not considered in the structured interviews because none were directly involved in income-generating activities. All interviews were done face-to-face and conducted in Spanish.

In Cx, at least one individual per household was interviewed. When possible, two men from the same household were interviewed separately, to corroborate the information obtained from each. Demographics were later substantiated by visiting health practitioners at the local medical clinic, Casa de Salud, as this is the only institution holding information on the population at ejido level. In addition, formal and informal meetings were held with local authorities of Cx, to determine the spatial extent of the community and its structure.

Further meetings were conducted with other key informants, such as the reserve's authorities, local organic honey production organisations and distributers, representatives of the Calakmul Municipality, the Rancher Association of Calakmul, to understand the dynamics of ranching and apiculture from different perspectives. Visits to local apiaries, honey packing and distribution houses, and large-scale cattle and sheep ranches were conducted during phase 1 of the study to obtain first-hand information on these local practices.

Potential participants were approached directly in their houses between 13:00 and 19:00. The researcher (always C.A.V.) introduced herself, described the aims and benefits of the study, and invited their participation. In case of acceptance, they were asked if it was convenient to perform the interview immediately, or to provide a more suitable time. All interviewees agreed to undertake the interview and agreed that the questionnaire could be conducted immediately. The researcher and interviewee sat in private to conduct the questionnaire. Occasionally, the researcher was invited to visit the workplaces (ranch or apiary) of the interviewee.

Before beginning the questionnaire, a Participant Information Sheet (Appendix 2) was read out to the interviewee, explaining the types of questions involved, the confidentiality of their responses, and their right to decline to answer questions or to end the interview at any point. Most participants in the CBR lack basic reading and writing skills, so participants were asked to express their verbal consent to participate before they started the questionnaire.

Only in the event of their agreement to become a participant in the study could the questionnaire begin. Interviews were audio recorded, except when participants did not agree to this. In this case, the researcher filled out a paper-based questionnaire. When the interview was finished, the snow-ball technique (Biernacki & Waldorf, 1981) was applied, with participants being asked to suggest other potential participants for the study. This led to the completion of 88 interviews, with 61 farmers in Cx and 27 key informants from other ejidos in the CBR: 11 long-established ranchers and 16 honey producers.

Local community leaders and staff from the local NGO Pronatura Peninsula de Yucatan helped to identify potential interviewees and acted as gatekeepers during the interviews, facilitating access and trust (Singh & Wassenaar, 2016). The snowball technique was used during the survey to identify more participants.

The information from the questionnaires was transcribed to an anonymised electronic format and all questionnaire audio files and sheets were destroyed. A content analysis was performed on all open-ended questions, to identify common ideas and to classify them into the following categories: motivations for cattle and sheep ranching, motivations for honey production, and perceived benefits of these activities (Fink, 2009; Bryman, 2012). A code book was then constructed to organise and code the data extracted from the survey questionnaires in a database suitable for cost-benefit analysis.

4.3.4. Facilitating the uptake of sustainable livelihoods

During summer 2019, results from the cost-benefit analysis were shared with 35 villagers, both men and women, during a community meeting in Cx. The attending farmers reviewed and validated the retrieved information. Discussions were held on the perceived challenges of ranching and its implications for wellbeing, which were transcribed by a designated person. During the meeting, farmers were invited to join a training programme in organic honey production organised by the researcher, to be run by farmers from local apiculture organisations: Calakmiel, Asociación de Apicultores Orgánicos de Calakmul AC, and the Unión de Sociedades Apícolas Ecológicas de Calakmul.

A total of 21 villagers (12 men and 9 women) from Cx and Cy attended the training in honey production. Women directly expressed their desire of joining the event, which was a surprising outcome as they are not economically active in these villages. The training provided information on the biology of bees; investment, set-up, management, profits, and development of honey enterprises at individual and community scales; and the benefits of honey production versus other forest livelihoods. Ranchers were guided through an in-situ honey production facility for practical learning. Pictures of the training are provided in Appendix 7.

After the training, two focus-group discussions took place: one with ranchers to explore their views and the willingness to convert to honey production ($n = 14$), and another with newly established honey producers ($n = 7$) to explore their views and experiences in this activity. Through scenario planning, ranchers were asked to reflect on the potential benefits and wellbeing obtained through apiculture versus ranching. Plenary notes were taken by the researchers running the discussions, whilst participants' contributions were transcribed by one of the trainers. The size of participant groups constituted a manageable number, as larger groups would have presented logistical challenges and would have risked denying a voice to inarticulate members. The focus groups yielded a rich collective view that would not have been possible in straightforward interviews (Silverman, 2011). Results from the discussions were transcribed to an electronic format and a content analysis was performed in order to identify common ideas and to classify them into the following categories: advantages and disadvantages of honey production, and contributions of this activity to human wellbeing (Fink, 2009).

4.4. Results

Men from 50 households in Cx ($n = 50$) were interviewed with structured questionnaires. Most of these were young and middle-aged men (Figure 4.3).

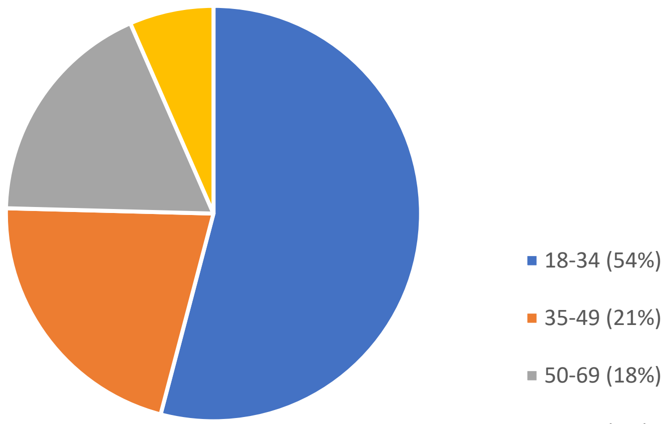


Figure 4.3. Age of male individual interviewed with structured questionnaires in 50 households in Cx. The annotated lists show segments clockwise from the top.

4.4.1. Evaluation of rural livelihoods

4.4.1.2. Socioeconomic dynamics of Cx

Socioeconomic and environmental factors were identified as the main drivers of ranching in Cx. Increasing crop failures due to climate changes along with increasing, yet sporadic, cash obtained by subsidies and remittances, were the most relevant. Details of all these are provided in this section.

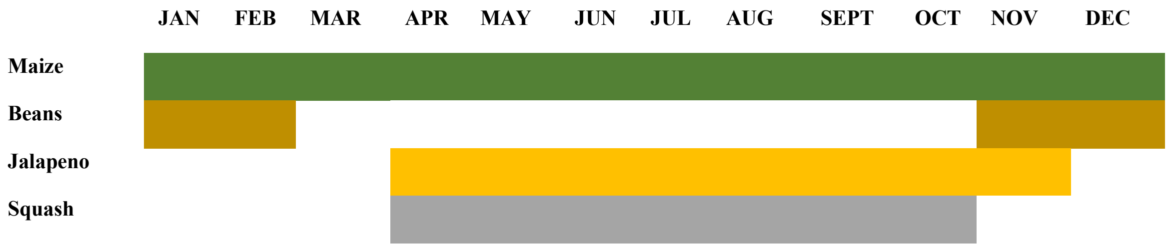
Arable farming was the main livelihood in all sampled households (*n* = 50, 100%). However, all interviewees diversified their activities to supplement their food and income at different times of year. The most common supplementary activities were labour in other farms (*n* = 39, 78%), subsistence hunting (*n* =37, 74%), ranching (*n* = 25, 50%), local commerce (*n* = 9, 18%), small-scale beekeeping (*n* = 2, 4%).

Farmers in all households (*n* = 50) reported growing crops for subsistence purposes: maize (*Zea mays*) and beans (*Phaselus vulgaris*) under the milpa system of rotational farming in plots of 1.5 to 3 ha. Additionally, most relied on commercial crops for cash income: chilli crops supported 86% of the households (*n* = 43), whilst squash provides income for 76%, (*n* = 38). These crops were cultivated in larger plots of 2 - 4 ha. Farmers reported working on arable farming the whole year and obtaining different harvests depending on the crop type and rainfall patterns (Table 4.1). Farmers dedicated to chilli and squash reported investing more labour and resources into these crops than the milpa.

Farmers in all sampled households stated that arable farming is an unstable livelihood. Farmers described that there were "good" and "bad" farming years. "Good years" were described as the ones in which rain started in mid-May and remained until December, with enough intensity to keep the soils and crops viable. In "good years", they obtained enough yields of maize to satisfy three main purposes: feeding their families for one year; having seeds available for the next year's harvest; and selling remanent maize for cash. A total of 42 sampled households (84%), reported not selling maize in the last 8 years due to low yields obtained.

Farmers reported that in "good years" they obtained up to 2 tons of maize per hectare during the first harvest, and 1 ton during the second. If sold, one kg of maize was worth MXN $7.00 (GBP £0.30) on the first harvest and MXN $10.50 (GBP £0.46) during the second. All households growing chilli (n = 43) reported this as the most profitable crop, yet the most expensive in time and resources. Farmers invested large amounts of money in fertilizers, pesticides, and labour to successfully crop jalapeno, even in "good years". Despite this, the first harvest was reported to be sold at MXN $4.50 per kilo (GBP £0.49), whilst the second and third at MXN $3.00 or $2.50 per kilo, depending on the market prices. However, farmers reported that the price could reach up to MXN $43.50 (GBP £1.92) if the chillies were dried and smoked. For squash, farmers reported only selling its seeds to be later processed and commercialized as snacks. The value identified for this crop was $35 per kilo (GBP £1.33) for the first harvest and $30 per kilo (GBP £1.13) for further harvests. Obtaining exact numbers on the yields and profits of crops was not possible as farmers expressed inability to recall that level of detail.

Table 4.1. Months dedicated to arable farming for subsistence and commercial crops in Cx.



Farmers in all households (n = 50) reported observing changes in climate during the last 10 years. These included changes in rainfall timing, reduced amounts of rain during rainy season and intense atypical rains during dry periods, and severe droughts. Most households (n = 42, 84%) perceived that crop failures were directly caused by climate changes during the last 10 years. Increased crop pests and increasing need of fertilizer were also reported as impacts of changes in climate. Crop failures were reported for all crop types, which at the same time affected householders' economies and food security. Farmers estimated that maize, squash, and chilli harvests were reduced by more than half due to severe droughts in 2018. A farmer (47 years old) stated: "I only harvested half a hectare of milpa this year [2018] because of the terrible droughts. I cannot feed my family and the animals with that [referring to domestic animals kept in the backyard]. Now I must buy maize to eat but I have no money because the chilli harvest was low". Although all crops were reported to fail, the most affected according to the farmers was the jalapeno chilli. Less farmers in the sample households (n = 7) reported stopping cultivating this crop in the last 6 years as the costs where higher than the profits. Pests were also reported to be increasing in all crop types. Farmers related increasing pests to changes in climate, as they claimed that this problem was almost non-existent 10 years ago. The use of fertilizers was identified as an increasing concern in the area. Farmers claimed that every year, higher amounts of fertilizer were required to obtain crop yields. However, fertilizer was not available to all sampled households, as 42% (n = 21) reported not having the financial means to buy enough fertilizers for their crops. Old farmers (<60 years old) in eight households (n = 8) reported that in the 1990's fertilizers were not used on maize and squash, whereas recently they have needed to use them to raise crop yields. Despite the extra investment, they are still losing more than 50% of their crops in dry years. No households reported having insurance against crop losses.

Farmers from eight households (*n* = 8, 16%) did not perceived climate change as the direct driver of crop failures. Instead, they related the reduction in crop productivity to soil infertility, lack of technology and infrastructure, and reduced effort invested in this activity during a low-yield year.

4.4.2. Motivations for ranching

Most surveyed ranchers' households (*n* = 21, 84%) reported adopting ranching as a complementary livelihood due to the reduced income obtained from arable agriculture. Their insufficient income was attributed to climatic (described above) and commercial reasons. Farmer-ranchers stated that the local intermediaries who bought their crops largely determined the price, and usually offered "unfair" deals for the already disadvantaged farmers. Additionally, ranchers (*n* = 13) reported adopting ranching because jalapeno peppers increasingly required high amounts of labour and fertilizers, which subtract from the payment obtained for this crop. Unsuccessful crops due to changing rainfall patterns, and the lack of income to buy fertilizers to control new pests, were the main climatic-driven motivations for practicing cattle ranching.

Ranchers (37%) reported that the income from remittances sent by US-based family and government subsidies was an important determinant for adopting and/or expanding cattle ranching. With this extra income, they covered part of the costs involved in the setup, maintenance, and expansion of their ranches. They described the remittance income as being high due to the conversion rate of US dollars, yet sporadic (> 5 times/year). In contrast, subsidies represented a constant yet lower income which ranchers occasionally chose to invest in their farms. In Cx, 65% of the arable farmers had access to PROCAMPO subsides, which farmers reported occasionally using part of the income for their ranches. However, not a single rancher reported benefitting from other subsidies provided by SAGARPA (former Mexican Ministry for Farming, Ranching, and Fisheries) or subsidies from SEDESOL (former Ministry of Welfare). Farmers claimed that the paperwork required to obtain other subsidies apart from PROCAMPO was time consuming and complicated. Additionally, they reported needing the support of the ejido authority in charge of municipal affairs to obtain these benefits. Farmers reported a lack of assistance from the government or local NGO to access subsidies. Income from subsidies was not included in the cost-benefit analysis as farmers reported either not recalling the amounts received from the subsidies.

Most ranchers additionally (*n* = 21, 84%) referred to cultural and/or personal reasons for dedicating to ranching. They anticipated that although this activity required hard work and investment, it would be profitable in the future, as it was the best way to invest the money obtained through remittances. In addition, all reported obtaining social status in the community by practicing ranching, as cattle and sheep represented ownership of capital, equivalent to having money in a bank account. More cows represented more "money".

4.4.3. Costs and benefits of rural livelihoods

This section enumerates the economic, social, and ecologic costs and benefits of cattle and sheep ranching, and honey production in the CBR. Overall, cattle ranching presented higher costs and environmental impacts, with less benefits and access to markets, than sheep ranching and honey production. Honey production involved less costs, with higher benefits, less environmental impacts, and more access to markets (Table 4.2). More details are provided in the following sections.

Table 4.2. Cost and benefits, market access and environmental impacts of cattle and sheep ranching, and honey production in the CBR. Categories (high-moderate-low) were estimated relative to average land tenure, income, access, and environment. Evidence underpinning these categories is detailed in the sections below.

		Cattle ranching	Sheep ranching	Honey production
Costs	Land	High	Moderate	Low
	Water	High	Moderate	Low
	Labour	High	Moderate	Low
	Time	High	Moderate	Low
	Investment	High	Moderate	Moderate
	Infrastructure	Moderate	High	Moderate
	Technical abilities	Moderate	High	Moderate
Benefits	Profit	Low	Low	High
	Knowledge acquisition	Moderate	Moderate	High
	Potential for growth	Low	Moderate	High
	Collaboration opportunities	Low	Low	High
Market accessibility	Market collaboration	Low	Low	Moderate
	Access to subsidies	Moderate	Low	Moderate
	Market access	Low	Low	Moderate
Environmental impact	Deforestation	High	Moderate	Low
	Climate resilience	Low	Low	Moderate
	Human wildlife conflict	Moderate	High	Low

4.4.3.1 Cattle ranching

Cattle ranching was a common livelihood, practiced by 36% (n = 18) of the households. Ranchers described cattle ranching as a family enterprise, where mostly male members of the family contribute physically and/or financially to its development. All cattle ranchers (n = 18 households,100%) reported that the money and efforts spent in the start-up and development of this activity were sporadic and therefore, not returned in subsequent benefits. All ranchers reported to have spent at least two years in setting up their ranches. The maintenance and expansion of these ranches depended on the availability of cash-money obtained by subsidies, remittances, and chilli crops, and access to a labour workforce.

The minimum infrastructure and labour requirements identified for this activity included: 10 ha of land (at least), pasture (Mombasa grass seeds *Panicum maximum*), fences (made with local woods), barnyard, water drinker (at least 2 units), water containers (for watering pasture), water sprayer (for animals' hygiene), vaccines, medicines, drugs to prevent internal and external parasites, cattle registration (although not done by most ranchers in Cx). The minimum labour workforce required were 15 men working sporadically for 8 hours per day during the year to clear the forest and maintain pasture and animals, and additional average daily work of 5 hours on the ranch usually done by three persons.

The infrastructure, income, time, and resources invested in cattle ranching in Cx resulted in highly variable outcomes. The investment needed to start up a ranch with 10 cows on 10 ha of land, and to maintain the animals and land for 1 year, was estimated at MXN $323,530 (GBP £ 12,944), based on ranchers' reports. This estimate represented a benchmark for costs of an enterprise with the basic requirements identified for cattle farming, with breakdown of costs presented in Table 4.3. These expenditures under-estimate the full costs, because interviewed farmers were unable to recall all their expenses and income related to the activity. The same issue was encountered for subsidies for ranching, as farmers were unable to provide details.

Additionally, ranchers reported that cows required *c.* 45 litres of water per day, solely for drinking purposes, giving a total of 13,500 litres each month. Additionally, ranchers reported needing large amounts of water for cow hygiene and health purposes, and for maintaining pastures in dry months. The costs of these were not included in Table 4.3 because farmers couldn't recall metrics on water requirements and associated costs, as water is obtained from multiple sources in different times.

Despite the income required, ranchers reported obtaining variable income from cattle farming. Seven households (n = 7) reported selling an average of two calves per year. Reports showed that a calf of up to 210 kg can fetch MXN $40 per kg, while a calf weighting more than 210 kg can fetch MXN $38, providing farmers with *c.* MXN $16,800 per year (GBP £ 672). Ranchers reported selling old cows more frequently than calves, as they receive $20 per kilo for old cows. They described that selling old cows gave them cash to buy calves, which represented a "good" investment to grow their capital. The price of cows and calves was reported to vary considerably, with a market value that depends on prices established by the intermediaries.

Reports showed that cattle were sold when ranchers required cash-money as these livestock represented their only means of getting cash, along with sporadic sale of successful chilli crops. Examples included, family emergencies, purchase of fertilizers and maize when needed, and community events. Of the surveyed households with ranchers, 89% (n = 16), reported not consuming cattle even in times of food scarcity, due to dietary preferences and to preserve their capital assets.

Table 4.3. Start-up costs for ranching 10 cattle on 10 ha of land with the minimum requirements and annual expenses for cattle and land maintenance. Annual income from an established cattle ranch is estimated at MXN $ 16,800. Prices shown here relate to 2018, and are estimated to have risen 6.85% by 2023 in line with inflation (INEGI, 2023). Subsidies were not included in this estimate as farmers did not provide concrete data on this.

Cost component	Description	Expenditure (MXN)
Start-up costs		
Labour for forest clearance	Removing native vegetation (usually with machetes). An average of 4 men are hired to support with forest clearance on 8-hour shifts. Labour workforce increases with number of hectares.	$15,000

Pasture	Purchase and installation of pasture Mombasa grass (*Panicum maximum*). Usually bought as seeds.	$20,800
Fences	Made of wood available in the forest. Price considers sawing of wood, transportation, tools, and hardware.	$16,550
Barnyard	Labour for sowing and maintaining pasture, including manual irrigation using water containers.	$40,000
Water drinkers	Essential for maintaining animals and pasture	$9,500
Animals	*Bos taurus* varieties most common	$155,000
Cattle registration	Paperwork and fees paid to the Registro Agrario Nacional. Most ranchers in Cx do not do this.	$1,500
Total		**$258,350 (£10,336)**
Annual cattle maintenance		
Hygiene	Cleaning and maintenance of animals. Includes drugs to prevent internal and external parasites.	$2,700
Health	Considers vaccines and medicines. Vet visits are not included there are no vets in the area.	$14,480
Total		**$17,180 (£687)**
Annual land maintenance		
Personnel	Labour for cleaning the land and sowing pasture. Around 15 men are hired to support with this sporadically during the year, for 8-hour shifts. Family members involved do not receive payment for their job.	$42,000
Material	Considers broken wire and fences, and replacement of water containers.	$6,000
Total		**$48,000 (£1,920)**

Challenges for cattle ranching in Cx were identified as a lack of technical assistance on animal health, the farmers' lack of technical knowledge, the hilly landscape, and the limited opportunities to expand ranches because available land is limited to owned plots.

All surveyed households with ranchers (n = 18) reported impacts of droughts on cattle farming. Water scarcity was the principle and growing problem, especially during the dry season. During this time, farmers reported having to travel to other villages to collect water from large natural aguadas. This involved, for most, renting vehicles, buying large water containers, paying for petrol, and paying water fees to the local authorities. In extreme cases, farmers reported bringing water trollies from Xpujil, the nearest urban centre about 70 km away, which demands high expenditures of time and money. Farmers were unable to afford these expenses (n = 9), and reported transporting water to their ranches by hand, walking long distances at least twice every day. Although ranchers identified that pasture was affected by droughts, they took no mitigative action to address this issue. Despite the problems caused by droughts, all cattle farmers (n = 18) stated that they aimed to expand their enterprises by converting more land to pasture and buying more cattle.

4.4.3.2. Sheep ranching

Sheep farming was another important and growing livelihood in Cx, with seven households dedicated to this livelihood. As with cattle, sheep farming was also a family activity supported by different members of the family. Farmers (n = 5) reported having both sheep and cattle, containing the animals in the same area, whilst other farmers (n = 2) reported keeping sheep in their backyards. The average size of the area in which farmers raised sheep was an area of 1 to 2 ha.

The minimum infrastructure and labour requirements identified for this activity included: 1 ha of land (at least), pasture (Mombasa grass seeds *Panicum maximum*), fences (made with local woods), huts and structures (to protect sheep from rain and predators), water drinker (at least 2 units), water sprayer (for animals' hygiene), vaccines, medicines, livestock registration (although not done by most ranchers in Cx), labour (to maintain pasture and animals), average work of 2-3 hours 3-4 days a week spent in the ranch.

The estimated cost of investment to start farming 20 sheep in 1 hectare, and to sustain the stock for 1 year, was MXN $156,450 – GBP £6,259 - (Table 4.4). This estimate was obtained with data provided by local farmers, who were not aware themselves of how much they invest or earn from this activity. The estimate considers the minimum infrastructure, material, and labour requirements found in Cx. Not a single farmer was able to answer all the questions related to the expenses and earnings of sheep farming. Despite this, all farmers stated that they want to expand the enterprise. It is nevertheless noteworthy that start-up costs are more than 3 times cheaper for sheep than cattle, but running costs are 1.2 times greater for sheep than cattle.

Each sheep weighing between 20 and 35 kg was sold for MXN$32 per kg. The average number of sheep sold by long-established livestock farmers in the larger Calakmul region was 5 animals/year, giving a potential income of MXN $5,600 (GBP £207). However, the number of sheep reported to be sold varied between years, depending on the cash money needs of the ranchers. All sheep ranchers in Cx were newly established ranchers (>2 years), so they could not report profits. Farmers were confident that this activity would be profitable once they grew the enterprise and obtained more sheep.

Table 4.4. Start-up costs for farming 20 sheep over one ha, considering the minimum requirements for this activity and annual expenses for sheep and land maintenance. The annual income estimated for sheep ranching is of MXN $5,600. Prices could grow up to 6.85% in 2023, due to inflation (INEGI, 2023).

Cost component	Description	Expenditure
Start-up costs		
Labour for forest clearing	Removing native vegetation usually with machetes and herbicide. One person is hired to support with clearing (8-hour shift). Labour increases with number of hectares.	$4,000
Fences	Made mostly of wood and wire to protect animals from predators. Wood available on the forest.	$35,290
Huts	Made of wood available in the forest, requires tin for roof to protect animals from sun and rain. Estimate considers sawing of wood, transportation, tools, and hardware.	$4,250
Pasture	Purchase of pasture. Less seeds are used as sheep feed on native vegetation.	$1,200
Water drinkers	Essential for maintaining animals	$1,080
Animals	*Ovis aries* is the most common species	$31,500
Animal registration	Paperwork and fees paid to the Registro Agrario Nacional. Most ranchers in Cx do not do this.	$700
Total		**$78,020 (£3,121.42)**
Annual sheep maintenance		
Hygiene	Cleaning of animals to prevent them from ticks and other insects. Estimate includes water containers needed hygiene purposes.	$10,800
Health	Considers vaccines and medicines. Vet visits are not included there are no vets in the area.	$12,820
Total		**$23,620 (£945)**

Annual land maintenance		
Personnel	Labour for cleaning the land and sowing pasture.	$50,400
Material	Considers broken wire and fences, and replacement of water containers.	$4,410
Total		**$54,810 (£2,193)**

In recognition of water scarcity in Cx, there was a consensus that sheep could be more profitable than cows. This idea was further supported by the fact that sheep can breed twice per year, compared to cows that only breed once, providing farmers with more income. Farmers also recognized that sheep required less workforce and pasture, as they can also browse on forest herbs.

Sheep ranchers reported encountered or perceived challenges to this livelihood. Climate change-related lack of water and droughts was the most frequently reported issue (n = 7, 100%). Another major disadvantage perceived for sheep was their lower resilience compared to cattle. All farmers reported high rates of illness in their animals (respiratory and gastrointestinal problems) and high number of snakebites. Ranchers reported that sheep were highly sensitive animals to environmental changes, with even minor changes in temperature and humidity affecting their health. This represents a problem for ranchers as they risk losing animals, exacerbated by their lack of skills in treating ill animals and in taking preventative measures. Ranchers also reported that the presence of felids in the region, and the lack of support for installing electric fences, was a challenge for expanding their ranches. Ranchers that had lost sheep from felid attacks kept their livestock in their backyards instead of their plots (*n* = 2).

Despite these challenges, sheep ranching was usually perceived as a better option in terms of management than cattle ranching. Farmers reported that sheep required less water than cows (sheep: ~12 litres, cows: ~45 litres per day solely for drinking), less land per animal (up to 25 sheep in 1 ha vs 1 cow in 1ha), lower pasture requirements (as sheep are left to eat native vegetation), less labour (2-3 people for sheep vs up to 8 people for cows), and less time (3 hrs 4-5 days/week for sheep versus up to 6 hours 7 days/week). However, sheep required more care and protection and were considered less profitable.

4.4.3.3. Honey production

Apiculture was a common activity in the central area of the CBR. All the interviewees from honey-producing communities in the Calakmul area reported this activity as a profitable livelihood in relation to other common livelihoods in the area (*n* = 15). All bee farmers reported requiring less investment, workforce, time, and resources for this activity than for other common livelihoods, including arable farming.

Start-up costs for 20 hives, and maintenance of the apiary for one year, were estimated to total MXN $111,814 (GBP £4,473), considering the minimum infrastructure, labour and other requirements detailed in Table 4.5. The estimate was calculated for an apiary of 20 beehives because with this number the business can be profitable in the first year. Materials included in the estimation consider the regulations for producing organic honey, which require stainless steel utensils. The resulting estimate was cheaper in both start-up and running costs than cattle and sheep farming.

After one year of honey production, apiculturists reported the need of further investment to maintain and grow the enterprise. This second investment was estimated in MXN $46,344 (GBP £1,854) for 20 extra beehives. With more beehives, the production of honey was reported to increase while the costs were reduced, representing an economy of scale. According to local apiculturists interviewed for this study, honey had a production cost of MXN $20 per kg (GBP £0.80) by 2018. Every year, honey producers reported to grow the number of beehives and therefore their revenue.

The investment for starting in honey production was reported as higher for organic than non-organic honey. However, organic honey was regarded as bringing in higher profits, fetching MXN $50 per kg compared to MXN $32 per kg for inorganic honey in 2018.

The average annual production of organic honey from 20 beehives was estimated at 1,200 kg, which yields a revenue of MXN $60,000 (GBP £2,222) in the first year. This was much higher than the highest annual revenues obtained from cattle, of MXN $16, 800, and sheep, of MXN $5,600. Profits were reported to be higher with expansion of the apiary.

Honey producers (n = 12) reported being motivated to start this activity by subsidies for sustainable livelihoods provided by the reserve or by the municipality, or as part of NGO Pronatura projects. Honey producers mentioned receiving subsidies in kind, not income. The most common items that honey producers received were expensive stainless-steel utensils necessary for organic honey production, which motivated the uptake of this activity by reducing the costs of the enterprise. By 2018, producers no longer received any support from external institutions, and considered themselves profitable and independent.

The long-established honey producers interviewed for this study reported that they received support from the protected area authorities or the local government (municipality) when starting this activity between 2006-2012. Honey producers mentioned receiving subsidies in kind, not income. The most common items that honey producers received were expensive stainless-steel utensils necessary for organic honey production. During talks with the CBR managers, I was informed that these items were purchased with subsidized money from the national Conservation Programme for Sustainable Development (PROCODES in Spanish). This programme aims to promote the sustainable use of natural resources in protected areas. However, according to the CBR managers, during 2006-2012 there were more funds available and supporting honey production was a priority in the reserve. When the funds became scarce, they had to prioritize other more urgent activities. Following the growth in honey production, local NGO Pronatura also provided support for this activity during the same period. Occasionally, PROCODES funds are used for supporting settled honey producers in a couple of selected communities. Pronatura did not have any honey production programs at the time when this study took place (2018). However, by the time of the study (2018), the interviewed honey producers were not receiving any support from these institutions.

Table 4.5. Start-up costs, maintenance costs during the first year, and re-investment costs for growing an apiary during the second year, for organic apiculture. The annual income for honey production was estimated in MXN $60,000. Prices could grow up to 6.85% in 2023, due to inflation (INEGI, 2023).

Cost component	Description	Expenditure
Start-up costs		

Bee collection	Farmers collected wild bees (*Apis melifera*) from the forest. Costs refer to materials needed for bee collection: wooden boxes (made with local tress), rope, and bate.	$8,300
Beehives	Cost of 20 beehives, usually made by farmers using forest wood (depending on farmers' abilities) or bought locally.	$20,900
Structures	Costs for the construction of bench-style structures made of different materials (usually a mix of cement and wood) to keep boxes off the ground.	$16,544
Material	Costs of different material needed for collecting and storing honey: smokers, stainless-steel double uncapping tank, stainless-steel uncapping knife, stainless-steel uncapping fork, strainers, bee brush, and buckets (5).	$28,260
Clothing	Costs of veil, suit, gloves used for protection in the apiary.	$1,600
Water	Costs of small water containers required in all apiaries to provide water to the bees (2 units per apiary)	$600
Total		**$76,204 (£3,048.7)**
Maintenance (first year)		
Bee collection	Costs of materials needed for bee collection: wooden boxes (made with local tress), rope, and bate. New bees needed to be collected after a year as bee colonies tend to leave the beehives.	$710
Health	Costs of maintenance of the bee colonies. Bees need protection against pests.	$500
Personnel	Costs for the payment of three persons hired in harvest times to support collection of honey and cleaning the ground vegetation found in the apiary.	$20,000
Transportation	Costs of the trips between apiary and village and distribution of honey to collection centres.	$14,400
Total		**$35,610 (£1,425)**
Investment in second year to grow enterprise (20 extra beehives)		
Bee collection	Costs of materials needed for bee collection: wooden boxes (made with local tress), rope, and bate.	$8,300
Beehives	Cost of 20 beehives, usually made by farmers using forest wood (depending on farmers' abilities) or bought locally, and for replacement and maintenance of previously owned beehives.	$20,900
Structures	Costs of material and construction of structures to keep new beehives.	$16,544
Water	Costs of water supply for more hives.	$600
Material	Costs of extra material for honey collection and storage: smokers, stainless-stell barrels, spatulas, mixers, strainers, and containers.	$2,700
Total		**$46,344 (£1,854)**

4.4.4. Facilitating the uptake of sustainable livelihoods

4.4.4.1. Perceptions of alternative livelihoods

Honey producers, both new and long-established, perceived this activity as one that improves their wellbeing. They described social, economic, and ecologic benefits, including aspects of health, family and other social relationships, community structure, and knowledge. A honey producer (32-year-olds) mentioned: "Since I work in organic honey, I am rich! I supply for my family, I bought myself a truck for taking water to my milpa, and I even went on holiday". Another honey producer (aged 57) stated: "A long time ago I had cows since my father had cows in Veracruz. I soon realized that ranching is not sustainable in Calakmul because of the soils and the droughts. I started thinking of the bees as flying cows. Now, I make money, I mange my business, and I live in a beautiful forest. I like to help other villagers who complain about the region's deprivation to see things the way I do. At the end the more the merrier in this business".

According to the interviewed apiculturists, an important aspect of honey production was that it allowed them to work as cooperatives; in contrast to ranching which represented a competitive enterprise. Under the cooperative scheme, honey producers could benefit from shared skills and responsibilities, whilst increasing production and reducing costs. However, they saw challenges to working as a group, which included conflicts of power and difficulties for guaranteeing a high quality in the honey. A big concern in the area was the fact that the procedures and guidelines for organic honey production were not always followed thoroughly by individuals, reducing the quality of the total production, and thus affecting their profits. To succeed, honey producers recognized the need of continuous cooperation, commitment, adaptability, and putting communal benefits before individuals.

Additionally, honey producers identified financial, environmental, and social challenges to this practice that affected its development (Table 4.6). In contrast, ranchers perceived more financial, environmental, and idiosyncratic challenges and disadvantages to honey production, as shown in Table 4.6.

Table 4.6. Financial, environmental, social, and idiosyncratic advantages and disadvantages of honey production perceived by beekeepers and ranchers in the CBR. These were identified through the focus group discussions and open-ended questions in the questionnaire surveys.

Beekeepers

	Advantages	Disadvantages
Financial	Becomes profitable during first year	Requires off-front capital for investment
	Provides cash-money in two critical times: when the fields are sowed and during droughts	Lack of capacity building for start ups
	Honey is sold at a better price than crops (e.g., $50 honey vs $7 maize)	Honey price changes each harvest and is dependent on unfair intermediaries
	More profit with less time and labour invested (1-2 hr/ 3 days/week) except for harvest times.	Lack of technical skills and knowledge (technical, organic certification process, legal registration of cooperatives)
	Potential to sell different products	Poor regional cooperation
	Less space required: opportunities for non-ejidatarios and land-less villagers	Organic certification processes are expensive and complicated
Environmental	Makes farmers value nature as wildlife improves quality of honey	Increasing plagues and illness of bees
	Supports wildlife during droughts through water available in apiaries	Increasing deforestation in the ejidos threaten quality and production of honey
	More resilient to climate impacts than agriculture	Changing rainfall patterns affect flowers' phenology and quality of honey

	Helps crop pollination	Fertilizers used in crops damage bees
Social	Potential to develop relationships with other producers and develop knowledge	Poor communication strategies between local honey associations and cooperatives
	Potential to set up as cooperatives (benefits include sharing skills, reducing work, increasing production, reducing costs - economy of scale)	Conflict of power, quality control of honey (conventional honey sometimes sold as organic)
	Potential to bring external attention, investment, and recognition to the region	Isolated communities in forested areas are less available to distribute their honey
	Benefits farmers health, less physical effort reduces injuries and pain; less contact with chemicals.	Lack of technical capacities to maintain the business.
	Allows women to participate in family-economies	NA
Ranchers		
Financial	Possibility to have more money and time available	More climate resilient than other practices but still dependent on rainfall
	Less water required therefore less trouble	Unstable prices of honey
	Less space required therefore less work	Markets are not strong enough to sustain this practice in all the region
		Harder for isolated areas to access distribution chains and markets
Environmental	NA	Deforestation and use of pesticides endanger this activity
Idiosyncratic	NA	Bees leave the beehives when they perceive conflicts among people
	NA	Bee's stings are dangerous and unpleasant
	NA	Fear of losing initial investment due to lack of technical and business expertise

4.5. Discussion

4.5.1. Socioeconomic dynamics and drivers of ranching

The resources and income obtained through diverse livelihoods largely determines the socioeconomic conditions of the rural communities in the CBR. However, the adoption and success of these livelihoods are largely determined by environmental conditions (Alayón-Gamboa & Ku-Vera, 2011; Geoghegan et al., 2001; Chowdhury, 2006; Turner II, 2010). As in Cx, previous studies have found that most rural communities in Calakmul depend on milpa cultivation for subsistence, but have changed their livelihood strategies due to climatic variability and other factors such as globalization, market liberalization, and government subsidies, either by intensifying arable farming and cattle/sheep ranching or incorporating off-farm income (Alayón-Gamboa & Ku-Vera, 2011; Radel et al., 2010; Schmook et al., 2013; Mardero et al., 2020; Dobler-Morales et al., 2020). Despite the harsh conditions of the CBR, ranching has expanded and intensified in the area, in response to diverse drivers.

In Cx, as in other communities of the CBR, ranching was identified as a growing enterprise (Ericson et al., 2001; Busch & Vance, 2011; Schmook et al., 2014). Despite the challenging environmental conditions, incentives for ranching have been identified in the CBR. These include: the availability of land (ejidatarios own between 40-150 ha depending on the ejido), the lower risks compared to crop cultivation, given unfavourable conditions for crop production due to shallow soils and climate variability; the higher social prestige of ranching; and the increasing investment of remittances and subsidies in this activity (Busch and Vance, 2011; Ericson et al., 2001). Investing surplus income in ranching provides a relatively liquid asset in case of a costly emergency (Busch & Vance 2011, Turner II, 2010).

Government-incentivised subsidies are a common driver of ranching in the CBR. However, farmers in Cx benefited only from a PROCAMPO subsidy, which is widely invested in pasture throughout the CBR despite being designed for basic staple crops (Schmook & Vance 2009). Not a single rancher in Cx benefited from federal or municipal subsidies granted for ranching. Scott (2010) identified that peasants in the most isolated and deprived areas in rural Mexico struggle to access subsidies, as they are usually illiterate and lack identify cards and other required documentation. After fieldwork for this study was completed in 2018, a new federal administration took the presidency in Mexico, bringing more and stronger subsidies for the development of Mexican farmlands. This study did not consider subsidies granted after 2018 in the CBR. Further studies of this matter would provide insights on the impacts of recent policies on rural livelihoods in the CBR.

Food provision was not found to be a motivation for ranching in Cx. Cattle are not considered to be a food source in this ejido, as farmers refused to eat them even in times of need (personal observations). Although farmers reported reduced crops and income, they still do not eat beef because slaughter and preparation require a high investment and labour. In the Yucatan Peninsula, almost 70% of the meat consumed by rural communities originates from hunting large species of ungulates (Weber, 2006). Alternatively, they consume poultry and other animals that they raise in their backyards.

The main driver of ranching in the CBR were the increasing climate change-related crop failures. Climate change poses risks to tropical rural livelihoods, particularly for those heavily reliant on natural resources (Hallegatte et al., 2016). Smallholder farmers are highly vulnerable to climate impacts. Studies have shown that these farmers suffer from disproportionate impacts on their crops and thus, income and food security are increasing globally (see Harvey et al., 2014 and Mutekwa, 2009 for Africa; Harvey et al., 2018; Donatti et al., 2019 for Central America; Touch et al., 2017; and Aryal et al., 2020 for South Asia). Harvey et al. (2018) showed that climate change is having significant adverse impacts on smallholder coffee and maize farmers across the Central American region. Although farmers use different risk-coping strategies, these are insufficient to prevent them from remaining food insecure. Thus, experiencing livelihood insecurity.

Livelihood insecurity, defined as a situation where existing livelihood strategies fail to provide sufficient benefits and are largely compromised in the future, serves as a significant catalyst for livelihood diversification, particularly in rural areas (Niehof, 2004). Livelihood diversification refers to the process through which individuals, households, and communities undertake various activities to act as "safety nets" or enhance wellbeing (Baffoe & Matsuda, 2018). In the CBR, honey production can provide a safety net for wellbeing under current climate changes, whilst simultaneously preserving biodiversity and associated NCP. This is particularly relevant in the climate change context, as degraded forests are recognised to be less resilient to climate change than relatively undisturbed natural, biodiversity-rich forests (Thompson et al., 2009), impacting their capacity to provide NCP. A varied array of species enables forests to thrive in a wide range of climatic conditions. Thus, forest livelihoods should yield relatively higher incomes, while crop production should yield relatively lower incomes in extreme climates (Wunder et al., 2018).

Alternatively, engagement in non-farm activities is among adaptation strategies to climate-induced crop failures adopted by smallholders. Off-farm jobs can absorb rural surplus labour and enable to reduce income uncertainties, increasing agricultural productivity (Yaro, 2013; IPCC, 2014). For many isolated rural communities in the CBR, off-farm jobs are reduced or unavailable. This reinforces the importance of honey production as means of income and sustainable use of nature, sustaining economic and environmental needs related to human wellbeing.

4.5.2. Costs, benefits, and perceptions of rural livelihoods

An analysis of the economic, social, and environmental costs and benefits of rural livelihoods allowed to identify that honey production is a more profitable, sustainable, and resilient alternative than ranching in the CBR. Cattle ranching presented higher costs in terms of initial investment, land and water demands, labour, time, infrastructure, and technical abilities than sheep ranching and honey production. Current constraints for cattle ranching in other communities of the CBR include water scarcity and reduced labour due to men migrating to the United States (Schmook et al., 2014). Sheep farming required less investment, land, water, labour, and time. However, sheep require more infrastructure and technical abilities to protect these highly sensitive animals from environmental stressors. In other ejidos of the CBR, sheep farming is preferred as it requires less land than cattle, making this activity more appealing for non-ejidatarios living in the area (Marshall et al., 2021; Schmook et al., 2014). However, sheep and other livestock predation by felids is increasing in the region, affecting farmers' economies (Zarco-González et al., 2018; Marshall et al., 2021). In contrast, honey production requires less investment and resources compared to ranching. It is important to highlight the difficulty of comparing like to like between honey production and ranching, particularly in terms of profits because a big apiary will always give more revenue than a small ranch and vice versa. However, this work attempted to compare between feasible alternatives and to recognise the capacity for expansion of each.

Honey production also presented more benefits than ranching in terms of profit, knowledge acquisition, opportunities for growth and collaboration. Other studies in the Yucatan Peninsula showed that forest honey production is a profitable activity, which can be set up with relatively low investment (Magaña et al., 2016; Uc & Magaña, 2017; Chan-Chi et al., 2017). In the CBR, ejidos in the central area have been able to start this activity even with small initial funding (around MXN $15,000 – GBP £700) provided by the CBR authorities (Zuniga-Morales, 2018 *personal communication*). Knowledge acquisition was identified as a benefit for farmers in the CBR. Honey production has been recognized for providing opportunities for farmers in different regions to gain or develop skills, or to improve knowledge in aspects such as ecological understanding, bee behaviour, pest control, and management of beehives; technological, managerial, and business-related knowledge; and traditional knowledge (Echazarreta et al., 1997; Bogale, 2009; Aynalem Abejew & Mekuriaw; Chan-Mutul et al., 2019; Chan-Chi et al., 2017). Honey production has opportunities for growth and expansion in the CBR, due to the low investment and resources requirements, and the high-quality organic honey obtained in the preserved forests, along with a large regional and international market. Campeche is the second largest state for honey production in Mexico, which together with Yucatan and Tabasco contribute *c*. 40% of the country's total honey exports, achieving a revenue of USD $68 million dollars in 2020 (SADER, 2021). Beyond this economic value, honey production also brings a very different benefit in its potential for bringing transformative changes to the social structures and dynamics of the CBR villages, towards more inclusive and just societies. Apiculture has been widely recognized as a possible method of empowering rural women and other vulnerable groups, as it provides a product with high market potential while being more easily adapted to economic and land tenure constrains (Pocol & McDonough, 2015). This was found to be particularly important in Cx where women are not economically active or participate in communal decisions, yet they showed interest and willingness to learn about this activity during the training we provided, even though they were not initially considered as participants. Here women expressed the need to generate income for their households through an activity that allowed them to work independently of men in the community and that did not demand high physical labour (as does milpa cultivation).

In terms of access to markets and subsidies, all livelihoods in Cx were disadvantaged by the isolated location of the village and the lack of communication channels. Communities living inside a biosphere reserve have the potential to access funding for conservation purposes (Pagiola et al., 2005), through the CBR managers and local NGOs. However, the allocation of these funds has resulted in winners and losers among the buffer zone communities (Schmook, & Vance, 2009). The winners have been the communities located in the centre of the reserve, due to their location and relationships with CBR authorities. Studies are needed on the conservation funding available in the area and the factors determining their allocation, to understand the wider determinants of socioeconomic development in the region.

Ranching was found to have higher environmental impacts than honey production in the CBR. The conversion of forest to pasture not only increases deforestation in the region but may result in profound and perhaps irreversible land use transformations, affecting the integrity of the forests. Other impacts include the compression of the fragile limestone soils in the CBR and inhibition by pasture of the regrowth of native forest vegetation (Ericson et al., 2001). Furthermore, associated deforestation and biodiversity loss to ranching magnifies impacts of climate change by reducing carbon sequestration (Garnett, 2009), increasing the vulnerability to climate change of already vulnerable livelihoods in the area. In contrast, beekeeping in forested areas has been recognized and used globally as a productive conservation strategy, for its benefits in biodiversity and economies (e.g., Kassa Degu & Regasa Megerssa, 2020 in Ethiopia; Brown, 2006 in the Brazilian Amazon; Vinci et al., 2018 in Mexico; Chanthayod et al., 2017 in Laos; Decourtye et al., 2010 globally; Hinton et al., 2020 in Fiji). Honey production in the CBR benefits from preserved forests, as plant diversity improves the perceived quality of the honey, whilst deforestation and fertilizers hamper it. Apiculture has also created a new interest in conservation, as there are ejidos putting areas of primary forest into production as a "pasture" for the bees (Acopa & Boege, 1998). However, there is no information on the impacts of the growing populations of *Apis mellifera* on native insect communities of the CBR. Information on the interaction of honeybee species in Calakmul would contribute to the long-term sustainable management of this practice, as other regions have reported negative impacts on native species (Paini, 2004 in 14 countries around the globe; Badano & Vergara, 2011 in the Gulf of Mexico). Honey production was perceived as more resilient to climate changes than ranching. This was mainly because livestock and pasture demand more water. However, other studies have proven this practice vulnerable to drought in the Yucatan Peninsula (Lazos-Chavero et al., 2002) and other regions (Gajardo-Rojas et al., 2002; Flores et al., 2019). Studies are needed in the CBR on this matter to assess the vulnerabilities to climate change.

Despite the negative environmental impacts of ranching, it can provide economic benefits to farmers if practiced at small scale, by functioning as a long-term source of income and a relatively liquid asset in case of emergency (Radel et al., 2017). Keeping it at small scales, can allow the maintenance of forests and their biodiversity, and the preservation of the multifunctional landscapes of the CBR's ejidos. Ranching did not provide a constant income for the studied farmers, as they sold livestock mainly in times of need. In contrast, honey production profits were obtained during specific months of the year (usually, during drought periods).

The main aim of this study was to identify farmers' perceptions and needs on alternative livelihoods, rather than to make a robust economic assessment of them. Information on the investments and profits of rural livelihoods was collected directly from farmers instead of from larger datasets (such as SAGARPA's or FAO's), with the aim of co-creating an information baseline with farmers, and motivating awareness of the costs and benefits of their activities. However, obtaining financial information on rural livelihoods in the CBR was challenging, because farmers were mostly illiterate and not aware of, or did not keep records of, their expenses and profits. Farmers usually relied on forest resources (such as woods, bees, water) and their own or other farmers' skills for a range of services (e.g., sowing wood, building fences, beehives, and larger infrastructure). Many indirect or hidden costs were not declared as expenditures, where farmers repurposed materials that they already have in their households (e.g., chainsaws, gasoline, oil, hoes, metal, etc). Data collection with ranchers was still more challenging, as this is usually a family activity whereby different household contribute with income, and the investments and profits are not continuous because farmers put money into it when available, usually taking more than 3 years to set up an initial ranch. Dobler-Morales et al (2021) likewise found it challenging to collect information on yields and profits of agriculture in the region as record-keeping is uncommon.

Farmers perceived many of the benefits described above for honey production. Ranchers, nevertheless, perceived more disadvantages than advantages to apiculture. The perceived disadvantages were related to beliefs and misinformation. Similarly, Singh & Singh (2019) found that negative perceptions on apiculture amongst Indian rural communities could be resolved by providing relevant information through various training programmes and financial facilities. Despite the negative perceptions of ranchers on apiculture, there is high potential in Cx for development mainly amongst women inhabitants, who did not share those perceptions.

The success of honey production in the CBR could be affected, positively and negatively, by international markets. Calakmul has a large market for organic honey, as the State of Campeche has the second largest honey production in Mexico after Yucatan. This state contributes substantially to a total supply that positions Mexico as one of the largest honey exporter countries (World Bank, 2021), representing an advantage for the CBR farmers. It is estimated that 90% of the honey produced in the Yucatan Peninsula is sold to Europe, United States, and Saudi Arabia, where it is highly valued due to its high quality determined by the floristic varieties of the region (Soto-Muciño et al., 2015). The rising demand for honey in these and other countries, has followed with malpractice in honey production, particularly in China. As the current demand outstrips its supply, various illegal practices have been reported such as dilution and mixing with corn or rice syrup (Ahmad & Khairatun, 2021; Sadiku et al., 2020). Thus, the success of apiculture might be dependent on a healthy export market, as it is vulnerable to China's push to monopolise global honey production.

Apiculture can constitute a sustainable alternative for the long-term wellbeing of this rural community, along with subsistence agriculture, and ranching on a small scale. A diversification of livelihoods in Cx has the potential to make rural families less vulnerable to economic instability, by ensuring an income in critical times of drought and failing crops. At the same time, collaborating with ranchers to introduce environmentally friendly activities can support conservation efforts (Gueye, 2018). Due to the closeness of this community to the core zone of the CBR, this village can further benefit from forest biodiversity.

4.6. Conclusion

Rising environmental and socioeconomic challenges are threatening the wellbeing of many farmers and their families in the CBR. Livelihood diversification has been an important adaptation strategy of local inhabitants since the modern colonization of the region in the 1980s (Gurri-García, 2018). This strategy resulted in integrated agricultural-forest mosaics which allowed a multifunctional landscape to develop that still sustains the cultivation of rainfed crops, ranching, beekeeping, hunting, and other livelihoods in the area (Porter-Bolland et al., 2006; O'Farrell & Anderson 2010; Schmook et al., 2013), without necessarily affecting the integrity of the forest. However, increasing climate change impacts and other societal challenges are changing the dynamics of the CBR's ejidos and the forests.

Transformative changes in the personal sphere are the necessary first step for the long-term wellbeing of rural communities in the CBR, towards the adoption of more sustainable and resilient livelihoods at a household and ejido level. The livelihoods and wellbeing of the very deprived rural communities of the CBR are considered highly vulnerable to climate and regional socioeconomic changes (Alayón-Gamboa & Ku-Vera, 2011; Dobler-Morales et al., 2021). Thus, national and local governments have recognized the need for economic development in the region (PND, 2019; PED, 2021). However, the vast forest and its associated biodiversities, are rarely considered as an asset or opportunity for increase resilience, income, and wellbeing as forest is generally considered a deterrent to economic development. Changes in the political sphere are further needed to support the conservation and sustainable development of the region and the distribution and growth of honey production and other potential sustainable livelihoods.

Apiculture can potentially provide farmers in Cx with a more lucrative income and, at the same time, a sustainable alternative addressing the four main elements of wellbeing: 1) basic human needs by providing alternative employment to rural farmers; 2) economic needs by providing income and economic diversity, 3) environmental needs by preserving the ecosystem function and the provision of associated NCP, whilst reducing drivers of change (e.g., deforestation and fragmentation); and subjective happiness by fostering access to nature, sense of place, and social relationships and community vitality (Summers et al., 2012).

Farmers could potentially switch partially or fully from a livelihood with low profit, reliance on remittances and government subsidies, and negative environmental impact, to one with higher profit, independence, and positive environmental impact. Ranchers could keep livestock in a small scale as capital insurance rather than source of income. This can potentially prevent further deforestation of the forests in the CBR. Furthermore, a switch from ranching to honey production directly addresses the issue that the most impoverished communities tend to be those deepest in the forest, where their ability to convert forest to pasture or other farmland is hampered by environmental protection regulations, and expenses are highest for protecting livestock from depredation by wild predators. Switching to honey turns these disadvantages into advantages because a protected forest has higher floral biodiversity from which to make better quality honey. It also allows social inclusion and equity as women can form part of these enterprises. In the Calakmul context, honey production has the potential to bring transformative changes to the economic, social, and environmental dynamics of the area for the wellbeing of its inhabitants.

Chapter 5: General Discussion

Can deprived human societies benefit economically from nature and can nature improve their broader wellbeing? Can local-scale transformative changes contribute to address global challenges? It is widely recognized that biodiversity underpins human wellbeing (Diaz et al., 2006). However, the direct relationship between these two variables is often conceptualized in a theoretical way, whilst in practice, nature is often considered a barrier for economic development (Duran et al., 2015). Currently, little is known about the role that biodiversity plays for the wellbeing of different human groups living in and around tropical forests, and on how they conceive wellbeing in relation to their natural resources and in face of current environmental and societal challenges, such as climate change.

The links between biodiversity, NCP, and human wellbeing, along with institutions and governance in the context of anthropogenic drivers, were described in different chapters. Chapter 2 showed that hunting of wild vertebrates is still a widespread and frequent cultural practice in tropical forests, which supplements people's diets whilst also providing crop protection, recreation, and/or income. However, climate change is currently impacting this practice. This combined with the high frequency of overexploitation of wildlife are likely to threaten the long-term viability of mammal populations in the forest. Chapter 3 went on to demonstrate that climate-change impacts are further threatening food security of isolated rural communities through loss and damage of subsistence livelihoods, such as hunting and arable farming. Lastly, Chapter 4 showed that climate impacts on arable farming are further risking the conservation of the forest as rural communities expand ranching in response to climate change-related crop failures. This chapter also showed that organic honey production, a practice that benefits from biodiversity, works as a sustainable and resilient livelihood, which enhances the wellbeing of these communities by providing high economic profits whilst maintaining forest cover.

This general discussion is partitioned into four sections. Sections 1 and 2 present an analytical and conceptual discussion of the thesis, respectively. In section 3, I attempt to provide a synthesis of the results from these chapters in terms of their conservation and societal values in the CBR and on a wider scale, when relevant. The final section 4 provides evidence-based recommendations for local and regional stakeholders, including ejidos and their authorities, municipal and federal governments, protected area managers, honey producer associations, local NGOs, and academics, along with final considerations and a general conclusion. These recommendations can potentially support the wellbeing of communities and the vitality of the natural resources of the CBR, contributing to transformative changes from local to global scales.

5.1. Analytical discussion

In this thesis I have provided empirical evidence on the benefits that biodiversity provides for of the wellbeing. Integrating different frameworks allowed a broader understanding of the links between people and nature, whilst focusing on people's wellbeing in the context of climate risks. In this context, the SES framework allowed a broader understanding of the interactions between both socioeconomic and natural elements, and the links with different actors and governance systems. At the same time, the IPBES framework allowed an analysis on how different material, non-material, and regulating NCP support to different degrees the elements of human wellbeing (basic human needs, economic and environmental needs, and subjective happiness), resulting in a wider understanding of the links between biodiversity and human wellbeing through NCP, which are particularly strong for human communities living in the world's relatively well-preserved tropical forests This research showed that isolated human communities living in forested areas rely directly on biodiversity for economic and food security, along with cultural and personal wellbeing. The integration of different frameworks further allowed for identifying elements of transformative change needed for long-term sustainability and resilience and those catalysed by this work, based on the framework proposed by Palomo et al. (2021).

Lastly, considering different elements of wellbeing, beyond economic needs was highly important for this work, as it allowed identifying wider values and needs of rural and indigenous communities and relating these to biodiversity and NCP in a wider scope. Qualitative data allowed to recognize how rural and indigenous peoples conceptualise wellbeing from their own perspectives and to set their own wellbeing priorities (Tsuji et al., 2023).

5.2. Conceptual discussion

Climate change is affecting the livelihoods, food security, and overall wellbeing of rural communities. This study showed that the magnitude of climate hazards and the severity of their impacts on different livelihoods, are changing the dynamics of SES, affecting the resilience of rural communities. Resilience was defined as the system's ability to adapt or transform in the face of change, particularly unexpected change, in ways that continue to support human wellbeing (Chapin et al. 2010, Biggs et al. 2015). The ability to adapt of the rural communities under study was limited due to the severe impacts of climate change on both social and ecological systems. Thus, transformational adaptation measures are needed to cope with current conditions in the SES (Lonsdale et al., 2015).

This research showed different elements for transformative change towards sustainability and resilience. This study showed that natures' values and knowledge types influence transformative changes at a personal sphere (Palomo et al., 2021). For example, hunters' values on nature along with their traditional ecological knowledge can play a key role in adopting sustainable practices in face of climate change. This study also contributed to triggering changes in ranchers' positive values of nature and in the political sphere of transformation (e.g., though capacity building and knowledge exchange in honey production as a first step to transform ranchers' values of nature). It also identified the need of change in the political and practical spheres, through community engagement and local regulatory instruments (e.g., regulating hunting and adopting more sustainable practices for reducing pressures on the ecosystem and wild populations and the need of financial instruments for the uptake of honey production).

In the context of transformative changes, honey production provides an opportunity for improving human wellbeing through biodiversity as a NbS to climate change adaptation (Seddon et al., 2019). Although this activity was not considered as a climate change adaptation strategy by local communities, this research shows it has the potential to enhance human wellbeing and nature, assessed under the IPBES framework (Diaz et al., 2015; see Figure 1.3.) in the context of climate change. This practice supports different aspects of human wellbeing, provides income during in times of drought, whilst maintaining ecosystem function and the provision of NCP, including those relevant for food security as wild game. At the same time, this activity can promote positives values to nature and the maintenance NCP from an individual to regional levels, influencing institutions and governance systems. At the same time, it allows for other anthropogenic assets (e.g., arable farming practices, livestock at a small scale, and other) to coexist and complement economic benefits, whilst reducing pressures in the ecosystem (e.g., limiting livestock ranching to a small-scale to provide income in times of need). Lastly, this practice farmers to cope with climate change (anthropogenic driver) and minimises the sensitivity of ecosystems by reducing the pressures affecting ecosystem function (deforestation and over-exploitation, Seddon et al., 2019).

Additionally, this practice provides can act as a NbS to climate change adaptation in the context of SES. Honey production can be considered a NbS as is aligned with the eight principles proposed by (Cohen-Shacham et al., 2019). Honey production embraces nature conservation and maintains cultural and biological diversity over time, as honey producers benefit from well-preserved forests, whilst being complementary to and benefiting from conservation across a biosphere reserve at a landscape level (principle 1 & 5). Honey production can be implemented in an integrated manner with other solutions to climate change and poverty reduction (e.g., construction of water containers for wild fauna and agricultural activities; principle 2). At the same time, this activity is determined by site-specific natural and cultural contexts and considers local and scientific knowledge. It requires evidence from a combination of science and local ecological knowledge posed by local honey producers (principle 3). Adopting apiculture as an alternative livelihood also produces societal benefits and income generation in a fair and equitable way in a manner, promoting the participation of women in male dominated practices, whilst providing benefits from individual to regional scales (principle 4). Additionally, honey production is relevant and can be upscaled at a regional level as it is already a common practice at a regional level (principle 6), whilst providing win-win opportunities for long-term economic benefit and nature conservation (principle 7). Furthermore, honey production has been part of the livelihood diversification strategies supported by protected areas. In the context of climate change, it has the potential to be included in local policy design and measures of action (principle 8).
In this sense, apiculture provides an alternative for climate adaptation and a long-term sustainable livelihood. This activity supports the present needs of a population, ensuring the wellbeing of humans and nature in a SES, and without compromising the ability of future generations to meet their own needs. It provides economic viability, social equity, ecological integrity, and resilience (Clark & McGillivray, 2007; Matson et al., 2016). However, this study showed that NbS might not be enough to cope with the impacts of the climate extremes in the region and need to be complemented with other actions that support the resilience of the SES to climate changes.

5.3. Livelihood sustainability

The main outcomes of Chapter 2 included an assessment of the hunting and wild game consumption frequencies in the CBR, along with a detailed description of hunting practices and the motivations and factors that drive hunting and game consumption in villages with different environmental, socioeconomic, and cultural features. Results showed that hunting and wild game consumption are frequent in the CBR despite the level of deprivation, ethnicity, and location of the villages, as this practice is deeply rooted the cultures of these communities. This study also showed that hunting not only provides food for hunters and their families, but also provides ecological knowledge, recreation, crop protection and additional income. All these benefits obtained from hunting are at risk due to accelerating climate impacts over the last decade, which are modifying hunting practices and affecting the game availability in the forest. Additionally, the high hunting and game consumption frequencies enumerated in this study suggest increasing human pressures on the wild mammal populations. However, interviews with hunters and community leaders showed that these communities, which own and manage the communal forests in the buffer zone of the CBR, lack community-based sustainable practices for hunting and have poor regulation of this activity. The awareness of elder hunters of the risks that unsustainable hunting and climate change pose to the long-term maintenance of this practice suggest that these communities, in their roles as custodians of communal forests, are willing to manage the wildlife resources within their forests. However, to operationalise management, they currently lack a centralised monitoring of hunting frequencies and game population densities.

Chapter 3 described how rural communities in the CBR perceive climate-related risks to their subsistence livelihoods of arable farming and hunting. This chapter built on the findings of Chapter 2 in relation to hunting and underpinned the findings of Chapter 4 on climate-impacts on arable farming. Interviews showed that multiple interacting climatic and non-climatic stressors affect the vulnerability of rural livelihoods. Villagers described their perceptions of climate changes that have occurred in the area during the last decades. Their views were aligned with local and regional climate changes described in scientific studies (Mardero et al., 2020; De la Barreda et al., 2020), demonstrating that rural communities possess valuable knowledge of the environmental conditions in the areas they inhabit and interact with daily. Discussions with the communities showed that villagers perceived themselves as highly vulnerable to climate risks. Moreover, farmers have responded to the changing climate in different ways, yet most of these actions have not sufficed to reduce climate risks. Although, villagers relied on resilient framing strategies, such as the milpa, and on other sources of meat for protein intake, the increasing and interacting pressures from climate and non-climate stressors, along with their reduced adaptive capacity, are pushing the CBR's villagers to the limits to adaptation. In face of increasing climate change impacts projected from global to regional scales to 2050 (IPCC, 2022), farmer-hunters in the region might rely on more radical yet integral strategies to adapt to the changing conditions. Understanding villagers' perceptions, views, and preferred development pathways is crucial for building long-term adaptation strategies, ejidos resilience, and wellbeing. In this context, nature-based solutions are well positioned to provide a sustainable alternative for livelihood diversification and adaptation opportunities.

Chapter 4 showed that honey production is a sustainable and more resilient livelihood option than agriculture. Thus, it provides a potential solution to economic deprivation and biodiversity loss in the region. The economic and environmental cost-benefit analysis in this chapter revealed that livestock ranching required many financial, natural, and human resources which are scarce in the CBR. Moreover, the subsequent conversion of forest to pasture further exacerbates regional precipitation extremes and depletes wild game in the forest that supplement the diet of these communities. Individuals were finding economic security by other means, through honey production from apiaries within the forest. They saw benefits to forest biodiversity in raising the quality of their honey, and strength in numbers through increasing the size of their honey-producer community. However, results from the focus group discussions performed in this study showed that ranchers perceived more disadvantages than advantages to apiculture, despite having received training in this activity. Established honey producers also described challenges that this activity has in the region, which need attention from various stakeholders locally and regionally. Despite the challenges, honey production still has the potential to act as a profitable livelihood for Calakmul farmers, as it supports, and is supported by, local biodiversity and regional and national markets.

Global challenges such as climate change and biodiversity loss require transformative changes in societies, from local to global scales (IPBES, 2019). The area-specific scope of knowledge that we have generated in this study will facilitate opportunities for local-scale nature-based solutions to the global-scale challenges of climate change. This study contributes directly to understand how people in the CBR perceive wellbeing, and the pathways they envisage to achieving economic and food security for their descendants. The information obtained in this study can support the villages in the CBR to adopt more sustainable, resilient, or profitable practices and livelihoods. This study, as many others, aims to make a fundamental contribution to the bulk of understanding necessary to address the global-scale issue of living sustainably with nature (Madden, 2004; Díaz et al. 2015). Additionally, it can contribute to finding ways of mitigating the two biggest drivers of biodiversity loss: land conversion and overexploitation (Hoang & Kanemoto, 2021; Gardner et al., 2019), through the implementation of sustainable practices capable of reducing levels of deforestation and defaunation, whilst supporting climate change adaptation and mitigation (Ontl et al., 2020), and food security (Glamann et al., 2017).

Climate change and biodiversity loss are mutually reinforcing challenges for humanity. Global temperatures are increasing and regional to local climates are becoming more extreme, all to the detriment of biodiversity, and global, regional, and local biodiversity is declining, which itself exacerbates climate change (Jing et al., 2022). However, the links between these challenges, also present an opportunity for a double benefit, of stabilising climate by restoring biodiversity and ecosystem functions, which provide nature's contributions to people and support human wellbeing (Pörtner et al., 2021).In this context, the Mexican Government has developed a strong framework for climate-change adaptation, with a vision for nature-based adaptation, which encompasses communities and their infrastructure and ecosystems, all protected from climate extremes and resilient to climate change (SEMARNAT & INECC, 2015). This vision is reflected in the Nationally Determined Contributions (SEMARNAT & INECC, 2015; 2020; 2022) to the United Nations Framework Convention on Climate Change. Mexico's plan for realising this vision involves, amongst other actions, the integration of nature-based solutions in national and local policies for adapting to and mitigating climate change impacts. Examples of nature-based solutions included in these plans include reforesting watersheds, preserving, and restoring ecosystems, and increasing the connectivity of protected areas with equitable participation of the population (SEMARNAT & INECC, 2020). These actions have the potential to positively contribute not only towards adapting to climate change but also towards guaranteeing food and water security and other benefits obtained through nature. However, big challenges remain for the government and for different stakeholders in Mexico for adopting, implementing, and scaling-up nature-based solutions in the country (Pérez & Becerril, 2023).

The effects of climate change and biodiversity loss are disproportionately affecting the poorest communities in Mexico (Álvarez, 2016; Ochoa & Ayvar, 2015), as evidenced in this thesis. Over the last ten years, climate change has severely affected the Calakmul region, negatively impacting its wildlife and the livelihoods of the deprived ejidos living in these forests. This PhD project aimed not only to generate knowledge on how communities perceive and live these issues, but also to facilitate the uptake of sustainable actions on the ground to enhance nature's contributions to people, which helps to improve ecosystem function, and nature's capacity to sequester carbon. Nature-based solutions create options for addressing societal challenges through transformative changes (Girardin et al., 2021).

Transformative changes at local scales can lead to a harmonious alignment with nature globally. Many small actions on the ground, all motivated by a shared vision for wellbeing, can achieve the transformative change needed to "bend the curve" on biodiversity loss, and mitigate climate change (Leclère et al., 2020). However, agreement on the shared vision still requires clarity and consensus from global to local scale. All the United Nations-led initiatives to address biodiversity loss and climate change are underpinned by the same vision of "living in harmony with nature". This notion dates to the 1982 World Charter for Nature, which recognised nature's intrinsic value, and established the imperative of keeping human activities within Earth's limits. In the face of ongoing human population growth, however, we cannot realistically aspire to a state of harmony, and can only strive to live in harmonious alignment with nature's cycles and processes (Doncaster, 2022, pers. comm). This reading of the United Nations' vision is focused on the pathway that sustains wellbeing, instead on the artificial idea of arrival at a finite state of wellbeing.

Transformative change means a fundamental change in our aspirations for wellbeing, which includes valuing, restoring, and maintaining natural capital (Diaz et al., 2019b). Natural capital underpins the four other capitals that drive prosperity: human, social, manufactured, and financial. Currently, human societies lack any agreement on how to value natural capital. This has been eloquently explained by Dasgupta (2021) in his observation that nature's qualities of *mobility*, *silence,* and *invisibility* defy economic measurement, exposing it to unregulated human activities, and underpinning the worldwide collective failure to engage sustainably with the natural environment. Dasgupta (2021) proposed that a true understanding of the value of natural capital requires understanding that economies are embedded within nature, not external to it.

5.4. Recommendations

At a local scale, the CBR has the potential to sustain its local and small-scale economies derived from nature. Its vast continuous forest and natural resources, its relatively low human population densities, and the close relationship between local communities and nature, could potentially allow a sustainable and resilient development. However, political interests have previously acted as a barrier for achieving sustainable development in the region. In the last decade, international institutions in collaboration with the former municipal administration, created the Municipal Development Program of Calakmul with a vision of achieving sustainability by 2040. The aim of this programme was to develop Calakmul as the first sustainable municipality in the country, through strategies that integrated human wellbeing and the conservation of nature (Araujo-Monroy, 2014). However, as the government administrations changed, the plans to implement this programme became mired in conflicting political interests (Zuniga-Morales, 2022 pers. comm).

This research has shown that the rural communities in the CBR value the different NCP provided by their communal forests; yet these communities faced a more pressing issue: deprivation enhanced by climate change impacts on their livelihoods, economies, and food and water security. In this context, local hunters found themselves overexploiting the natural resources of the forests for food (and other purposes). Capacity building based on knowledge of wild species behaviour and ecologies can support farmers to adopt more sustainable practices, and support ejidos to self-monitor the natural resources available in their communal forests. This shared knowledge can work as a first step towards sustainable practices in the CBR. Additionally, it can improve the governance in isolated ejidos and strengthen their role of custodians of their communal forests to sustainably self-manage their wildlife resources. Examples from community-based monitoring in the Arctic have demonstrated that community wildlife monitoring, co-created by different stakeholders provides rich opportunities for benefitting communities, managers, and external researchers, whilst increasing institutional resilience (Hovel et al., 2020; Brook et al., 2009). Ejidos in the CBR can benefit from the support of academics and local NGOs for continuous wildlife monitoring. This research has also shown that smallholder farmers perceived that ranching could provide a profitable alternative to climate-vulnerable arable farming. The subsequent conversion of forest to pasture exacerbates climate extremes and depletes wild game in the forest, hunted by these communities. This study showed that apiculture, in contrast, can work as a sustainable and resilient livelihood for forest communities to support local economies, whilst preserving ecosystems and NCP. Further benefits from apiculture include the alignment of this activity with the protected-area regulations and goals, which can improve the relationships between protected area managers and the rural communities. However, different local and regional constraints hamper the full development of this activity at larger scales. Locally, honey producers struggle to access financial support to grow their enterprises, particularly in the most isolated communities. We recommend that the municipality and CBR authorities make available subsidies for honey production accessible to the most isolated communities in the southern part of the reserve. Apart from financial support, these villages would also benefit from further training in honey production and from technical support for different administrative matters, including guidance on the processes for legally registering as a cooperative, guidance on the process for organic certifications, and honey distribution. It is important to consider that many people in this communities are illiterate and/or unfamiliar to administrative processes. Experienced honey producers would benefit from financial support and training for packing and branding their honey products and for obtaining and processing honey by-products that are demanded locally and regionally, such as bee pollen, propolis, bee bread, royal jelly, and beeswax.

Apiculture is a growing rural economy in many parts of the world, particularly Africa, where it has proven capable of benefitting people and nature (Moinde, 2016; Musinguzi et al., 2018). In 2017, Mexico was considered the third largest honey exporter in the world after China and Argentina (Güemez-Ricalde, 2017). In the country, Campeche is one of the main producers that contribute to exports (Martínez-Puc et al., 2018), so more honey in Calakmul has the potential to benefit national sales and local ecosystems. These regional and national conditions, along with the rich and preserved ecosystems in the region, make apiculture a suitable livelihood, both economically and ecologically in the CBR (Acopa & Boege, 1998; Martínez-Puc et al., 2018). It is important to highlight that even though this activity has functioned as a sustainable livelihood worldwide, its profitability and success over time will depend on the social and economic conditions of the local context. Thus, honey production represents a solution to environmental and economic challenges for the Calakmul region and wider Yucatan Peninsula due to the regional market and related market chains available (Zamudio, 2017).

In the CBR, apiculture has many advantages over ranching for subsistence farmers: the more people in a honey cooperative the better, because they bring economies of scale in the purchase and maintenance of expensive equipment, and the sale of products, whereas more ranchers only increase competition amongst themselves, driving down profit.

Furthermore, this activity has the potential to trigger path shifting and restructuring transformative changes in the communities towards more sustainable livelihoods and inclusive societies (O'Brien & Sygna, 2013). Honey production can bring path shifting changes by reducing deforestation and land degradation from growing cattle ranching, whilst restructuring rural livelihoods and ecosystems. Additionally, it has the potential to restructure communities' social dynamics allowing women to participate in income-generating activities. Examples from Vietnam showed that adopting honey production as an alternative livelihood allowed women to expand their social networks and broaden their horizons and scope of influence, sustaining the transformation process at household (Devkota, 2020).

In the CBR, honey production presents an opportunity for women to contribute to household economics in a way that truly changes the dynamic in these communities in terms of gender inequalities, as has been proven in other parts of the world (Serra & Davidson, 2021; Olana & Demrew, 2018). Supporting the organisation and establishment of women-led honey production cooperatives in the CBR would increase the interests and participation of local women in this activity.

5.4.1. Final considerations

This research project provides an example of the guiding principle of transformative change: think *globally*, act *locally* (Chan, 2019), for local engagement with a global vision, based on local and scientific knowledge. Additionally, livelihood diversification to organic honey production can work as a NbS to climate change adaptation with potential for upscaling to regional level. If apiculture takes off amongst the communities targeted in this study, it could spread to others, bringing regional benefits, for both people and nature, allowing for system-wide changes (Schreuder & Horlings, 2022). However, success relies on people aligning their individual interests (transformative changes in the personal and practical spheres) with the best interests of their community and on external factors shaping regional and global market dynamics (transformative changes in the political sphere; O'Brien & Sygna, 2013; Palomo et al., 2021). In the same context, sustainable hunting practices and the implementation of self-imposed regulations in the studied ejidos can motivate others in the CBR to sustainably manage their resources.

Successful examples of local actions for global changes include the indigenous Green Belt Movement started by Wangari Maathai in Kenya in 1977. She planted trees in the desert aiming to combat poverty, which became a forest belt that now extends across the entire continent. This movement inspired the United Nations Billion Tree Campaign in 2006, which grew into the Trillion Tree Initiative at the 2020 World Economic Forum, considered a multinational nature-based solution to the problem of greenhouse gases (Seddon et al., 2020; Mori, 2020).

Biodiversity loss and climate change are global-scale problems that need internationally coordinated efforts, grounded in sound biodiversity science (Seddon et al., 2019). National governments must commit to actions that follow from the United Nations Paris Agreement to slow global warming, and the United Nations goals for sustainable development (United Nations, 2023). However, local-scale and bottom-up initiatives need actioning within a framework of top-down regulations. Transformative change can be self-reinforcing only when it is carried out with evidence of the benefits for people and nature. Lifestyle choices are a shared responsibility of individuals, to self-regulate demand for, and governments, to regulate supply of, unsustainable practices (Wynes & Nicholas, 2017). We can all contribute to preserving nature and to reducing climate change. The rural communities of the CBR clearly understand the wider consequences of their individual efforts to sustain their livelihoods; they are hampered in initiating actions to transform their prospects by dwindling resources for adapting to climate change. The survival of these communities over coming decades depends not only on individual initiatives such as apiculture to preserve the forests, and government assistance to address water shortages that imperil food security, but ultimately and urgently on international actions to stop the global climate warming that fuels local droughts.

5.4.2. Conclusions

Can deprived human societies benefit economically from nature and can nature improve their broader wellbeing? Yes. This study showed that for the CBR villagers, the best opportunities for a resilient and profitable future in the CBR are provided by nature. The vast communal forests represent the best asset of the CBR ejidos, as they can provide sufficient food, water, and economic profit for current and future generations, if their ecological integrity is preserved through a harmonious alignment between people and nature.

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Appendix 1: Questionnaires on hunting and wild game consumption in the Calakmul Biosphere Reserve

Questionnaire for male hunters in the CBR

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____
Cristina Argudin Violante
Researcher in charge of study

1. How long have you lived in this community?
2. Where are you originally from?
3. To your knowledge, is there hunting in your village and/or its surrounding natural areas?
   a. Yes.
   b. No.
4. Do you hunt regularly?
   a. Yes
   b. No
   c. Prefer not to say
5. If yes, how often do you hunt?
   a. _______ times a week.
   b. _______ times a month.
   c. Other.
6. How many people hunt in your village?
7. Where do these people hunt the most?
   a. Inside their properties (ejido).
   b. Inside the properties of family and friends.
   c. Inside natural reserve areas.
   d. Everywhere.
   e. Do not know/prefer not to say.
8. Which are your preferred prey species?
9. Are these species always available?
10. If not, do you catch any alternative prey?
11. What is the main motivation of hunting?

   a. Food
   b. Commercial
   c. Other. If other, explain.

12. If a., how many people feed from the prey?
    a. Family. How many individuals?
    b. People involved in hunting event.
    c. Community.
    d. Other.
13. For how long have you hunt?
14. In which area do you prefer to hunt?
    a. Easy access
    b. Prey availability
    c. Other
15. Why do you prefer this/these area/s?
16. How many km do you have to walk in order to find prey?
17. How much time do you spend in hunting?
18. How do you catch game (methods)?
19. Have you noticed any changes in prey abundance or availability during the last 5 or 10 years?
20. If yes, which species are less abundant?

Questionnaire on game consumption for women

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____
Cristina Argudin Violante
Researcher in charge of study

1. How long have you lived in this community?
2. Where are you originally from?
3. To your knowledge, is there hunting in your village and/or its surrounding natural areas?
   a. Yes.
   b. No.
   c. Prefer not to say.
4. Does your husband or sons hunt regularly?
   a. Yes
   b. No
   c. Prefer not to say.
5. If yes, how often do they hunt?
6. How many people hunt in your village?
   a. _________.
   b. Do not know/prefer not to say.
7. Where do these people hunt the most?
   a. Inside their properties (ejido).
   b. Inside the properties of family and friends.
   c. Inside natural reserve areas.
   d. Everywhere.
   e. Do not know/prefer not to say.
8. How often do you cook/eat wild meat?
9. Do you cook wild meat for any special occasion (e.g., birthday, religious celebration, other)?
10. Which are your preferred prey species?
11. How many people feed from these species?
12. Have you noticed any changes in wild meat consumption during the last 5-10 years?

Appendix 2: Participant Information Sheets for all surveys of this study

Participant Information Sheet used for surveys on hunting practices (Chapter 2)

Study Title: Questionnaire on hunting practices in the Calakmul Biosphere Reserve, Mexico

Researcher: Cristina Argudin Violante
ERGO number: 55051

Please read this information carefully before deciding to take part in this research. It is up to you to decide whether or not to take part. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
Humans obtain multiple benefits from ecosystems in the form of ecosystem services. These services are the foundation of human wellbeing. Unsustainable human activities threaten the health of ecosystem and therefore the provision of ecosystem services and the wellbeing of people that live and depend on ecosystems. This PhD project, developed in the University of Southampton, aims to improve the wellbeing of the rural communities living in the Calakmul area, through the conservation of the natural resources of which they have stewardship. This project aims to evaluate and understand the hunting frequencies, patterns and motivations for hunting in three communities of the CBR.

Why have I been asked to participate?
You have been asked to participate because you are an active member of this community where hunting is a common practice. We want to understand the frequency and motivations for this activity, which is of interest for this study.

What will happen to me if I take part?
You will answer a questionnaire, which will take 30 minutes to complete. You will be asked to answer questions about the hunting practice and motivations behind this activity. The interview will be transcribed on paper by the researcher (Cristina Argudin). After the questionnaire is applied, you are able to make any questions related to the subjects of the interview.

Are there any benefits in my taking part?
With the completion of this questionnaire, you will be contributing to our efforts to understand the hunting patterns in the CBR. With this, along with the camera-trap surveys of wildlife that we are performing in the area, we will be able to assess the impacts of hunting and stat building on sustainable practices that can bring long-term benefits for the wellbeing of the people in the community, particularly for food security.

Are there any risks involved?
There might be a risk of discomfort or anxiety while asking some questions relating to hunting. If you feel distressed or anxious at any moment, please let me know. If you are not willing to talk about the subject of interest of this study, you can let me know and we can finish the interview at any moment.

Will my participation be confidential?
All your answers will be treated in confidence. No information will be asked about your personal identity or the location of your domicile or workplace. The "Participant number" will be used to keep record and distinguish questionnaires between each other. You should know

that anyone will have access to these information, except my direct supervisor. If he access your information, this will be only for research purposes. After the transcription of the information, files containing the interview will be teared up.

What should I do if I want to take part?
If you want to take part in the study, you should let me know at the moment. Verbal consent will be asked at the beginning of the interview. If you want to take part in the study but you are not available at the moment, we will set a convenient date, time and location to perform the interview.

What happens if I change my mind?
You have the right to withdraw the interview at any time. In this case, you should let me know and the interview will be stopped as soon as you request it. In this case, the paper file will be deleted at this moment.

What will happen to the results of the research?
The results of the research will be shared with the community at different stages. As well, the results of these interviews will be used to assess which practices help to ensure the long-term wellbeing of the people and the natural resources of the community.
Results will also be used for academic purposes. They will be presented at professional conferences and they will be published in scientific journals of Biological Sciences, Ecology and Conservation.

Where can I get more information?
If you require more information about the study or if you have any concern regarding the project, you are welcome to contact Pronatura Peninsula de Yucatan.

What happens if something goes wrong?
If you have any complaint about the interview, you should contact the Research Governance Office of the University of Southampton at the following email address: rgoinfo@soton.ac.uk

Thank you.
Thank you for taking the time to listen to the information sheet and considering taking part in the research.

Participant Information Sheet used for surveys on villagers' perceptions of climate risks (Chapter 3)

Study Title: Semi-structured interviews on climate change and food security in the Calakmul Biosphere Reserve, Mexico

Researcher: Cristina Argudin Violante
ERGO number: 71885

Please read this information carefully before deciding to take part in this research. It is up to you to decide whether or not to take part. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
Climate change is affecting the livelihoods of many rural communities around the world. This project, developed in the University of Southampton, aims to determine the vulnerability of hunting to climate change, related to food security of the communities of the Calakmul Biosphere Reserve (CBR). The study has two phases. During phase 1, I will conduct interviews to assess the vulnerability of hunting to climate change, looking into how specific changes in climate have affected this activity (impacts) and how dependent the communities in the CBR are to game for food security (sensitivity); I will also ask about how the communities have coped with these changes in climate and what alternative options there are for protein intake (adaptative capacity). Phase 2 will take place after doing the interviews in two communities. I will run two workshops with the interviewees (including the communities' authorities who are also hunters and will also be interviewed) to validate the results at a community level, to integrate traditional knowledge, and to design together context-specific best practices for hunting in a changing climate.

Why have I been asked to participate?
I am currently developing phase 1 of the project. You have been asked to participate in because you are an active member of this community where hunting is a common practice. We want to understand how climate change is affecting this activity and its impact on the food security of the area, which are of interest for this study.

What will happen to me if I take part?
You will participate in a semi-structured interview, which will take around 30 minutes. You will be asked to answer questions about the hunting practice and the changes in climate that you have observed. The interview will be transcribed on paper by the researcher (Cristina Argudin). After the interview, you will be able to make any questions related to the subjects of the interview.

If you decide to take part of this interview, you might be approached later by myself to invite you to take part in the phase 2 of this project which involves participating in a couple of workshops to assess the vulnerability of the hunting practices with implications on food security at a community level.

Are there any benefits in my taking part?
With the completion of this questionnaire, you will be contributing to our efforts to understand the impacts of climate change on the food security of the CBR. The information obtained in this interview will feed future workshops for designing best practices for hunting based on the communities' knowledge and needs.

Are there any risks involved?
There might be a risk of discomfort or anxiety while asking some questions relating to hunting. If you feel distressed or anxious at any moment, please let me know. If you are not willing to talk about the subject of interest of this study, you can let me know and we can finish the interview at any moment.

Will my participation be confidential?
All your answers will be treated in confidence. No information will be asked about your personal identity or the location of your domicile or workplace. The "Participant number" will be used to keep record and distinguish questionnaires between each other. You should know that no one, except from me and my direct supervisor will have access to this information. If he accesses your information, this will be only for research purposes. After the transcription of the information, files containing the interview will be deleted or destroyed through confidential waste.

What should I do if I want to take part?
If you want to take part in the study, you should let me know at the moment. Verbal consent will be asked at the beginning of the interview. If you want to take part in the study but you are not available at the moment, we will set a convenient date, time and location to perform the interview.

What happens if I change my mind?
You have the right to withdraw the interview at any time. In this case, you should let me know and the interview will be stopped as soon as you request it. In this case, the paper file will be deleted at this moment.

What will happen to the results of the research?
The results of the research will be shared with the community at different stages. Two workshops will take place after the interview phase, for the communities to validate the information and to design adaptation strategies considering best practices for hunting in a changing climate. The results of these interviews along with the workshops will support best practices that help to ensure the long-term wellbeing of the people and the natural resources of the community.

Results will also be used for academic purposes. They will be presented at professional conferences, and they will be published in scientific journals of Biological Sciences, Ecology, Anthropology and Conservation.

Where can I get more information?
If you require more information about the study or if you have any concern regarding the project, you are welcome to contact Pronatura Peninsula de Yucatan.

What happens if something goes wrong?
If you have any complaint about the interview, you should contact the Research Governance Office of the University of Southampton at the following email address: rgoinfo@soton.ac.uk

Thank you.
Thank you for taking the time to listen to the information sheet and considering taking part in the research.

Participant Information Sheet used on surveys with ranchers on land use in Calakmul (Chapter 4)

Study Title: Questionnaire survey of land use in Calakmul: newly and long-term established ranching activities.

Researcher: Cristina Argudin Violante
ERGO number: 48868

Please allow me to tell you the motivation for our research, why we are requesting your participation in a questionnaire survey, and why you might wish to give us your time for the interview. The following information should help you to decide whether or not you want to take part, but please feel free to ask further questions. If you are happy to participate, I will ask you to express your verbal consent.

What is the research about?
This questionnaire survey is one of several questionnaires that we are running in local communities, which form a major part of my PhD project at the University of Southampton UK. The project is being developed in collaboration with Operation Wallacea and Pronatura Peninsula de Yucatan. These organisations have been running sustainability projects in the area for many years. The questionnaire is the first stage in a two-part process, which will end next year with us bringing answers to questions that you may have of a specific or general nature related to sustainable land use in your area.

My project aims to improve the wellbeing of rural communities living in the Calakmul area through sustainable use of the natural resources of which they have stewardship. Humans obtain multiple benefits from ecosystems in the form of ecosystem services. These services, such as food, timber, water, climate regulation and ecotourism, are the foundation of human wellbeing. Unsustainable human activities threaten the health of ecosystems and therefore the provision of ecosystem services and the long-term wellbeing of people that live and depend on ecosystems. The questionnaires are designed to evaluate the economic costs and benefits of alternative forms of land use in the region, specifically ranching and honey production. This first year of the PhD project will also include survey estimates of jaguar and puma activity, to evaluate the costs and benefits of these felids to the local ecology and economy. Next year, I will assimilate the data acquired across all surveys, for the purpose of providing your community, and neighbouring communities, with the knowledge that you need to make informed decisions about current options for land use that will bring long-term benefits to you and your ecosystem.

Why have I been asked to participate?
You have been asked to participate because you are in the ranching business, which is a focus of this study.

What will happen to me if I take part?
You will answer a questionnaire, which will take 40 minutes to complete. I will ask you questions about the characteristics, incomes and expenses of ranching. In addition, I will ask about the management and practices of this activity. I will transcribe your answers on paper. After completion of the questionnaire, you will have an opportunity to ask any questions related to the subjects of the interview. I will assimilate all questions from interviews, and endeavour to provide answers during the next year of fieldwork.

Will my participation be confidential?
All of your answers will be treated in confidence. No information will be asked or recorded either about your personal identity, or about the location of your domicile or workplace other than the identity of the municipality. A "Participant number" will be recorded only to distinguish questionnaires between each other. It is important for you to understand that some questions will relate to your income and expenses. Your answers will be anonymous because we retain no information on your identity or location, and nobody will have access to

your answers except for my direct supervisor, Professor Patrick Doncaster at the University of Southampton and myself. We will use all of your answers only for the research purposes stated above. Paperwork created during the interview will be shredded after transcription of the information.

Are there any benefits in my taking part?
By contributing to this questionnaire, you will be contributing to our efforts to understand the economic and environmental costs and benefits of alternative forms of local land use. With the knowledge we gain from these surveys, we aim to help local communities in making informed decisions about the long-term benefits to wellbeing of their land-use choices.

Are there any risks involved?
There might be a risk of discomfort while asking about incomes, expenses and questions relating to economic issues. If you prefer not to talk about the incomes and expenses of the materials/activities involved in ranching, we would be happy instead to hear about the names of your suppliers or distributors, or the brands of your materials or products.

What should I do if I want to take part?
If you wish to take part in the study, please let me know now. Verbal consent will be asked at the beginning of the interview. If you wish to take part, but you are not available now, we will set a convenient date, time and location to perform the interview.

What happens if I change my mind?
You can withdraw from the interview at any time. The interview will be stopped as soon as you request it. In this event, I will immediately shred any paperwork related to the interview.

What will happen to the results of the research?
The analysis of collated data from the questionnaires will be shared with local communities at different stages. Shared results will include information summarising average economic costs and benefits of different types of land use, obtained from the collation of all surveys. Shared results will not involve singling out information from any one questionnaire. The analysis of collated data will also be used for academic purposes. It will be presented at professional conferences, and published in scientific journals of the environmental sciences.

Where can I get more information?
If you require more information about the study or if you have any concern regarding the project, you are welcome to contact Pronatura Peninsula de Yucatan with Antonio Lopez Cen at antoniolc@pronatura-ppy.org.mx, phone number 981 81 6 03 74.

What happens if something goes wrong?
If you have any complaint about the interview, you should contact the Research Governance Office of the University of Southampton at the following email address: rgoinfo@soton.ac.uk

Thank you.
Thank you for taking the time to listen to the information sheet and considering taking part in the research. Do you have any questions for me?

Participant Information Sheet used on surveys with honey producers on land use in Calakmul (Chapter 4)

Study Title: Questionnaire survey of land use in Calakmul: honey production.

Researcher: Cristina Argudin Violante
ERGO number: 48868

Please allow me to tell you the motivation for our research, why we are requesting your participation in a questionnaire survey, and why you might wish to give us your time for the interview. The following information should help you to decide whether or not you want to take part, but please feel free to ask further questions. If you are happy to participate, I will ask you to express your verbal consent.

What is the research about?
This questionnaire survey is one of several questionnaires that we are running in local communities, which form a major part of my PhD project at the University of Southampton UK. The project is being developed in collaboration with Operation Wallacea and Pronatura Peninsula de Yucatan. These organisations have been running sustainability projects in the area for many years. The questionnaire is the first stage in a two-part process, which will end next year with us bringing answers to questions that you may have of a specific or general nature related to sustainable land use in your area.

My project aims to improve the wellbeing of rural communities living in the Calakmul area through sustainable use of the natural resources of which they have stewardship. Humans obtain multiple benefits from ecosystems in the form of ecosystem services. These services, such as food, timber, water, climate regulation and ecotourism, are the foundation of human wellbeing. Unsustainable human activities threaten the health of ecosystems and therefore the provision of ecosystem services and the long-term wellbeing of people that live and depend on ecosystems. The questionnaires are designed to evaluate the economic costs and benefits of alternative forms of land use in the region, specifically ranching and honey production. This first year of the PhD project will also include survey estimates of jaguar and puma activity, to evaluate the costs and benefits of these felids to the local ecology and economy. Next year, I will assimilate the data acquired across all surveys, for the purpose of providing your community, and neighbouring communities, with the knowledge that you need to make informed decisions about current options for land use that will bring long-term benefits to you and your ecosystem.

Why have I been asked to participate?
You have been asked to participate because you are in the apiculture and honey production business, which is a focus of this study.

What will happen to me if I take part?
You will answer a questionnaire, which will take 40 minutes to complete. I will ask you questions about the characteristics, incomes and expenses of honey production. In addition, I will ask about the management and practices of this activity. I will transcribe your answers on paper. After completion of the questionnaire, you will have an opportunity to ask any questions related to the subjects of the interview. I will assimilate all questions from interviews, and endeavour to provide answers during the next year of fieldwork.

Will my participation be confidential?
All of your answers will be treated in confidence. No information will be asked or recorded either about your personal identity, or about the location of your domicile or workplace other than the identity of the municipality. A "Participant number" will be recorded only to distinguish questionnaires between each other. It is important for you to understand that some questions will relate to your income and expenses. Your answers will be anonymous because we retain no information on your identity or location, and nobody will have access to your answers except for myself and my direct supervisor, Professor Patrick Doncaster at the

University of Southampton. We will use all your answers only for the research purposes stated above. Paperwork created during the interview will be shredded after transcription of the information.

Are there any benefits in my taking part?
By contributing to this questionnaire, you will be contributing to our efforts to understand the economic and environmental costs and benefits of alternative forms of local land use. With the knowledge we gain from these surveys, we aim to help local communities in making informed decisions about the long-term benefits to wellbeing of their land-use choices.

Are there any risks involved?
There might be a risk of discomfort while asking about incomes, expenses and questions relating to economic issues. If you prefer not to talk about the incomes and expenses of the materials/activities involved in honey production, we would be happy instead to hear about the names of your suppliers or distributors, or the brands of your materials or products.

What should I do if I wish to take part?
If you wish to take part in the study, please let me know now. Verbal consent will be asked at the beginning of the interview. If you wish to take part, but you are not available now, we will set a convenient date, time and location to perform the interview.

What happens if I change my mind?
You can withdraw from the interview at any time. The interview will be stopped as soon as you request it. In this event, I will immediately shred any paperwork related to the interview.

What will happen to the results of the research?
The analysis of collated data from the questionnaires will be shared with local communities at different stages. Shared results will include information summarising average economic costs and benefits of different types of land use, obtained from the collation of all surveys. Shared results will not involve singling out information from any one questionnaire. The analysis of collated data will also be used for academic purposes. It will be presented at professional conferences, and published in scientific journals of the environmental sciences.

Where can I get more information?
If you require more information about the study or if you have any concern regarding the project, you are welcome to contact Pronatura Peninsula de Yucatan with Antonio Lopez Cen at antoniolc@pronatura-ppy.org.mx, phone number 981 81 6 03 74.

What happens if something goes wrong?
If you have any complaint about the interview, you should contact the Research Governance Office of the University of Southampton at the following email address: rgoinfo@soton.ac.uk

Thank you.
Thank you for taking the time to listen to the information sheet and considering taking part in the research. Do you have any questions for me?

Study Title: Questionnaire on hunting practices in the Calakmul Biosphere Reserve, Mexico

Researcher: Cristina Argudin Violante
ERGO number:

Please read this information carefully before deciding to take part in this research. It is up to you to decide whether or not to take part. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
Humans obtain multiple benefits from ecosystems in the form of ecosystem services. These services are the foundation of human wellbeing. Unsustainable human activities threaten the health of ecosystem and therefore the provision of ecosystem services and the wellbeing of

people that live and depend on ecosystems. This PhD project, developed in the University of Southampton, aims to improve the wellbeing of the rural communities living in the Calakmul area, through the conservation of the natural resources of which they have stewardship. This project aims to evaluate and understand the hunting frequencies, patterns and motivations for hunting in three communities of the CBR.

Why have I been asked to participate?
You have been asked to participate because you are an active member of this community where hunting is a common practice. We want to understand the frequency and motivations for this activity, which is of interest for this study.

What will happen to me if I take part?
You will answer a questionnaire, which will take 30-40 minutes to complete. You will be asked to answer questions about the hunting practice and motivations behind this activity. The interview will be transcribed on paper by the researcher (Cristina Argudin). After the questionnaire is applied, you are able to make any questions related to the subjects of the interview.

Are there any benefits in my taking part?
With the completion of this questionnaire, you will be contributing to our efforts to understand the hunting patterns in the CBR. With this, along with the camera-trap surveys of wildlife that we are performing in the area, we will be able to assess the impacts of hunting and stat building on sustainable practices that can bring long-term benefits for the wellbeing of the people in the community, particularly for food security.

Are there any risks involved?
There might be a risk of discomfort or anxiety while asking some questions relating to hunting. If you feel distressed or anxious at any moment, please let me know. If you are not willing to talk about the subject of interest of this study, you can let me know and we can finish the interview at any moment.

Will my participation be confidential?
All your answers will be treated in confidence. No information will be asked about your personal identity or the location of your domicile or workplace. The "Participant number" will be used to keep record and distinguish questionnaires between each other. You should know that anyone will have access to these information, except my direct supervisor. If he access your information, this will be only for research purposes. After the transcription of the information, files containing the interview will be teared up.

What should I do if I want to take part?
If you want to take part in the study, you should let me know at the moment. Verbal consent will be asked at the beginning of the interview. If you want to take part in the study but you are not available at the moment, we will set a convenient date, time and location to perform the interview.

What happens if I change my mind?
You have the right to withdraw the interview at any time. In this case, you should let me know and the interview will be stopped as soon as you request it. In this case, the paper file will be deleted at this moment.

What will happen to the results of the research?
The results of the research will be shared with the community at different stages. As well, the results of these interviews will be used to assess which practices help to ensure the long-term wellbeing of the people and the natural resources of the community.
Results will also be used for academic purposes. They will be presented at professional conferences and they will be published in scientific journals of Biological Sciences, Ecology and Conservation.

Where can I get more information?

If you require more information about the study or if you have any concern regarding the project, you are welcome to contact Pronatura Peninsula de Yucatan.

What happens if something goes wrong?
If you have any complaint about the interview, you should contact the Research Governance Office of the University of Southampton at the following email address: rgoinfo@soton.ac.uk

Thank you.
Thank you for taking the time to listen to the information sheet and considering taking part in the research.

Appendix 3 Pictures of training provided to farmer-hunters in the CBR

Figure A4.1. Camera-trap and acoustic device (Audiomoth), used for wildlife monitoring in the CBR.

Figure A4.2. Field trainng for farmer-hunters in the CBR for monitoitn wildlife with camera-traps and acoustic sensors.

Figure A4.3. Training to farmer-hunters in the use of camera-traps.

Figure A4.4. Site visited for wildilfe trainng (left) and instalation of camera and acustic device as part of training (right).

Appendix 4: Questionnaires on perceived climate risks for subsistence livelihoods in the Calakmul Biosphere Reserve

Questionnaire for male farmer-hunters on perceived climate risks for arable farming and hunting

Participant number: ________   Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____
Cristina Argudin Violante
Researcher in charge of study

1. How old are you?
2. Where are you originally from?
3. How long have you lived in this community?
4. Have you perceived any changes in climate during your lifetime?
5. Please describe these changes in detail.
6. Do you believe that these changes in climate have affected your livelihoods?
7. If so, please describe in detail how these have affected arable faming?
8. Please describe in detail how these have affected hunting?
9. How have you coped with climate-related impacts on arable-farming?
10. How have you coped with climate-related impacts on hunting?
11. In your opinion, what would you need to better cope with these changes?
12. In your opinion, which are the most important livelihoods for food security (consider all livelihoods beyond arable farming and hunting0?
13. What are the main sources for food in your household?
14. What are the most important elements of your diet?
15. If one of these is missing, where do you get food from?
16. When you don't hunt or get wild game, what other sources of meat/protein do you have?
17. Do you hunt differently than your ancestors (father/grandfather)?
18. Have your eating habits have changed over time?
19. If yes, please describe how your habits have changed.
20. In what other ways climate change has affected your wellbeing?

Questionnaire on climate risks for food security for women

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. She has understood her rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____
Cristina Argudin Violante
Researcher in charge of study

1. How old are you?
2. How long have you lived in this community?
3. Where are you originally from?
4. How many people live in your household?
5. Please describe what you eat during a week.
6. Which are the most important elements of your diet?
7. Where do you obtain these items/products? Describe in detail.
8. In your opinion, which of these sources is the most important?
9. How frequently you consume meat (any type) in a week?
10. How often do you eat/cook wild meat?
11. Do you have a different diet today compared to when you were a kid?
12. Do you perceive that climate change has affected your diet?
13. If so, please describe in detail.
14. If so, how have you responded to these changes?
15. In your opinion, have these changes affected the nutrition, traditions, and/or wellbeing of your family?
16. Have you noticed any changes in wild meat consumption during the last 5-10 years?
17. If so, in your opinion, what factors have caused these changes in game consumption?
18. Do you consider wild meat an essential part of your diet?
19. In your opinion, do you have a sufficient and healthy diet?
20. If not, what would make it better?

Appendix 5: Pictures of the focus group discussions in two villages of Calakmul

Figure A5.1. Focus group discussion in C2 (left) and C1 (right).

Figure A5.2. Participants of the focus groups in C1 (top) and C2 (bottom).

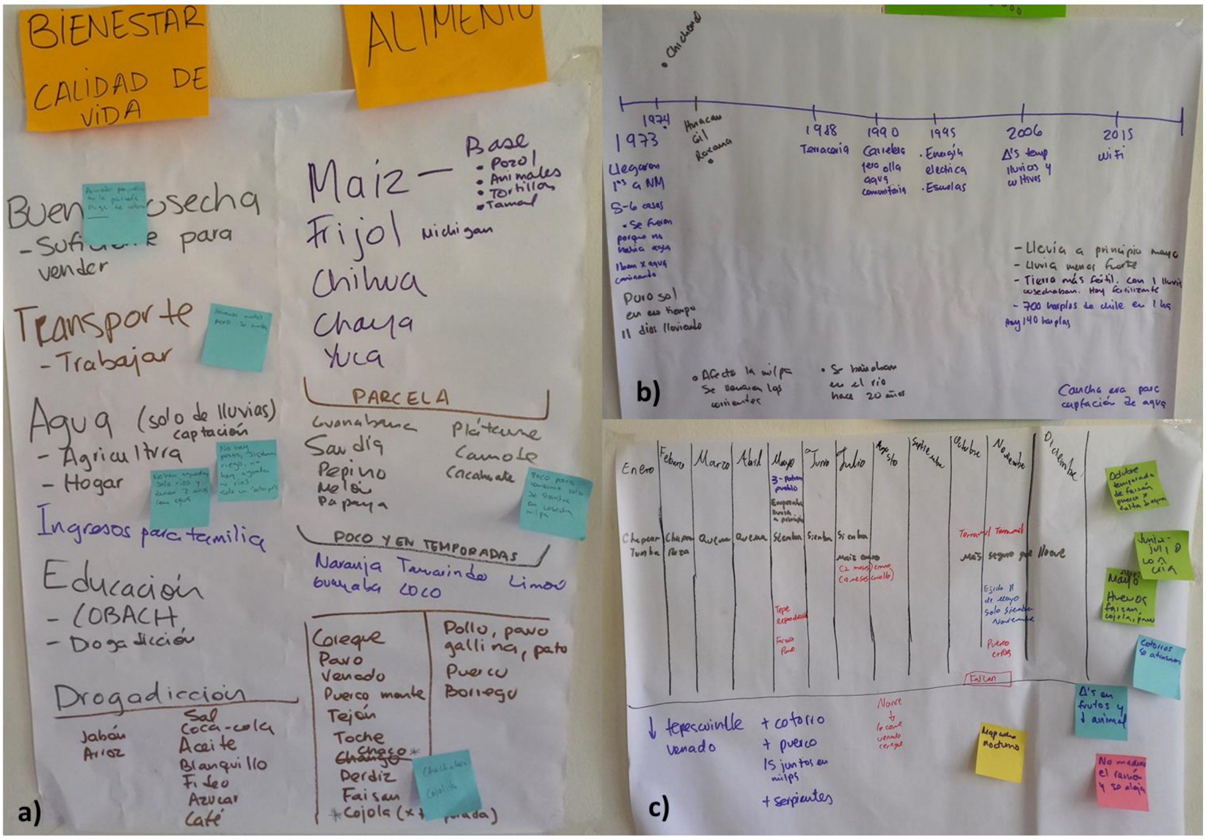

Figure A5.3. C2 villagers' views on various discussed topics in a focus group: a) perceived wellbeing and most important elements of their diets; b) timeline on perceived changes in climate; and c) agricultural calendar.

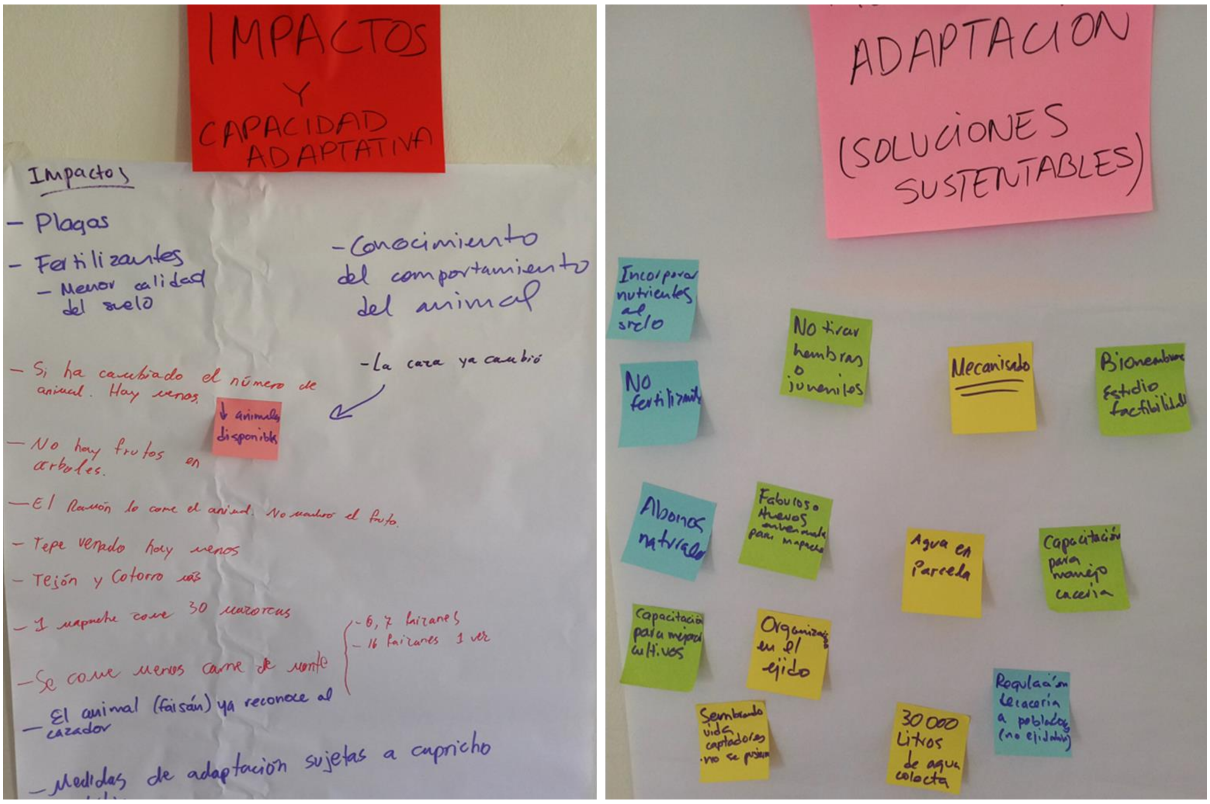

Figure A5.4. Perceived climate impacts on C2's livelihoods and agreed adaptation measures.

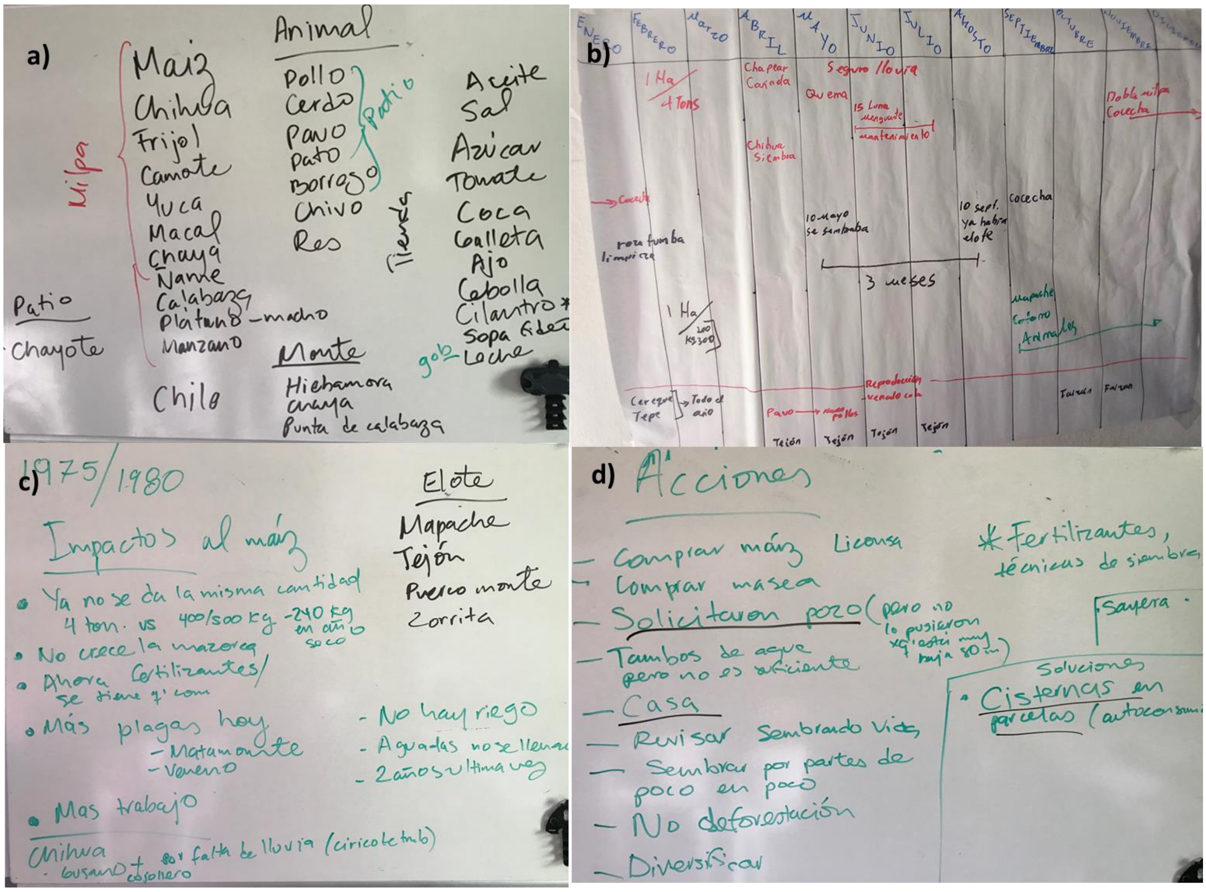

Figure A5.5. C1 villagers' views on various discussed topics in a focus group: a) most important elements of their diets; b) agricultural calendar, c) perceived climate impacts on arable farming, and d) past and future actions to reduce climate risks.

Appendix 6: Questionnaires to evaluate the land-use practices in the Calakmul Biosphere Reserve

Questionnaire 1: Questionnaire on the socioeconomic dynamics in Cx

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____

Cristina Argudin Violante
Researcher in charge of study

1. Where are you originally from?
2. How long have you lived in this village?
3. How many people live in this household?
4. What are the ages of all people in your household?
5. What are your main economic activities?
6. Of these, which is the most profitable in your opinion?
7. What services are available in the community?
8. What services would you like to have in the community?

Questionnaire 2: Questionnaire to newly established ranchers to assess the costs and benefits of livestock ranching in the CBR

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____

Cristina Argudin Violante
Researcher in charge of study

Questions related to livelihoods

1. How long have you lived in the community?
2. What are your main income-generating activities (maximum of 5)? How do they rank in profit for you (1 being the most profitable)? Which of these activities do you dedicate most time to per week (1 being the most time)?

Activity	Profit	Time
• ______________________	______	______
• ______________________	______	______
• ______________________	______	______
• ______________________	______	______
• ______________________	______	______

Questions related to ranching and business start up

3. How long have you been involved in ranching and the business has been operating?
4. Why did you decide to keep livestock?
5. What species and how many head of livestock do you keep?

Species	Number of individuals
Cows	
Bulls	
Sheep	
Goats	
Others	

6. To what uses do you put your livestock?

Use	Cows	Bulls	Sheep	Goats	Others
Self-consumption					
Meat production					
Milk production					
Leather or wool production					
Sale					
Arable farming					
Breeding					
Other					

7. What funds did you use to obtain your livestock? Please select one or more of the following options:
   a) Own money
   b) Subsidies from government (local, SAGARPA, etc)

c) Community funds
d) Other (specify)____

8. What is the purchase cost of an animal (or who is your supplier)?

Species	Cost	Supplier
Cows		
Bulls		
Sheep		
Goat		
Others		

Questions related to operational needs

Space

9. What is the tenancy of the land in which you keep your livestock?
a) Private property_____ b) Community owned______ c) Ejido_______
10. How many hectares do you own? Of these, how many are designated to ranching?
11. Did you have to cut down forest in order to keep livestock? If so, how many hectares were removed? If you feel comfortable answering, how much did it cost to remove it?
12. What kind of pasture or forage do you use? Please describe how you set up the pasture or forage and how many hectares of pasture did you need to start up the business. How much did you spend on pasture and set up (only initial cost, not maintenance), or who was your supplier of pasture?
13. Do you have fences to keep/protect livestock in your property? If yes, what material are the fences made of?
a) Wood b) Concrete c) Electric d) Other
14. How many kilometres of fence do you have?
15. Where did you buy the fences and who is your supplier? If electric, how do you get electricity? a) Generator b) State electricity c) Other. How much do you spend monthly on electricity to keep the fences operating?

Equipment and infrastructure

16. Once you had established the necessary space for livestock, what containers did you need?

Item	Cost or Supplier	How long they last?
Water dispensers		
Water containers		
Food containers		
Other		

17. Do you require any infrastructure for keeping or protecting livestock?

Item	Quantity	Set up cost
Breeding constructions		
Stables		
Food storage		
Nursery buildings		
Other		

18. Do you need any machinery on the ranch? If yes, which machines do you need and what is was the purchase cost (or who was your supplier)?
19. If your farm is dedicated to milk production, what kind of infrastructure do you need to milk livestock? How much do you invested on it (or who is your supplier)?

Food

How do you feed your cattle?

Species	Type of food	Amount per month	Cost or Supplier
Cows	Pasture Forage Packed food Other		
Bulls	Pasture Forage Packed food Other		
Sheep	Pasture Forage Packed food Other		
Goats	Pasture Forage Packed food Other		
Other	Pasture Forage Packed food Other		

21. Are there any other needs in term of nutriments for livestock (for example, vitamins or dietary supplements)? If yes, what quantities do you need and how frequently? How much do you invest in this (or who is your supplier)?
22. Do you have special or extra requirements for livestock? For example if they are breeding, or young, do you feed them differently? If yes, how do you do this? How much does it cost and how often do you need to make this expense (or who is your supplier)?

Water

23. Where do you obtain water to keep livestock? Who is your main supplier of water?
24. How many litres of water per week do you need for livestock to drink?
25. For what other feeding needs you use water? How many litres do you need?

Breeding

26. Do you breed livestock? If yes, how do you do the breeding process?

    Own males___ Insemination____ Other____

27. What expenses do you incur in relation to birth and nursing? How often do you breed livestock?

Hygiene

28. Do you need products/machines related to sanitary issues? If so, what products do you need? What is the cost of these products or the brand/supplier, and how often do you change them?

Health

29. In your experience, what are the main illnesses of livestock?
30. How often do you use preventive medicines for livestock? What proportion of your annual outlay goes towards preventative medicines?
31. How often do you use curative medicines for livestock? What proportion of your annual outlay goes towards curative medicines?
32. Do you have veterinary consultations? If so, how often and how much do you spend on this or who do you call in case of need?
33. Are there any other measures you take to ensure the health of livestock?

Insurance

34. Do you buy any insurance for livestock? Does this insurance cover damages to infrastructure? How often do you buy insurance? How much does it cost or who is your supplier?

Maintenance

35. How often do you need to change the pasture?
36. How much water do you need to keep the pastures in good conditions? Do you have an irrigation system?
37. Do you need fertilizers? How much does this cost or who is your supplier and how often do you need them?
38. How often do you give maintenance to fences, buildings, containers, or other infrastructure?

Personnel

39. How many people are involved in the farm? Do you employ a farm manager or other management personnel? How many full-time farm labourers do you hire? How many seasonal farm labourers?
40. Do you have to hire people or is the community involved in this activity?
41. How many hours per day do you and these people dedicate to livestock business?
42. How many people receive profits from this business?

Management

43. Are there any differences between rainy and dry seasons relating to livestock management?
44. In the last 5 years, have there been changes in climatic conditions that affect cattle or cattle management?
45. What are the main threats of your livestock? (1 being the most severe)
    a) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
46. Which of these affects your income more severely? (1 being the most severe).
    a) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
47. In case of jaguar attacks, have you ever received any compensation for livestock depredation by felines? If yes, how were you compensated and who provided the compensation?
48. Do you obtain any subsidies from institutions (local government, CONANP, NGO, SAGARPA, etc)? If yes, which one and how does it work?
49. How did you gain skills for ranching? Did you receive any training? If yes, who provided it and how much did it cost or who was the supplier?
50. Of all the needs of livestock, which requires the biggest expense? (1 being the most expensive)
    Food___ Water____ Health____ Breeding____ Infrastructure___ Maintenance___

Profits

51. Once the animal is ready, how do you sell it?
52. If you feel comfortable answering, how much do you earn for any animal you sell? How often do you sell and how many?
53. Are there any other earnings that you obtain from livestock? If yes and feel comfortable answering, how much do you get and how often?
54. How easy is to sell your animals (or derived products)? Where do you sell them?
55. To sell an animal, do you need to transport it? If yes, where do you usually take them?
56. Do you invest in publicity, marketing or advertisement?
57. If you feel comfortable answering, how much do you obtain as net income per year from ranching, after expenditures?
58. In your opinion, is livestock ranching a profitable business? If not, do you foresee a time when it will be?
59. Are the earnings enough to cover all the expenses needed on the farm?
60. In your opinion, which of these areas of your life have improved/declined since you began to keep cattle?
    a) Food security (family and community)
    b) Increase in income
    c) Less work in agriculture
    d) Other (specify) __________
61. Are you thinking of expanding the business?
62. In your opinion, do you need any improvement in livestock management?
63. In your opinion, has ranching becoming more/less frequent among the ejidos? What situations motivated this change?
64. Do you buy any insurance for livestock? Does this insurance cover damages to infrastructure? How often do you buy insurance? How much does it cost or who is your supplier

<u>Questionnaire 3:</u> Questionnaire to long-established cattle ranchers to assess the costs and benefits of cattle ranching in the CBR

Participant number: ________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____

Cristina Argudin Violante

Researcher in charge of study

Questions related to business start up

1. How long have you lived in this community?
2. How long has the business been operating?
3. Do you know what was the main activity in this community before ranching?
4. Do you have other activities besides ranching that bring an income?
5. What breeds of cattle and how many do you have?

Breeds	Number of individuals

6. What is the main use you give to cattle? Please tick all that apply.

Use	Tick
Meat production and sale	
Milk production and sale	
Leather production and sale	
Sale of animals	
Other	

7. Of these, which represents your main income?
8. What is the purchase cost of an animal (or who is the supplier)?

Breeds	Cost	Supplier

9. How do you manage your cattle?
   a) Free range
   b) Contained in barn
   c) Other: __________________

Questions related to operational needs

<u>Space</u>

10. What is the tenancy of the land in which you keep cattle?
    b) Private property_____ b) Community owned______ c) Ejido_______
11. How many hectares do you own? Of these, how many are designated to ranching?

12. Did you have to cut down forest in order to keep cattle? If so, how many hectares were removed? If you feel comfortable answering, how much did it cost to remove it?
13. What kind of pasture or forage do you use? Please describe how you set up the pasture or forage and how many hectares of pasture did you need to start up the business? How much did you spend on pasture and set up (only initial cost, not maintenance) or who was your supplier?
14. Do you have fences to keep/protect cattle in your property? If yes, what material are the fences made of?
    b) Wood b) Concrete c) Electric d) Other
15. How many kilometres of fence do you have?
16. Where did you buy the fences and who is your supplier? If electric, how do you get electricity?
    a) Generator b) State electricity c) Other.
    If you feel comfortable answering, how much do you spend monthly on electricity to keep the fences operating?

Equipment and infrastructure

17. Once you had established the necessary space for cattle, what containers did you need?

Item	Cost or Supplier	How long they last?
Water dispensers		
Water containers		
Food containers		
Other		

18. Do you require any infrastructure for keeping or protecting cattle?

Item	Quantity	Set up cost
Breeding constructions		
Stables		
Food storage		
Nursery buildings		
Others		

19. Do you need any machinery on the ranch? If yes, which machines do you need and what was the purchase cost (or who was the supplier)?
20. If your farm is dedicated to milk production, what kind of infrastructure do you need to milk cattle? How much do you invested in it (or who is your supplier)?

Food

21. How do you feed your cattle? In case of different breeds, do you feed them differently?

Species	Type of food	Amount per week	Cost or Supplier
Cows (general)	Pasture Forage Packed food Other		
Breeds			

22. Are there any other needs in term of nutriments for cattle (for example, vitamins or dietary supplements)? If yes, what quantities do you need and how frequently? How much do you invest in this (or who is your supplier)?
23. Do you have special or extra requirements for cattle? For example if they are breeding, or young, do you feed them differently? If yes, how do you do this? How much does it cost and how often do you need to make this expense (or who is your supplier)?

Water

24. Where do you obtain water to keep cattle? Who is your main supplier of water?
25. How many litres of water per week do you need for cattle to drink?
26. For what other feeding needs you use water? How many litres do you need?

Breeding

27. Do you breed cattle? If yes, how do you manage the breeding process?

    Own males___ Insemination____ Other____

28. If you feel comfortable answering, what expenses do you incur in relation to birth and nursing? How often do you breed cattle?

Hygiene

29. Do you need products/machines related to sanitation? If so what products do you need? What is the cost of these products or the brand/supplier, and how often do you change them?

Health

30. In your experience, what are the main illnesses of cattle?
31. How often do you use preventive medicines for cattle? What proportion of your annual outlay goes towards preventative medicines?
32. How often do you use curative medicines for cattle? What proportion of your annual outlay goes towards curative medicines?
33. Do you have veterinary consultations? If so, how often and how much do you spend on this or who do you call in case of need?
34. Are there any other measures you take to ensure the health of cattle?

Insurance

35. Do you buy any insurance for cattle? Does this insurance cover damages to infrastructure? How often do you buy insurance? How much does it cost or who is your supplier?

Maintenance

36. How often do you need to change the pasture?
37. How much water do you need to keep the pastures in good conditions? Do you have an irrigation system?
38. Do you need fertilizers? How much does this cost or who is your supplier and how often do you need them?
39. How often do you give maintenance to fences, buildings, containers, or other infrastructure?

Personnel

40. How many people are involved in the farm? Do you employ a farm manager or other management personnel? How many full-time farm labourers do you hire? How many seasonal farm labourers?
41. Do you have to hire people or is the community involved in this activity?
42. How many hours per day do you and these people dedicate to cattle business?
43. How many people receive profits from this business?

Management

44. Are there any differences between rainy and dry seasons relating to cattle management?
45. In the last 5 years, have there been changes in climatic conditions that affect cattle or cattle management?
46. What are the main threats of your cattle? (1 being the most severe)
    b) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
47. Which of these affects your income more severely? (1 being the most severe).
    a) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
48. Do you obtain any subsidies from institutions (local government, CONANP, NGO, SAGARPA, etc)? If yes, which one and how does it work?

49. How did you gain skills for ranching? Did you receive any training? If yes, who provided it and how much did it cost or who was the supplier?
50. Of all the needs of cattle, which requires the biggest expense? (1 being the most expensive)
Food___ Water____ Health____ Breeding____ Infrastructure___ Maintenance___

Profits

51. Once the animal is ready, how do you sell it?
52. If you feel comfortable answering, how much do you earn for any animal you sell? How often do you sell and how many?
53. Are there any other earnings that you obtain from cattle? If yes and feel comfortable answering, how much do you get and how often?
54. How easy is to sell your animals (or derived products)? Where do you sell them?
55. To sell an animal, do you need to transport it? If yes, where do you usually take them?
56. Do you invest in publicity, marketing or advertisement?
57. If you feel comfortable answering, how much do you obtain as net income per year from ranching, after expenditures?
58. How long did it take for the business to turn a profit?
59. Are the earnings enough to cover all the expenses needed on the farm, or do you have other activities to support ranching?
60. Are you thinking of expanding the business?
61. In your opinion, what are the factors that determine the success of your business?

Questionnaire 4: Questionnaire to long-established ranchers to assess the costs and benefits of non-cattle livestock ranching in the CBR

Participant number: _________ Date: ______/________/_______

[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]

I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____

Cristina Argudin Violante
Researcher in charge of study

Questions related to business start up

1. How long have you lived in this community?
2. How long have you been dedicated to livestock ranching?
3. What are the main activities in the community besides from ranching?
4. Do you have other activities besides ranching that bring an income?
5. What species of livestock and how many do you have? Why do you chose these species rather than cows?
6.

Species	Number of individuals
Sheep	
Goats	
Others	

7. What is the main use you give to livestock? Please tick all that apply.

Use	Tick
Self-consumption	
Meat production and sale	
Milk production and sale	
Wool production and sale	
Sale of animals	
Other	

8. Of these, which represents your main income?
9. What is the purchase cost of an animal (or who is the supplier)?

Species	Cost	Supplier
Sheep		
Goat		
Other		

10. How do you manage your livestock?
   d) Free range
   e) Contained in barn
   f) Other: ___________________

Questions related to operational needs

Space

11. What is the tenancy of the land in which you keep your livestock?
   c) Private property_____ b) Community owned______ c) Ejido_______
12. How many hectares do you own? Of these, how many are designated to ranching?

13. Did you have to cut the forest in order to keep livestock? If so, how many hectares did you remove? If you feel comfortable answering, how much did it cost to remove it?
14. What kind of pasture or forage do you use? Please describe how you set up the pasture or forage and how many hectares of pasture did you need to start up the business. How much did you spend on pasture and set up (only initial cost, not maintenance) or who was your supplier?
15. Do you have fences to keep/protect livestock in your property? If yes, what material are the fences made of?
    c) Wood b) Concrete c) Electric d) Other
16. How many kilometres of fence do you have?
17. Where did you buy the fences and who is your supplier? If electric, how do you get electricity? a) Generator b) State electricity c) Other.
    If you feel comfortable answering, how much do you spend monthly on electricity to keep the fences operating?

Equipment and infrastructure

18. Once you had established the necessary space settled for livestock, what containers did you need?

Item	Cost or Supplier	How long they last?
Water dispensers		
Water containers		
Food containers		
Other		

19. Do you require any infrastructure for keeping or protecting livestock?

Item	Quantity	Set up cost
Breeding constructions		
Stables		
Food storage		
Nursery buildings		
Others		

20. Do you need any machinery on the ranch? If yes, which machines do you need and what was the purchase cost (or who was the supplier)?
21. If your farm is dedicated to milk production, what kind of infrastructure do you need to milk livestock? How much do you invested on it (or who is your supplier)?

Food

22. How do you feed livestock?

Species	Type of food	Amount per month	Cost or Supplier
Sheep	Pasture Forage Packed food Other		
Goats	Pasture Forage Packed food Other		
Others	Pasture Forage Packed food Other		

23. Are there any other needs in term of nutriments for livestock (for example, vitamins or dietary supplements)? If yes, what quantities do you need and how frequently? How much do you invest in this (or who is your supplier)?

24. Do you have special or extra requirements for livestock? For example if they are breeding, or young, do you feed them differently? If yes, how do you do this? How much does it cost and how often do you need to make this expense (or who is your supplier)?

Water

25. Where do you obtain water to keep livestock? Who is your main supplier of water?
26. How many litres of water per week do you need for livestock to drink?
27. For what other feeding needs you use water? How many litres do you need?

Breeding

28. Do you breed livestock? If yes, how do you manage the breeding process?

    Own males__ Insemination___ Other___

29. What expenses do you incur in relation to birth and nursing? How often do you breed livestock?

Hygiene

30. Do you need products/machines related to sanitation? If so what products do you need? What is the cost of these products? If you don't know or don't want to answer, name the brand/supplier, and how often do you change them?

Health

31. In your experience, what are the main illnesses of livestock?
32. How often do you use preventive medicines for livestock? What proportion of your annual outlay goes towards preventative medicines?
33. How often do you use curative medicines for livestock? What proportion of your annual outlay goes towards curative medicines?
34. Do you have veterinary consultations? If so, how often and how much do you spend on this or who do you call in case of need?
35. Are there any other measures you take to ensure the health of livestock?

Insurance

36. Do you buy any insurance for livestock? Does this insurance cover damages to infrastructure? How often do you buy insurance? How much does it cost or who is your supplier?

Maintenance

37. How often do you need to change the pasture?
38. How much water do you need to keep the pastures in good conditions? Do you have an irrigation system?
39. Do you need fertilizers? How much does this cost or who is your supplier and how often do you need them?
40. How often do you give maintenance to fences, buildings, containers, or other infrastructure?

Personnel

41. How many people are involved in the farm? Do you employ a farm manager or other management personnel? How many full-time farm labourers do you hire? How many seasonal farm labourers?
42. Do you have to hire people or is the community involved in this activity?
43. How many hours per day do you and these people dedicate to livestock business?
44. How many people receive profits from this business?

Management

20. Are there any differences between rainy and dry seasons relating to livestock management?
21. In the last 5 years, have there been changes in climatic conditions that affect livestock or livestock management?

22. What are the main threats of your livestock? (1 being the most severe).
c) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
23. Which of these affects your income more severely? (1 being the most severe).
a) Droughts ___ b) Jaguar attacks ____c) Theft ___d) Illness ___ e) Other ___
24. Do you obtain any subsidies from institutions (local government, CONANP, NGO, SAGARPA, etc)? If yes, which one and how does it work?
25. How did you gain skills for ranching? Did you receive any training? If yes, who provided it and how much did it cost or who was the supplier?
26. Of all the needs of livestock, which requires the biggest expense? (1 being the most expensive)
Food___ Water____ Health____ Breeding____ Infrastructure___ Maintenance___

Profits

27. Once the animal is ready, how do you sell it?
28. How much do you earn for any animal you sell? How often do you sell and how many?
29. Are there any other earnings that you obtain from livestock? If yes and feel comfortable answering, how much do you get and how often?
30. How easy is to sell your animals (or derived products)? Where do you sell them?
31. To sell an animal, do you need to transport it? If yes, where do you usually take them?
32. Do you invest in publicity, marketing or advertisement?
33. If you feel comfortable answering, how much do you obtain as net income per year from ranching, after expenditures?
34. How long it take for the business to turn a profit?
35. Are the earnings enough to cover all the expenses needed on the farm, or do you have other activities to support ranching?
36. Are you thinking of expanding the business?
37. In your opinion, what are the factors that determine the success of your business?

Questionnaire 5: Questionnaire to established honey producers to assess the costs and benefits of apiculture in the CBR

Participant number: ________ Date: ______/________/_______
[The identity of participants and of the community where they are from will not be asked. However, a Participant number code will be assigned to each interview. There will be a separate key for this code, to keep record of the number of interviews and the identity of the municipality.]
I have read the Participant information sheet to the participant. S/he has understood their rights, has had an opportunity to ask questions, and has consented to take part in this study. Consent will be obtained verbally at the beginning of the interview:

____
Cristina Argudin Violante
Researcher in charge of study

Questions related to business start up

1. How long have you lived in this community?
2. Why did you decide to dedicate to honey production?
3. How long have you been dedicated to honey production? For how long has the enterprise been operating?
4. Aside from apiculture, what other activities bring income for you?
5. What are the main activities in the community apart from honey production?
6. Is honey production managed by the community? If so, how many people operate the business?
7. How many beehives are needed to initiate honey production?
8. Where and how do you get the beehives?
   a) Catching native swarms _____ b) Purchased______
9. If purchased, how much does it cost to get them (or who is your supplier)? How many beehives and bee types did you start with, and what was their cost (or who was the supplier)?

Amount of beehives to start business	Beehive price (single) or Supplier

Bee Type	Cost or Supplier
Queen	
Drone	
Worker	
Other	

Questions related to operational needs

Equipment and infrastructure

10. Once you have the bees, what materials and infrastructure, do you need for the apiary?

Item	Amount	Cost (per item) or Supplier
Beehives		
Bases		
Comb foundation		
Protective clothes		
Signs		
Others		

11. Do you use feeders and water dispensers in the apiary? If yes, how many do you have and how much do these cost (or who is the supplier)?

Item	Amount in apiary	Cost per item or Supplier
Feeders		

Water containers		

12. Do you need infrastructure for the business? If yes what kind and what was the cost (or who was the supplier)?

Item	Use	Amount	Cost per item or Supplier
Buildings			
Machinery			
Beekeeping utensils			
Honey extraction and processing utensils			
Packing utensils			
Labelling and publicity			
Transport			
Other			

Space

13. How many hectares do you own? Of these, how many are used for apiculture?
14. Did you have to cut down forest to set up the apiary? If so, how many hectares were removed? If you feel comfortable answering, how much did it cost to remove it?
15. Do you plant any floral species around the apiary? If yes, what kind of plants? Why do you do this and how often? Where do you get the plants from and how much do they cost (or who is the supplier)? What native plant species support the beehives?
16. How many beehives do you currently have in your land?

Food

17. How are the bees fed and how often?
18. Do you prepare any artificial food for your bees? If yes, what do you use and what are the costs (or who is the supplier?

Type of food	Cost or Supplier/Brand	Frequency of use
Support food		
Boost food		
Supplementary food		
Other		

Water

19. Which of the following activities require water, and how much per week?

Activities	Litres per week
Water supply for beehives	
Honey production process	
Hygiene of materials	
Food preparation	
Other	

20. Where do you obtain water? Who is your supplier?

Hygiene

21. Are there any measures you have to take to keep the apiary clean? If so, explain. Are there any expenses associated with this?
22. Is there any regulation that you have to follow for hygiene issues, in the apiary and in honey processing?

Health

23. What are the main illnesses that bees are exposed to?
24. What are the sanitary controls you undertake to keep the bees healthy?
25. Do you have a veterinarian responsible for health issues? If yes, how often do you need them and how much does it cost or who is your supplier for veterinary services?
26. What proportion of your annual outlay is designated to health issues?

Maintenance

27. Do you take any preventive measures to protect beehives from diseases/predators? If yes, please explain. How often you need to take these measures?
28. In order to sustain the productivity of the beehive, do you change the queen? If yes, how often do you do this, where do you get if from?
29. Are there any other methods related to productivity and breeding that you use?
30. Are there other needs to keep your productivity high? If yes, what are these needs?
31. Do you have insurance for the beehives? If yes, where and how do you get it? What does it include? How much you invest in this and how often (or who is your supplier?

Personnel

32. How many people work in the apiary? How many of these are dedicated to the following activities?
    Beekeeping _______
    Honey production _______
    Sale and distribution ________
    Marketing _______
    Others _______
33. Do you employ a manager or other management personnel? How many full-time labourers do you hire? How many seasonal farm labourers? From the people involved in the business, how many are from the community?
34. When the enterprise started, did you receive training for apiculture? If yes, who provided this training?
35. Are all the employers of the apiary trained? If yes, how often they receive training and who provides it?

Time

36. How much time per day is dedicated to beekeeping/honey production/sale?
37. Since the beginning of the season, how much time is needed to produce honey? Then how much time takes to process the honey (extraction, processing, packing, labelling, etc.)?

Sale and distribution

38. How many kilograms of honey can you produce in a year? Is production constant over the year? Are there months where there is no production?
39. What other products apart from honey do you obtain and sell?
40. Where and how do you sell your products?
41. Given that Campeche is one of the biggest honey producers, is it a competitive market or one that benefits from more producers?
42. Who is your main buyer?
43. What makes your product(s) competitive in the market?
44. How do you distribute your product(s)?
45. Do you invest in publicity, local fairs, marketing, etc?
46. Do you have any certification that enhances your sale of your product(s) (for example, Organic Certification, Fair Trade, etc.)? How did you obtain this?
47. Do you obtain any subsidies from institutions (local government, CONANP, NGO, SAGARPA, etc)?
48. Do you receive, or have you received at any point, help from organizations or institutions?

Profits

49. If you feel comfortable answering, how much do you obtain from honey production as net income per year after costs?
50. In your opinion, what are the main threats to apiculture?
    a) Plagues/parasites/illness b) African bees c) Droughts/Rain d) Theft e) Other
51. Of these, which represents the principal economic loss to you?
52. Are there any differences between rainy and dry seasons relating to bee management or honey production?
53. In the last 5 years, have there been changes in climatic conditions that affect the beehives or its management?
54. In your opinion, what factors determine the success of your business?

Appendix 7: Pictures of training in honey production and focus group discussion

Figure A7.1. Training in honey production (theory sessions); a) session delivered by local apiculturists and b) female trainer to encourage women participation.

Figure A7.2. Training in honey production (practical sessions).

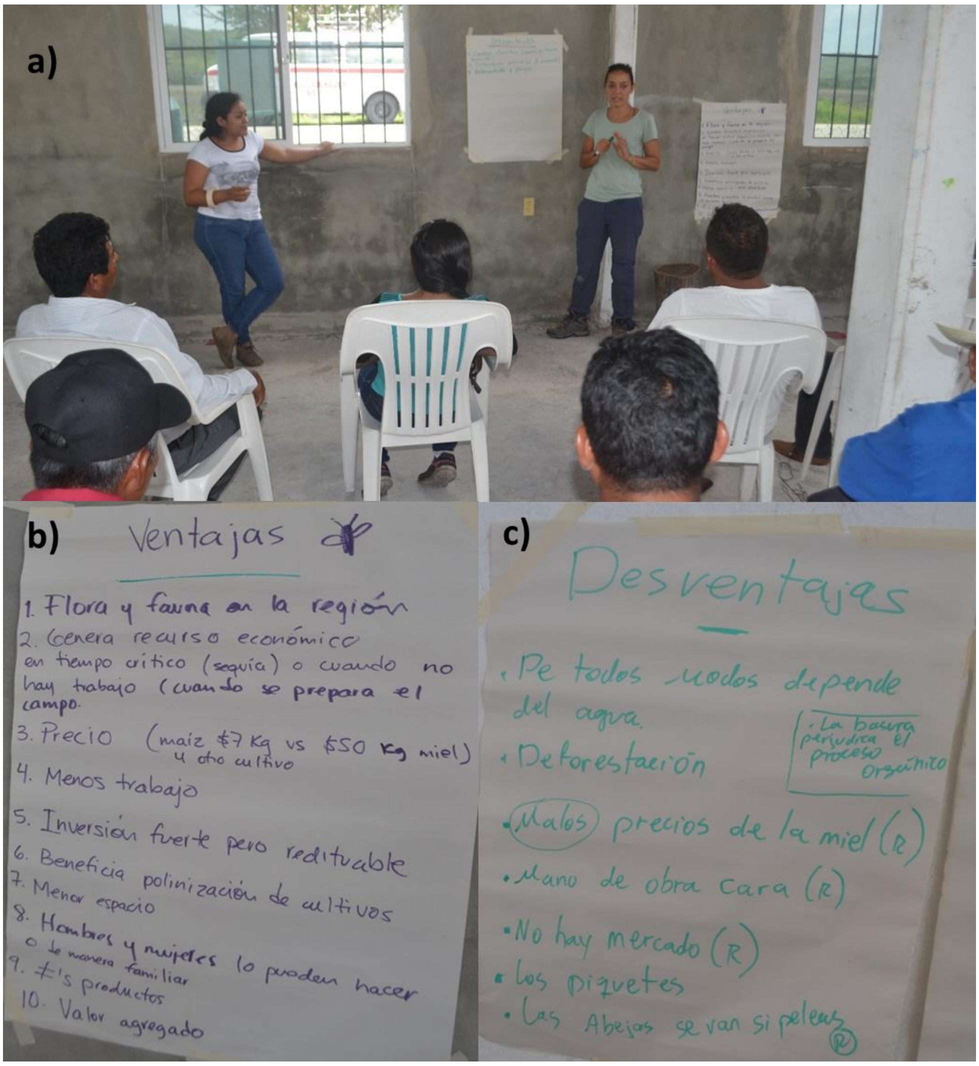

Figure A7.3. Examples of focus group discussions; a) discussions with newly established honey producers, b) & c) perceived advantages and disadvantages of honey production, respectively mentioned during the discussions.

Figure A7.4. Participants of the training in honey production for two villages in the CBR.

Annex I: Density of felids in the CBR

Context

At the start of this PhD project, one of the main aims was to monitor large mammal populations in the Calakmul Biosphere Reserve (CBR) to assess the integrity of its tropical forests. The initial plan was to run wildlife surveys for 2 years, with different conservation tools: camera-traps to monitor felids (as indicators of ecosystem integrity) and their prey, and acoustic recorders to quantify gunshot frequencies in the CBR to evaluate the impacts of hunting on game populations. The first surveys were done from February to August 2019, after securing funding for fieldwork. The subsequent surveys, initially planned for 2020 and 2021, were prevented by the COVID-19 pandemic and its associated travel restrictions. Furthermore, the rural communities in the CBR self-isolated until late 2021 prohibiting the entrance of foreigners to the ejidos.

The data obtained in 2019 nevertheless allowed development of two different projects during the pandemic in collaboration with colleagues: 1) estimation of the population densities of jaguars (*Panthera onca*) and ocelots (*Leopardus pardalis*) in the CBR, in collaboration with a former master's student at the University of Toulouse, and 2) the evaluation of the activity patterns of felids and their potential prey, which resulted in a research paper in collaboration with a colleague at the University of Sussex. This Annex presents the felid densities estimated for the CBR in 2019. The manuscript of the paper on the activity patterns of felid and their prey, currently in revision for the journal *Biotropica*, is presented in Annex 2.

In 2022, I was able to resume the wildlife and gunshot surveys, which are currently running in the CBR, thanks to a collaboration with Mexican researchers at the Institute of Biology of the National Autonomous University of Mexico (UNAM). This collaboration was initiated with a Global Partnership Award granted to me by the University of Southampton in 2022. The aim is to continue monitoring the CBR's forests until 2024, to robustly assess the ecosystem integrity along with the impacts of hunting on these forests.

This annex presents the population densities of felids in the CBR calculated with data obtained in 2019. This study was done in collaboration with Juliette Penez, a former postgraduate student in Zoology at the University of Toulouse, whose dissertation project had been supervised by Patrick Doncaster and me. I aim to share these results to provide a preliminary picture of the state of the ecosystem and its populations, relevant for the sustainability and resilience of the forests and the livelihoods of the rural communities inhabiting the area. The information presented in this document is part of a technical report prepared for the CBR authorities (originally in Spanish), who rely on this data for management purposes. In late 2023, I will be integrated the results obtained during 2022-2023, with this information to assess the ecosystem integrity of the CBR.

Contributions

This project was envisioned and led by me in collaboration with my supervisor Prof Patrick Doncaster. I initiated the idea for the study and developed its aims and objectives. The selection of the survey site, the scouting trips to potential survey locations, and setup of camera traps was done by me with the support of personnel from Operation Wallacea. Esteban Dominguez, a local guide and honey producer in the CBR, and I checked the batteries and SD cards of the cameras monthly. The data were retrieved, filtered, and analysed by me. The identification of felids to individual level was done by me and corroborated by Juliette Penez, a former master's student at the University of Toulouse. Juliette estimated the density of jaguars and ocelots for her dissertation project and created the map with spatial representation of captures of felids in the CBR, presented in this document. Juliette's work was supervised by me and Patrick Doncaster. Thus, the results presented in this document were obtained by Juliette Penez. The introduction, discussion, and conclusion sections in this document, were written by me. Patrick Doncaster revised the document and provided feedback and suggestions. The results and the methods were adapted from the work done by Juliette. Fieldwork was conducted with resources obtained with my CONACyT studentship (472259), a Rufford Small Grant (31803-2) and an Idea Wild Grant.

This document is not considered a data chapter of my PhD thesis, as data was mostly analysed by Juliette Penez. Additionally, the wildlife surveys are ongoing and further data needs to be analysed and integrated to obtain a robust assessment of the ecosystem integrity of the CBR.

Abstract

Neotropical felids can play a key role in regulating the ecosystems, thus making useful indicators of ecosystem integrity. The Calakmul Biosphere Reserve (CBR) in Southern Mexico, which comprises the largest extension of tropical forest in the Americas, after the Amazon, is considered to be a stronghold for felid populations in Mexico due to its large extension and conservation status. However, little is known about the populations of large predators and the state of the ecosystems in the area. This study aims to provide an estimate of the population density of jaguars and ocelots in the CBR, as part of a larger study that will use felids to assess the ecosystem integrity of the CBR's forests. For this initial study, individuals were sampled between February and August 2019 using camera traps placed over 81 km^2 and analysed using spatially explicit capture-recapture methods (SECR). The density of each population was estimated using maximum likelihood and Bayesian methods. Our results showed an average of 2.37±1.38 jaguars in 100 km^2 and 13.19±5.94 ocelots per 100 km^2. The jaguar density obtained in the CBR was lower than in other parts of the Selva Maya and similar to those calculated for small reserves in the Yucatan Peninsula. In contrast, ocelot density was higher than in the Belize and other regions of Southern Mexico. Monitoring over a longer period and in other sites of this large reserve can provide more accurate estimates on the density of felids.

Introduction

Ongoing biodiversity loss is one of the greatest threats to humanity (IPBES, 2019; Ceballos et al., 2015). Assessing the state of ecosystems through reliable biodiversity indicators is one of the major goals of the Convention of Biological Diversity, in face of increasing anthropogenic-driven threats to biodiversity and human wellbeing (Dobson et al., 2011; CBD, 2021). In this context, ecological integrity is a key concept for evaluating the condition of an ecosystem (Brown & Williams, 2016). Ecological integrity is defined as the capacity of the ecosystem to support a balanced, integrated, adaptive biological system having the full range of elements and processes expected in the natural habitat of a region (Parrish et al., 2003). Ecological integrity can be inferred from an ecosystem's capacity to sustain ecological processes such as predator-prey systems. Because of anthropogenic pressures such as habitat loss, changes in community assemblages and composition lead to a subsequent loss of species interactions, disrupting functions at the top of ecological hierarchy (Valiente-Banuet et al., 2015).

Large felids as top predators in the Neotropics, are necessary for maintaining biodiversity and ecosystem function (Ripple et al. 2014). Evidence shows that the occurrence of apex predators is associated with a high biodiversity value, providing a direct link between strategic conservation of flagship species and wider conservation goals (Sergio et al., 2008). Therefore, apex predators can be used as main receptors of anthropogenic impacts by analysing modifications in their population viability, habitat functions, and species interactions. Predator-prey systems can also be used as significant receptors of anthropogenic impacts because these are the most visible elements of ecological integrity, i.e., they are associated with large animals, occupying high trophic levels, which have large spatial habitat requirements, and in turn are highly impacted by landscape transformation.

The long-term ecological viability of apex predators in Mexico is at risk due to ecological integrity loss. Three Neotropical top predators in the country, jaguars (*Panthera onca*), ocelots (*Leopardus pardalis*), and margays (*Leopardus wiedii*), are catalogued as endangered and one, the jaguarondi (*Puma yagouarondi*), is categorized as threatened (NOM-059-SEMARNAT, 2010). The current extent of habitat left for all extant apex predators (both, Neotropical and Nearctic) is now less than 40% of their historical range. Furthermore, the remaining natural habitat for apex predators is characterized by very low ecological integrity conditions for all species (Mora, 2018).

The Calakmul Biosphere Reserve of Southern Mexico is considered a stronghold of felid populations in Mexico, due to the presence of five of the six felid species in the country, its large extension (more than 723,200 ha), and its large extents of continuous forest. However, the status and density of most felids is still unknown. Pressures on wildlife derived from human activities have increased in recent years, changing the landscape through habitat loss, fragmentation, land-use change, and habitat degradation, contributing to increasing threats to wildlife populations (Pérez-Flores et al., 2021).

The aim of this project was to assess the viability of large felid populations in the CBR by systematically monitoring this group with camera-trap surveys during 2019. To this end, we used jaguar and ocelot detections to estimate population densities with the first application in CBR of a maximum-likelihood approach to spatially explicit and sex dependent capture recapture models. This aim is part of a larger goal of assessing the ecosystem integrity of the tropical forests of the CBR using felids as indicators of ecosystem health.

Methods

Camera trap surveys were conducted in in the southern buffer zone of the CBR with no human inhabitants (18º08'-18º38'N, 89º31'-89º44'W). A total of 36 passive infrared digital cameras activated by a heat-motion sensors (Bushnell Trophy HD, Cuddeback C1, and Browning Strike Force Extreme) were positioned on and off trails, individually or in pairs, with a total of 27 camera-trap stations. The camera-trap grid followed the standardised

CENJAGUAR design for jaguars and their prey (Chávez et al., 2007), whereby nine contiguous 3×3-km cells, totalling an area of 81 km^2, within our study site were each assigned three camera stations, with one positioned next to an aguada if present, and all stations separated by a minimum of 1 km (Figure 1). Cameras were positioned on trees ~50cm off the ground and set to take a burst of three photos whenever activated across the 24-hour period. Data were collected continuously from February to August 2019. The cameras were checked once each month to verify their functioning and change the SD card and/or batteries. Cameras were active 183 days, making a total sampling effort of 4,941 camera-trap days. A total of 482 pictures of jaguars and 900 of ocelots were collected. Species identification and other metadata (e.g., time and date) encoded for using Timelapse software (Version 2; Greenberg, 2018) and jaguar and ocelot individuals were identified using Hotspotter software (Crall et al., 2013). Jaguar and ocelot photographs that could not be reliably identified (12 and 44 respectively) were excluded from density analyses. The non-invasive wildlife surveys performed in this study were approved by the University of Southampton's Ethics Research and Governance Board (ERGO ID: 48865 "Ecology of felids and their prey in the Calakmul Biosphere Reserve").

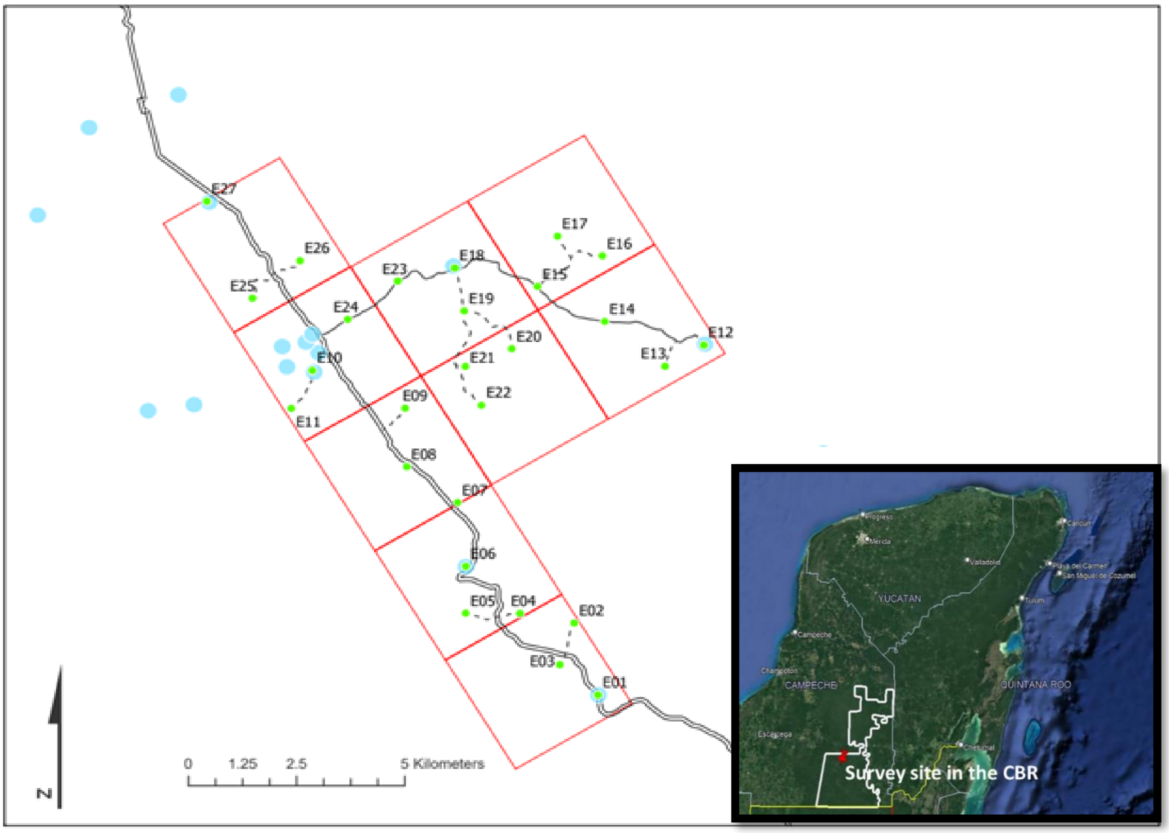

Figure 1. The study area in the Calakmul Biosphere Reserve, showing the location of camera-trap stations (small green dots), temporary water bodies (i.e., temporary ponds "aguadas"; large blue dots), roads (double line), access roads (single line) and tracks (dotted line). E1, E4, E6, E8, E10, E11, E13, E15, E17, E18, E20, E22, E25 and E26 were double camera stations, and the rest were single. Some tracks were made to set the cameras, others were pre-existing.

Two types of spatially explicit capture–recapture (SECR) models were used: a maximum-likelihood approach (r package secr; Efford et al., 2009); and a Bayesian approach of Markov and Monte Carlo simulations (r package SPACECAP; Gopalaswamy et al., 2012) to estimate the density of felids. The maximum-likelihood approach allows three choices of possible models for population density estimates: (i) not accounting for sex differences in detection probability; (ii) incorporating sex-specific detection probabilities; and (iii) excluding all potential activity centres falling outside suitable habitat (Zimmermann & Foresti, 2016). In contrast, the Bayesian approach deals well with issues presented by individual heterogeneity in capture probabilities and provides non asymptotic inferences, which are more appropriate for the small samples of capture data that are typical of photo- capture studies (Gopalaswamy et al. 2012).

The Maximum likelihood and Bayesian models require the capture-recapture history of the individuals on each camera-trap station, in combination with the spatial distribution of the captures and recaptures (Noss et al. 2012). Both assume: 1) closed model capture-recapture sampling (conventional SECR analysis); 2) independent activity centres for captured individuals; 3) fixed locations for activity centres during the sampling period; 4) a declining probability of detecting an individual at a camera station with increasing distance of the trap from the individual's activity centre; and 5) independent capture events (Foster & Harmsen, 2012; Gopalaswamy et al., 2012). Camera-trap records were restricted to periods of ≤90 camera days - three periods of 60 days (hereafter 60_1, 60_2 and 60_3) and two of 90 days (hereafter 90_1 and 90_2) - to minimize risk of violating the assumption of demographic closure, on which conventional SECR models depend for accurate density estimations (Otis et al., 1978; Royle et al., 2014). For selecting inputs and models for the maximum likelihood and Bayesian approaches, we followed Pina-Covarrubias (2019) and Zimmermann & Foresti (2016) for jaguars and Noss et al. (2022) for ocelots.

For the maximum likelihood method, we generated a series of alternative areas of influence (known as masks) around the camera-trap arrays using increasing buffer widths of 1, 3, 5, 7, 9, 11, 13, 15, 17, 20, 25, and 30 km for jaguars (Zimmermann & Foresti 2016) and 1, 2, 3, 4, 5, 6, 7, 9 and 11 km for ocelots (Noss et al., 2012). We ran a series of null nonspatial models, associated with each rectangular buffer, assuming constant values for the baseline encounter probability (g0; i.e., encounter probability when the distance between the activity centre of an individual and the camera trap is zero) and the spatial scale parameter (σ). Following Royle et al. (2014), we chose the best model by selecting a buffer with a width of 2–3σ, which guarantees that individuals outside the area of influence have zero detection probability by the camera-trap array during the sampling period. Using the mask associated with the best model, we ran a mixture of alternative SECR equivalents to conventional capture–recapture models, to explore their effect on g0, while keeping σ constant (Zimmermann & Foresti 2016).

Fifteen different models were built with the secr.fit() function to obtain the density estimate as a function of the captured data by fitting the spatial maximum likelihood detection model. The result depended on the mask area previously selected as the best model. The fifteen models used are derivatives of the three main types of models used in SECR analyses and have only a variation of the g0 parameter compared to the null model. In this study, we studied the population without separating the sexes into two different classes, thus results obtained are referred as 'no_sex' models hereafter. The models including a variation of the capture probability as a function of time either according to occasions (Mt) or linearly (MT). Models including a behavioural response - 'trap happy' if the individual tends to be attracted to the device or 'trap shy' if it tends to avoid it - which is set following the response at the time of the first capture (Mb) or an evolutionary response depending each time on the previous one (MB). The Mk and MK models were also used, for which the probability of capture depends on the location, either specific to all sites (MK) or specific to each site (Mk). Additionally, the finite mixture models, here Mh2, where the dataset is divided into two classes and where the capture probabilities is calculated by grouping these classes. A variable with two potential values can be added to the model to identify the two classes. From these models, three others were used in the analysis which are combinations of the previous models (Mbt, Mbk, MBk). The last five models used here are variants of the Mh2 and MK models using a different type of algorithm than the default: the Nelder-Mead algorithm (Zimmermann & Foresti, 2016; Royle et al., 2014).

The models were then compared with Akaike's Information Criterion (AIC) method to obtain the model that appeared to best estimate the population density of each species by minimising possible biases and errors related to the model variance (Burnham & Anderson, 2002). In the case where several models were valid (when delta AIC < 2) an estimate of the density based on these models was calculated with the function model.average() (Zimmermann & Foresti, 2016).

In a second step, several models were created by changing characteristics of the best selected model to indicate differences in capture probability according to sex (model 'sex' hereafter). Indeed, studies have already shown that the probability of capture can depend on the sex of the individual for jaguars and ocelots (Foster et al., 2016; Satter et al., 2019b). To do so, the sex covariate was identified as the one separating the two classes. These models were in turn compared with AIC. By dividing the population for each session into two distinct classes based on their sex, the SECR models also provided sex ratio estimates for our jaguar and ocelot populations. These results are presented in the results section. It is expected that these results will indicate whether separating the jaguar and ocelot populations into two classes based on sex better represents the populations we are dealing with or not.

For the Bayesian approach, the SPACECAP package in R were used to estimate our population densities with a Bayesian method. It presents an interface which simplifies the analysis (Gopalaswamy et al., 2012). Three datasets are required to obtain density estimations: a capture effort's file as for the analysis with secr, which also includes the UTM coordinates of the sites, 2) information about the individual, the site where the capture took place and the day of the capture, and 3) the coordinates of the potential interest centres of the individuals that might be captured by the cameras within the state space.

The state spaces were identified during the SECR analysis when we selected the best mask area for each session. Then QGIS 3.16 software was used (2021) to create a grid containing the coordinates of the different interest centres. The activity centres were separated by 1 km each for jaguars and 0.5 km for ocelots. It refers to 1 km2 and 0.25 km2 pixel respectively. To compare the results between Bayesian and maximum likelihood methods, two different grids were built. Firstly, a grid like the mask area of SECR was created. Then, in contrast to the rectangular shape of the buffer zone used in SECR, the shape of the zones including the activity centres was the result of circles of perimeter X km around each camera (X referring at the best mask area value). By doing this, the state space is more refined. We did not make any assumptions about the suitability or not of the potential activity centers as it is not rare to see individuals out of the reserve. Thus, every potential activity centre in the state space was supposed to be a suitable habitat for both jaguars and ocelots.

The model was defined with four parameters: trap response absent; spatial capture-recapture model; half normal detection function; Bernoulli encounter process. The trap response model was absent, thus no specific behavioural response of the individual was assumed once it has encountered a trap (neither trap happy nor trap shy). The detection function is the model we chose as a prior and which was supposed to adequately represent our data. Following Noss et al. (2012), we selected the half normal function which was assumed to fit the data well. Finally, the selection of the Bernoulli process allowed us to analyse our data in a binary way under a model which considers that each individual has its own probability of being captured or not on a sampling occasion. This method is also used in the maximum likelihood analysis. Indeed, we indicated that we wanted a maximum of one encounter per individual per occasion and per site by selecting the proximity detector. We therefore needed the Bernoulli model to identify the probability of encounter for each individual and thus estimate the population density.

The Bayesian analysis via SPACECAP also included a Markov Chain Monte Carlo (MCMC). The MCMC method draws random samples from the target posterior distribution given by the Bayesian analysis. It is used because obtaining a large number of posterior results makes it possible to identify the characteristics of this same distribution in a relatively stable way (Royle et al., 2014). To this end, we opted to repeat 100,000 iterations of the MCMC process with the first 10 000 being the burn-in values, i.e., values needed to stabilize the MCMC process but are not considered in the final output.

Results

Jaguar density in the CBR

A total of 12 jaguar individuals were identified within the surveyed area of 81 km^2. Of these, two were females, seven males, and three individuals could not be identified by sex. Different density estimates were obtained with the maximum likelihood and the Bayesian analyses. The maximum likelihood analysis showed different results for the “no_sex” and “sex” models in the different sessions (60_1, 60_2, 60_3, 90_1, and 90_2). The density considering the differences between males and females was not available for session 60_2 as no females were captured during this period (Table 1). The Bayesian analysis gave higher densities than maximum likelihood method, on both models used: the model with the fitting grid to the camera-trap positions and the rectangular shaped grid (Table 1). The average density of jaguars per 100km^2 in the CBR resulted of 2.37±1.38 individuals.

Table 1. Density estimations obtained for jaguars with the Maximum Likelihood method for both ‘sex’ and ‘no_sex’ models and the best model associated (2) the Bayesian method, according to the session.

Session	**Maximum likelihood**			**Bayesian**	
	Best model	No_sex (ind./100km^2)	Sex (ind./100km2)	Fitting grid (ind./100km2)	Rectangular grid (ind./100km2)
60_1	Mbk	1.95±0.90	2.02±0.99	2.23±0.60	2.17±0.70
60_2	Mbk	1.13±0.52	X	1.67±0.84	1.09±0.31
60_3	Mb	3.49±2.86	2.75±2.02	7.71±8.15	6.60±6.51
90_1	Mbk	1.56±0.63	2.96±3.01	2.11±0.58	2.12±0.70
90_2	M0	3.83±2.53	4.01±2.56	2.30±1.20	2.96±2.47

Ocelot density in the CBR

A total of 17 ocelot individuals were found within the surveyed area of 81 km^2. Of these, five were females, 11 males, and one which the sex could not be recognized. None of the sessions presented all 17 individuals simultaneously. The first period contained 13 ocelots with a total of 46 captures. During the second 60-day period, eight individuals were identified and seven during the last session with 12 detections for each period. The maximum number of individuals over a period was reached during session 90_1 with 15 individuals for 54 captures. Finally, eight individuals were identified during session 90_2 with 16 detections. For most of the study sessions, the best mask area identified with SECR was 3 km. The only exception was the mask area of session 60_2 which was of 5 km.

The ocelot densities obtained with the maximum likelihood method ranged from 9.96±6.84 to 14.69±5.07 ind./100 km2 when sex was not a studied component. The densities obtained by identifying males and females as two different classes were overall slightly higher than previous results (Table 4).

The Bayesian method identified different density values for ocelots (Table 4). An average density of 13.19±5.94 ocelots per 100 km^2 was determined out of the best density estimates we obtained.

Table 2. Density estimations obtained for ocelots with (1) the Maximum Likelihood method for both 'sex' and 'no_sex' models and the best model associated (2) the Bayesian method, according to the session it refers to.

Session		**Maximum likelihood**		**Bayesian**	
	Best model	No_sex (ind./100km^2)	Sex (ind./100km^2)	Fitting grid (ind./100km^2)	Rectangular grid (ind./100km^2)
60_1	Mbk	13.42±6.06	17.67±7.81	11.17±2.53	10.45±3.24
60_2	M0	11.22±7.30	11.22±7.30	10.79±10.20	6.88±7.14
60_3	M0	14.52±7.82	15.68±8.46	21.11±13.95	21.39±13.03
90_1	Mbk	14.69±5.07	15.33±5.41	12.87±2.52	13.03±3.14
90_2	M0	11.98±5.49	12.45±6.00	13.67±6.25	13.99±6.32

Discussion

The results of this study suggest lower jaguar densities in the CBR than in the last decade. The obtained jaguar density was lower than the one estimated by Chávez (2010) of 3.3 to 6.6 ind./100 km^2 for the CBR. Similarly, the result of this study was lower than Harmsen et al. (2010) estimation of 3.5 and 11 individuals per 100 km^2 in a protected area in Belize. However, similar densities were obtained by Piña-Covarrubias et al. (2023) who reported 2±3 individuals per 100 km^2 for two small reserves northern Yucatan Peninsula. In contrast, our result showed a higher jaguar density for the CBR than for private reserves in northern Mexico, where a density of 1.87±0.47 ind./100 km^2 was estimated (Gutiérrez-González et al., 2015). According to these results, the jaguar population in the CBR is smaller than in other parts of the Selva Maya, with the number of jaguar individuals dropping over the last decade. Due to the large extension of the reserve, its relatively undisturbed forests, and its high connectivity with other reserves, we expected to find a higher population density than in the small, fragmented, and human-dominated reserves of the northern Yucatan Peninsula.

The low density found in this study can be explained by environmental and methodological issues. In 2019 when the surveys were conducted, extreme droughts and reduced precipitations were registered in the CBR, which extremely affected both wildlife and people (Pérez-Flores et al., 2021). These factors could have affected the presence and distribution of felids in the CBR, thus obtaining a low density in this study. Additionally, the density of jaguars was calculated with data obtained during six months over one year. A longer-term survey at a different time, can provide more accurate data on the density of this large felid. The density calculated for ocelots, showed a large population compared to others in adjacent areas. Satter et al. (2019) estimated a higher density in Belize, and Monterrubio-Rico et al. (2018) and Pérez-Irineo & Santos-Moreno (2014) a higher population in adjacent areas of the Selva Maya. However, our estimates were similar to those previously reported for the northern Yucatán Peninsula (14 individuals/100 km^2; Torres-Romero et al., 2017). This study presents the first preliminary estimate of ocelot density in the CBR. Further monitoring is needed to provide a more reliable estimate of the population in the area.

For both jaguars and ocelots, the “sex” model was more reliable than the no_sex. This can be explained by the fact that the camera-traps used for this survey were placed mostly on trails. Previous studies have shown that felids show a strong male bias for trail use (Harmsen et al., 2011). Thus, this model had more reliability than others.

The results from our study extended to all the potential habitats of the CBR (5,146 km^2 according to Chávez, 2010) would give a total of approximately 120 jaguars and 680 ocelots. These estimates should be taken with caution, given the small scale (81 km^2) and the short duration of our study (six continuous months of monitoring). It has been demonstrated that a small sample area with optimal camera-traps locations can lead to biased density estimates (Foster & Harmsen, 2012) and thus extrapolation of these results may not be accurate. A population of 300 individuals has been estimated as minimum for ensuring the viability of jaguars in the Mexican Selva Maya over the next 100 years (De la Torre et al., 2017). De la Torre et al. (2017) estimated a jaguar population of 700±1000 individuals in the whole Selva Maya, over an area of 89,000 km^2. The results of this study are not in line with this estimate.

Monitoring over a longer period and at different sites of the CBR is needed for a better estimate of felid populations. The results of our surveys in 202-2023 in different areas of the reserve might contribute to evaluate the viability of felid populations or assessing the ecosystem integrity in the CBR.

Jaguar individuals identified in the CBR in 2019

JunE15C2JG88a_I_00011a (Individual 1, female)

MayE14JG79_I__00001 (Individual 2, male)


FebE1C1JG41_03010288 (Individual 3, female)


MarE1C1JG28d_03170250 (Individual 4, male)

AprE24JG71b_IMG_0152 (Individual 5, male)

AprE24JG72b_IMG_0179 (Individual 6, male)

AprE1C2JG55e_IMG_5954 (Individual 7, male)

MarE14JG38c_I_00007c (Individual 8, male)

AprE23JG62_I__00009 (Individual 9, male)

AprE1C2JG54d_IMG_5587 (Individual 10, male)

AprE23JG60_I__00004 (Individual 11, male)

AprE23JG66_I__00078 (Individual 12, male)

ANNEX 1

Ocelot individuals identified in the CBR in 2019


AprE24OL99b_IMG_0077 (Individual 1, female)


AprE23OL97_I__00064 (Individual 2, male)


JunE12OL114_I__00006 (Individual 3, male)


FebE17OL22c_I_00034c (Individual 4, female)


AprE24OL101a_IMG_0164 (Individual 5, male)


FebE12OL19_I__00009 (Individual 6, male)


MayE20C2OL111a_DSCF0127 (Individual 7, male)


FebE6C2OL17i_03030141 (Individual 8, male)


JunE15C1OL117b_IMG_0077 (Individual 9, female)


MarE1C1OL40g_03190328 (Individual 10, female)


AprE1C2OL72c_IMG_4947 (Individual 11, female)


JulE20C1OL128a_IMG_0067 (Individual 12, male)

ANNEX 1

AprE1C2OL73f_IMG_5601 (Individual 13, male)

AprE24OL102a_IMG_0170 (Individual 14, male)

JunE20C2OL119c_DSCF0054 (Individual 15, female)


FebE18C1OL26b_I__00144 (Individual 16, male)

AprE24OL98_IMG_0053 (Individual 17, male)

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ANNEX 1

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Annex 2: Neo-tropical felid activity patterns in relation to potential prey and intra-guild competitors in the Calakmul Biosphere Reserve, Mexico

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Short title: Felid-prey activity in the Calakmul Biosphere Reserve

Abstract

Predator behaviours influence, and are influenced by, prey and competitor behaviours. Jaguars (*Panthera onca*), pumas (*Puma concolor*) and ocelots (*Leopardus pardalis*) coexist throughout their geographic range as the three largest predators in a multi-predator community across diverse environments. This study tested for non-random segregation and overlap in the activity patterns of these felids and their shared prey in the southern buffer zone of the Calakmul Biosphere Reserve, in southern Mexico, using camera traps during February to August 2019. We detected little temporal segregation between the nocturnal activities of jaguars, pumas, and ocelots, although pumas were more active closer to dawn. Jaguars had low activity overlap with species likely to be common prey, whereas ocelots had high overlap with their potential prey. Pumas displayed finer-scale similarities in activity with species likely to be common prey. In an understudied area of conservation importance, this study shows that temporal segregation is an unlikely mechanism of coexistence. Further research should incorporate spatio-temporal avoidance and dietary differences to improve our understanding of the mechanisms that drive coexistence between generalist species in a diverse assemblage of threatened felids.

1. INTRODUCTION

The activity patterns of terrestrial carnivores are influenced by a number of factors, including niche partitioning amongst their competitors (Hayward & Slotow, 2009; Lucherini *et al.*, 2009; Durant *et al.*, 2010; Karanth *et al.*, 2017), but also behavioural overlap with their prey (Linkie & Ridout 2011, Ramesh *et al.* 2012, Foster *et al.* 2013, Azevedo *et al.* 2018, Vilella *et al.* 2020). Many carnivores coexist with other predators that fill similar dietary and habitat niche dimensions, and are subject to intra-guild competition (Fedriani *et al.*, 2000; Durant *et al.*, 2010). Behavioural and morphological adaptations can minimize the potential for negative interactions amongst such competitors (St-Pierre *et al.* 2006, Hunter & Caro 2008, Sánchez-Barradas & Villalobos, 2020), by separating their niches along a behavioural dimension (Hutchinson, 1959). For sympatric carnivores, substantial differences in body mass and the subsequent size of prey selected can facilitate coexistence (Kiltie, 1984; Karanth & Sunquist, 1995; Rosenzweig, 1996; Hayward, 2006), whereas subdominant carnivores may occupy an opportunistic niche that maximises resource use whilst minimising competitive encounters (Ramesh *et al.*, 2012). In this study, we investigate whether the coexistence of three large predators in an understudied, but critical, area for conservation could be simply facilitated by differences in activity patterns that also relates to the activity patterns of known key prey species.

Amongst Neotropical terrestrial predators, jaguars (*Panthera onca*), pumas (*Puma concolor*), and ocelots (*Leopardus pardalis*) are the three largest felids in a more diverse multi-predator community, where jaguars are typically the dominant competitor (Elbroch & Kusler, 2018), and ocelots dominate within the mesopredator community (Oliveira *et al.*, 2010). The mechanisms potentially facilitating coexistence include selection for different prey (Farrell, *et al.*, 2000; Scognamillo *et al.*, 2003; Novack *et al.*, 2005; De Azevedo, 2008; Foster *et al.*, 2010) and spatio-temporal variation in space use (Harmsen *et al.*, 2009; Romero-Muñoz *et al.*, 2010; Herrera *et al*., 2018). All three felids select for similar habitats and spatial segregation alone is not thought to be a strong coexistence mechanism (Di Bitetti *et al.*, 2010; Boron *et al.*, 2018; Massara *et al.*, 2018). Ocelot occupancy can even increase in areas of high jaguar occupancy (Davis *et al.,* 2011). Some dietary differentiation occurs between species, most notably with ocelots which, at 20% of the body mass of the large felids, select for small prey including rodents, opossums, and reptiles (Emmons, 1987; Villa Meza *et al*., 2002; Bianchi *et al.*, 2014). In certain contexts, coexistence between the similar sized jaguar and puma can be facilitated by selecting for different prey within a common pool of prey species (Foster *et al* 2010). In Belize, jaguars select armadillo and peccary (white-lipped and collared), while pumas select paca and deer, although both predators will eat all of these species (Foster *et al.* 2010).

Temporal segregation has been recorded between jaguars and pumas in some regions (Monroy-Vilchis *et al.*, 2009; Romero-Muñoz *et al.*, 2010), and is considered to be a mechanism for reducing interactions and competition between morphologically similar species (Di Bitetti *et al.*, 2010). Alternatively, when activity patterns are similar, differences in prey species consumed may drive coexistence (Foster *et al.*, 2010; Harmsen *et al.*, 2011). Activity patterns of ocelots may reflect adaptations both for efficient predation and avoidance of larger competitors (Emmons, 1987), although it is difficult to un-confound these two factors. However, ocelots have been shown to increase nocturnal behaviour in response to higher puma densities which suggests avoidance behaviour (Massara *et al.*, 2012).

Activity patterns of predators can show high overlap with activity of the prey species they select for in a local area (Emmons *et al.,* 1989; Di Bitetti *et al.,* 2006; Harmsen *et al.,* 2011; Foster *et al,.* 2013; Pratas-Santiago *et al.,* 2016; Herrera *et al*., 2018). For example, jaguars shift activity patterns from nocturnal to diurnal when switching from wild to domestic prey (Rabinowitz & Nottingham, 1986). The activity patterns of jaguars and pumas vary considerably within and amongst study areas. Both species have shown predominantly nocturnal activity in Central and Western Mexico (Monroy-Vilchis *et al.,* 2009; Núñez *et al.,* 2002), in Cockscomb Basin Belize (Harmsen *et al.,* 2009; Harmsen *et al.,* 2011) and in the Venezuelan llanos (Scognamillo *et al.,* 2003) and Corcovado and Santa Rosa National Parks in Costa Rica (Herrera *et al*., 2018). They are reported as crepuscular in four biomes of Brazil (Foster *et al.,* 2013) and in the Gran Chaco, Bolivia (Maffei *et al.,* 2004); as diurnal in Pantanal, Brazil (Crawshaw & Quigley, 1991) and in Blue Creek in Belize (Dobbins *et al.,* 2018); and as active all day and night in Pantanal, Brazil (Schaller & Crawshaw, 1980). These differences are likely influenced by differences in prey community compositions, seasonal availability of prey, and human disturbance. In contrast, ocelots and their small-bodied prey (i.e., rodents and opossums) are typically nocturnal across their range (Emmons *et al.*, 1989; Di Bitetti *et al.*, 2006; Pratas-Santiago *et al.*, 2016).

The Calakmul Biosphere Reserve (CBR) in the Yucatan Peninsula, contains the largest expanse of tropical forest in Mexico, connecting to south to the forests of Central America. Although there are no recent studies of the ecology of felids in CBR, evidence suggests that it holds stable populations of large felids (Ceballos et al, 2002; Chavez, 2010; Rodriguez-Soto et al, 2011). The area presents an opportunity to study felid ecology in a vast and relatively undisturbed ecosystem that is understudied relative to its conservation importance. Recent encroachment by humans, however, raises the urgency of setting a knowledge baseline for felid ecology and coexistence mechanisms in this region, for monitoring future ecological disturbances if the reserve becomes further encroached by humans. Here, we analysed the activity patterns of jaguars, pumas, and ocelots in the CBR, and we specifically tested for evidence of temporal segregation between felids, and temporal overlap with other co-occurring species that are potential prey. This is the first study of circadian activity patterns of the three felids and their prey in the CBR.

2. METHODS

1. Study site

The study was conducted in the southern buffer zone of the CBR, in southern Campeche (18o08’-18o38’N, 89o31’-89o44’W) on the Yucatan Peninsula, Mexico (Fig. 1). The study site is situated within tropical semi-deciduous forest which is the primary forest type across the CBR (Martínez & Galindo-Leal, 2002). The wider CBR, comprises 723,185 ha, lies within a larger network of protected forests that covers 10.6 million ha of connected forest within Mexico, Belize and Guatemala (Vester et al., 2007). Water availability is highly variable between and within years, and is typically limited to temporary ponds, known as aguadas, during the dry season, which extends from April to November (Reyna-Hurtado et al., 2010; Reyna-Hurtado et al., 2019).

2. Data collection

A total of 36 passive infrared digital cameras activated by a heat-motion sensors (Bushnell Trophy HD, Cuddeback C1, and Browning Strike Force Extreme) were positioned on and off trails, individually or in pairs, with a total of 27 camera-trap stations in 2019. The camera-trap grid followed the standardised design of the ‘National Census of the Jaguar and its Prey’ (CENJAGUAR; Chávez et al., 2007), whereby nine contiguous 3×3-km cells, totalling an area of 81 km2, within our study site were each assigned three camera stations, with one positioned next to an aguada if present, and all stations separated by a minimum of 1 km (Fig 1). Cameras were positioned on trees ~50cm off the ground and set to take a burst of three photos whenever activated across the 24-hour period. Data were collected continuously from February to August 2019, avoiding the peak rainy season after August to prevent camera damage from flooding. The cameras were checked once each month to verify their functioning and change the SD card and/or batteries as necessary. Cameras were active 183 days, making a total sampling effort of 4,941 camera-trap days. Animals in photos were identified to species with reference to field guides (Reid, 2006) and species identification and other metadata (e.g., time and date) encoded for using Timelapse software (Version 2; Greenberg, 2018).

To avoid pseudoreplication, each photographic record of a species was treated as an independent event if separated by at least 30 minutes from a capture of the same species at the same camera-trap station (Sollmann, 2018). Where possible, we identified jaguars and ocelots by cataloguing the spot pattern shown on both flanks in photographs a pair of cameras. This allowed to understand the minimum number of individuals that the activity patterns were based upon for these two species.

3. Potential prey species

Based on previous dietary studies and observed predation events in the CBR and the Yucatan Peninsula (Aranda & Sánchez-Cordero, 1996; Ávila-Najera *et al,*, 2018; Piña-Covarrubias, 2019; Pérez-Flores *et al.,* 2020), we considered 10 species that are potential prey for at least one of jaguars, pumas, or ocelots in the CBR for which we had sufficient sample sizes for analysis (see Table S1 for full details): Baird's tapir (*Tapirus bairdii*), collared peccary (*Pecari tajacu*), brocket deer (*Mazama* sp.), white-tailed deer (*Odocoileus virginianus*), ocellated turkey (*Meleagris ocellata*), great curassow (*Crax rubra*), white-nosed coati (*Nasua narica*), paca (*Cuniculus paca*), agouti (*Dasyprocta punctata*), and common opossum (*Didelphis virginiana*). Low sample sizes ($n < 20$ independent capture event) for nine-banded armadillo (*Dasypus novemcinctus*) and white-lipped peccary (*Tayassu pecari*) precluded their inclusion. Common prey species for jaguars and pumas in the Yucatan Peninsula are frequently document as being medium-large prey, which are primarily ungulates. There have been no published diet studies of ocelots from the Yucatan Peninsula, so we use studies from outside of this area (Villa-Meza et al., 2002; Moreno et al., 2006; Aliaga-Rossel et al., 2006). While we accept this reduces the robustness of our inferences of ocelot prey within the Yucatan Peninsula, we use this information to infer potentially common prey species where smaller prey, including agoutis, pacas, and common opossums, are typically the most common prey of ocelots.

4. Statistical analysis

Activity patterns for each species were classified by the proportion of activity records detected at different periods of the day, as in Foster *et al.* (2013). Species were classified as: diurnal if activity records predominantly occurred between an hour after dawn (06:30 h) and an hour before dusk (19:00 h); nocturnal if activity records predominantly occurred between an hour after dusk and an hour before dawn; crepuscular if activity records predominantly occurred an hour either side of dawn and dusk; and cathemeral if evenly distributed across the 24-hour cycle.

Species specific activity patterns were estimated with non-parametric kernel densities, using the '*densityPlot*' function in the '*Overlap*' package (Meredith *et al*., 2018). Overlap in activity patterns amongst felids and between felids and their prey was estimated using the '*overlapEst*' function to calculate an overlap coefficient (Δ) that ranged from 0 (no overlap) to 1 (complete overlap). Alternative versions of this coefficient were used, depending on sample sizes: Δ_1 for < 50 activity records, and Δ_4 for ≥ 50 activity records, as recommended by Meredith *et al*. (2018). A confidence interval (CI) was calculated for each pairwise activity overlap by bootstrapping the original sample 1,000 times. Finally, a Mardia-Watson-Wheeler (MWW) test was applied to each pair-wise comparison amongst felid species, and felid with prey species, to identify whether the pair shared a similar temporal distribution of activity.

All analyses were run in R version 4.0.3 (R Core Team, 2017). Data and codes used for statistical analyses and production of figures are available on GitHub.

3. RESULTS

The study period yielded a total of 2,616 independent camera-trap records of predator and prey species. The dataset included 95 jaguar, 85 puma, and 117 ocelot records. Sample sizes were generally higher and more variable for prey species, with 94 tapir, 136 collared peccary, 101 brocket deer, 478 white-tailed deer, 260 agouti, 239 coati, 23 paca, 37 common opossum, 578 great curassow, and 373 ocellated turkey records. We identified 12 jaguars, including two females, seven males, and three individuals that we could not identify their sex, and 17 ocelots, including five females, 11 males, and one individual that we could not identify their sex.

1. Species activity patterns

Jaguars, pumas, and ocelots displayed nocturnal behaviours with some crepuscular tendencies (Table 1; Fig. S1). Jaguars and ocelots had activity peaks in the middle of the night, whereas pumas had the greatest activity peak closer to dawn. Amongst prey species tapir, opossums, and paca had nocturnal behaviours with peaks in the middle of the night, whereas brocket deer showed a cathemeral behaviour Table 1; Fig. S1). All other prey species showed diurnal behaviours with peaks in activity closer to dawn and/or dusk, other than coatis which displayed an activity peak at midday.

2. Species activity overlap

All three felids showed high overlap in their nocturnal activity patterns (Figs 2 and 3; jaguars and ocelots: $\Delta_{4} = 0.87$ CI: 0.77-0.93; jaguars and pumas: $\Delta_{4} = 0.75$, CI: 0.62-0.85 pumas and ocelots: $\Delta_{4} = 0.77$, CI: 0.63-0.86). Activity patterns of jaguar and ocelot were indistinguishable with near identical peaks in activity (MWW test: $W = 0.15$, $p = 0.93$; $\Delta_{4} =$ 0.87), although both differed detectably from puma (jaguar and puma: $W = 11.8$, $p = 0.002$; ocelot and puma: $W = 8.9$, $p = 0.02$).

The proportion of activity overlap between jaguars and potential prey was high only for nocturnal species (Figs 3 and 4), including tapir ($\Delta_{4} = 0.81$, CI: 0.69-0.89) and common opossums ($\Delta_{4} = 0.75$, CI: 0.62-0.85), which were likely only incidental prey for jaguars (Table S1). These nocturnal mammals had indistinguishable activity patterns from jaguar (tapir: $W =$ 4.97; $p = 0.08$; opossum: $W = 4.8$; $p = 0.09$). Activity overlap with jaguar was relatively high for brocket deer ($\Delta_{4} = 0.69$, CI: 0.56-0.79) and paca ($\Delta_{4} = 0.61$, CI: 0.47-0.74), and relatively low for collared peccary ($\Delta_{4} = 0.48$, CI: 0.39-0.58) as well as for diurnal species, which were likely more common prey for jaguar.

Compared to jaguars, pumas had higher activity overlap with potential prey that had more diurnal tendencies and were likely to be common prey (Figs 3 and 4; Table S1). Puma activity overlapped most with brocket deer ($\Delta_{4} = 0.83$, CI: 0.56-0.79) and was indistinguishable from their activity patterns ($W = 1.99$, $p = 0.36$). Activity overlap with puma was also relatively high for paca ($\Delta_{4} = 0.65$, CI: 0.52-0.76), opossum ($\Delta_{4} = 0.67$, CI: 0.55-0.78), white-tailed deer ($\Delta_{4} = 0.64$, CI: 0.54-0.73), and tapir ($\Delta_{4} = 0.71$, CI: 0.69-0.89).

The proportion of activity overlap between ocelots and potential prey involved high overlap with nocturnal species (Figs 3 and 4), including common opossums ($\Delta_{4} = 0.78$, CI: 0.65-0.87) and relatively high for paca ($\Delta_{4} = 0.65$, CI: 0.51-0.76), both of which were likely common prey (Table S1). For both paca and common opossums, activity patterns were indistinguishable from those of ocelots (paca: $W = 6.00$, $p = 0.05$; common opossum: $W =$ 6.1, $p = 0.05$).

4. DISCUSSION

Ecological niche segregation between felids typically occurs in spatial, temporal, or dietary dimensions, or some combination of these (Crashaw & Quigley, 1991). In our study, we found that temporal segregation was not a clear driver of coexistence and that, for jaguars at least, activity patterns did not coincide with species that are likely to be key prey. In highly disturbed protected areas of the Northern Yucatan Peninsula, Piña-Covarrubias (2022) likewise found no temporal segregation between the nocturnal jaguar and puma and no major overlap with the activity patterns of their main prey. In contrast, Ávila-Najera *et al* (2016) in the Selva Maya, and Harmsen *et al*. (2011) in Belize, detected activity overlap of nocturnal jaguars and pumas with their prey. Similarly, in Northern Mexico, jaguars and pumas were mainly nocturnal, and their activity patterns overlapped with those of deer and domestic cow calves (Gutiérrez-González & López-González, 2017).

We did not detect a trend of temporal segregation between these three nocturnal predators which contrasts to some studies across their range where temporal segregation is strong, including in southern Bolivia (Romero-Munoz *et al*., 2010) and in the Paraguayan Chaco (Taber *et al*., 1997). However, fine-scale differences in activity patterns were detected, particularly between morphologically similar jaguar and puma. Although pumas and jaguar were both nocturnal, pumas presented a higher activity peak closer to dawn, which reduced activity overlap with jaguars. This difference in activity patterns caused pumas to have a higher overlap with potential prey species than did jaguars, particularly with peccary, that were previously reported as main prey of jaguars. Such fine-scales differences in activity patterns could play a key role in facilitating the coexistance of predators in the CBR (Di Bitetti *et al*., 2010; Herrera *et al.*, 2018), but further research is required. Such trends were also found in Costa Rica (Herrera *et al*., 2018) and in Belize (Davis et al., 2011) with almost identical activity patterns between the jaguars and ocelots, but with differences in activity patterns being greater between these two felids and pumas as the intermediate sized felid.

The near identical activity peaks of jaguars and ocelots suggests that trophic segregation determines their coexistence, which could be assumed based on large morphological differences driving distinct prey preferences (Emmons 1987, Farrell *et al*., 2000, Herrera *et al.,* 2018). Ocelot activity overlapped highly with common opossums, a nocturnal species that has the potential to be a main prey species. However, jaguars did not strongly overlap their activity patterns with their reported preferred prey of collared peccary. They did overlap with the activity of tapirs, which jaguars have been observed hunting in the CBR (Pérez-Flores *et al*., 2020), 2020), and to a lesser extent brocket deer. This could suggest differences in preferred prey in the CBR to what was previously observed (Aranda & Sánchez-Cordero, 1996), but it could also indicate that jaguars were not necessarily detected during periods of active hunting because tapir and opossums are unlikely to be common prey. The near identical activity patterns of jaguars and ocelots could potentially increase mortality risk for ocelots, although evidence remains scarce (ocelot remains in jaguar scats: Gonzalez-Maya *et al*., 2010; hunting of an ocelot by a jaguar observed directly: Perera-Romero *et al.*, 2021). Further research into spatio-temporal avoidance of jaguars by ocelots could reveal further mechanisms that facilitate their co-existence in the CBR.

Our results contribute to this growing body of evidence that mechanisms of coexistence vary considerably throughout the geographic range of these felids but also that behaviour of felids can be similar within vast stretches of habitat compared to smaller reserves (Piña-Covarrubias et al., 2019). We conclude that temporal and trophic segregation, the latter implied through differences in overlap with shared prey, were not strong mechanisms determining coexistence of felids in the CBR. Further research on this community of predators and their prey should add the spatial to the temporal dimension, which in combination are suggested mechanisms of coexistence elsewhere (Foster et al., 2013; Porfirio et al., 2016; Gutierrez-González & Lopez-González, 2017). In the meantime, we rule out temporal segregation as a means of coexistence between predators, which informs understanding and conservation of these species within the CBR, a key area of conservation in Central America.

TABLE 1. *Sample size (n) of independent records for each species, with the proportion of diurnal, nocturnal, and crepuscular records. Activity schedule is based on the proportion of activity records (diurnal >50% records during the day; nocturnal >50% of records during the night; cathemeral <50% records falling within any day, night, dusk, and dawn period).*

Species	*n*	*Diurnal*	*Nocturnal*	*Dusk/Dawn*	*Activity schedule*
Felids					
Jaguar	95	0.19	0.63	0.18	Nocturnal
Puma	85	0.25	0.52	0.24	Nocturnal
Ocelot	117	0.12	0.64	0.24	Nocturnal
Large mammal prey (>15kg)					
Tapir	94	0.03	0.82	0.15	Nocturnal
Collared peccary	136	0.59	0.15	0.26	Diurnal
Brocket deer (sp.)	101	0.33	0.44	0.24	Cathemeral
White-tailed deer	478	0.61	0.16	0.23	Diurnal
Small mammal prey (<15kg)					
Agouti	260	0.61	0.03	0.37	Diurnal
Coati	239	0.84	0.03	0.13	Diurnal
Paca	23	0	0.91	0.09	Nocturnal
Common opossum	37	0	0.92	0.08	Nocturnal
Terrestrial birds					
Great curassow	578	0.62	0.01	0.38	Diurnal
Ocellated turkey	373	0.69	0.03	0.28	Diurnal

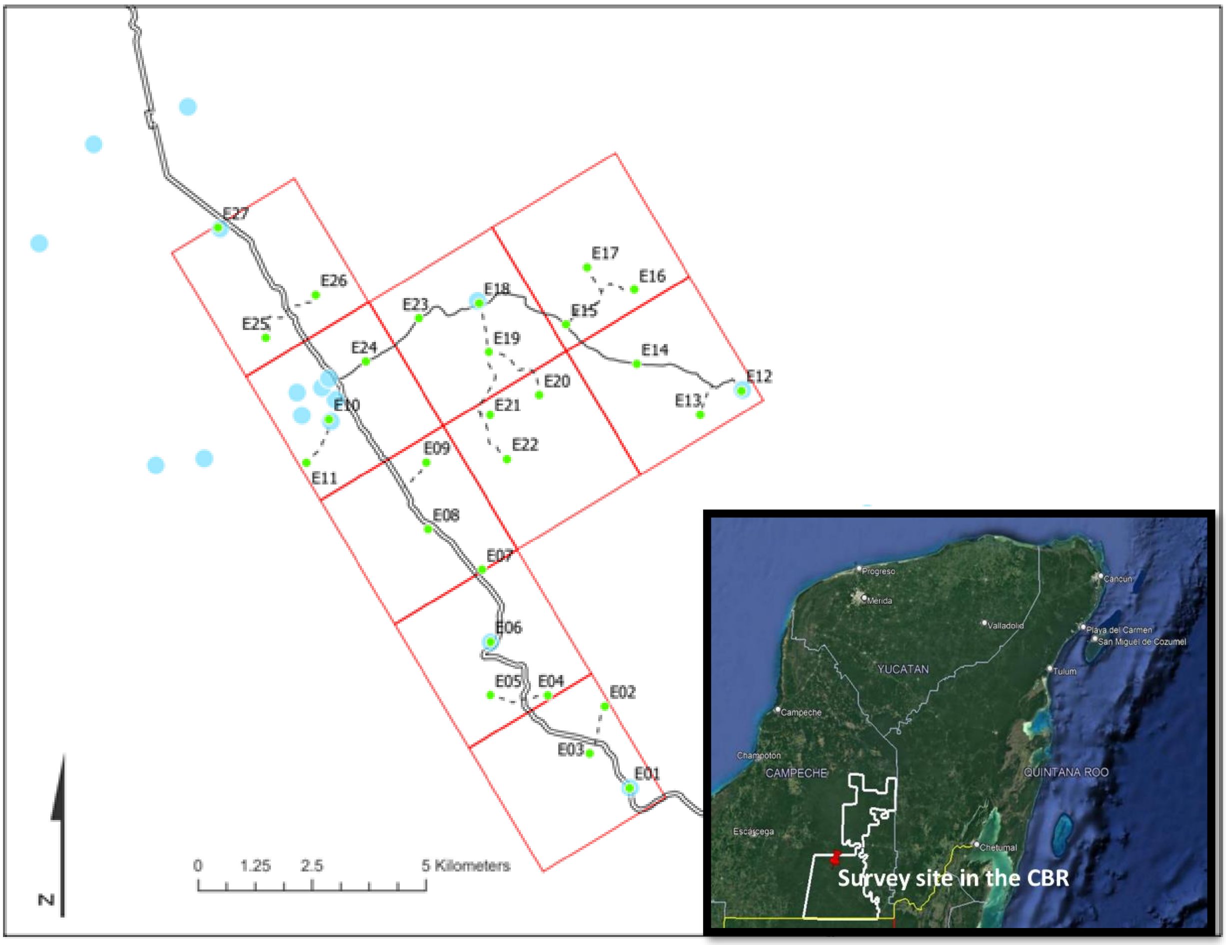

FIGURE 1. *The study area located in the Calakmul Biosphere Reserve, showing the nine 3×3 km cells (red squares) and locations within them of camera-trap stations (small green dots), temporary water bodies (i.e. temporary ponds "aguadas"; large blue dots), roads (double line), access trail (single line) and tracks (dotted line). Stations E1, E4, E6, E8, E10, E11, E13, E15, E17, E18, E20, E22, E25 and E26 were double camera station and the rest were single. Some tracks were made to set the cameras, others were pre-existing. The inset map shows the location of the study site (red pin) within the wider Calakmul Biosphere Reserve (white outline) in the Yucatan Peninsula, Mexico, taken from Google Earth.*

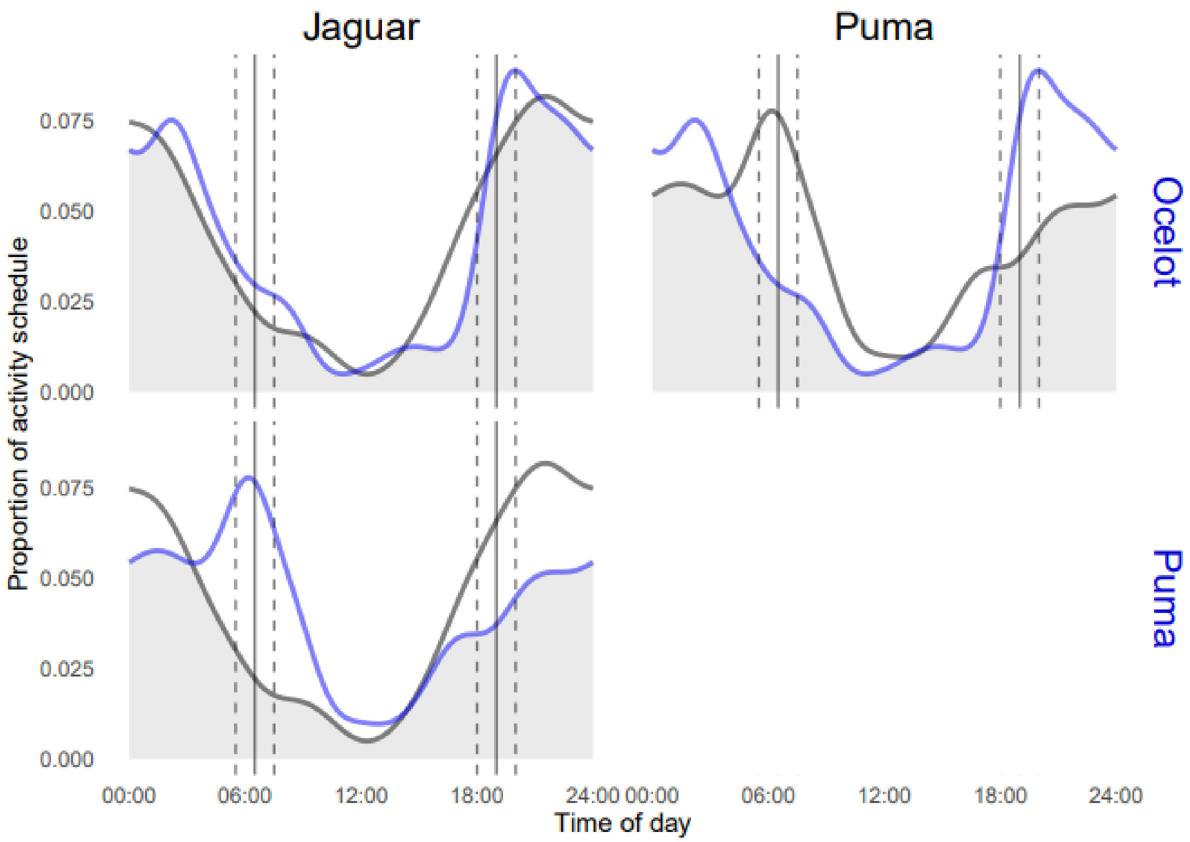

FIGURE 2. *Activity patterns of predators in the Calakmul Biosphere Reserve. Pairwise comparisons of species activity overlap are shown in each figure with the identity of each activity pattern for each predator indicated by colour, and overlap in grey shading. Dawn and dusk are shown (vertical, solid lines) with 30-minute seasonal variation around these time periods (vertical, dashed lines).*

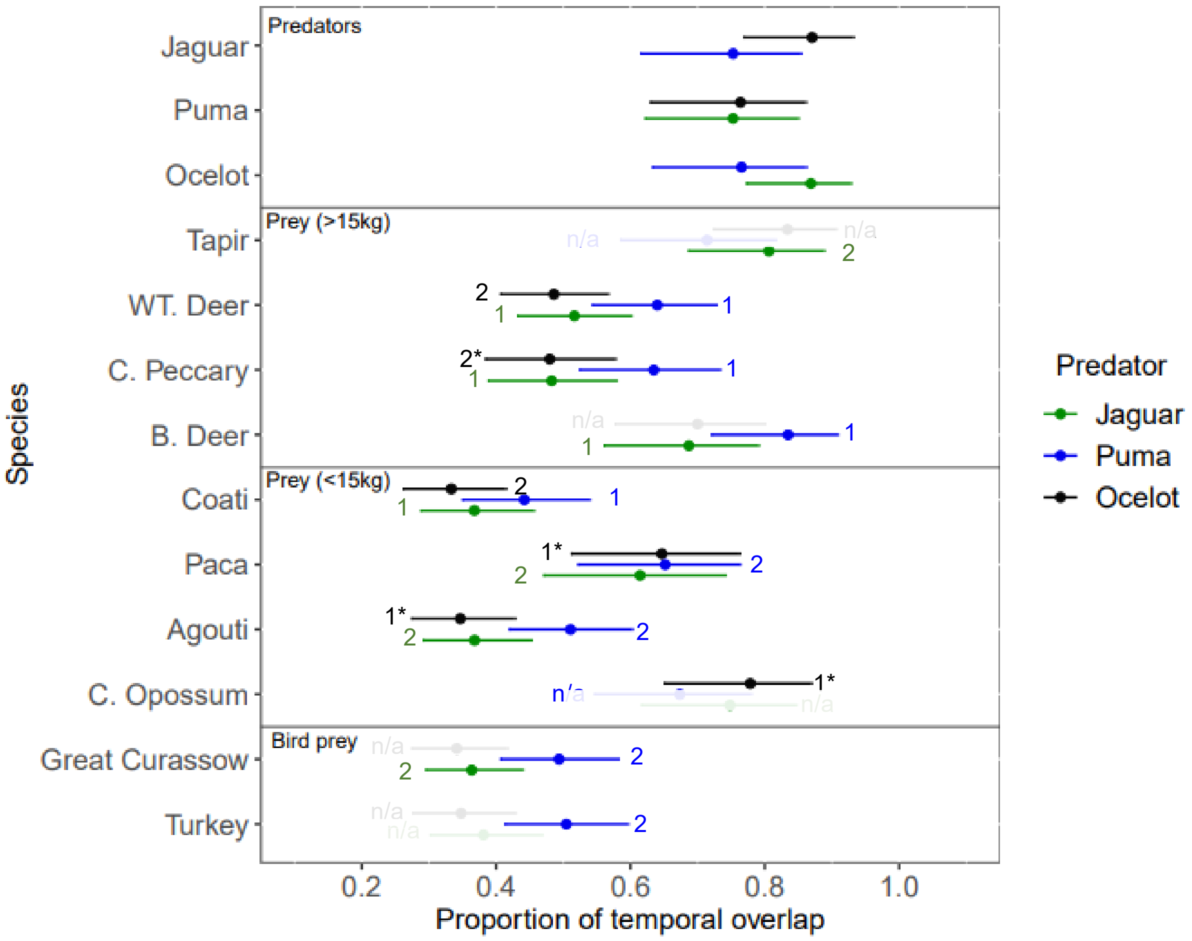

FIGURE 3. *Overlap in activity patterns between y-axis species and jaguar (dark green), puma (blue), and ocelot (black). Bars represent 95% confidence intervals in the estimation of activity overlap after bootstrapping kernel density estimates from activity records 1,000 times. Numbers (and n/a) next to bars indicate potential importance rankings of each prey to each predator, based upon jaguar and diet studies in the Yucatan Peninsula (Aranda & Sánchez-Cordero, 1996; Piña-Covarrubias, 2019;* Ávila–Nájera et al 2018*), whereby 1 = potential common prey; 2 = occasional or at least documented potential prey; n/a = prey not documented.*

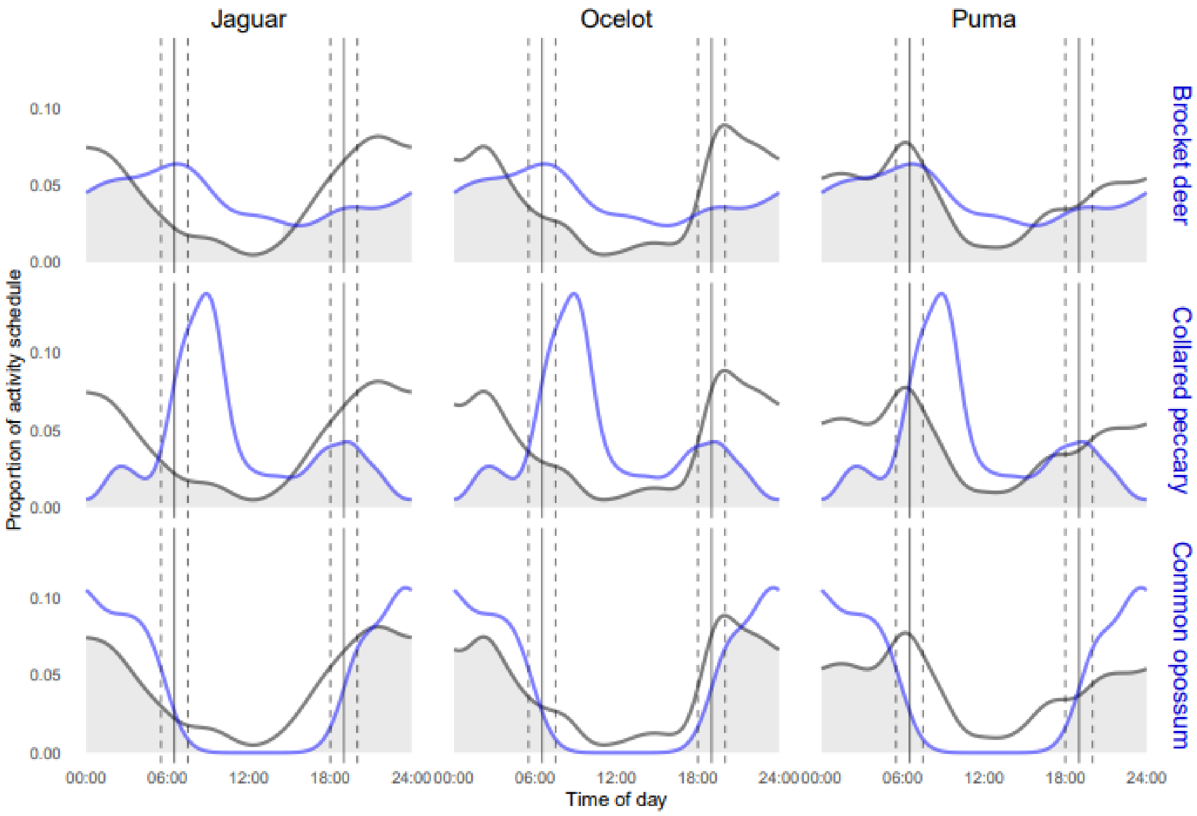

FIGURE 4. *Activity patterns of predators (black) and three representative potential common prey species (blue). Grey shading shows overlap in pairwise species activity patterns; dawn and dusk are shown (vertical, solid lines) with 30-minute seasonal variation around these time periods (vertical, dashed lines). Prey species were chosen as they are likely common prey species of jaguars (collared peccary) and pumas (brocket deer) and common ocelots (opossums).*

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DATA AVAILABILITY STATEMENT

ANNEX 2

All data used for the analysis in this manuscript, and fully reproducible and annotated R scripts, are available on Github in the following repository: https://github.com/osmiddleton/Biotropica-2023-Calakmul_mammal_activity_patterns. The authors will make the data available upon request, if these cannot be accessed through Github.

DISCLOSURE STATEMENTS

The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

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