Social-Ecological Resilience in Agriculture: Producer Experiences in Central and Northern Costa Rica

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The agriculture sector, while essential for human well-being, faces substantial challenges related to climate change, biodiversity loss, and social inequality. The purpose of this research was to determine how agricultural producers strengthened the social-ecological resilience of their production systems in response to these key challenges. Resilient agricultural systems provide a myriad of social and ecological benefits to communities through essential ecosystem services. Therefore, deepening our understanding on how best to support and enhance resilience among agricultural producers is imperative, while also recognizing that beneficial management strategies are often highly location-specific. Focused on producers in Costa Rica's Central Valley and Northern Zone, the objectives of this study were to identify the local strategies and practices producers employed to build their social-ecological resilience and examine the barriers that limited their resilience. The final research objective was to contribute to the literature on social-ecological resilience indicators in the context of agriculture using insights from this study. To address these objectives, I conducted semi-structured interviews with crop and livestock producers in Alajuela, San José, and Cartago. Participants were asked questions aimed at uncovering information related to eight resilience indicators. These indicators were: species and varietal diversity, landscape diversity, sustainable resource use, availability and exchange of seeds and livestock, innovation in management practices, local networks and institutions, gender, and autonomy. Findings from this study revealed how producers experienced and perceived aspects of their production systems which have been identified in the literature to influence resilience. These insights can guide future agricultural management practices both in and outside the study area, promoting viable, sustainable, robust, and resilient food systems.

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1. Introduction

1.1. Thesis Structure

This thesis is comprised of six sections. In this first section, I introduce the context of the research, as well as the research objectives and the guiding theoretical and conceptual framework. The second section contains a review of the literature related to the social and environmental challenges that impact agricultural production, the forms of production that best respond to those challenges, and the various ways social-ecological resilience in agriculture can be measured. Section three outlines the methodology and methods I utilized both to conduct this research and to analyze the resulting data. In section four, I present the key findings from this study, which I then discuss in the context of the relevant literature in section five. Finally, in section six, I conclude by summarizing the research outcomes and contributions of this study, as well as provide recommendations for future research.

1.2. Research Context

The agriculture sector is a substantial contributor to numerous human-induced problems globally (Lynch et al., 2021; Ortiz et al., 2021). Of the three main climate pollutants associated with climate change, namely methane, nitrous oxide, and carbon dioxide, agriculture is responsible for around half of all anthropogenic methane emissions and nearly three-quarters of anthropogenic nitrous oxide emissions (IPCC, 2019). Carbon dioxide emissions associated with agriculture are harder to quantify, however, around 13% of global anthropogenic carbon emissions from 2007 to 2016 were a result of the conversion of forest and peatland ecosystems into land for agricultural use (IPCC, 2019; Lynch et al., 2021). Land-use change for agricultural purposes is also one of the leading causes of biodiversity loss in terrestrial ecosystems (Kanianska, 2016). The high impact of agriculture on biodiversity can be attributed to the "drastic simplification" of natural ecosystems that occurs when land is used for anthropogenic purposes (Baudron et al., 2009, p. 2627). This simplification is due to the removal of most plant species and the resulting elimination of other organisms, including insects and larger fauna (Baudron et al., 2009).

Agriculture is uniquely positioned as both a significant contributor to ecological challenges including climate change and biodiversity loss, and as one of the world's most vulnerable sectors to the implications of these challenges (Dudley & Sasha, 2017; Parker et al., 2019). Additionally, social factors including gender inequality and limited access to information in rural areas also contribute to the vulnerability of food production (Anderson et al., 2021; FAO, 2024a). As a sector that is "critical for human well-being," building the capacity of agricultural systems and the people who manage them to respond, adapt, persist, and even thrive in the face of complex and uncertain challenges is extremely important (Bennett et al., 2014, p. 65). One way to support the advancements of such systems is through research into the development of resilient agriculture (Bennett et al., 2014).

Resilience in the context of agricultural production refers to the ability of a system to cope with and respond to challenges (Meuwissen et al., 2019). Bennet et al. (2014, p. 66) define resilient agriculture as a system which meets food and development-related needs at local and global scales, "over both the short and very long terms," without undermining Earth's systems. Resilient agriculture therefore must be persistent and adaptive, and transformative when necessary, to ensure systems can respond to changing environmental conditions and human needs (Bennett et al., 2014). Various regions in Latin America, including communities in Costa

Rica, are at the forefront of the expansion of resilient agriculture (Altieri & Toledo, 2011; Harron & Matthew, 2022).

1.3. Study Area

This study is concentrated on producers in Costa Rica. Costa Rica is located in Central America between Nicaragua and Panama, as shown in Figure 1.1 (a), and borders both the North Pacific Ocean and the Caribbean Sea. Primary data collection for this research took place in Costa Rica's Central Valley and Northern Zone; displayed in Figure 1.1 (b), these regions include the provinces of Alajuela, San José, and Cartago. According to the United Nations Food and Agriculture Organization (FAO), around 36% of land in Costa Rica is used for agricultural production; the sector also accounts for 14% of the country's employment, indicating both agriculture's ecological and social significance in Costa Rica (2024c). Despite this significance, agriculture contributed to only 4.7% of Costa Rica's gross domestic product (GDP) in 2021 (OECD, 2023a), down from 5.6% in 2013 and 13.7% in 1994 (OECD, 2017). One explanation for the declining contributions of agriculture to Costa Rica's GDP is the transition that some communities, particularly in the Northern Zone, are making from economies focused on agricultural production to tourism-based economies (Matarrita-Cascante et al., 2010).

Agricultural producers in Costa Rica tend to fall into one of two categories: medium and large-scale farms producing for export, and small-scale farms producing primarily for the domestic market (OECD, 2017). While medium and large farms in Costa Rica are consolidating, the number of small farms, comprising areas of five hectares or less, is increasing, now making up the majority of agricultural systems in the country (OECD, 2017). These production systems tend to be less competitive and experience slower growth than larger production systems (OECD, 2017). Interestingly, most of the "flat and fertile" land used for agricultural production in Costa Rica is owned by large-scale producers, while small-scale producers often occupy less fertile areas on sloped land (World Bank Group et al., 2014, p. 5). Out of these small-scale producers, over a third grow *Coffea arabica* L. (coffee) as their principal crop (OECD, 2017).

Figure 1.1. (a) Map of the Americas highlighting the location of Costa Rica. (b) Map of Costa Rica showing the country's seven provinces. Costa Rica's Northern Zone and Central Valley are outlined in bold. Figure created using MapCreator.io.

In general, Costa Rica is recognized globally as a key model for sustainable development (Harron & Matthew, 2022). In 2019, Costa Rica received the Champions of the Earth award, the highest environmental honour presented by the United Nations, for its efforts in conservation (Murillo, 2024). The national government also committed to a policy plan related to climate change adaptation, which, among other goals, aims to promote biodiversity conservation on farms that have forest cover, as well as promote water security through the proper management of water basins (FAO, 2024c). Despite these efforts, certain agricultural practices in Costa Rica continue to drive biodiversity loss and threaten ecosystem health, including high rates of pesticide use and large areas dedicated to monocultures (Fournier et al., 2018; OECD, 2017). Monocultures refer to the continual cultivation of the same plant species on the same unit of land for several years (Franco et al., 2022). In the Central Valley, monocultures exist largely for coffee production, while in the Northern Zone, they are commonly used to produce *Ananas comosus* L. (pineapple) (Hergoualc'h et al., 2012; Rodríguez Echavarría & Prunier, 2020). Table 1.1 compares many of the biophysical characteristics of the Central Valley and the Northern Zone.

In terms of socioeconomic characteristics, Costa Rica has one of the lowest poverty rates in Latin America (World Bank Group, 2023). Before the COVID-19 pandemic, 13.7% of the population lived below the poverty line for upper-middle-income countries, set at 6.85 US dollars per day per capita (World Bank Group, 2023). In 2023, that number dropped to 12.7%, its lowest since 2010 (World Bank Group, 2024). In rural areas of Costa Rica, those experiencing poverty tend to be landless workers and small producers growing traditional products (Pomereda, 2003). Small-scale producers in Costa Rica still face a lack of agricultural infrastructure, low education levels, and inadequate integration into supply chains as barriers to reducing poverty (OECD, 2017).

Table 1.1. Biophysical characteristics of Costa Rica's Central Valley and Northern Zone

Biophysical Characteristics	Central Valley	Northern Zone
Latitude and Longitude	9°51'51.98"N, 83°55'9.98"W (Cartago)	9°13'60.00"N, 83°34'59.99"W (La Fortuna)
Average Annual Temperature	22.6°C	25.7°C
Average Annual Percipitation	2,789 mm	2,887 mm
Average Elevation (above sea level)	1000 m	975 m
Soil Classification	Lithosols and Latosols	Latosols and Andosols
Physiology	Mountainous and hilly	Primarily plains, wetlands, and tropical rainforests
Predominant Types of Agriculture	*Coffea arabica* L., *Bos taurus* L., and vegetable production.	*Bos taurus L.* and crops including *Oryza* sp. L., *Saccharum officinarum* L., *Ananas comosus* L., *Musa acuminata L., Phaseolus vulgaris* L., *Coffea arabica* L., and *Zea mays* L.
Population Density (people per km²)	322.4/km²	106.1/km²
Anticipated Effects of Climate Change	Storms and floods are predicted to increase in frequency, impacting water and sanitation systems as well as agricultural production. Infrastructure near mountains are becoming increasingly vulnerable to landslides generated by intense precipitation.	The number of very hot days (35°C and above) is predicted to increase, with implications for human health, agricultural production, and ecosystems. Droughts are anticipated to increase in intensity and frequency, affecting water availability and agriculture.

(Fisher & Ryan, 2006; Tully & Lawrence, 2012; World Bank Group, 2021a, 2021b; World Bank Group et al., 2014).

The average monthly household income in Costa Rica in 2023 was 1,049,142 colones (2,905 CAD) (Instituto Nacional de Estadística y Censos, 2024). In 2024, that number jumped to 1,119,660 colones (3,041 CAD) (Instituto Nacional de Estadística y Censos, 2024). Despite continued economic growth in Costa Rica, income inequality has held stable at relatively high levels (World Bank Group, 2024). Vulnerable groups, including the country's Indigenous populations, Afro-descendants, and Nicaraguan migrants have benefitted the least from increased economic prosperity (World Bank Group, 2024). Additionally, between 2021 and 2023, 16.2% of Costa Rica's population experienced moderate or severe food insecurity (FAO, 2024b). Looking at female adults only, that number rose to 18.6% (FAO, 2024b). Moderate food insecurity refers to compromised quality and quantity of food, while severe food insecurity indicates missed meals, reduced food intake, and in some cases, going multiple days without food (Statistics Canada, 2024).

Regarding employment, 54.4% of people in Costa Rica, aged 15 to 64, had a paid job in 2018 (OECD, 2020). This is below the Organisation for Economic Co-operation and Development (OECD) average of 57.1% (2020). Consequently, the unemployment rate in Costa Rica in 2018 was well above the OECD average (OECD, 2020). In the same year, men made up 68% of those formally employed, indicating women were underrepresented in the labour market (OECD, 2020). Nevertheless, Costa Rica fared relatively well based on the United Nations Development Programme's (UNDP) Gender Inequality Index (GII), which is measured using data regarding reproductive health, empowerment, and labour market participation (UNDP, 2024). In 2022, Costa Rica was ranked 58th out of 166 countries and was given a GII score of 0.232, 0 being the marker of equality for women and men, and 1 being the greatest gap of inequality possible for each measure (UNDP, 2024).

Concerning the UNDP's Human Development Index (HDI), Costa Rica also performed well, ranking 64th out of 193 countries in 2022 (UNDP, 2024). The HDI measures the average achievement of a country on a scale between 0 and 1 concerning three key aspects of human development: "a long and healthy life, access to knowledge, and a decent standard of living" (UNDP, 2024, para. 1). In 2022, Costa Rica's HDI value was 0.806, up from 0.659 in 1990, indicating substantial increases in human development over a 30 year period (UNDP, 2024). Still, according to the OECD (2023b), Costa Rica's educational outcomes are weak. Despite a strong focus on education, demonstrated through greater spending relative to GDP compared to most other OECD countries, only 43% of adults aged 25-63 had completed upper secondary education in Costa Rica in 2021 (OECD, 2023b). This is significantly lower than the OECD average of 79% (2023b). Owing to the country's commitment to increasing education levels, the portion of the population aged 25-34 lacking upper secondary education in Costa Rica decreased by 11% between 2016 and 2023 (OECD, 2024).

1.4. Research Question and Objectives

The goal of this research study is to contribute to existing knowledge, while adding location-specific context, regarding how producers can best create and improve socially and ecologically resilient agricultural production systems in the face of persistent environmental and social challenges. This thesis considers the following research question: How do producers strengthen the social-ecological resilience of their production systems? This study is focused on producers in Central and Northern Costa Rica and reveals how they experience and perceive aspects of their production systems which have been identified in the literature to contribute to social and ecological resilience.

My specific research objectives are to:

1. Identify the local strategies and practices producers employ to build their social-ecological resilience;
2. Examine the barriers that limit the social-ecological resilience of producers; and
3. Use insights from this research to support the literature on social-ecological resilience indicators in the context of agriculture.

Resilient agricultural systems promote healthy communities, ensure dependable food supply, allow farmers to adapt to changing environmental conditions, and provide economic stability through job production and support for rural livelihoods (FAO, 2024a). To achieve these benefits, it is necessary to understand what challenges threaten producers' ability to build resilient production systems. Additionally, because sustainable management practices are often location-specific (Altieri & Nicholls, 2017), it is important to understand what approaches are most beneficial to producers in a local context. By developing insights into the barriers and strategies that affect the capacity of producers in Central and Northern Costa Rica to build resilient production systems, this research will contribute to the literature seeking to develop an indicator framework to measure social-ecological resilience in the context of agricultural production.

1.5. Theoretical and Conceptual Framework

1.5.1. Resilience

This research is grounded in resilience theory, particularly in the context of social-ecological systems. Resilience is defined by Walker et al. (2006, p. 2) as "the capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity." Holling (1973, p. 14) first popularized resilience in the context of ecology, and described it as "the measure of the persistence of systems and their ability to absorb change and disturbances and still maintain the same relationships between populations." Holling (1973) posited that seeking a state of equilibrium, which had previously been the dominant approach to the management of ecological systems, was not, in fact, a viable or even desirable aspiration. Rather, he argued, most systems naturally experience instability due to "random events" and it is these events that build the system's resilience and "capacity to persist" (Holling, 1973, pp. 13, 15).

Carpenter et al. (2001) expounded this theory by clarifying three properties associated with resilience. These properties are:

i) the total change a system can experience while retaining the same structure and function;
ii) the ability of a system to self-organize; and
iii) the capacity of a system to learn and adapt (Carpenter et al., 2001).

Folke (2006, p. 261) noted that these properties of resilience present a perspective which guides thinking away from attempts to control a system, towards managing systems "to cope with, adapt to, and shape change." This approach to management is especially beneficial in fluctuating environments where processes and outcomes are difficult to predict (Folke, 2006). In particular, Folke (2006) and others (Carpenter et al., 2001; Wilkinson, 2012) have noted the utility of a resilience approach in analyzing social-ecological systems.

1.5.2. Social-Ecological Systems

Social-ecological systems are complex adaptive systems "with feedback and cross-scale dynamic interactions that include ecological, social, and economic elements" as well as the interactions between those elements (Viñals et al., 2023, p. 2). Walker and Salt (2012) describe complex adaptive systems as having:

i) independent and interacting components;

ii) selection processes regarding components and the results of their interactions; and

iii) constant new and changing components which add variation to the system.

Walker and Salt (2012) used a farm to illustrate their point, explaining that the producer, the management practices, the crop(s), the soil, and the market all interact and change over time. While it is possible to control certain aspects of the system for a length of time, the entire system cannot be controlled at once (Walker & Salt, 2012). To extend the example, climate change, biodiversity loss, and social inequality are all possible emergent components that are likely to add variation to an agricultural system.

The study of social-ecological systems entails focusing on the interconnections between ecosystems and society in three primary ways (Berrouet et al., 2018). First, by analyzing how ecosystems function and provide services to satisfy human needs; second, through understanding how the demand for and use of ecosystem services by humans impacts ecosystems; and third, by examining how social and ecological systems respond to change (Berrouet et al., 2018). Below is a brief discussion of each focus identified by Berrouet et al. (2018) in a context specific to agricultural production.

Agriculture is a clear example of society's reliance on the services that ecosystems provide. Bengochea Paz et al. (2020, p. 1) call food production "the most basic and tangible example of humans' dependence on nature." Agriculture also exemplifies the immense impact that humans have on ecosystems. For example, in addition to agriculture's role in greenhouse gas emissions discussed previously, the sector also contributes heavily to the transgression of planetary boundaries related to nitrogen and phosphorous cycles and is responsible for almost 70% of all freshwater withdrawals globally (Harron & Matthew, 2022; Sandström et al., 2023). Agricultural systems are also exposed to a high degree of change, generally due to various disturbances including gradual changes such as climate change or shifts in consumer preferences; shocks such as market fluctuations, floods, droughts, or heatwaves; and regular perturbations such as La Niña and El Niño events (Labeyrie et al., 2024). The increasing strength and irregularity of disturbances affecting agricultural production has led to an increase in interest in resilience thinking to address these challenges (Labeyrie et al., 2024).

1.5.3. Social-Ecological Resilience

Resilience theory has considerable use in the context of social-ecological systems because it explicitly acknowledges that people fundamentally shape ecological systems and vice versa (Sinclair et al., 2017). A principal idea in the study of social-ecological systems is that the two components are intrinsically linked and that distinctions between the two are largely arbitrary and artificial (Folke, 2006). This is particularly true when communities and their economic activities are dependent on functional ecosystems (Adger, 2000). However, it is important for this theoretical framework to define social resilience and ecological resilience separately before discussing them as one joint concept.

Social resilience refers to the capacity of a society to respond to shocks and disasters related to environmental, social, economic, or political factors (Adger, 2000; Haydari et al., 2023). Mechanisms for building social resilience are dependent on a society’s structure, level of equity and diversity, social capital, and values (Saja et al., 2018). For example, household structure, the mobility of individuals and families, the ability of individuals to meet their basic needs, community inclusiveness, the availability of social supports and networks, and community leadership and engagement are all relevant factors to social resilience (Haydari et al., 2023). Additionally, Adger et al. (2005, p. 1037) posit that a diversity of livelihood options, "strong institutions, early warning systems, and a high capacity" to respond to crises are vital to social resilience as well.

The 'ecological' aspect of social-ecological resilience corresponds to Holling's (1973) original definition, referring to the amount of disturbance an ecosystem can experience before it transitions into a different state (Folke et al., 2002). Resilience theory is now common in the field of ecology (Adger, 2000), particularly in relation to the roles of biodiversity and landscape heterogeneity in influencing how a system responds to disturbances (Adger et al., 2005). For example, biodiversity improves resilience when different species respond to environmental instabilities in various ways, so that the regression of one species coincides with increases in another; landscape heterogeneity bolsters resilience by providing various habitats for a diversity of organisms, leading to increased species biodiversity (Adger et al., 2005; Cursach et al., 2020).

1.5.4. Conceptual Framework

Returning to the idea of social and ecological resilience as intrinsically linked, Cinner and Barnes (2019, p. 52) note that the "interdependent relationship between people and ecosystems" can be a source of resilience for social-ecological systems. In particular, human activities which impact the structure and function of ecosystems can also influence the services that those ecosystems provide, with resulting contributions to human health and well-being (Cinner & Barnes, 2019). Ecosystem services refer to the direct and indirect benefits that result from the interactions between humans and nature (Teixeira et al., 2022).

The Millennium Ecosystem Assessment (MEA) recognizes four types of ecosystem services: cultural, provisioning, regulating, and supporting (Alcamo, 2003). Cultural services are the non-material benefits that humans derive from ecosystems including education, ecotourism, beautification, recreation, and instilling a sense of place and belonging (Alcamo, 2003; Power, 2010). Provisioning services are most closely associated with agricultural production and refer to the products directly obtained from ecosystems, including food, forage, and fibre (Alcamo, 2003; Gordon et al., 2010). Regulating services are the benefits that result from the regulation of ecological processes, which tend to be the most overlooked by humans, including flood control, pollination, erosion control, microclimate regulation, water purification, and air quality maintenance (Alcamo, 2003; Costanza et al., 2017). Finally, supporting services are those which maintain the functioning of the other three services through basic ecosystem processes such as soil formation and retention, nutrient and water cycling, habitat formation, and production of oxygen (Alcamo, 2003; Costanza et al., 2017).

Figure 1.2 is a visual representation of the framework that guided the organization of key concepts, and the relationships between those concepts, that were relevant to this study. Specifically, this conceptual framework combined the purpose of this research with fundamental ideas from the literature to guide the research design and analytical process that I employed. At the centre of the conceptual framework are agroecosystems, which is a term used in this research to refer to the complex features of systems working to produce food, including the environment and the people and resources involved (Duru et al., 2015).

Viñals et al. (2023) note that landscape management decisions must consider resilience *of* what, *to* what, and *for* what. These considerations are necessary, particularly in agroecosystems, to identify what challenges threaten the system, and what features of the system need to be resilient to face those challenges (Viñals et al., 2023). In the context of this research, the resilience *of* producers and their production systems *to* agriculture-related environmental and social challenges is *for* the purpose of building and maintaining sustainable and viable systems of production.

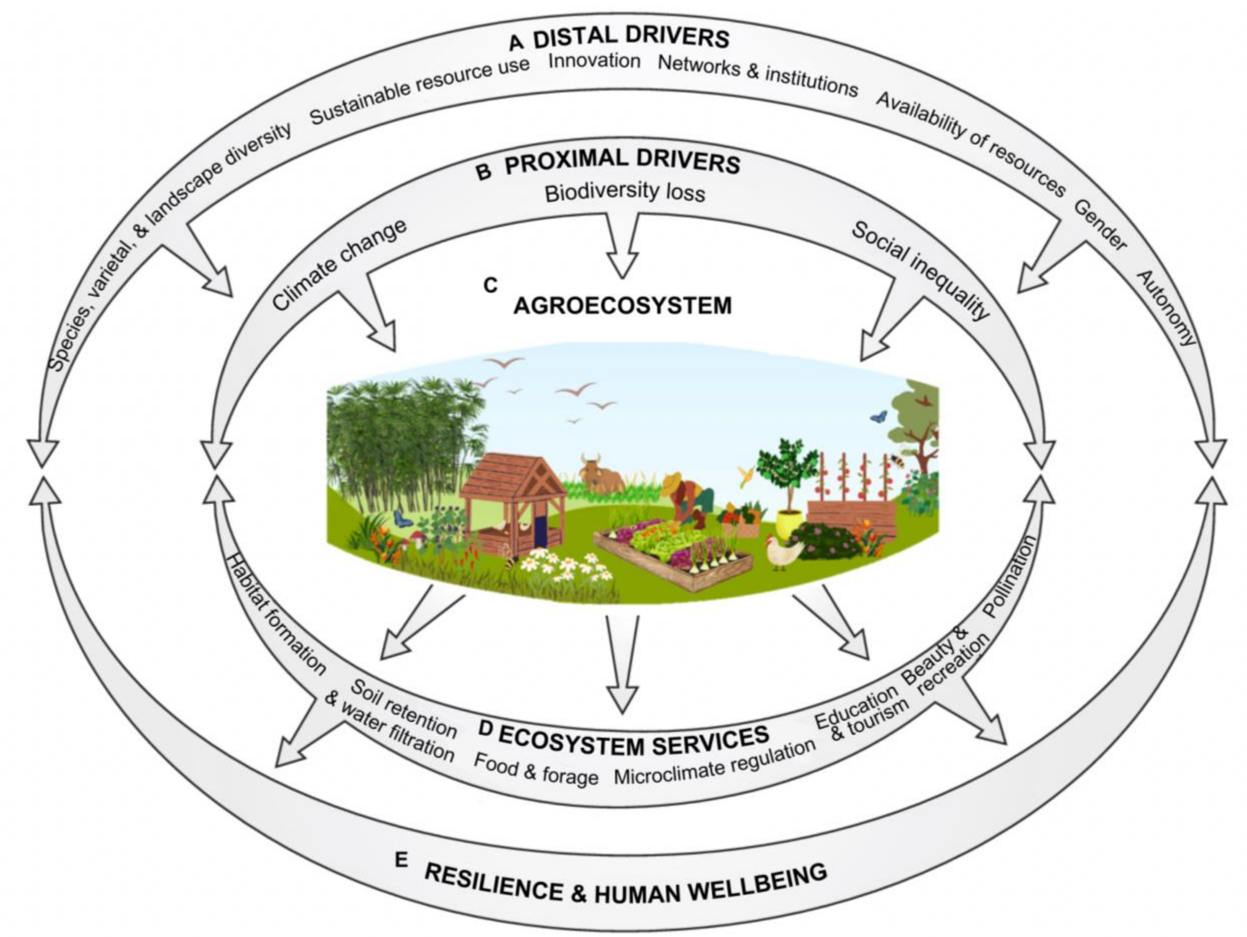

Figure 1.2. Conceptual framework presenting agroecosystems as social-ecological systems. Adapted from Cinner and Barnes (2019). Proximal drivers (B) are the human-caused activities which directly affect agroecosystems (C). Distal drivers (A) are characteristics of systems which mediate proximal drivers by influencing how people interact with agroecosystems. Ecosystem services (D) are the benefits provided to humans by well-managed agroecosystems, which contribute to resilience and human well-being (E). Arrows within the framework represent connections between components.

The proximal drivers shown in Figure 1.2, which include climate change, biodiversity loss, and social inequality, are the activities which directly impact and threaten the functioning of agroecosystems, and which producers must work to build resilience against. Distal drivers are the structural qualities that impact agroecosystems by influencing how proximal drivers affect the system (Cinner & Kittinger, 2015). In this framework, distal drivers include species and varietal diversity, landscape diversity, sustainable resource use, innovation, networks and institutions, availability of resources, gender, and autonomy.

Agroecosystems, impacted directly and indirectly by both proximal and distal drivers, provide services to humans which have the potential to contribute to well-being and the resilience of the system. Examples of these benefits are outlined in Figure 1.2 as ecosystem services and include various cultural, provisioning, regulating, and supporting services. The final aspect of this conceptual framework are the arrows representing the cyclical nature of the different drivers and components involved. For example, ecosystem services are a result of agroecosystems, however they also impact and are impacted by proximal drivers. Consider habitat formation, a supporting ecosystem service resulting from landscape heterogeneity in agricultural systems. Habitat formation has a positive impact on biodiversity conservation but may also be negatively impacted by the direct or indirect effects of climate change. Similarly, human well-being both impacts and is impacted by the structural characteristics that influence agroecosystems.

2. Literature Review

In this section, I set the foundation of my research by synthesizing the concepts, history, and ideas relevant to this study. This literature review is divided into three parts which correspond to the research objectives described in section one. First, I delineate the main challenges associated with agricultural production to form a deeper understanding of the limitations which impact producers' social-ecological resilience. Next, I identify the strategies producers employ to build their resilience, focusing on agroecological principles and the historical context which has kept this form of production from widespread adoption. Finally, I examine the various ways social-ecological resilience has been measured in the literature and consider which set of indicators is most valuable in the context of this study.

2.1. Challenges in Agriculture

To understand how producers can build the social-ecological resilience of their production systems, it is important first to understand what challenges they may face and, as Viñals et al. (2023) posit, to address: resilience *to* what? In this part of the literature review, I describe three significant challenges associated with food production: climate change, biodiversity loss, and social inequality. These challenges are the result of human activities which have made agriculture an increasingly precarious sector. This section will focus on how agricultural systems, including the people most closely involved with them, are vulnerable to these challenges, and what potential solutions exist. I conclude by discussing each challenge in the context of Costa Rica specifically.

2.1.1 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) recently reported with high confidence that the impacts of climate change have already begun affecting weather extremes in every region of the world (2023). In addition to causing widespread loss and damage to nature and people, the increasing intensity and severity of variations in the climate has directly impacted food production (IPCC, 2023). Climate change poses several challenges to agricultural production, including unpredictable precipitation, changing seasonal weather patterns, and increasingly frequent extreme weather events, floods, and droughts (Mbow et al., 2019). These impacts directly affect production by altering growing seasons and decreasing yields (Mbow et al., 2019; Mijatović et al., 2013). In northern regions, growing seasons are anticipated to lengthen, while in tropical locations, growing seasons are predicted to shorten (Motha & Baier, 2005; Stewart et al., 2022). The indirect impacts of climate change on agricultural production include declining water quality and availability, growing pest populations, increasing rates of diseases, and diminishing populations of natural pollinators (IPCC, 2022). Additionally, in regions where precipitation is anticipated to intensify, increased soil erosion may begin to impact crop nutrition in the long term (Djihouessi et al., 2022). The consequences of these impacts include compromised crop production and decreased food security at a global, regional, and local level, particularly in remote or especially vulnerable areas (Altieri & Nicholls, 2017). Food security is defined as “physical, social, and economic access to sufficient, safe, and nutritious food” that meets the “dietary needs and food preferences for an active and healthy lifestyle” for all people at all times (FAO, 2002; Peng & Berry, 2019, p. 1).

Like crop production, livestock production is also vulnerable to climate change. The main causes of this vulnerability include:

i) declining quality and availability of pastures and forage crops;

ii) increasing costs and scarcity of feed grain;

iii) growing frequency of heat stress and resulting impacts on livestock health, growth, and reproduction; and

iv) increasing diseases and pest populations (Gaughan et al., 2009; Izaurralde et al., 2011; Thayer et al., 2020).

Livestock are a significant calorie and protein source and provide an important form of income generation for rural communities (Zhang et al., 2017). The impact of climate change on livestock production is therefore a serious threat to the livelihoods of many agricultural communities (Zhang et al., 2017).

Smallholders, defined as "small-scale farmers, pastoralists, forest keepers, and fishers who manage areas between one and 10 hectares" (FAO, 2013, para. 5), are particularly vulnerable to climate change. Vulnerability refers to the propensity of "exposed elements," which can signify human beings or their livelihoods, "to suffer adverse effects when impacted by hazard events" (Cardona et al., 2012, p. 69). The vulnerability of many smallholders stems from a reliance on rainwater to irrigate crops, and because they often have limited access to institutional resources and technical supports (Harvey et al., 2017). Additionally, low income, inappropriate national policies, diminishing local institutions, environmental degradation, market failures, and limited capacity to find alternate livelihood sources all combine with climate change pressures to increase the vulnerability of smallholders (Altieri & Nicholls, 2017; Mijatović et al., 2013).

It is paramount that farmers build the resilience of their production systems to withstand the impacts of extreme weather events. It is also important that efforts to increase ecological resilience to climate change do not sacrifice social resilience and livelihood viability in the process. Research by Smith and Oelbermann (2010) found that farmers in Durika, Costa Rica were interested in climate change adaptation strategies only if there was minimal economic risk involved, and if the benefits could ensure maintained or increased agricultural productivity and food security. The following paragraph is a brief description of an example of a successful approach to adaptation which addressed social and ecological issues in tandem to improve overall resilience.

The Community-Based Adaptation through Coastal Afforestation (CBACC-CA) initiative was created and implemented through a joint effort between the Global Environment Facility, the United Nations Development Programme, and the Bangladesh national government (Rawlani & Sovacool, 2011). The goal of the project was to reduce the vulnerability of coastal communities in Bangladesh to monsoons and storm surges, which were increasing in frequency and severity due to climate change, while also prioritizing opportunities for economic development for community members (Rawlani & Sovacool, 2011). Coastal communities in the region were once protected from flooding by natural, diverse mangrove ecosystems; however, a reliance on farming and forestry for economic development had since decimated those ecosystems (Rawlani & Sovacool, 2011). The CBACC-CA initiative worked to implement a "Forestry, Fisheries, and Food" model, which integrated aquaculture and food production with reforestation (Rawlani & Sovacool, 2011, p. 859). The results of the project merged climate change adaptation with location-specific and context-appropriate livelihood opportunities, resulting in the creation of a resilient system less vulnerable to collapse (Rawlani & Sovacool, 2011).

2.1.2. Biodiversity Loss

Agriculture is a significant driver of biodiversity loss (Norris, 2008). In particular, the intensification of agriculture, including through the use of agrochemicals to control pests and weeds, as well as the use of synthetic fertilizers and genetically modified crops, is considered along with the extension of agricultural landscapes to be among the main causes of biodiversity loss globally (Brunetti et al., 2018). Newbold et al. (2014) found that in tropical and sub-tropical forests around the world, transforming habitats, largely for agricultural expansion and intensification, caused a consistent reduction in species richness and abundance, which in turn fundamentally altered the structure of ecological communities. Research by Bar-On et al. (2018) found that the global biomass of livestock, namely cattle and pigs, had become far greater than that of wild mammals; while the biomass of domesticated poultry was three times greater than that of wild birds. This data reveals the ways in which humans have replaced wild biodiversity with a select few species chosen for consumption.

While biodiversity conservation and food production are often at odds, biodiversity remains an essential component of agriculture and is indispensable for sustaining life in general. High biodiversity in soils has been shown to provide protection against soil-borne diseases, positively impact nutrient and water use efficiency, and contribute to ecosystem resilience when disturbances arise (Wall & Nielsen, 2012). Biodiversity can also act as a safety net in times of food insecurity due to low agricultural production or during seasonal gaps (Sunderland, 2011). For example, Sunderland (2011) noted that wild-harvested meat constituted a large portion of protein intake for many rural communities; this was particularly true when there was a lack of alternative domesticated protein sources available.

Research from Keesing et al. (2010) found that increased biodiversity can protect humans and other organisms from the transmission of infectious diseases, and can reduce the prevalence of established pathogens. Additionally, in a report by the World Health Organization (WHO) and the Convention on Biological Diversity (CBD), biodiversity was noted to play an important role in the provisioning of essential medicines (2015); while biodiversity loss threatened not only the medicinal plants themselves, but the traditional knowledge that often accompanies their use (WHO & CBD, 2015).

Conflicts between agriculture and biodiversity are a significant challenge, but they are not inevitable (Thrupp, 2000). In regions where livelihoods are closely connected to ecosystems and the use of natural resources, there is potential to integrate biodiversity conservation into agricultural production. Tang et al. (2012) found that in the purple-soiled hilly region of southwestern China, biodiversity conservation succeeded through complex agricultural, forestry, fishery, and livestock-breeding systems. Although the authors note that the diversity in these systems is not as varied or dense as in natural forests, they are still beneficial in rural communities where biodiversity conservation cannot take precedence over the economic viability of a production system (Tang et al., 2012). Later in this literature review, I further examine forms of agricultural production outside the prevailing conventional model. These systems are based on diversity at the landscape, farm-system, and species level, and work to create synergies rather than trade-offs between biodiversity and agricultural production.

2.1.3. Social Inequality

There are several social issues connected to the current, dominant system of agricultural production. For example, Gowdy and Baveye (2019) note that agricultural mechanization and resulting rural unemployment have led to unprecedented global migration from rural to urban areas. In Costa Rica specifically, data from 2014 suggests a 31% increase in the population living in urban areas since 1984 (OECD, 2017).

Additionally, the pervasiveness of gender inequality in agriculture has led to the exclusion of women from many aspects of production. Gender can be a powerful factor in influencing how an individual experiences and responds to stressors and crises, including climate change and biodiversity loss, especially when one's livelihood is closely connected to the environment (Nnadi et al., 2023). Women tend to take on a dominant role in smallholder agriculture in many countries in the Global South (Godfray et al., 2010), yet are often not granted equal access to productive resources, such as inputs, labour, equipment, seeds, land, technologies, extension services, and credit systems (Achandi et al., 2018; Anderson et al., 2021). Research by Nnadi et al. (2023) in southeastern Nigeria found that compared to men, women had fewer overall opportunities for developing human capital in the agricultural sector.

When women *are* able to participate fully in various aspects of agricultural production, past research indicates that families and communities benefit. For example, in a systematic review of the literature, Anderson et al. (2021) found that reducing gender inequality could lead to greater economic benefits for women, their households, and communities, due to increased productivity. Additional research demonstrates that when women have greater control over agricultural inputs and resources, child health, nutrition, and education improve (Beuchelt & Badstue, 2013; Rawe et al., 2015). These improvements are due in part to the fact that women tend to spend substantially more of their income on their families than men do (Rawe et al., 2015). In an ecological context, women also tend to be valuable contributors to creating and maintaining biodiverse farming systems (Zimmerer et al., 2019). Thrupp (2000) found that numerous practices tied to increasing biodiversity came from rural women in agricultural communities who held knowledge regarding the use of plant and tree species for food, fuel, fodder, and particularly for medicine.

Beyond gender, social supports for producers were also inadequate in the context of the COVID-19 pandemic and the resulting shocks to the global food system (Ghosh-Jerath et al., 2022). The pandemic impeded both global and national supply chains by decreasing food exports and imports (Ghosh-Jerath et al., 2022). At the local level, access to food was disrupted by various restrictions that impacted the availability of farm inputs and transportation, as well as due to the price of food relative to income (Ghosh-Jerath et al., 2022). In Kenya, research by Merchant et al. (2022) found that the COVID-19 pandemic impacted agricultural production by limiting access to markets, increasing labour costs, and impeding the availability of inputs. These impacts had lasting effects on rural livelihoods as well as food security and nutrition (Merchant et al., 2022). The pandemic exposed severe vulnerabilities in the global food system which must be addressed to avoid the same negative outcomes during future unanticipated perturbations.

Shortening food supply chains by reducing the distance between agricultural production and final consumption is one way to increase the resilience of food systems (Little & Sylvester, 2022). Short food supply chains (SFSC) strengthen resilience in a myriad of ways, including by:

i) contributing to the local economy and re-establishing personal, trust-filled relationships amongst producers, and between producers and consumers;
ii) reducing economic uncertainty related to market volatility and ensuring regular cash flow for producers; and
iii) better preserving agricultural biodiversity than longer supply chains (Chiffoleau & Dourian, 2020).

Additionally, research suggests SFSC can promote greater gender equality, as a higher number of women are employed in sales and logistics activities in short supply chains compared to longer supply chains (Malak-Rawlikowska et al., 2019). Reconnecting farmers with consumers through SFSCs can occur in a variety of ways, including through on-farm sales, farmer's markets, online sales, and local shops owned by farmers or cooperatives (Little & Sylvester, 2022).

An important strategy to reduce the vulnerabilities of agriculture to various threats, including climate change, biodiversity loss, and social inequality, is to empower communities and combine the valuable knowledge they possess with external information to create localized approaches to bolstering resilience (Mijatović et al., 2013). This necessarily involves taking both an ecological and social approach to resilience.

2.1.4. Agricultural Challenges in Costa Rica

Specific vulnerabilities to the various challenges associated with agriculture, as well as possible avenues toward resilience, differ between communities, regions, and countries. It is therefore important to cultivate a deeper understanding of these challenges in a context specific to this study. The following paragraphs will analyze climate change, biodiversity loss, and social inequality as they relate to agricultural production in Costa Rica.

2.1.4.1. Costa Rica and Climate Change

Costa Rica is expected, and has already begun, to experience adverse effects due to climate change (OECD, 2017). Mean monthly temperatures are anticipated to rise by 1.48°C by 2050 and by 3.08°C by 2100 under a high-emissions scenario (World Bank Group, 2021a). Precipitation patterns are anticipated to become increasingly irregular, with greater rainfall, storms, and floods predicted in the Central Valley, while increasingly frequent instances of drought are expected in the Northern Zone (World Bank Group, 2021a, 2021b). Over recent decades, the intensity of natural hazards, particularly droughts and floods, has swelled in Costa Rica, the latter of which has led to increased instances of disasters including landslides (OECD, 2017). Landslides account for 30% of all disasters in Costa Rica (Quesada-Román, 2021); they also threaten agricultural production considering many small-scale producers manage systems located on slopes (World Bank Group et al., 2014).

Agriculture, forestry, and other land use (AFOLU) in Costa Rica accounts for 38% of the country's net carbon emissions (Banerjee et al., 2024). The main contributors in this sector to greenhouse gas emissions in general include the cultivation of *Oryza sativa* L. (rice), *Coffea arabica* L. (coffee), *Saccharum officinarum* L. (sugar cane), and *Musa acuminata* L. (bananas), as well as the rearing of livestock (Banerjee et al., 2024). Livestock production, particularly *Bos taurus* L. (cattle), contributes heavily to methane emissions in Costa Rica (Government of Costa Rica, 2018).

The national government has recently begun focusing intently on reforestation to address climate change as well as biodiversity loss. Some of these efforts have included agroforestry, specifically silvopastoral systems, which have the potential to reduce emissions from AFOLU (Banerjee et al., 2024). Agroforestry, as Nair described it, is a "new name for a set of old practices" (1993, p. 13). It is an approach to integrated land use involving the deliberate combination of woody perennials and crops or livestock on the same unit of land, leading to ecological or economic interactions between the components (Nair, 1985, 1993). Silvopasture is one form of agroforestry which combines pastureland or animals with trees (Nair, 1993). The IPCC called agroforestry an important and promising approach to climate change adaptation, chiefly for the benefits that well-managed systems can provide to mitigation through carbon sequestration, the provisioning of ecosystem services, and biodiversity conservation (Quandt et al., 2023).

2.1.4.2. Costa Rica and Biodiversity Loss

Costa Rica is often lauded as a model for sustainable development (Harron & Matthew, 2022). One reason for this recognition is the country's widely successful Payments for Ecosystem Services (PES) program. This program pays landowners with forests for employing practices including agroforestry, sustainable forest management, and reforestation for the ecosystem services provided by these activities, namely carbon sequestration, biodiversity protection, water regulation, and beautification (UNCC, n.d.). Since its inception in 1997, this program has included nearly one million hectares of forest (Porras et al., 2013). It also contributed substantially to the 50% of forest cover that had been restored in Costa Rica by 2013, up from a low of 20% in the 1980s (Porras et al., 2013).

Costa Rica's government has also prioritized increasing protected areas throughout the country, which has contributed to reductions in ecosystem degradation and biodiversity loss (Banerjee et al., 2024), the latter of which is of particular importance given Costa Rica's status as one of the planet's main biodiversity hotspots (Pheasey et al., 2023). Home to 5.4% of Earth's biodiversity, Costa Rica is ranked as the 20th most biodiverse country in the world (Banerjee et al., 2024). When considering species density, Costa Rica jumps to first due to its relatively small size, occupying only 0.03% of the Earth's surface (Banerjee et al., 2024).

Despite the advancements made to protect biodiversity in Costa Rica, certain agricultural practices, including high rates of pesticide use, continue to threaten ecosystem health and contribute to biodiversity loss, particularly in the context of resident and migratory birds and benthic macroinvertebrates (Fournier et al., 2018). In 2000, Costa Rica had the highest rates of agrochemical use in Central America (OECD, 2017). Between the 1970s and 2018, pesticide use in the country doubled, which had a severe impact on wetland ecosystems (Fournier et al., 2018). Wetlands tend to be extremely biodiverse, and in the sub-basins of the Frío River in northern Costa Rica, Fournier et al. (2018) found pesticide residues in concentrations known to threaten the health and diversity of organisms in these ecosystems.

Monocultures are also prevalent in Costa Rica. By definition, this form of agriculture lacks biodiversity; Andrén and Kätterer (2008) note that if weed control is successful, there may be only one aboveground species involved in these systems. Among the most widespread monocultures in Costa Rica are plantations producing *Ananas comosus* L. (pineapple). Costa Rica is a leading exporter of pineapples, occupying a 50% share of the world market (OECD, 2017). A 15% increase in the production of pineapples in Costa Rica between 1997 and 2015 resulted in the conversion of many smallholder farms to monocultures controlled by large agribusinesses (OECD, 2017; Shaver et al., 2015). Research on pineapple plantations in northeast Costa Rica found that the presence of these monocultures contributed to a concentration of "land, labour, and financial resources" (Shaver et al., 2015, p. 83). The transformation from small-scale farms to large monocultures work to homogenize the agricultural economy of communities, as well as lead to a loss of producer autonomy and diminished food security, decreased agricultural biodiversity, reduced forest cover, and isolated forest patches, all of which have been shown to negatively affect biodiversity conservation (Shaver et al., 2015).

2.1.4.3. Costa Rica and Social Inequality

Despite Costa Rica's relatively positive ranking under the UNDP's Gender Inequality Index, women in the country continue to face inequities, particularly in the agriculture sector.

Overall, women in Latin America have less access to land than men (Sylvester & Little, 2021). The same is true in Costa Rica, where data from 2015 indicated less than 16% of farms were owned or operated by women (Sylvester & Little, 2021). Women in Costa Rica also have fewer opportunities to participate in the PES program mentioned previously (World Bank Group, 2020), and are underrepresented in agroecological organizations (Sylvester & Little, 2021).

The marginalization of women in agriculture is detrimental for a variety of reasons. For one, women in Costa Rica are important actors in conservation, as well as in the management of sustainable forest and agricultural systems; however, they often are held in marginal roles in these sectors, preventing the full scope of benefits their unhindered participation could foster (World Bank Group, 2020). Research has found significant overlap between women-owned or operated farms in Costa Rica with national priority zones for "forest conservation and sustainable management, forest landscape and ecosystem restoration, and the promotion of low-carbon production systems" (World Bank Group, 2020, para. 13). Despite this overlap, the 2019 Gender Action Plan, a key aspect of Costa Rica's national strategy to reduce emissions from forest degradation, found that women's participation in these efforts have not been prioritized and their potential contributions have largely been overlooked (World Bank Group, 2020).

Diversifying income opportunities in rural areas is one possible avenue for increasing gender equality and providing a myriad of other benefits to communities. Increased job opportunities could work to improve gender equality as more women become directly involved in production activities; they could also prevent or slow migration away from rural areas (Mukhlis et al., 2022). Of course, the creation of new jobs requires considerations regarding how to best reduce the potential for increasing women's workload (Mukhlis et al., 2022).

Tourism initiatives are one strategy employed by rural communities to create jobs and diversify income sources (Artal-Tur et al., 2019). In Costa Rica, tourism accounts for around 7% of the national gross domestic product, and employs 3% of the population directly and 9% indirectly (Echeverri et al., 2022). Ecotourism, a responsible form of travel which prioritizes natural resource conservation and support for local livelihoods (Almeyda Zambrano et al., 2010), is a particularly important aspect of Costa Rica's economy, as well as a significant mechanism for achieving national goals related to environmental protection and poverty reduction (Little & Blau, 2020).

Ideally, the beneficiaries of ecotourism are citizens; however, in Costa Rica, tourist expenditures often end up in the United States or Europe due to foreign investors and chain resorts (Almeyda Zambrano et al., 2010). To bring the benefits of ecotourism to rural, often impoverished communities in Costa Rica, the concept of agritourism was introduced in 1994 as a long-term development strategy (Djuwendah et al., 2023; Little & Blau, 2020). Similar to ecotourism, agritourism is based on principles of economic prosperity, the preservation of nature, and self-reliance (Little & Blau, 2020). Possible economic benefits of agritourism include the creation of new jobs and diverse sources of income for producers; while social benefits include "a chance to preserve local customs, increase pride, increase farmers' social status, and improve women's social standing" (Little & Blau, 2020, p. 9). Potential environmental benefits include ecosystem protection, resource conservation, and reduced use of agrochemicals replaced by organic methods (Djuwendah et al., 2023; Little & Blau, 2020).

Despite Costa Rica's standing as a leader in the industry, little research has been done to understand the potential benefits and drawbacks of agritourism initiatives in Costa Rica (Candelo et al., 2019). In fact, research into food and beverage-related tourism in general has focused mainly on European and North American studies, with little attention paid to countries in the Global South (Candelo et al., 2019). This is an unfortunate oversight given the dependence of many smallholder farmers on the income generated from the production of raw materials in food and beverage supply chains (Candelo et al., 2019).

2.2. Building Social-Ecological Resilience in Agriculture

As outlined in section one, understanding agriculture as a complex social-ecological system explicitly acknowledges the intricate connection between these systems and people (Cinner & Barnes, 2019). Building the resilience of agroecosystems is desirable in most cases to increase the magnitude of disturbance that systems can absorb without shifting to a different state (Walker et al., 2006). Resilience is therefore extremely important to agricultural production due to the number of changes and challenges with the potential to undermine these systems, including, for example, "climate change, an increasingly connected social and trade system, declines in pollinators, and increases in pests and diseases" (Bennett et al., 2014, p. 65). Humans have the capacity to plan for and anticipate future changes, however, these interventions must be considered carefully so they do not negatively alter or disrupt the ecosystem services provided by agroecosystems, particularly food production (Bennett et al., 2014; Viñals et al., 2023). In the following portion of this literature review, I discuss the path toward social-ecological resilience in agriculture. I begin with an analysis of how conventional modes of production came to be the dominant arrangement and what barriers exist to increasing the resilience of agricultural systems, followed by a discussion on transitioning to sustainable production methods.

2.2.1. The Industrialization of Agriculture

Following the end of World War II, agriculture in so-called developed nations began shifting toward a standardized, production-oriented model, increasingly relying on what Duru et al. (2015, p. 1238) called "off-the-shelf technologies," including synthetic fertilizers and pesticides. As a result, diverse agricultural systems producing a variety of crops relevant to local contexts were greatly reduced (Duru et al., 2015). Then, in the 1960s, the Green Revolution brought many of these technologies to the Global South, mainly parts of Asia and Latin America, transforming agricultural systems in these regions as well (Norton, 2016; Wu & Butz, 2004). The result of these transformations led to inefficient water use, biodiversity loss, soil and water pollution, and considerably reduced crop species and varietal diversity (Mbow et al., 2019), accompanied by the widespread use of fertilizers to account for the nutrient requirements of crops, and the extensive use of pesticides to purge vegetative competition and repel insects (Norton, 2016).

The Green Revolution was effective in significantly increasing food production in regions suffering from widespread hunger (Wu & Butz, 2004). Additionally, increasing yields on productive land ensured that marginal lands could be saved from conversion for agricultural use (Robertson & Swinton, 2005). However, the Green Revolution was also effective in "divorcing agriculture from ecology" by replacing ecological processes including nutrient cycling and pest suppression with external inputs, namely fertilizers and pesticides (Robertson & Swinton, 2005, p. 39). Fertilizers and pesticides are two essential components for specialization and increasing farm size, both of which were core developments associated with agricultural industrialization (Goulet et al., 2023). The environmental costs associated with the industrialization of agriculture are great, and include "groundwater depletion, soil loss, the degradation of freshwater ecosystems, greenhouse gas emissions, and biodiversity loss" (Gowdy & Baveye, 2019, p. 1).

Additionally, industrial agriculture has led to a complex and disengaged food system which does not prioritize the needs of local communities (Little & Sylvester, 2022). This is evidenced by the emergence of laws considering seeds as intellectual property, which have led to increasingly consolidated agribusinesses controlling the production of genetically modified or conventionally bred seeds, as well as the production of agrochemicals that are specifically formulated to accompany those seeds (Clapp, 2020). These systems, which often require farmers to sign agreements barring them from saving patented seeds for replanting the following season, work to entrench farmers in a cycle which requires them to rely almost entirely on external inputs that must be repurchased each year. Halewood et al. (2021) argue that these systems also cause a loss of agency for small-scale farmers and local communities as managers of crop diversity. This history is important as it contributes to an understanding of the lack of resiliency in conventional agricultural systems, as well as provides context for current agricultural debates around the future of food production.

2.2.2. Barriers to Increasing Resilience in Agriculture

Climate change is by nature an evolving challenge, and as such, many producers will need to alter their management practices to respond. Shifting growing seasons, heatwaves, floods, and droughts, all of which are anticipated to increase in intensity and frequency with a changing climate, will impact food production and require farmers to adopt innovative strategies and management practices (Izaurralde et al., 2011). Altieri and Nicholls (2017) argue this point is being exploited by proponents of biotechnology to drive the use of genetically modified crops, and to posit this option as the only viable route to agricultural resiliency.

Outside of reducing emissions, van Noordwijk et al. (2021) note that the dominant model for avoiding future mass food insecurity due to climate change has largely focused on crop improvements through genomics. The underlying idea is that the generation of new drought and heat-resistant crop varieties will ensure the adaptation of agricultural systems to the effects of climate change (van Noordwijk et al., 2021). This prioritization of research at the molecular level of agricultural production reflects the emphasis that science policies often place on goals related to economic growth and national competition (Vanloqueren & Baret, 2009).

Recent research suggests, however, that because climate change will largely be in the form of climate *shifts,* adjacent systems often carry solutions to issues regarding suitable local crop varieties, meaning system-level adaptations can be more effective than modifying just one component in a system (van Noordwijk et al., 2021). The complexity and diversity involved in context-specific agricultural systems has been shown to increase resilience to climate change but it is flawed agricultural policies and market pressures which are limiting the large-scale adoption of these methods (van Noordwijk et al., 2021; Vanloqueren & Baret, 2009). Adger et al. (2005) concur that struggling to control and engineer nature is a less effective approach to managing issues within the food system. Instead, governance systems should be focused on "life-supporting ecosystems," such as agricultural systems in their entirety, as a source of resilience for societies (Adger et al., 2005, p. 1038).

2.2.3. An Agroecological Transition

Agroecology is a form of agricultural production that has been practiced for thousands of years; although formal definitions only emerged in the 1970s (Altieri, 2018). It has since been considered a radical alternative to industrial farming, and has only recently emerged from political marginality as a viable solution to the challenges plaguing agricultural production

(Goulet et al., 2023). Agroecology generally refers to an approach to agriculture that is sensitive to environmental and social contexts, and which is concerned primarily with the sustainability of production systems (Hecht, 2018). Within the confines of an agricultural field, this translates to a focus on the ecological relationships between, for example, predators and prey, and crops and weeds (Altieri, 2018; Hecht, 2018). Agroecological principles are place and context-specific, yet they share several common features such as high diversity at various spatial and temporal scales and dependence on local resources and varieties, all of which have been shown to enhance production resilience (Altieri & Nicholls, 2017). Common agroecological practices are outlined in Table 2.1.

As much as agroecology is a scientific discipline involving certain key agricultural practices, it is also a socio-political movement (Zaremba et al., 2021). In that sense, agroecology draws heavily from agrarian social thought and movements, many of which are affiliated with La Vía Campesina (Acevedo-Osorio & Chohan, 2020). La Vía Campesina is an international peasant movement committed to climate and environmental justice, peasant rights, dignity for migrant and waged workers, and the defence and protection of land, water, and territories (Martínez-Torres & Rosset, 2014). Agroecology is also heavily dependent on social networks, and the co-creation and sharing of knowledge (FAO, n.d.). Because agroecological methods of production require location-specific knowledge that is tailored to particular cultural, economic, environmental, political, and social contexts, social networks play an important role in fostering the process of developing or reimplementing agroecological practices (Altieri & Nicholls, 2017; FAO, n.d.). Particularly important is the "blending of knowledge from different actors," including women and men, indigenous communities, producers who utilize traditional practices, and the global scientific community (Barrios et al., 2020, p. 234).

Table 2.1. Common elements of agroecological production systems with examples

Element	Example
Vegetative cover over soils to conserve soil and water.	No-till farming, mulching (covering soil with organic material), use of cover crops.
Regular supply of organic material and promotion of life in soils.	Steady addition of manure or compost, preservation of living roots in soil year-round.
Nutrient recycling mechanisms.	Agroforestry systems, mixed crop-livestock systems, crop rotations and inter-cropping using nitrogen-fixing plants.
Pest regulation and control.	Introducing or conserving natural enemies, diversification, use of biological control agents.
Multiple-use capacity of landscape.	Edible forests, mixed systems, ecotourism, areas for recreation.
Sustained production with little or no reliance on damaging chemical inputs.	Use of on-farm instead of off-farm inputs, use of varieties and species adapted to location.

(Altieri, 2018).

The High Level Panel of Experts (HLPE) on Food Security and Nutrition, a body of the United Nations, developed 13 principles of agroecology that are visualized in Figure 2.1. These principles offer an effective blueprint to "frame, define, and operationalize" an otherwise complex and broad term (Zaremba et al., 2021, p. 1). The principles are organized around three philosophies for progress toward sustainable food systems: improving resource efficiency, strengthening resilience, and securing social equity (HLPE, 2019). The United Nations Food and Agricultural Organization (FAO) defines sustainable food systems as those which prioritize food security and nutrition in the present without compromising the economic, social, and environmental bases of food security and nutrition for future generations (2018). Sustainable food systems therefore must: be profitable throughout, benefit society, and have a "positive or neutral" impact on the environment (FAO, 2018, p. 1).

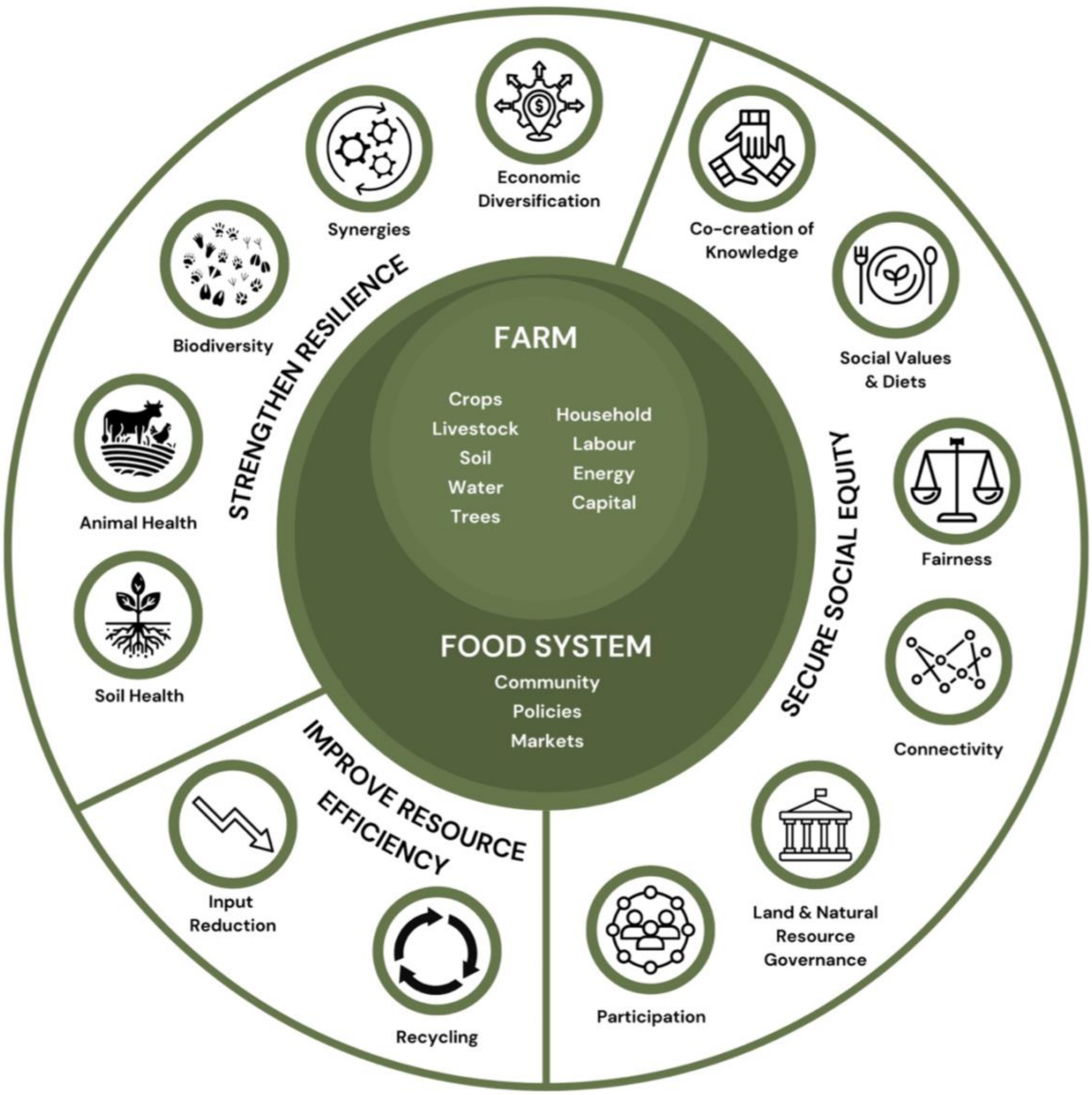

Figure 2.1. The 13 principles of agroecology surrounding the components that shape these systems. Adapted from Agroecology Info Pool (2019).

An example of an organization embracing a broad definition of agroecology is Organicampo in Santa Marta, Colombia. Comprised of five families and led by women practicing organic horticulture, members of Organicampo worked as a collective, practiced agroecological methods such as crop rotation and integrated pest management, produced on-farm natural inputs, and sold their products locally (Acevedo-Osorio & Chohan, 2020). Organicampo was also involved with decision-making processes regarding Peasant Reserve Zones, which are a legal tool used to prevent agribusiness land concentration and secure smallholder access to land (Acevedo-Osorio & Chohan, 2020). Organicampo is a clear demonstration of the benefits of agroecological principles to social-ecological resilience and the empowerment of producers.

Transitioning to agroecological forms of production is a systems-focused avenue for increasing the social-ecological resilience of agricultural systems. Duru et al. (2015) refer to an 'agroecological transition' as a shift away from standardized, production-oriented agriculture towards biodiversity-based agriculture. This transition necessitates viewing agriculture as an ecosystem, where the priority is not high yields of a specific commodity, but "the optimization of the system as a whole" (Altieri, 2018, p. 89). This system is often referred to as an agroecosystem*,* which is defined as a somewhat domesticated environment that is managed for the production, distribution, and consumption of food, fuel, and fibre (Duru et al., 2015). In some cases, the term agroecosystem is also used to include the institutions, infrastructure, resources, and people involved in these processes, making it an appropriate term for encompassing the complexity of social-ecological resilience (Duru et al., 2015). This is an important note, considering a review by Teixeira et al. (2022) found that studies on agroecosystems often lack an interdisciplinary approach.

2.3. Measuring Social-Ecological Resilience in Agriculture

Currently, the literature on social-ecological resilience lacks a clear or established indicator framework, particularly in the context of agriculture (Viñals et al., 2023). In this study, an indicator refers to "a variable that describes the state of a system," helping to represent a complex phenomenon of study (Gabrielsen & Bosch, 2003; Walz, 2000, p. 613). Indicators conventionally used to measure ecological resilience in agricultural production, for example, the incidence of pests and diseases (Altieri & Nicholls, 2002) or drought frequency (Srinivasa Rao et al., 2019), do not adequately account for a system's social dimensions. Similarly, indicators of social resilience, including food security or education levels (Kaye-Blake et al., 2019), are not indicative of ecological resilience and therefore are insufficient in assessing the full scope of social-ecological resilience (van Oudenhoven et al., 2011).

One option for measuring social-ecological resilience involves examining what Viñals et al. (2023) refer to as the heterogeneity of a system. In this context, heterogeneity includes economic, cultural, and biological diversity, each of which aids in dispersing risks to production systems (Viñals et al., 2023). Research by Panpakdee et al. (2021) found diversity to be a significant indicator of social-ecological resilience in organic rice farming, noting specifically the importance of plant species and rice varietal diversity, as well as diversity in income sources and marketing channels. Additionally, Bennett et al. (2014, p. 69) noted that diversity in "crops, cropping systems, farm sizes, agricultural landscape types, institutional arrangements, policies, and food systems" all contribute to the creation of opportunities for innovation in management and ultimately for building resilience.

Another indicator framework that assesses both social and ecological factors in resilience is the measurement of ecosystem services. As mentioned previously, the Millennium Ecosystem

Assessment (MEA) recognizes four types of ecosystem services: cultural, provisioning, regulating, and supporting (Alcamo, 2003). Each of these services is fundamentally linked to human health and well-being (MEA, 2005), and their protection and enhancement aids in strengthening social-ecological systems (Wood & DeClerck, 2015). One benefit to using ecosystem services as an indicator framework of social-ecological resilience is that this approach is intelligible to a variety of stakeholders, ensuring that outcomes are useful for a broad range of actors (Teixeira et al., 2022).

The literature on climate change adaptation may also be useful in measuring social-ecological resilience. For example, in a systematic review on the topic, Owen (2020) posited five markers for evaluating the effectiveness of initiatives in increasing resilience to climate change. These markers are:

i) reducing risk and vulnerability;

ii) developing resilient social systems;

iii) improving the environment;

iv) increasing economic resources; and

v) enhancing governance and institutions (Owen, 2020).

Vernooy (2022) built onto this list in his review, adding possible indicators for each of the five markers in the context of food production. For example, regarding reducing risk and vulnerability, Vernooy (2022) proposed indicators related to diversified farming systems and diversified nutrition; while under resilient social systems, he posited indicators such as gender equity and inclusiveness, autonomy, and seed and food security. Concerning improving the environment, Vernooy (2022) recommended indicators including the generation of new agroecological knowledge, the adoption of innovative practices, and the use of varieties and species with greater adaptive capacity or increased nutritional value. In relation to increasing economic resources, Vernooy (2022) suggested measuring on and off-farm income-generating opportunities, as well as connections among actors across value chains. Finally, for enhancing governance and institutions, Vernooy (2022) posited farmer participation in policy creation and the implementation of policies which support diversification as possible indicators (Vernooy, 2022).

Within the context of climate change, Mijatović et al. (2013) posited a set of indicators to measure the role of agricultural biodiversity in increasing the resilience of traditional agricultural systems. Agricultural biodiversity is defined broadly by Frison et al. (2011) as involving every level of an agroecosystem, including those components used directly in management and those which are indirectly involved. For example, agricultural biodiversity includes the genetic variability within varieties and breeds, the different varieties and breeds themselves, the species diversity of crops, trees, and livestock which make up the foundation of the farm system, and the ecosystems where producers manage these systems (Frison et al., 2011). Agricultural biodiversity also encompasses those indirect components which impact agricultural systems, including pollinators, wild flora and fauna, and water flows (Bhattarai et al., 2015).

The indicators proposed by Mijatović et al. (2013) include maintenance of species and varietal diversity, heterogeneity of landscapes, sustainable use of resources, transmittance of traditional knowledge across generations, innovation in management practices, local networks and institutions, availability and exchange of seeds and livestock, gender, and autonomy (Mijatović et al., 2013). These indicators share some commonalities with those proposed by Vernooy (2022), including attention to diversity, access to seeds, innovation, gender equality, and autonomy. The purpose of the indicators developed by Mijatović et al. (2013) are to help researchers identify practices that can be strengthened to build resilience and to allow for comparisons of resilience across communities and landscapes. This set of indicators most closely addresses the first and second objectives of this study, which are to identify local strategies and practices employed by producers to build social-ecological resilience and examine the barriers that limit their social-ecological resilience. Adopting Mijatović et al.'s (2013) indicators also addresses the final objective of this study, which involves using insights from this research to support the literature on social-ecological resilience indicators in the context of agriculture.

3. Methodology and Methods

3.1. Methodology

In this section, I describe the methodology and methods I utilized to conduct this research, including a review of the literature, semi-structured interviews, as well as purposive sampling and thematic data analysis. I also discuss the limitations associated with this research and what strategies I employed to address those limitations. The purpose of this research is to determine how agricultural producers strengthen the social-ecological resilience of their production systems. I chose a qualitative approach to account for and assess the subjective and personal nature of such experiences. Qualitative research often intends to provide "detailed descriptions of individuals and events" (Alshenqeeti, 2014, p. 39). It is also a growing field increasingly being recognized for its value in contributing to understandings of complexity (Moon et al., 2016). Of the methods used by qualitative social science researchers, interviews and surveys are the most common (Alshenqeeti, 2014).

This research was informed by an interpretivist paradigm and the tenets of phenomenology. Phenomenology is concerned more with descriptions of lived experiences than with objects of study, such as the scientific drivers of climate change (Polkinghorne, 1989; Sundler et al., 2019). Descriptions of lived experiences include both "*what* was experienced and *how* it was experienced" (Neubauer et al., 2019, p. 91). Similarly, an interpretivist paradigm aims to focus on the richness of the insights collected as opposed to delivering a definite and generalizable observation of reality (Alharahsheh & Pius, 2019). In the context of this research, consideration of these philosophies occurs through a focus on understanding how selected producers experience and interpret their resilience.

3.2. Data Collection

3.2.1. Literature Review

Before collecting primary data for this research, I conducted a review of the literature to gain insight into existing knowledge on social-ecological resilience in the context of agriculture. This literature review provided the basis on which I built the research objectives and the overall design of this study. It served to define and contextualize the vulnerabilities of agricultural systems and outline the practices that can bolster resilience, as well as the ways in which scholars measure agroecosystem resilience. The literature review also informed the interview guide, which encouraged participants to discuss information related to indicators of resilience proposed by Mijatović et al. (2013). Table 3.1 outlines these indicators and is included later in this section.

To conduct the literature review, I searched electronic journal databases located in the University of Waterloo library, as well as Google Scholar, using various combinations of key terms including “social-ecological resilience,” “resilient agriculture,” “resilient agroecosystems,” “Costa Rica,” “social-ecological resilience indicators,” “climate change,” and “agricultural biodiversity.” I relied mainly on secondary literature, chiefly peer-reviewed journal articles and books. The purpose of my review was to identify gaps in the literature and investigate past research. To accomplish this, I completed a scoping review, which does not require the extensive, sweeping approach of a systematic review (Munn et al., 2018). Scoping reviews are limited, however, by the often broad nature of the findings they produce, which may limit the depth of information gathered (Tricco et al., 2016). Therefore, additional steps are often required on the part of the researcher to “synthesize and draw useful conclusions” from the information that is collected (Hanneke et al., 2017, p. 6).

3.2.2 Semi-Structured Interviews

Qualitative interviews, the method of data collection chosen for this study, involve two or more people and the exchange of information through a sequence of questions and answers (Sheppard, 2020). Specifically, interviews are the process through which one person attempts "to elicit information or expressions of opinion or belief from another person or persons" (Young et al., 2018, p. 11). The purpose of interviews is to contribute to conceptual or theoretical bodies of knowledge that are rooted in the experiences, and the meanings attached to those experiences, as expressed by respondents (DiCicco-Bloom & Crabtree, 2006). Researchers often use interviews for four primary reasons, according to Dunn (2006):

i) to fill knowledge gaps that other methods are unable to fill;

ii) to explore complexity, particularly in behaviours and motivations;

iii) to amass a diversity or consensus of opinions or experiences; and

iv) to show respect for and empower the people who are the sources of the data.

Qualitative interviews are an appropriate data collection method for this research as my aim is to explore the complexity of social-ecological resilience through an understanding of the experiences of producers. Another essential aspect of this research is ensuring that the producers involved feel respected and that their experiences are valued as important sources of knowledge (Dunn, 2006).

Semi-structured interviews offered the best avenue for conducting this research. I wanted to avoid the 'yes' or 'no' or otherwise brief responses that are often elicited by structured interviews (Alshenqeeti, 2014), while also allowing participants the freedom to discuss what they deemed relevant. This was important to ensure the necessary topics were addressed by respondents, which is not always guaranteed in unstructured interviews with few set parameters

(Young et al., 2018). Semi-structured interviews provided both versatility and flexibility, ensuring I could contextualize the data collected (Kallio et al., 2016). Flexibility specifically is beneficial when investigating complex issues where processes are difficult to foresee (Young et al., 2018), such as those present in social-ecological systems.

Semi-structured interviews also tend to be successful in creating rapport and reciprocity between the interviewer and the interviewee, which was important for this research. Rapport involves establishing trust and respect between the interviewer and participant, while also creating a safe and calm environment for the respondent to share accurate and complete information (DiCicco-Bloom & Crabtree, 2006). Reciprocity allows the interviewer the freedom to ask follow-up questions based on the participant's answers, as well as grants space for the participant's own expressions where they deem necessary (Kallio et al., 2016). When participants are given the freedom to highlight what they deem to be important, they may underscore issues the researcher had failed to previously consider, reducing any bias that may have impacted the creation of the interview guide (Young et al., 2018). This gives me confidence that the interviewees provided me with honest and instructive information on their experiences of resilience, and thus more reliable data to inform my conclusions.

3.2.3. Interview Process

Interviews for this study took place following approval of this research by the University of Waterloo Ethics Board. Before agreeing to take part in this research, all participants were given the chance to review the details of the study. Once participants confirmed their interest, I obtained verbal consent from each participant. Participants had the option to refuse or agree to: taking part in the interview, having their interview audio-recoded, and the use of anonymous quotations in any paper resulting from the research. Participants were provided with the opportunity to complete the interview in either Spanish or English. Each participant was then assigned a unique identification number to ensure confidentiality. In the following sections of this thesis, participants are referred to by a letter of the alphabet instead of their identification numbers. For example, Participant A, Participant B, and so on.

I followed a pre-determined interview guide to conduct 12 semi-structured interviews. This interview guide can be found under Appendix A. The interview guide provided set parameters to ensure each interview covered the same key points. I then asked follow-up questions to encourage participants to expand on certain concepts. The six women who participated in this study were asked whether they felt they had equal access to agricultural information and resources based on their gender. The male participants were not asked this question because the literature indicates that in many cases women in agriculture continue to be at a disadvantage compared to men, particularly concerning access to land, credit, labour, information, technology, and extension services (Achandi et al., 2018; Huyer, 2016). I allowed space at the end of each interview for the participants to discuss anything they felt was important but that had not previously been mentioned. Of the 12 interviews, three were conducted in English, and nine in Spanish. The interviews conducted in Spanish were translated to English by a translator.

I asked participants questions specifically aimed at gathering information based on the set of resilience indicators developed by Mijatović et al. (2013). These indicators included species and varietal diversity, landscape diversity, sustainable resource use, availability and exchange of seeds and livestock, management innovation, local networks and institutions, gender, and autonomy (Mijatović et al., 2013, p. 9). Varietal diversity refers to diversity within crop species and is realized through the inclusion of multiple varieties of the same crop (Gatto et al., 2021).

The interview guide was designed to encourage each participant to discuss aspects of these eight indicators, with the aim of understanding what role they played in producers' social-ecological resilience.

Some of the measurements I employ differ slightly from what Mijatović et al. (2013) outline in their study. These changes are intended to account for what is appropriate in the context of this research. I also did not include a ninth indicator proposed by Mijatović et al. (2013), transmittance of traditional knowledge across generations, as measuring for this indicator is beyond the scope of this research. Table 3.1 outlines the indicators and measurements used to assess social-ecological resilience in this study, along with why they are important.

Table 3.1. Eight indicators of social-ecological resilience in agricultural production systems

Indicator	Importance	Measure
Species and Varietal Diversity	Agricultural biodiversity aids farmers in adaptation, particularly when varieties and breeds with stress-resistant traits are adopted.	The number of species and varieties of cultivated crops per production system.
Landscape Diversity	Landscape heterogeneity provides various beneficial ecosystem services.	The number of landscape components in a production system, such as infrastructure, water, forest patches, trees and shrubs, pastureland, and arable and permanent cropland.
Sustainable Use of Resources	The conservation and protection of natural resources provides a buffer against extreme weather events.	Efficient use of water resources and conservation or improvement of soil health.
Innovation in Management Practices	Novel challenges which cannot be addressed using traditional methods require access to new information, the exchange of knowledge, and the adoption of innovative management practices.	Adjustment and re-establishment of traditional practices, and the development of new management systems.

Local Networks and Institutions	Local networks and institutions support the exchange and dissemination of knowledge and information within and between communities.	Existence of institutions which support producers, and local networks which facilitate connections among community members.
Availability and Exchange of Seeds and Livestock	A diversity of available local and new species, varieties, and breeds is essential for strategies aimed at building resilience.	Existence of formal and informal seed exchange networks, community seed banks, and local markets.
Gender	Including and integrating the knowledge and concerns of women into resilience-building enhances the effectiveness of these practices, particularly in the context of household food supply.	Whether women have equal access to information and resources compared to men.
Autonomy	When producers have autonomy regarding land management and agricultural practices, they can implement practices that correspond to their needs and the resources available to them.	Producers have agency and choice in what they produce and how their production systems are managed.

Adapted from Mijatović et al. (2013).

3.3. Sampling

I employed purposive sampling for this study. Purposive sampling is beneficial when the researcher is aiming to increase depth of knowledge, as well as when the research requires selecting participants that are most likely to provide relevant and useful information (Campbell et al., 2020). Purposive sampling is commonly used in qualitative research, and allows for the "identification and selection of information-rich cases," allowing the researcher to efficiently use limited resources, such as time or money (Palinkas et al., 2015, p. 534; Vasileiou et al., 2018). In this context, purposive sampling allowed me to interview participants with the greatest knowledge and experience related to my research question within a limited timeframe.

The sampling frame for this study included producers in Costa Rica's Central Valley and Northern Zone who managed agroforestry systems, systems focused on dairy production, and systems based on diverse crop production. The sampling frame also included producers who were working to create and maintain sustainable agricultural systems; however, to limit participation in this study to only those producers who explicitly expressed their desire to manage sustainable systems would exclude farmers, often of an older generation, who had either not learned about, or not embraced, terms such as sustainability. For this reason, I chose to include farmers who may not have claimed to be working towards sustainability, but who managed traditional agricultural systems using various sustainable practices. Participation was also limited to producers over the age of 18 and to those able to communicate in either English or Spanish.

A total of 12 producers participated in interviews concerning the social-ecological resilience of their production systems. These participants managed systems across three provinces in Costa Rica: one in Alajuela, two in San José, and nine in Cartago. Figure 3.1 shows the location of each participant's production system within Costa Rica. Sample sizes in qualitative studies tend to be smaller than in quantitative research because of the "depth of case-oriented analysis" that is necessary for this approach (Vasileiou et al., 2018, p. 2). In phenomenological research, Creswell (2013) recommends a sample size of three to 25 participants, while Vasileiou (2018) suggests a sample size of at least 12 to reach data saturation. Saturation refers to "the point during a series of interviews where few or no new ideas, themes, or codes appear" (Weller et al., 2018, p. 2).

Saturation, though, may not be the most effective indicator to signify an appropriate sample size. Saturation assumes that data collection and analysis are happening at the same time, which is not always possible (Knott et al., 2022). Weller et al. (2018) posit salience as a more appropriate guide to estimating the adequacy of a sample size because it reflects the most important ideas and themes in the context of qualitative data. Therefore, achieving salience was the marker for a sufficient sample size in this research. Salience was measured in this study by how frequently an idea was mentioned during interviews (Weller et al., 2018).

Figure 3.1. Location of participant' production systems within Costa Rica.

3.4. Data Analysis

I used both deductive and inductive approaches to analyze the data set. I first developed a framework of themes (Azungah, 2018), based on the indicators of resilience proposed by Mijatović et al. (2013). These themes were applied in the analysis of the data set since, as previously mentioned, the interview guide was developed to encourage the participants to address the indicators offered by Mijatović et al. (2013). These indicators were created for use in determining resilience to climate change, however, they are also applicable in analyzing a broader view of social-ecological resilience. I also utilized an inductive approach, reviewing the data and creating codes based on participants' responses. This approach ensured themes emerged that were directly derived from the data (Azungah, 2018).

I conducted a thematic analysis of interview data using NVIVO 14. Thematic analysis is commonly used in the qualitative social sciences, aiding researchers in "systematically identifying, organizing, and offering insight" into ideas and themes in the data set (Braun & Clarke, 2012, p. 57; Rogers, 2023). Thematic analysis was useful for this research as it encouraged a focus on shared meaning across the data set (Braun & Clarke, 2012). Typically, when using thematic analysis, a researcher will also employ inductive coding (Riger & Sigurvinsdottir, 2016). In the context of my research, a combination of deductive and inductive approaches was most appropriate to answer the research question within my theoretical framework.

I followed a six-phase approach to thematic data analysis, as outlined in Braun and Clarke (2012). The first phase involved familiarizing myself with the data. This process was ongoing and began with conducting and transcribing the interviews, followed by a first and second read-through to ensure familiarity with the content (Rogers, 2023). Interviews were transcribed automatically using Otter.ai software. I then reviewed each transcription manually against either the original audio recording of the interview or the translated audio recording to ensure accuracy. The next phase was the process of generating initial codes (Braun & Clarke, 2012). These codes came from both the resilience indicators proposed by Mijatović et al. (2013), and directly from the data. The codes were primarily descriptive, as I largely refrained from interpreting the data during this step. This phase resulted in a large number of codes, many of which were aggregated in later phases.

The third phase outlined by Braun and Clarke (2012) involved searching for themes. I reorganized and relabeled the data in a second cycle of coding (Rogers, 2023) in order to fit broader themes with the resilience indicators. The following phase included reviewing themes, and ensuring they worked in relation to the data (Braun & Clarke, 2012). This process involved rereading the entirety of the data set and removing some themes that were not relevant to answering the research question. The penultimate phase was defining and naming themes (Braun & Clarke, 2012). The primary themes that emerged throughout the preceding analysis process were *diversity, ecosystem services, access to resources,* and *challenges in agriculture*. These themes, as Braun and Clarke (2012) recommend, are related yet not overlapping, and each is an essential part of answering my research question. These themes influenced how I considered the data and the initial codes from the indicators in relation to the literature. Finally, the last phase of Braun and Clarke's six-phase approach to thematic analysis was producing the report. In this case, phase six denotes the writing of this thesis and the unravelling of the story that the themes tell about the topic (Riger & Sigurvinsdottir, 2016).

3.5. Limitations

There are three key limitations in this study. The first relates to the sample size and sampling method I utilized. The second limitation concerns the potential for social desirability bias within participants' responses. The third and final limitation is regarding the process of translating interviews from Spanish to English.

3.5.1. Sampling Limitations

While the sample size is sufficient for this study and its scope, it could have benefited from more voices. Although I spent three months in Costa Rica to collect data for this research, institutional constraints and cultural norms limited the data collection period to four weeks. Small sample sizes are sometimes argued to impact the validity and generalizability of research (Faber & Fonseca, 2014). However, there are benefits that are worth noting. Research with fewer participants can often be conducted at a quicker rate than research with a large sample size, which is noted as particularly useful in international research (Hackshaw, 2008). The purposive sampling method I used often leads to smaller sample sizes compared to random sampling, and therefore is validated on the basis of credibility and utility, rather than numbers (Palinkas et al., 2015). Random sampling does not necessarily ensure each participant is "information rich" as is required for the intended depth of understanding needed for this type of research (Palinkas et al., 2015, p. 537). This research is foundational in nature and is intended to provide a baseline for larger studies in the future. From that standpoint, it provides an essential basis from which more in-depth research can take place, which can then expand on the existing data set, both to determine wider applicability within and across different cultures, as well as to expand the scope of each indicator's contribution to resilience.

3.5.2. Social Desirability Bias

A limitation of semi-structured interviews that is relevant to this research is the issue of social desirability. Social desirability bias refers to instances where a respondent answers an interview question with what they believe to be the preferred social response, regardless of whether it is true (Barriball & While, 1994). In an effort, deliberate or not, to please the interviewer, some respondents will embellish or omit certain information (Fontana & Frey, 2005). Differences in ethnicity, gender, education and socio-economic status between the interviewer and the respondent can enhance social desirability; while careful self-presentation of the interviewer can aid in overcoming this limitation by putting the respondent at ease (Barriball & While, 1994). It is possible my nationality, gender, or education influenced respondents to answer interview questions differently than if the interviewer had been Costa Rican or Hispanic, male, or a fellow producer. However, social desirability bias tends to be more common in studies where the topics are perceived by respondents to be "sensitive or controversial" (Bergen & Labonté, 2020, p. 783). In order to limit the possibility for social desirability bias in this study, I refrained from asking participants questions related to certain socio-economic characteristics. Though this research could have benefitted from this information, in particular participants' education levels, I prioritized ensuring respondents felt at ease and were comfortable answering questions in complete and truthful ways. Furthermore, social desirability bias can also occur when participants know their responses will be shared with other people (Larson, 2019). In light of this, the risks of social desirability were mitigated in my study, as all participants were assured that their responses would be kept confidential and not known to the wider community. As with all research, future studies are important to determine whether the results of this research are consistent with other findings.

3.5.3. Translating Interviews

In the process of translating interviews, it is possible to lose some richness in the data. Oftentimes, a translator must interpret not only the literal meaning of a word but also how the word "relates conceptually in the context" of the interview (Squires, 2009, p. 278). The interpretivist lens which influenced this research requires an acknowledgement of the power that language holds, and the idea that there is no neutral way to translate another person's words without encountering at least some bias on the part of the translator (Temple & Young, 2004). Despite this limitation, it was important not to restrict participation in this research to solely English speakers. Temple and Young argue that "if you cannot give voice to your needs you become dependent on those who can speak the relevant language to speak for you" (2004, p. 164). Producers who can speak English are not necessarily representative of a broad range of producers in Costa Rica, therefore the limitations involved with translating interview data are a necessary part of this research.

This limitation is similar, albeit more significant, to those most researchers face when conducting qualitative interviews. When transcribing, it can be difficult to accurately capture spoken word in writing, largely because many people speak in run-on sentences (DiCicco-Bloom & Crabtree, 2006). For this reason, the transcriber is often forced to decide when to add punctuation, which could effectively change the meaning intended by the respondent (DiCicco-Bloom & Crabtree, 2006). It is important again to acknowledge the subjective nature of human conversation in the context of the interview (Poland, 1995).

4. Results

This section presents information on the producers who participated in this study, as well as an overview of findings from their interviews. Relevant characteristics of participants and their production systems are presented in Table 4.1. These characteristics include participant's gender, size of production system, production elements, as well as the number of years participants have managed their systems.

All participants incorporated more than one production element into their system. Some, however, focused on the production of one primary crop with other elements included to a lesser extent. One producer focused on *Theobroma cacao* L. (cacao), while three participants managed systems primarily to produce *Coffea arabica* L. (coffee). Another producer grew coffee as one small part of their system. Of the six participants who produced dairy products, one utilized *Capra hircus* L. (goats) and the remaining five utilized *Bos taurus* L. (cattle). Four of the five participants with dairy cattle produced only milk and cheese, while the remaining participant produced milk and cheese in addition to yogurt, butter, and natilla, which is a dairy product similar to sour cream. The fruits and vegetables participants incorporated in their production systems included: root vegetables, for example, *Daucus carota* L. (carrots); tuber vegetables including *Solanum tuberosum* L. (potatoes) and *Ipomoea batatas* L. (sweet potato); bulb vegetables such as *Allium cepa* L. (onion) and *Allium sativum* L. (garlic); leafy greens, for example, *Brassica oleracea* L. (kale) and *Brassica eruca* L. (arugula); various fruits such as *Carica papaya* L. (papaya), *Psidium guajava* L. (guava), and *Musa acuminata* C. (banana); and legumes. Medicinal plants are considered in a separate category because participants who included them differentiated these plants from other vegetables. Finally, under meat production, producers included *Oreochromis niloticus* L. (tilapia) and *Gallus gallus* L. (chickens).

Table 4.1. Social characteristics of participants and physical characteristics of participants' production systems

Variable	Characteristics	Number of Participants
Gender	Female	6
	Male	6
Area of Land	< 1 hectare	1
	1-6 hectares	6
	7-14 hectares	3
	>15 hectares	2*
Production Elements	*Theobroma cacao* L.	1
	Coffea arabica L.	4
	Dairy Products	6
	Fruits & Vegetables	7
	Lumber & Wood	2
	Meat	3
	Medicinal Plants	3
Time Involved in Current Production System	1 year	1
	2-10 years	6
	11-20	2
	20-30	1
	>31 years	2

* The largest production system included in this study is 800 hectares.

The remainder of this section is separated into eight parts based on the selected indicators of social-ecological resilience. These indicators informed the deductive codes I used to analyze the data, and include species and varietal diversity, landscape diversity, sustainable use of resources, innovation in management practices, local networks and institutions, availability and exchange of seeds and livestock, gender, and autonomy. The findings from this study will be discussed further and in the context of the literature in the next section.

4.1. Species and Varietal Diversity

4.1.1. Species Diversity

Participants were asked about the type and number of cultivated crop species and varieties they produced to determine the level of agricultural biodiversity in each system. Only species and varieties discussed by participants during the interviews were included. Participants B, D, F, and K produced food crops for family or community consumption. Specifically, Participant D managed a system to provide food for a restaurant, and Participant K managed a system for a restaurant combined with an agritourism business. As shown in Figure 4.1, these four participants managed systems with a greater range of species diversity compared to systems managed by Participants A, C, E, and L for the purpose of selling one primary crop in national or international markets.

Participant B's production system comprised "an inventory of 300 plus plant species" all in various quantities. These species included numerous fruit trees, vegetables, and medicinal plants such as *Lavandula* sp. L. (lavender), *Mentha piperita* L. (peppermint), *Curcuma longa* L. (turmeric), and *Centella asiatica* L. (gotu kola). Participant B said of their production system:

"I feel that sometimes this is like a botanical garden because we have a lot of different species. But not all of them are in huge amounts. Maybe we can sell lemongrass or turmeric, but we have only a little bit of ashwagandha and we are not going to sell that, but it's interesting to have."

Similarly, Participant D had a wide variety of crops growing in their garden, including potatoes, sweet potato, *Manihot esculenta* C. (yuca), *Solanum* sp. L. (tomatoes), onion, *Phaseolus vulgaris* L. (beans), carrots, and various leafy greens such as kale, *Lactuca* sp. L. (lettuce), and arugula.

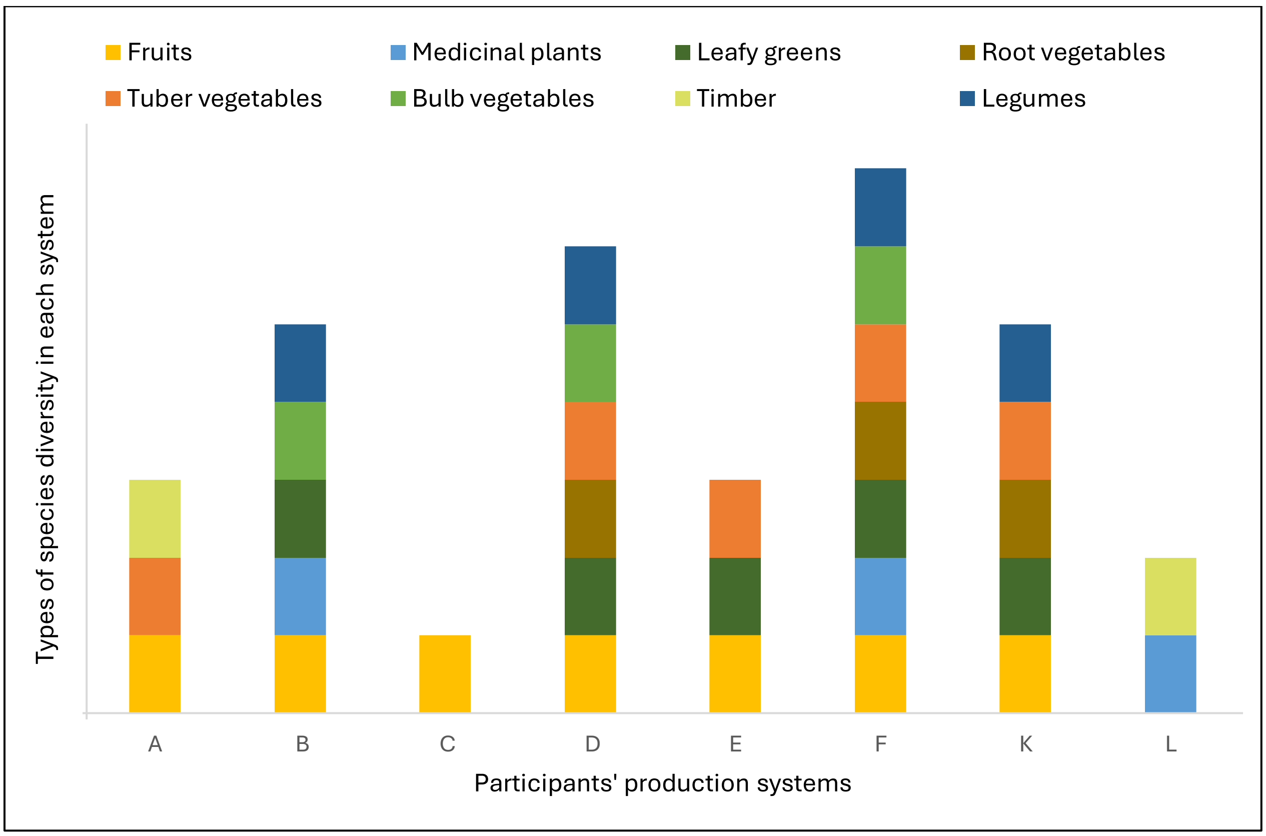

Figure 4.1. Types of cultivated crop species diversity in systems managed for crop production. Participants who only raised cattle for milk and cheese production are not included in this figure. Vegetable groupings are based on the edible part of each plant.

When Participant F first started their production system, they included 20 different crop species. Over the years, Participant F increased that number to as many as 75 crop species growing in their 460 square meter space. At the time of the interview, Participant F was growing 42 crop species, including *Morus* sp. L. (mulberry), whose berries they used to make yogurt, and whose leaves they fed to their goats. Participant F also grew beans, papaya, guava, *Persea americana* M. (avocado), *Musa balbisiana* C. (plantain), banana, *Zingiber officinale* R. (ginger), *Mentha suaveolens* E. (mint), turmeric, three types of lettuce, and eight different types of *Capsicum* sp. L. (peppers), "some spicy, some not as spicy," among other fruits, vegetables, and medicinal plants. For Participant K, the species diversity present in their production system fluctuated between seasons. In total though, the system produced around "80 different types of crops during the year" including legumes, several vegetables, and various fruit trees such as cacao, *Nephelium lappaceum* L. (rambutan) and *Citrus australasica* F. (finger limes).

Although Participants A, C, E, and L had less species diversity than the producers who grew food for family or community consumption, their systems were still quite diverse. For example, Participant A called cacao "the main actor of the movie," but emphasized the need to "have partners that will help the system," which is why they also grew guavas, *Malus domestica* B. (apples), *Citrus sinensis* L. (oranges), *Citrus reticulata* L. (tangerines), bananas, plantains, and *Citrus aurantiifolia* C. (limes), as well as *Zea mays* L. (corn), yuca, *Xanthosoma sagittifolium* L. (malanga), and timber wood species. Participant A explained that the diversity of species planted throughout their agroforestry system contributed to food security for their family, and at times provided enough to sell at community markets.

Participant C also had an abundance of fruit trees growing in their coffee-based agroforestry system, including orange, banana, lime, and guava trees. This diversity was deliberate, each tree intended to fill a certain role. Participant C explained:

> *"Some of [the trees] are nitrogen fixers, for example. Others are dedicated so that they can feed different species of birds, and others are dedicated to sustain the family, and also to feed the workers. Sometimes we have an excess of food, and we give it away to the community and family members."*

For Participant E, in addition to coffee, their production system included banana and plantain trees, as well as yuca. They also had a garden bed where they produced other vegetables, mainly leafy greens, for family consumption. Participant L produced coffee, as well as timber wood species and organic medicinal plants such as *Origanum vulgare* L. (oregano) which they used to make essential oils.

4.1.2. Varietal Diversity

Regarding diversity within species, one dairy producer in this study, Participant J, reported utilizing three different breeds of cattle: Jersey, Holstein, and Guernsey. Other dairy producers, Participants G, H, and I, utilized only Jersey cows. Concerning crop varieties, Participants A, C, E, and L, who were focused on producing either cacao or coffee, reported growing multiple varieties each. The number of varieties that these participants produced is shown in Figure 4.2.

Participants A, C, and L each described being in the process of testing new varieties to add to their production systems. Participant L had 40 coffee varieties on trial, while Participant C was testing one new variety, which they noted had a "good flavour" but was more susceptible than other varieties to "diseases and insects." Participant A was looking to expand production to include a greater number of varieties, particularly those with greater resistance to dry and rainy conditions. Participant A noted that variety selection was "a long process and a huge investment" because of the risk involved in trialling new varieties. Participant E described the importance of choosing varieties that are both "strong and highly productive."

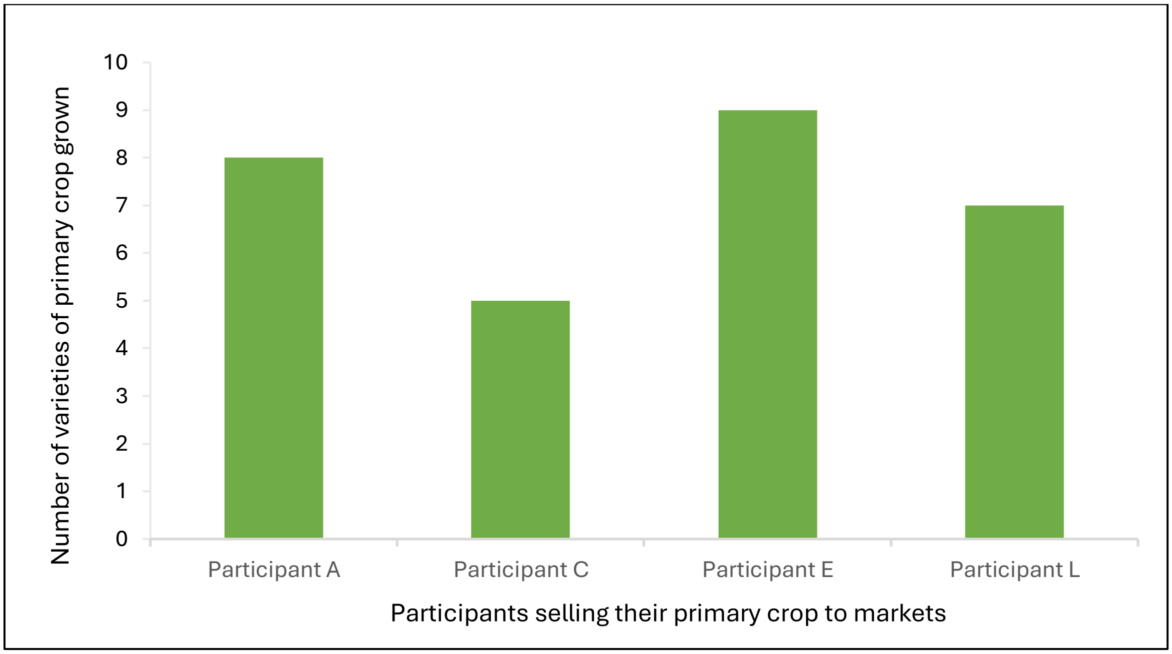

Figure 4.2. The number of varieties participants who produced for national or international markets grew of their primary crop. Participant A's primary crop was cacao, while Participants C, E, and L grew primarily coffee.

4.2. Landscape Diversity

Each participant was asked about the landscape heterogeneity of their production system. Participant responses are depicted in Figure 4.3. Built-up land cover was the most common landscape component mentioned by participants and included producers' own homes, buildings to support tourism initiatives, and permanent shelters for livestock and chickens.

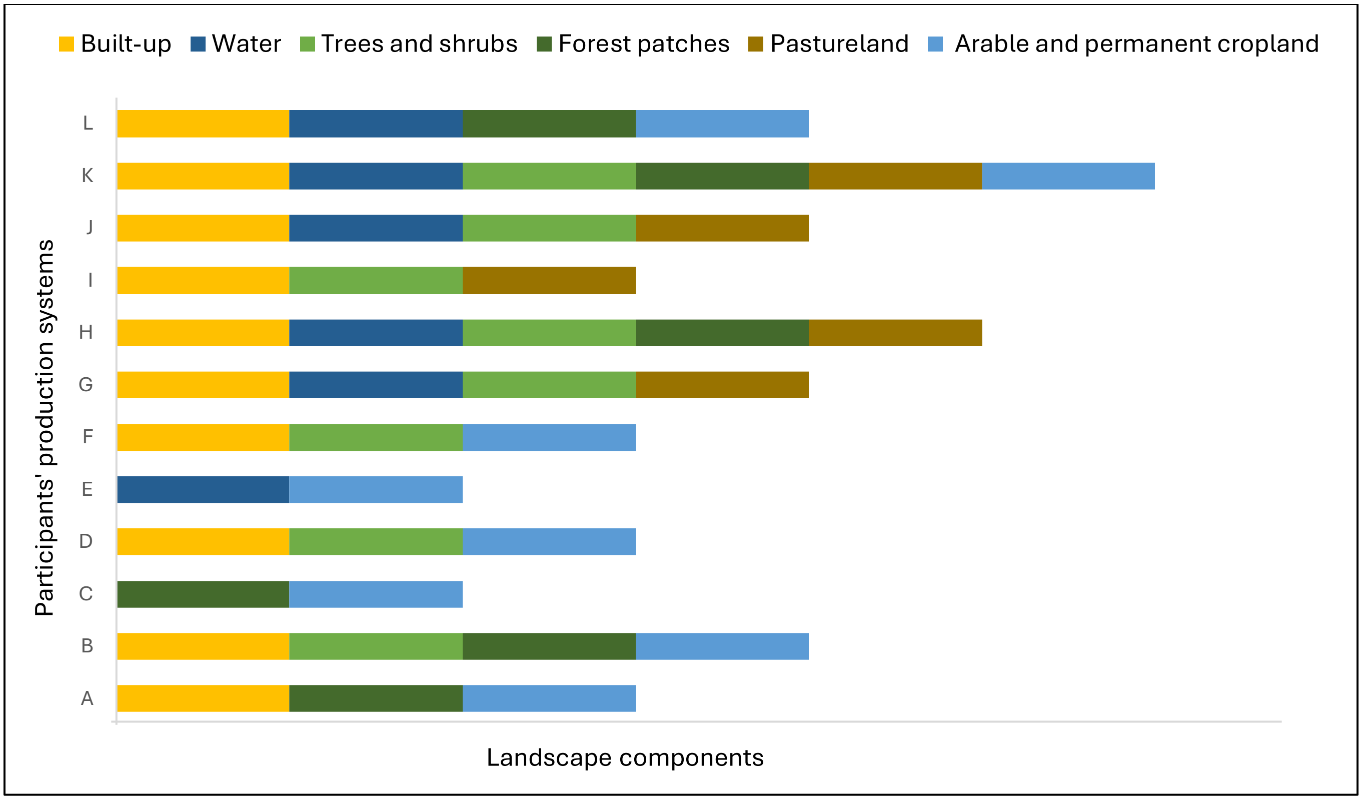

Figure 4.3. The landscape components in each participant's production system. Each landscape component is represented by a different coloured block. Built-up land comprises all human-made land surfaces, including infrastructure. Water refers to ponds, streams, creeks, springs, and rivers that sit or flow through participants' production systems. The category for trees and shrubs refers to scattered trees throughout pasturelands and production systems, as well as the use of living fences. Forest patches denote areas of land covered in trees that are not part of an agroforestry system, and pastureland consists of fields covered with grasses or other vegetation that is suitable for the grazing of livestock. Arable and permanent cropland refers to land with temporary crops and gardens, as well as crops that have occupied the land for a long time, such as coffee or cacao agroforestry systems.

The bodies of water that made up a portion of the landscape in some participants' production systems included a small creek, a pond, two springs, and two rivers. Many of the participants with this landscape component described the water sources as important to conserve. Both producers with a natural spring on their land, Participants E and H, said they did their best to protect the area around where the water emerged. For example, Participant E refrained from planting coffee trees in the area near their spring, while Participant H left half a hectare of forest cover surrounding theirs. Participant G said they planted Nacedero trees near the river which cut through their pastureland because the trees helped to "hold the ground" and aided in preventing erosion. Similarly, Participant J discussed leaving the trees that grew naturally around a creek in their pastureland to reduce erosion. Another producer, Participant L, noted the importance of having trees along the bank of the river that cut through their coffee system, to protect "the water from agricultural runoff" and prevent "excessive evaporation."

The final producer with water as a landscape component managed this part of their production system differently than the other producers. Participant K included a pond on their farm, which was created as a "sub-product of the water treatment system" developed to treat water after it had been used to clean the infrastructure where cows were milked. Instead of letting the "dirty water that comes out of the cow farm" run off into nearby waterways, the water was filtered through a natural purification process then used to produce tilapia in the pond.

The next landscape component, scattered trees and shrubs, provided a myriad of benefits that were noted by participants. As previously mentioned, trees growing around bodies of water helped producers control and prevent erosion. They also aided three participants in the creation of fencing for livestock. Additionally, three producers discussed how the shelter and shade provided by scattered trees benefited their animals. Participant F explained that "animals can suffer a lot on wind currents." To prevent undue distress to their goats, Participant F positioned the goats' infrastructure "where they would have trees and where they would be protected from the wind." And, because the location of their production system could get exceedingly hot, Participant F also noted the importance of putting the infrastructure where the goats were protected by shade, which helped keep "a good microclimate in the structure." Participant F also used the organic material produced by trees scattered throughout their production system as fodder for their goats.

Four participants had fruit trees scattered throughout their gardens or pastureland. Producers noted the benefits of the trees in providing additional sources of food, habitat for biodiversity, as well as beautification. When asked about the trees in their production system, Participant D emphasized the latter two benefits and explained:

> "*In reality, this is not a very big farm. We are in the middle of the city, so we do not have any forests. But we do plant trees. We have them scattered around the farm. One purpose is to generate shade, and they also bring in the native birds. Also, in March these trees provide a beautiful harvest of flowers that we use as a visual attraction to the farm.*"

Of the six producers who included forest cover as a land component in their production system, five emphasized the value of protecting ecosystems and conserving biodiversity. Participant K noted that "not every place" in their 15-hectare production system was "designed to have a maximum yield." Some areas "are thought out so they can be in harmony with the environment around them," Participant K explained. Participant B described how their production system followed a traditional permaculture design, utilizing four different zones. Starting at the centre and moving outwards, the first zone included infrastructure for housing, recreation, and agritourism. The next zone was comprised of vegetable gardens, followed by an "edible forest." The final zone was a second-growth forest. "This forest is mostly for biodiversity preservation or conservation" explained Participant B. "There are fruit trees in the forest, and we could harvest a few fruits, but right now it is not for production, it's for ecological conservation."

Participants A, C, and L each highlighted the benefits of forest cover for animal biodiversity specifically. Participant C said the "animals that live in the forest" often come into their coffee production system and “feed off certain fruits like bananas and oranges” which were intercropped in their agroforestry system. “We always see the flow of animals going from the forest into the coffee plantation” Participant C added. Additionally, Participant C noted the importance of bees in pollinating their coffee plants, concluding: “The forest is a very important part of production by providing shelter to all of these animals and insects.” Similarly, Participant L mentioned that forests near their coffee agroforestry system increased the populations of “natural predators” and helped control the populations of “pests that affect the coffee.”

Participant L also emphasized the “human element” as an additional benefit to biodiversity when discussing the benefits of forest cover. “The livelihoods of communities are enhanced or improved because of the protected areas around them” Participant L explained, adding “Clean air, clean water, beautiful forests to take a walk in, just to relax in, that’s all good for people.” Another “human element,” related to education, was described by Participant A. “Because we focus on ecotourism,” they said, “it’s really important to have the forest where we can have some trails; where we can explain not only about cacao, but about biodiversity and environmental topics, and even about insects and the importance of keeping the system in balance.” Participant A also mentioned the future benefits of keeping forested areas in their production system. They spoke of their young children and how what they are planting and protecting now will provide their children “with good economic support” in the future.

The final two landscape components are pastureland and arable and permanent cropland. Pastureland was discussed as a landscape component by five participants, each of whom managed systems solely or partially to produce dairy products using cattle. For five producers, arable and permanent cropland took the form of a fruit and vegetable garden. For seven producers, some of whom also had gardens, this land use component was an agroforestry system.

Three of these agroforestry systems were focused on coffee, one on cacao, and three on the production of a diversity of food crops.

Producers described receiving multiple benefits from their agroforestry systems in addition to food production, including carbon sequestration, microclimate creation, and reforestation. Specifically, Participants C and F both said they valued the carbon sequestration power of the trees in their agroforestry systems. Participant F stated their value for this service came from their belief that to be resilient, producers must focus on mitigation in addition to adaptation measures.

Participant L explained that the trees present in their coffee agroforestry system helped create a "microclimate developed through extensive shade cover." In terms of reforestation, Participant A discussed how they utilized their cacao agroforestry system to create "biological corridors" to reconnect forests fragmented by farmland. Participant A noted that there were "general remains of forest" in their production system already, which they had refrained from planting cacao on. Other areas had been deforested and degraded, left by the preceding owners. It was in these deforested areas that Participant A planted cacao trees, along with various other species, to reforest the area "under a mixed system."

4.3. Sustainable Use of Resources

All participants indicated they employed various strategies to conserve soil and water resources. These approaches are depicted in Figure 4.4 and discussed in-depth below. The exception is 'Trees near water sources,' as this practice and the resulting benefits were considered in section 4.2. In addition to the benefits of agroforestry already discussed, participants reported benefits to water and soil conversation as well, including increased water retention in soils and greater organic matter and soil cover resulting from leaf litter. Participant F described intentionally including tree species that aided in maintaining and "taking care of the hydrological resources" in their region. For example, Participant F planted Nacedero trees because of their ability to hold water in the ground around their roots. In terms of soil, Participant L discussed the benefits of the organic matter produced by trees, which helps nurture the soil below. The addition of leaf litter from trees aided two other producers in rebuilding soil that had previously been degraded by conventional agricultural practices.

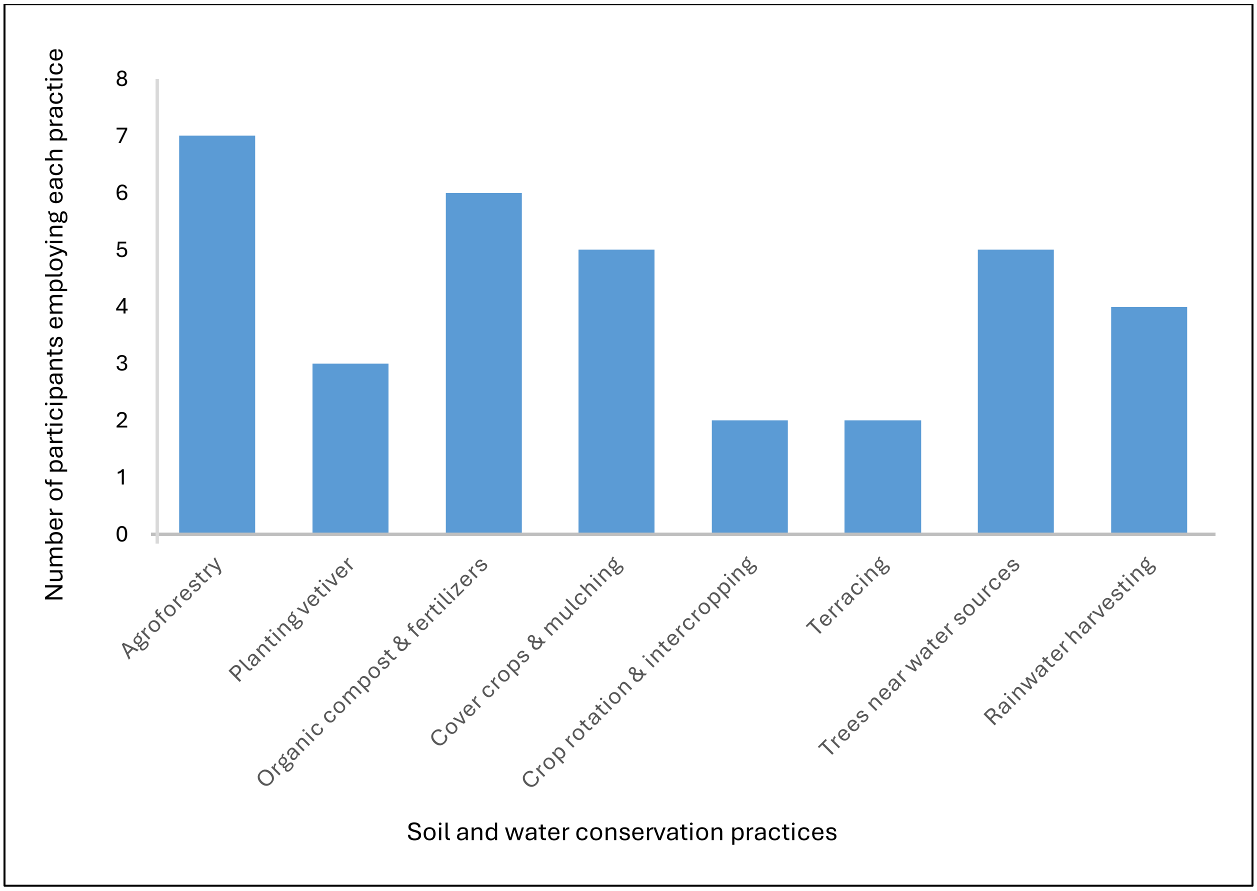

Figure 4.4. Systems and practices used by participants to conserve soil and water resources.

The three producers who discussed planting *Chrysopogon nigritanus* L. (vetiver grass) as a strategy for conserving soil mentioned either its utility as mulch or for holding soil in place, particularly in hilly areas. Participants B and F both said they prune vetiver grass and use the residue as mulch in their gardens. Participant A said that because their "land is quite steep in some areas," their priority was to prevent landslides and "protect the soil." To accomplish this goal, Participant A planted vetiver grass to keep "the soil more attached," before they began planting cacao trees, their primary crop. Similarly, Participant B discussed growing vetiver grass on terraced land to retain soil.

Participant F, who is also an agronomist, said in general, vetiver is great for planting on "contour lines" because of its ability to "hold and retain soil." In Participant F's production system, which is on flat ground, they discussed using the holding power of vetiver grass in a different way:

> *"What we're doing is surrounding the entire raised bed with vetiver grass so that the soil won't seep out. It has a root system that can grow up to seven meters in depth, roughly around 20-something feet, and it's completely vertical, so it creates a type of net. Initially, we would use Guadua, which is a type of bamboo. But the bamboo rots really easy, really fast, and we had to keep changing them every year and a half. And it doesn't retain the whole amount of the compost that we would put in the middle of the raised bed. Because underneath it, there would be seepage of the soil. The vetiver, in contrast, actually does this entire net around the raised bed, which allows us to capture and hold in most of the soil."*

Half of the participants discussed making their own compost or fertilizer to enhance soil quality. Participant B turned food scraps from their kitchen into compost, and also bought organic compost from other producers in their area who were trusted to "have good practices." Participant K employed a distinct method of composting called vermicomposting. This method involved utilizing earthworms to "transform the manure" they received from cows "into fertilizer that can be used for different crops." Two other producers, Participants H and I, said they harvested cow manure from inside the animals' infrastructure and applied it to pastureland and areas where they grew fodder for cut and carry, a practice whereby producers cut forage and carry it to the animals multiple times per day. Additionally, Participant F said they chose to incorporate goats into their production system because goats "create the best manure for producing organically."

Producers also reported using cover crops and mulching to keep their soil covered and protected. For example, Participant K said they did their best to ensure they never left "the soil naked" which helped avoid "radiation from the sun hitting the soil" while also contributing "to the retention of water." Similarly, Participant F kept their soil covered as protection from the "impact of the rain," which they received immense amounts of each year, and "to slow the rapid growth of weeds." Additionally, Participant H said they kept their pastureland covered in grass at all times to prevent erosion. Participant H did this by limiting their herd to 18 cows, thereby not exceeding the grazing capacity of the land.

Participant C explained they "always believed that the soil is the primary resource that we have as producers." They described the practices they used to keep the soil covered in their coffee production system and the benefits that these methods provided:

"All of the shade trees, they produce leaves that help to cover the soil and produce organic material. And that allows nutrient recycling. The same happens when we prune the plants we are cultivating. The leaves and the stems of the coffee plants that we prune are also being reincorporated into the soil as organic material. We don't utilize any herbicides to control the weeds. We use some manual techniques like cutting the vegetation with machetes. That allows for the soil to always be covered. We do not have any erosion on the farm because the soil is practically always covered. That also allows for a lot of beneficial microorganisms to develop and grow in the soil."

Of primary concern for many participants was preventing erosion and surface runoff. For this reason, Participant F said they planted cover crops. However, these crops also served additional purposes in their production system. Participant F explained:

"*We use Canavalia, a type of bean, and it has many functions. It works as a cover crop, it suppresses weeds. It is also absorbing nitrogen from the atmosphere and is fixing it into the soil. You can also eat the bean that is being produced by the plant."*

Participant B also used cover crops in their system, which they said helped "keep the humidity in the soil." They also employed a chop and drop method, a practice where plant residues are left on the ground near the plant to "add more organic matter to the soil" instead of being taken to a different location. In addition to planting cover crops, Participant B also practiced crop rotation and intercropping. Participant B's primary focus was on the health and quality of the soil, so they ensured they planted crops that took and provided various nutrients at different spatial and temporal scales. Participant D also employed crop rotation methods to prevent soil degradation and nutrient loss in their garden.

Two participants discussed utilizing terraces in their production systems. One producer, Participant E, lived in a region with "very steep hills." They explained that creating terraces was one way to "start taking care of the land" after decades of soil degradation from industrial practices employed by previous owners. After conducting soil analysis tests, Participant E found this degradation was impacting the productivity of their system and so implemented terraces to address the problem. After building terraces, Participant E noted they were able to apply their organic fertilizer more easily and had effectively transformed the economic viability and sustainability of their production system.

The final resource conservation method, harvesting rainwater, was practiced by one-third of participants. Participant F said they worked to capture "the water that lands on the roofs of the infrastructure" so they did not "waste potable water on irrigating the garden." Participant F expanded on this point and said:

> "*Here it rains a lot. But there are some times where we have droughts even though it might not look like it. For example, when we started with the garden, there were six months of drought. We had to come with a hose and hose down the garden which was costly and took a lot of time and manual labour. That is when we decided to start with a rainwater catchment system. Our water harvest tank can hold approximately 16,000 litres of water. Since that water is not potable, we use it for the garden when there's drought. We also use it to clean the infrastructure for the animals.*"

Participant D said rainwater was the sole water source for their production system. "We do not use water from the government" they explained, "we recycle the water that we get from the rain." Participant D stored the water in tanks and used it to irrigate their farm, which they said was "very necessary in the summertime" which is their region's dry season.

4.4. Innovation in Management Practices

A majority of participants discussed implementing innovative production practices in response to a variety of novel challenges. One example is Participant D, who used burnt oil, a by-product from the restaurant that their farm produced food for, to create "a type of soap" that is rich in potassium, which they applied to plants as an insecticide. By using an unavoidable by-product of cooking, one that is "not very well utilized" in the industry, and avoiding the need to buy external inputs, Participant D said they were making progress toward their goal of designing a "circular" production system. Participant D explained their reasoning for adopting this method:

> *"We have always been looking to do things organically and sustainably while keeping in mind the restaurant. We also want to be free of pesticides, which have been used around the world for so many years. We decided we wanted to make a change, and we became pioneers in our region by growing and consuming food that is free of pesticides. It has been very pretty to see how people from the community come to see and to learn about this whole new world and to eat what we are producing."*

Another example of an innovative practice adopted by Participant D, as well as by Participants E and F, is the on-farm making of biofertilizers. When Participant D was beginning their production system, they relied on the small number of organic fertilizers that were permitted in Costa Rica. This was a challenge though, due to the high cost and limited availability of these inputs. Participant D then began producing their own biofertilizer using a method known as 'Bokashi,' which is a form of composting that involves fermenting organic material using microorganisms. Participant D explained that adopting this practice helped their transition "from buying products to creating and using" their own, and even selling the excess.

Participant E made their biofertilizer by combining microorganisms with farm residues and coffee pulp, which is a by-product generated from processing coffee cherries. Participant F combined "indigenous microorganisms," which they acquired by collecting soil from the edges of forests, with *suero* to produce their biofertilizer. *Suero,* Participant F explained, is a fatty liquid rich in nutrients that naturally separates from goats' milk. Participant F applied this mixture both to the soil and directly to crops in the same manner as a foliar fertilizer. Additionally, Participant F noted that spraying the animal infrastructure with the biofertilizer helped to "reduce odours and prevent flies" from bothering the animals.

Participant F also discussed adapting their production system to better align with the conditions of the region. For example, the soil in their location contained a type of bacteria called protozoa, which greatly impacted soil salinity. Participant F noticed that many of the peppers and tomatoes they planted would "dry up" right as they were ready to be harvested. In response, Participant F began saving seeds from the plants that were resistant to the bacteria and only incorporated those varieties in their system moving forward.

Like Participant F, Participant B also found it important to adopt location-specific practices, particularly because they did not follow conventional agricultural methods. Participant B explained:

> *"I think it's very important that we see what works for us. Because we're in a very specific climate and have a specific soil pH. There are lots of different practices that could be really useful in some parts of the world, even in some parts of Costa Rica, that are maybe not for us, or maybe they are. It's part of the fun of doing agriculture that is not conventional. With conventional agriculture, you know that this chemical is going to*

kill all of the bugs that you don't want in the system. You use it and it works. Here, you have to be observing constantly."

Participant H noted that in the 40 years since they began raising dairy cows, there had been significant innovations in technologies that made production both easier and different. Participant H cited electricity being introduced to their community as one example. Before they had access to electricity, Participant H had to "milk the cows by hand" and "didn't have anywhere to store" the product. Now though, technology provided them with a "milking system that takes the milk directly to the tank."

One major challenge requiring innovation faced by Participant L, and discussed by Participant C, was a shortage of manual labour during the coffee harvesting season. For Participant L, coffee picking required "a lot of manual labour" due to the size of their production system; out of the 800 hectares of land they managed, 620 hectares were used for coffee production. To address this challenge, Participant L said they aimed to transition one-third of their production away from coffee. They described wanting to "diversify into other land uses" that still involved agricultural production, but which required "less people." Participant L mentioned wood production, carbon sequestration, medicinal plant production, and a combination of all three as options they had considered. "Maybe we will shift away from being so focused on the core, which is coffee" they explained, "but keep the same values of producing in a carbon neutral way, focused on principles of soil conservation and carbon sequestration with any new crop that is planted." Participant L also highlighted the importance of understanding that farmers are "not only producing a main product, such as coffee" but also "a lot of ecosystem services." They emphasized possible future avenues for commercialization based on ecosystem services provided by their system, such as fresh air and purified water.

Participant E also altered how they produced coffee to respond to the unique challenges they faced. They noted that coffee had been "produced in a very unethical way" in the past and described attempting to change that trend through their own system where they sought to incorporate increased biodiversity and create a circular model of production. Participant E explained:

> *"If we focus on sustainable practices like the ones we use, and if we start loving the Earth and we create a union between coffee and humans and everything that is flora and fauna, I believe that we can get a lot of benefits from it, and we can prove that you can do things differently with this product."*

Participant E added that an economic crisis they experienced a few years ago was their initial motivation to change their management practices. "We had to see what we could do differently, because we weren't making it like we used to, economically speaking," they said. Participant E decided to start processing their coffee as a result. They also adopted less conventional practices, including terracing and making biofertilizers, to improve the quality of their product.

When participants were asked about the main challenges they faced as producers, eight mentioned climate change. Participant J said climate change was the single biggest problem threatening their dairy production system. Participant C expressed the same belief for their coffee system and stated:

> *"I believe that every year it becomes harder for us to produce coffee. For example, sometimes we have droughts that are very prolonged. Then, all of a sudden, one day it will rain what it hadn't rained in the entire month. And that causes stress to the plants and it affects production. And I always say that when we see the production affected, our income is also affected. All of that economic sustainability is put at risk."*

For Participant C, the impacts of climate change necessitated certain changes to their management practices. For example, they used to heavily prune their shade trees to reduce cover over the coffee plants during certain months. However, "because of climate change," Participant C explained that the shade trees needed less and less pruning to provide adequate "shade for the crops during the entire year." Likewise, Participant D noted that their region did not experience its usual winter season the previous year. Instead, the heat of the summer continued throughout the year forcing them to adapt their production plan, as several crops they intended to plant would not have been able to cope with the constant heat.

In addition to innovation, responding to climate change also requires knowledge dissemination among producers. Participant F noted that many producers in their community were "maybe not conscious of the exact definition of climate change," however, they knew "very clearly that the seasons for planting and harvesting" were "changing" and felt the impacts on both biodiversity and profits. Participant F also noted that many producers lacked access to information related to "sustainable and regenerative agriculture" because of their remote location, or in some cases, due to a lack of internet access, so their only "knowledge is of conventional agriculture."

Participant K emphasized the importance of sharing information with other producers concerning both the consequences of conventional agriculture and the practices that increased his production system's resilience to climate change:

> *"I think it's because we weren't advised or warned that the conventional practices that we started a long time ago were detrimental to our farms. So, we lost the capacity to have resiliency towards these threats and these circumstances that we brought on ourselves. Being resilient and knowing how to prepare for climate change is hard for a lot of*

farmers because there is a lot of information that is not shared. And these techniques, regenerative techniques, are still practiced so little, studied so little, and understood so little. That is why we have to go bigger, we have to try harder, so that we can take this information to farmers so that we can raise their resiliency towards climate change."

Participant K further explained that they believed their own production system's resilience to climate change was the result of "observing nature" and "how she faces these types of problems," then working to implement those same solutions "with science." Participant K elaborated on the importance of sharing this information with other producers, stating: "It doesn't only matter what we do" to respond to climate change; "it has to be what us as farmers do in our zone, in our region, in our country, in our continent, and in the whole world."

4.5. Local Networks and Institutions

4.5.1. Local Networks

Each participant was asked if they felt connected to other producers in their region, and if so, how and why they were connected. Participants were also asked about the support they received from governmental and private institutions. Regarding local networks, most participants said they felt connected with other producers in the area, and that those relationships provided benefits to them and their production systems. There were, however, two exceptions. One dairy producer, Participant J, said they did not have any business relationships in their community that improved their production system. "Everyone manages their farm individually," they said. Participant J did mention having relationships with community members but refrained from discussing any personal benefits associated with those connections. A second participant said they did not feel connected to other coffee producers in their community because of their gender, and stated:

> *"In my community, all of the producers are male. All of the farms are managed by men. Most of the time, they believe that women don't know things or that women can't make it, and more than anything this is the case at the beginning."*

The remaining participants reported various benefits resulting from their connections to other community members. One participant said their community had organized as both coffee producers and as women. She explained that "in the last two years," they had formed a "women's association" which provided her with the opportunity to attend "meetings in the capital" of Costa Rica and to connect and work with a greater number of people.

Three dairy farmers, Participants H, I, and G, talked about having close relationships with fellow producers in their region; relationships which provided them with support, friendship, and a sense of community. Participant H explained:

> *"We're very united. If someone has a question or anything, we always help each other with whatever doubts we have. It's very nice to have that support because we're not working alone. We have a chat where anyone can ask anything and people will help out really, really fast."*

Participant I said their community was the reason they hadn't looked for a bigger farm elsewhere. They described having "a very good friendship" with the other producers in the area and noted that they "look out for each other."

Similarly, Participant A said community was the biggest factor they considered when deciding where to start their cacao production system. Their goal was to act "as a bridge between the academic and scientific community" and farmers in the area who may not have had access to formal education. Participant A added that they aimed to help farmers in their community develop viable and sustainable methods for producing cacao, citing their motivation as a desire to support the "excellent people" who lived and worked in their community.

In addition to personal benefits, producers also discussed various benefits to their production systems resulting from community connections and networks. Participant D described being part of a group of farmers who practiced sustainable forms of agriculture and who refrained from using pesticides. In addition to regular communication through WhatsApp, the farmers in this network engaged in community seed exchanges, particularly when unpredictable weather resulted in the loss of a crop. Participant D explained:

> *"We've had a very hard year this year. Unexpectedly, it has rained a lot, so many of us have lost a lot of the crops that we planted. We support each other by analyzing which crops were damaged, and who has seeds and we exchange them."*

In addition to sharing seeds, this group of producers also shared risk. Participant D explained that when a farmer in the network planted something new, they would share information about how it had worked for them, allowing the other producers to make an informed decision about whether they wanted to "take on the risk of planting" that crop. Participant D noted that they had set up "a good communication" system "between the few people who are in the sustainable agriculture community" in their area.

Participant B also described engaging in seed and seedling exchanges with community members, based on principles of reciprocity. For example, Participant B said:

> *"If we go to another farm, maybe we do a seeds trade, or people just give seeds to you. When you're in a farmer's network or community, people just say 'Oh, do you want to*

take this plant?' and it's a beautiful gift. Then when people come here it's like, 'Do you want this? Take it.' So that's really nice."

Participant B also discussed a "volunteer work party" they participated in, whereby different producers in the area took turns going "to each other's farms to help with a project." For Participant B, this meant 20 people helping to move "rocks, soil, and materials" to make way for a teepee they wanted to install. This system not only allowed producers to complete a project that required a concerted effort, but it also built "an initial connection and commitment" between the participating producers.

Participant K, one of the producers who managed a farm with the principal objective of producing food for a restaurant, said they relied heavily on other producers to supply products they did not grow themselves. Participant K described the connections they formed with other farmers through this business relationship, and how those connections allowed them to share knowledge and information regarding the regenerative practices they employed, which in turn led to the increased adoption of sustainable production methods in their community. Participant K explained:

> *"We try a lot to take advantage of the local products in the community. So, what we can't produce, we look for different producers in the region that are able to. We also try to open our doors to those farmers so that they can come, we can spend time together, and we can exchange information. This is so we can offer a product that has a higher nutritional value and a higher biological value for the health of the people."*

Participant F was similarly committed to the idea that community connections and knowledge exchanges can lead to adaptation and increased community resilience. Participant F stated:

> *"We need to think about the environment and the ecosystem that we are part of. Because maybe I have my farm good, but my neighbours have monocultures. Or maybe they're starting a small organic farm, but I have a monoculture and I'm contaminating them. So always there has to be community-level work. It's very important to have good relations between the neighbours of the farm. To me, that is how you make communities resilient."*

One example of this community-level work was discussed by Participant L, who detailed the presence of a "very proactive ASADA" in their community. An ASADA is a local administrative association for aqueduct and sewer systems in Costa Rica. Among other roles, they work to manage water sources and monitor water quality. Participant L explained that the community members who operated the ASADA where they lived acted as a sort of "local water administrative body" to ensure there was "conscious consumption of water in the community."

4.5.2. Institutions

All producers described receiving help from one or more of seven governmental or private institutions. Table 4.2 lists these institutions and the number of participants who mentioned them. Half of the participants discussed receiving support from the Ministry of Agriculture and Livestock, Costa Rica (MAG). Three dairy producers each said that the MAG provided them with infrastructure that aided in keeping their cows dry during frequent periods of intense precipitation. Participant J said the infrastructure they received from the MAG helped to "give a better life to the cows." Participant H described an incident where a nearby volcano erupted, and they were worried about their cows because of the ashes. "The MAG helped us by creating infrastructure for all the cows" Participant H explained, continuing "It's a miracle to have that now, because we can keep the cows dry no matter how much it rains."

Table 4.2. Number of participants who received support from one or more governmental or private institutions

Institution	Number of Participants Supported by Institution
Ministry of Agriculture and Livestock	6
Centre for Organic Farming	5
Association of Organized Producers in Santa Cruz	4
The Tropical Agricultural Research and Higher Education Center	2
Coffee Institute of Costa Rica	2
Institute of Rural Development	1
Non-Profit Organization	1

Participant D said they received support from the MAG through opportunities to participate in training programs, including a project called *Bandera Azul,* or Blue Flag. Through this program, at no cost to Participant D, agricultural technicians came to their farm and conducted analyses on the health of the system, then provided recommendations for future management practices. Participant A mentioned receiving support from the MAG, as well as the Centre for Organic Farming (INA) and the Tropical Agricultural Research and Higher Education

Center (CATIE) on a project they and their family were implementing. This project aimed to connect cacao producers directly to markets, avoiding intermediaries and in doing so, negotiating better prices for producers. When discussing the beginning stages of this project, Participant A explained that "everybody," referring to the institutions mentioned above, "wants to support us somehow." Participant A continued:

> *"I feel happy with the answers from CATIE, from different institutions. In a very good way, we have good connections with different private institutions and from the government as well. That is what we are going to move forward with next year for sure."*

Other producers who discussed receiving support from INA included Participant H, who said they benefited from courses related to research on cattle health and food. Participant E said they went to INA to "learn how to use microorganisms" to make biofertilizers. They also said that INA helped them to begin "doing things differently," starting by reducing their "herbicide use from six applications a year to only one application per year," and alternating between organic and synthetic fertilizers. After 30 years of soil degradation owing to unsustainable farming practices from previous landowners, Participant E said they were making progress toward their goal of restoring "60% of the soil that was lost."

Participant F reported receiving support from CATIE in the form of access to seeds. They noted that CATIE played "an important role in Latin America" by "providing technical assistance" to farmers; however, that assistance was often "too specialized." Participant F, who managed a small-scale, diverse system, explained that CATIE's assistance was heavily geared towards "cacao, coffee, and livestock systems," so producers who focused on broad and diverse forms of horticulture did not tend to receive the same level or quality of assistance.

All four participants located in or near Santa Cruz cited the Association of Organized Producers of Santa Cruz (ASOPROA) as a supportive institution. The participants said that ASOPROA provided them with training opportunities and connected them to other resources and institutions. For example, one participant said ASOPROA facilitated a connection between them and the Institute of Rural Development (INDER), from which they received a donation of tools to help with their production system. Another participant explained that ASOPROA helped connect them to governmental supports to ensure they obtained the correct certifications and were able to sell their products "without any hassle."

Finally, two coffee producers both said that they received support from the Coffee Institute of Costa Rica (ICAFE). In particular, Participant E said ICAFE helped them access hybrid coffee varieties. In addition to ICAFE, another participant also discussed their connection to a non-profit organization which sought to support and connect women coffee farmers in Costa Rica.

4.6. Availability and Exchange of Seeds and Livestock

Participants cited various methods for accessing both local and new varieties. These methods are displayed in Figure 4.5. Seven participants reported beginning their production systems by acquiring livestock or seeds from other local producers. Participants H, I, J, and K all acquired the first cows in their herds from other producers in their communities, then they each began breeding their own cattle. In terms of crops, Participant F said they looked for seeds that were already adapted to their location. They did this by reaching out to other producers, and even received some seeds as donations from local farmers. They explained:

> *"We started trying to get seeds that were lost and talking to producers in the area about which seeds are most viable. One has to be very strategic because a lot of hybrids and*

commercial seeds are not adapted to the region, a lot already come with a plan for fertilization in a chemical and conventional way. If you don't apply the chemicals just as they say, then you won't get the harvest that they say you will have. So, a lot of times, the best options are organic seeds that are from the region."

In their search for local plant varieties, Participant F found *ajo Tico,* or Costa Rican garlic. "It looks like an onion with thin leaves and a bulb" they explained. Participant F said the benefits of planting *ajo Tico,* which is endemic to the region, included its resistance to pests and diseases and the fact that it did not need synthetic fertilizer, only compost, to grow.

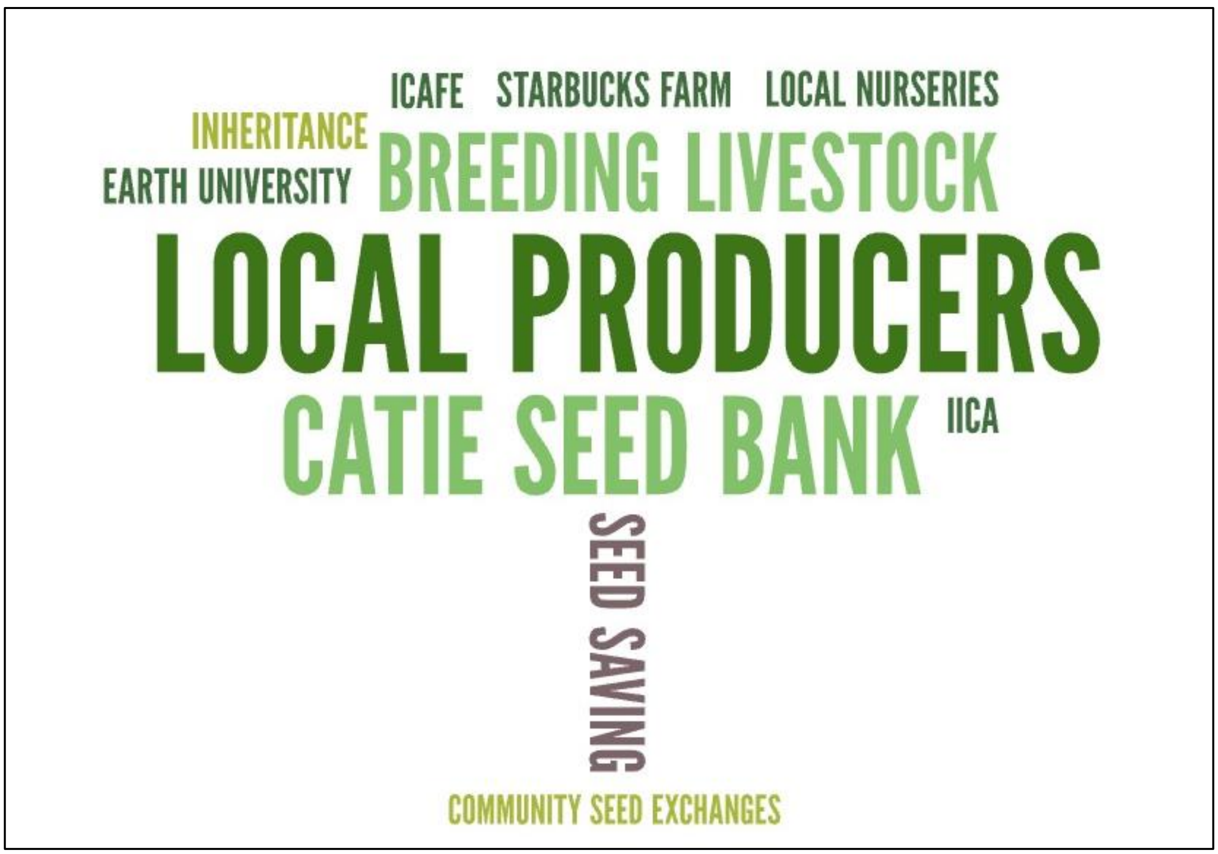

Figure 4.5. The various ways participants discussed accessing seeds and livestock. The size of each word or phrase corresponds to the number of participants who discussed utilizing each method. For example, 'local producers' is in the largest font because it was discussed by the greatest number of participants. Figure created using WordArt.com.

Participant D also relied on other producers to access seeds for their production system. "We have a person that brings us the seeds we use," Participant D said, adding "They come to our farm, and they have a test area where they try and see if the seeds work in a sustainable way or not." Participant D noted that they preferred this system over harvesting all of their own seeds, which they explained "doesn't always work" and can lead to "malformations" in the crops. Through this seed supplier, Participant D was assured that the seeds they received were safe and not genetically modified. For plants that were easier to harvest and replant, such as potatoes and sweet potatoes, Participant D relied on their own seed bank for materials.

Two other producers also practiced seed saving. Participant B kept a seed bank for various food crops, while Participant E had a seed bank specifically for non-hybrid coffee varieties. Participant E acquired their hybrid coffee varieties from various institutions, including ICAFE and a nearby Starbucks coffee farm. Another coffee producer, Participant L, said they relied on institutions including CATIE to research and develop new coffee varieties before trialling them in their production system. CATIE's seed bank was discussed by other producers as well, including Participant C, who sourced a new coffee variety from the institution, and Participant F, who described receiving donations of various vegetable seeds from CATIE. Participant A said they worked with CATIE, along with other institutions including the Inter-American Institute for Cooperation on Agriculture (IICA) and Earth University, to find varieties that best suited their production system and their objectives concerning quality and yield.

Participant C chose some of the coffee varieties they produced, including the variety they obtained from CATIE; however, the rest were chosen and planted by their father, who Participant C inherited their production system from. Participant C explained that some plants had been there for “more than 30 years” and credited the continued productivity and high-quality output of the system to the sustainable practices their family employed. Another producer, Participant G, also inherited important aspects of their production system. In particular, Participant G inherited cattle from their parents, as well as from their partner’s parents, which they used to breed their current herd.

The remaining methods participants in this study utilized to access seeds included local nurseries and community seed exchanges. Participant B said that in addition to saving seeds, they also obtained plants from local nurseries. However, they added that it was difficult to find nurseries producing organically in Costa Rica. Furthermore, Participant B, along with Participant D, also described engaging in community seed exchanges, the details of which were described in section 4.5.

4.7. Gender

Of the 12 interviews conducted for this study, six were with women and six were with men. The women were asked an additional question about whether they felt they had equal access to agricultural information and resources compared to the men in their communities. One woman did not answer the question. Of the remaining five women, three answered yes and two said no. One woman coffee producer who answered yes to having equal access to information and resources claimed neither came to her easily. She explained that she had always worked hard to claim space in her field by attending training sessions, reading, and educating herself with information online. She also described how women were often the leaders in projects like hers, which she managed alongside her daughter, where the explicit aim is to increase sustainability; yet women are often not acknowledged for this important work that they do. This producer also emphasized that although she felt she had equal access to agricultural information and resources, she believed that there were many other women producers for whom that support was “still not available, not in the way that it should be.”

Another participant who felt as though she had equal access cited her university education as the primary reason. She explained:

> *“I do think that I have equality because I was able to study at a university. I know where I can gather information. Or I can ask someone who does know. So, I have the ability to access and to reach the tools and resources that I need.”*

However, like the first producer, this participant also found it important to note that many women in her community and her country did “not have the same access to information” that she did. “In the trainings about coffee, the majority of the participants are male,” she explained, adding “When a woman wants to ask a question or learn something new, she is not looked at with good eyes.”

Another participant described feeling as though she had equal access to information and resources within her production system specifically, which was managed by both women and men. She noted that there were not many women farmers in her community, but explained she felt “really respected” within her core group of managers, partly because they had created a “horizontal system” in which all members had equal input in decision-making. Like the previous producer, this woman also noted that she attended university, which she said provided her with privileges not afforded to all women. She explained:

> *“I know of women who were not even able to go to high school. They follow the script of getting married and having kids…this kind of conservative lifestyle, which I respect but it’s not for me. I had the privilege of going to university and finishing it and having other opportunities.”*

These other opportunities allowed for this producer to work and live on her production system, while also generating additional income through online employment.

Two women producers in this study stated that they did not feel they had equal access to agricultural information and resources compared to the men in their communities. The first producer explained that farming was still a male-dominated profession, so “90%” of the other producers at the training sessions she attended were men. “It’s very hard, I won’t say it’s not,” she said regarding attending training courses and “being surrounded by men and people that are older,” who, she noted, often have conventional and established views on agricultural production which are based heavily on the use of agrochemicals. Interestingly, this participant noted that some men in the training courses she attended expressed gratitude for her participation because of the unique perspective she offered as a woman and as a young person. She also described that in her view, the agricultural sector was changing, however slowly, in how it embraced women, largely because “women have been butting ourselves in forcefully.”

The second producer who felt she did not have equal access to agricultural information and resources based on her gender said that unequal access to land in particular was a major problem in Costa Rica, and in Latin America in general. She cited unfair land ownership customs throughout much of history as one main reason. “In Latin America, most agricultural land is owned by men, and only a small amount is owned by women” she explained. She went on to note that this is mainly due to traditional practices, whereby a daughter who inherited land from her parents would receive that land in her husband’s name instead of her own. “The fact that as a woman your name doesn’t appear on the title of the land, it makes it so that you have less access to credits with banks” she explained, adding “You also have less access to training because the government will always only go through the owner of the land.”

The same producer also described *machismo*, or exaggerated masculinity, as another issue in the agriculture sector in Costa Rica, in which men are seen as having a greater role or greater knowledge surrounding agricultural practices compared to women. Other participants expressed similar views of having their knowledge and skills undervalued or needing to earn the respect of men in their communities and at training sessions. For example, outside of her core group of producers in which she felt she had equality, one participant described occasionally feeling as though external collaborators listened and responded better to the men on her team than they did to the women. Another participant explained:

> *"It's a world where your manual labour is going to be a man and you're going to have to gain that respect, and you can only do that through knowledge. If there's no knowledge you won't be respected. They will look at you like you don't know anything."*

Finally, a third producer discussed feeling a similar way and noted that her input was often valued less than men's, even when she objectively had more experience or knowledge.

Two participants noted one specific limitation they felt was hindering the full inclusion of women in agricultural spaces: the expectation that women complete a majority, if not all, of domestic labour tasks. The first participant explained:

> *"Women have been taught that they are the ones to clean, the ones to cook, and the ones to take care of the children. If you want to remove her from that bubble and you want to take her into training, you have to think very clearly about how you're going to do that. You could end up overworking her because she already has all of those other responsibilities and now, you're giving her another responsibility. And now she thinks, 'Oh, that's more work for me.' So, there are a lot of problems in trainings for*

women, it's not truly accessible. And that's where we have to start seeing how we can change."

The second participant raised a similar point, stating:

> *"Often women don't have enough time to look for information, since in a lot of homes, they have to realize all of the domestic labour, they have to take care of the kids or the elderly without help from the men."*

For this reason, this producer emphasized the importance of institutions that support women and that work to understand the cultural contexts within which many women live and work. Otherwise, efforts to include women in agriculture may inadvertently create more work for them or increase possibilities for conflict.

4.8. Autonomy

Seven participants said they felt as though they had autonomy over what they produced and agency over what agricultural practices they employed. Participant A said they did not feel there were any barriers preventing them from adopting certain practices in their cacao production system. In fact, Participant A felt there were "only possibilities in front" of them; possibilities to "produce cacao in an organic and sustainable way." They attributed these opportunities to the local climate where they lived, which Participant A said experienced "rain pretty much all the time," allowing them to explore and experiment with different practices. They also mentioned the institutions, including CATIE, IICA, and Earth University, that aided them in selecting the appropriate varieties for their goals.

Participants C and K were also content with how their production systems functioned. Participant C explained: "As of right now, I like a lot the way we are managing our farm. We want to continue with this sustainable way of production and continue learning and adapting to different situations." Participant K expressed a similar sentiment and stated:

> *"I feel very happy with what we have right now. And I feel very happy with what we have planned for the future. We have been in a process of modifying and adapting these systems so that they can be as productive and sustainable as possible. We are always transforming a little bit more. With what we have now in terms of biodiversity, and what we are going to have, we are very, very happy."*

Other participants reported feeling happy with their production systems, yet also expressed a desire to alter or develop them in some way in the future. For example, Participant J explained that they liked how their dairy farm was being managed, but added that they would like to eventually expand to include meat production. Participant B said they felt as though they had agency over what they produced, largely because they chose what to grow based on what they and the other production managers liked to eat. In the future though, Participant B's goal was to expand their production to eventually sell their produce at local markets and to create additional agritourism opportunities for "groups from universities." They described their hope that these endeavours could generate "a more sustainable economic system" for the farm through income diversification.

Alternatively, five producers discussed feeling as though their autonomy was limited in either how they managed their production systems, or in what they produced. For example, Participant I discussed their desire to better utilize the manure from their cattle by reintegrating it back into their production system; however, since Participant I rented and did not own the pastureland, they were limited to practices that the owner of the land approved of. Participant I explained:

> *"If the farm was mine, it would be nice to utilize more of the cow manure. Right now, we only use the more solid part. The other stuff that we wash away from where we are milking the dairy cows is not being utilized, it's just going downhill. I would make a tank so that I could collect the manure that is washed away when we're cleaning the pens. But one has to adapt to the options you have available."*

Another example is Participant L, who discussed their production system's dependence on synthetic inputs as a factor which limited their autonomy. Participant L stated that this dependence prevented them from implementing the practices they wanted to adopt. They explained:

> *"I would love to use less chemicals, but we are pressured by pests and disease and also cost. So, we need to use them. For a large-scale operation like ours and the nutritional needs of coffee, it's really hard to organically produce those fertilizers. But that's definitely something we would love to do. I would love to be less dependent and more self-sufficient when it comes to the sorts of inputs that farmers need."*

Participants G and E said they were happy with the production systems they managed, however, they both noted that their choice regarding what to produce was fairly limited by what was conducive to their respective landscapes. For example, Participant G, a dairy farmer, said their region was not well suited for producing crops other than forage for cattle, due to near-constant rain and high levels of humidity. Participant G added that they were still "very satisfied" with their production system. Similarly, Participant E described their region as a "coffee zone," due to the "topography of the land" as well as the "knowledge and history surrounding coffee" in the region. Participant E explained that their production system "had to accommodate" the zone but added that they had “fallen in love with” coffee and viewed their production as a “commitment” rather than an obligation.

Finally, Participant F cited consumer preferences as a factor that partially limited their autonomy over what they produced. Participant F said in part they did not feel forced to produce certain crops but noted that economic factors, including what consumers wanted to buy, required consideration to maintain the financial viability of the system. As an example, Participant F explained that although they may want to plant a pepper variety that is well-adapted to the region and which does not “require a lot of manual labour,” if consumers are not willing to buy this variety, they must adapt to what is profitable. And what is profitable may very well be a variety with “a more attractive flavour that requires more work” on the part of the producer. Participant F explained that “up to a certain degree, one does feel obligated” to plant certain crops, “because of the profitability, because that is how you can maintain the system” they concluded.

5. Discussion

This discussion will interpret and analyze key pieces of information presented in the preceding sections to explain the findings of this study and to illustrate their significance. This analysis is informed by the interview data, the conceptual framework that guided this study, and the relevant literature. One of the objectives of this study is to apply and strengthen indicators of social-ecological resilience in agriculture. Mijatović et al. (2013) developed their set of indicators to assist in identifying practices that can be supported to build resilience to climate change and to allow for comparisons of resilience across communities and landscapes. The following discussion is centred around eight of these indicators, also referred to as distal drivers in the conceptual framework presented in Figure 1.2, in the context of building social-ecological resilience to the relevant proximal drivers, namely climate change, biodiversity loss, and social inequality. This discussion also addresses the other objectives of this study by analyzing practices employed by producers to increase their resilience, as well as by discussing certain barriers to resilience.

The following paragraphs address each indicator of social-ecological resilience independently in the same format as the results section. Many of the ideas, however, are intricately connected. For example, gender inequality has the potential to negatively impact opportunities for innovation, which itself is heavily dependent on the existence and strength of local networks. The indicators are discussed separately to allow for adequate consideration of their individual utility. Together, they form an answer to the research question that directed this study, which asks how producers strengthen the social-ecological resilience of their production systems.

5.1. Species and Varietal Diversity

5.1.1. Species Diversity

Participants in this study reported utilizing a wide diversity of species and varieties in their production systems. According to the literature, resilient social-ecological systems, including agroecosystems, tend to have varied mechanisms for managing change and disturbances and chief among these mechanisms is diversity (Adger et al., 2005). When agricultural producers intentionally work to foster high levels of diversity within their production systems, they are better able to adapt to changing conditions (Mijatović et al., 2013). In agroecosystems, diversity "among and within species" increases redundancy and resilience to disturbances as different groups respond to change in different ways (Adger et al., 2005; Vernooy, 2022, p. 878). Simply put, if one species or variety fails for any reason, another is there to fill its role (Vernooy, 2022).

This study found that producers managing systems for family or community consumption included a higher degree of species diversity than those managing systems to produce one primary crop to sell in national or international markets. This finding is consistent with research by Fifanou et al. (2011), who reported that subsistence farmers often maintained higher crop diversity to meet nutritional needs. In addition to meeting nutritional needs, producers in this study reported utilizing assorted crop species to supplement income, promote biodiversity, produce fodder for livestock, fix nitrogen into the soil, and improve food security. These findings support the research on diversity-rich production systems, which generally states that these systems provide the means for producers to diversify their diet and income, increase the stability of their system, minimize risk, and reduce the prevalence of insects and diseases (Adger et al., 2005; Altieri, 1999; Kahane et al., 2013; Sunderland, 2011; Tang et al., 2012).

Numerous producers in this study practiced intercropping and crop rotation to incorporate increased species diversity into their production systems. Crop rotation, the practice of planting various crops in succession on the same unit of land (Castellazzi et al., 2008), has been found in the literature to be an effective practice for disrupting pest and disease life cycles, improving resource use efficiency, increasing soil quality, and ensuring diverse responses to stress, each of which makes important contributions to strengthening production system resilience (Borron, 2006; Costa et al., 2024). However, the benefits associated with crop rotation are dependent on the functional complementarity of the crops chosen; meaning crops that perform the same function will lead to redundancy instead of resilience (Costa et al., 2024). Data collected for this study focused on the number of cultivated crop species (and varieties) present in production systems, as recommended by Mijatović et al. (2013), rather than the quality of the relationships between crops. Though the number of species involved in production systems is important due to the valuable role of diverse genetic material in adaptation, Bravo-Peña and Yoder (2024, p. 10) suggest that simply seeking to increase crop numbers to bolster resilience is less important than creating "positive ecological interactions" among crops within production systems. Future studies should consider both the dynamics between chosen crops as well as the number of cultivated crop species in production systems to best support resilience-strengthening practices.

5.1.2. Varietal Diversity

Increasing the varietal diversity present in production systems is also an important method for strengthening resilience (Mijatović et al., 2013). High varietal diversity ensures production systems contain sufficient genetic diversity to reduce the risk of all components becoming susceptible to a stressor simultaneously (Keneni et al., 2012). When one component *is* susceptible, it is more likely that the other components will be able to compensate for that loss due to the increased availability of resources (Keneni et al., 2012). In this study, three participants described utilizing between five and nine varieties of *Coffea arabica* L. (coffee) in their production systems. Past research found that 40% or more of coffee-producing areas in Costa Rica are expected to decrease in their suitability for production by 2050 (Läderach et al., 2017). The specific climate impacts anticipated to drive this decline include higher temperatures and altered precipitation patterns leading to reduced growth among coffee plants, increased pest pressures, and lower yields and quality (Bracken et al., 2023; Kahsay et al., 2023). Varietal diversity can aid in reducing these negative impacts by allowing producers to select and produce numerous varieties based on their productivity and tolerance to inclement weather (Poncet et al., 2024). In support of this notion, participants in this study reported selecting new varieties based on these qualities, as well as flavour. Furthermore, research by Harvey et al. (2018) also found that many smallholder coffee producers in Central America, including in Costa Rica's Central Valley, have begun introducing new varieties into their production systems as a strategy for adapting to climate change.

Another reason for the effectiveness of high varietal diversity in increasing production resilience stems from the practices used to attain that diversity. Many smallholder producers, including two of the participants in this study, save seeds from highly successful plants each year, which contributes to the development of local landraces (Borron, 2006). Landraces are "geographically or distinctive populations" of species that are characterized by local genetic adaptation and high genetic diversity (Borron, 2006, p. 14; Villa et al., 2005). In addition to being well-adapted to the conditions of a region, landraces benefitted two producers in this study by helping them avoid a barrier to resilience associated with utilizing varietal diversity as an adaptation strategy. Harvey et al. (2018) proposed that technology-based adaptation strategies, such as the use of new varieties, are often less accessible to smallholder farmers. The authors noted that accessing hybrid seeds from commercial sources is often more resource-intensive, particularly regarding capital and labour, than adopting practices that rely on existing resources (Harvey et al., 2018). Participant A in this study supported this point when they noted that, in their experience, obtaining new cacao varieties through institutions had been a long process requiring substantial investments.

Concerning livestock production, only one participant in this study reported including more than one breed of cattle in their system. Research by Magne et al. (2016) in southern France found that dairy cattle herds with more than one breed saw benefits to both milk production and animal reproduction compared to herds with only one breed. In this study, data regarding milk production and animal reproduction was not collected, therefore it is not possible to affirm whether the participant who utilized various breeds of cattle increased their resilience by doing so. Dumont et al. (2020) noted that evidence related to herd composition and its role in impacting resilience is scarce. Future studies are required to better understand the "technical and economic performances" of herds with a diversity of breeds to identify if and how they respond to disturbances differently compared to herds containing one breed (Dumont et al., 2020).

5.2. Landscape Diversity

Landscape diversity, or landscape heterogeneity, refers to the variety of cover, and the spatial patterning of that cover, over landscapes (Fahrig et al., 2011). Landscape diversity is a valuable indicator of social-ecological resilience because of the different ecosystem services provided by assorted landscape components (Mijatović et al., 2013). Participants in this study managed production systems containing between two and six landscape components, with an average of 3.5 each. Participants frequently discussed beneficial ecosystem services resulting from the inclusion of scattered trees and shrubs, forest patches, and agroforestry components within their production systems. As described previously, ecosystem services are the direct or indirect benefits that result from interactions between people and nature (Teixeira et al., 2022). These services are both fundamental to human well-being (MEA, 2005) and necessary for agricultural production (Power, 2010). Agriculture is often engaged primarily with increasing provisioning ecosystem services, frequently at the expense of cultural, regulating, and supporting services (Gordon et al., 2010). However, this is not an unavoidable trade-off. Participants in this study demonstrated various strategies which revealed a strong focus on developing and enhancing all ecosystem services through landscape diversification.

Participants in this study described valuing and utilizing scattered trees throughout their production systems specifically for the cultural ecosystem services they provided. Cultural services can refer to a variety of areas, such as human-nature relations, spiritual enrichment, inspiration, and cognitive development (Balázsi et al., 2021; Pascua et al., 2017). In this study, participants reported cultural services in the domains of beautification, recreation, instilling a sense of community, education, and agritourism. For example, in Participant D's experience, scattered trees throughout their city-based production system added a visual appeal to their farm; while "beautiful forests" near Participant L's system enhanced community well-being and opportunities for recreation. Assandri et al. (2018) found in Trentino, Italy, that managing agricultural landscapes to preserve aesthetic and cultural values often led to conserving traditional characteristics of the land. Through this conservation, the recreational capacity of the land increased and native biodiversity was protected (Assandri et al., 2018). The results of this study, along with Assandri et al.'s (2018) research, indicate the positive impact that managing systems partially for the provisioning of cultural ecosystem services can have on the broader scope of social-ecological resilience.

Based on the experiences of producers in this study, including scattered trees throughout agricultural systems also provided various regulating and supporting ecosystem services. Mijatović et al. (2013) found that out of 172 studies focused on the use of agricultural biodiversity in increasing resilience to climate change, 32.5% of cases in areas exposed to drought, unpredictable rainy seasons, floods, and other extreme weather events relied on the integration of trees in production systems to increase resilience. Participants in this study reported using scattered trees and shrubs for a variety of resilience-strengthening functions, including to prevent erosion near springs, rivers, and creeks and to provide shade and shelter for livestock. This latter practice, referred to as a windbreak or shelterbelt, influences the microclimate of a production system by reducing and redirecting wind flow, subsequently protecting livestock as well as crops and infrastructure from severe weather events (Atangana et al., 2014). Other beneficial services provided by windbreaks include erosion control, the creation of wildlife habitat, the provisioning of tree products, and improving the aesthetics of landscapes (Brandle et al., 2021). These services illustrate the wide-ranging benefits, beyond the provisioning of food, that the inclusion of scattered trees can provide to production systems. Additionally, research by Harvey (2000) found that windbreaks in Monteverde, Costa Rica, significantly increased tree and shrub seed deposition in agricultural landscapes by attracting birds from adjacent forests. This finding is particularly important in the context of the promotion of forest regeneration on degraded land in Costa Rica (Harvey, 2000).

It was established in the literature review that agricultural production and biodiversity conservation have traditionally been seen as contradictory pursuits (Bar-On et al., 2018;

Newbold et al., 2014). In the past, conservation efforts have concentrated on 'pristine' habitats, largely discounting the conservation potential of human-altered landscapes, including agricultural land (Tscharntke et al., 2005). However, increasing acknowledgement has been made of the importance of "population exchanges among areas of different disturbance regimes," pointing to the meaningful role agricultural systems can play in biodiversity conservation when they are close to natural landscapes (Tscharntke et al., 2005, p. 857). Five participants in this study acknowledged the importance of protecting ecosystems and conserving biodiversity by keeping forest patches within their production systems. In a global synthesis of conservation studies, Wintle et al. (2019) established that small and relatively isolated patches of complex ecosystems, including forests, located in fragmented landscapes, such as agricultural lands, are likely to contain high levels of biodiversity and have a high conservation value. The experiences shared by participants in this study support this conclusion. For example, one producer specifically noted the benefits that the forest adjacent to their agroforestry system provided to pollinators in the form of habitat creation. This finding is bolstered by research from Proesmans et al. (2019) and Ricketts (2004), who found, in Belgium and southern Costa Rica respectively, that forest fragments near agricultural land served as important habitat for pollinators.

In addition to habitat creation, the presence of forest patches near agricultural land contributes greatly to pest control services (Haan et al., 2020). Findings from this study support the literature suggesting that proximity to forest fragments increases pest suppression: one participant explained that the forest near their coffee agroforestry system increased the presence of natural predators and aided in pest control. Decocq et al. (2016) maintained through their research on small forest patches in Europe that proximity to forest fragments contributed significantly to natural enemy diversity, resulting in positive social and ecological benefits to resilience. These benefits include reduced spending on inputs, lower yield losses due to pests, and a decreased need for damaging chemical pesticides (Decocq et al., 2016).

Regarding agroforestry, Kuyah et al. (2017) contend that including these systems as landscape components in agricultural production is an ideal management practice for supplying a range of regulating ecosystem services, including pollination and pest regulation, carbon sequestration, soil fertility improvement, erosion prevention, and water and wind regulation. Additionally, the literature suggests agroforestry is beneficial for habitat formation, which is an important supporting ecosystem service (Nguyen et al., 2013). Participants in this study valued their agroforestry systems for many of the same functions that are discussed in the literature. For example, Thrupp (2000) demonstrated that agroforestry-based coffee systems in Central and South America commonly have over 100 different plant species occupying fields, including leguminous trees, fruit trees, and trees used for fuel and fodder. Many of these trees function as habitat for organisms including birds, which benefit agroecosystems through pest control services, seed dispersal, and the addition of fertilizer (Thrupp, 2000). Many mammalian species also rely on shaded agroforestry systems for habitat, as well as for food, nesting, mating, and foraging (Somarriba et al., 2004). Research from Turrialba, Costa Rica, found that coffee agroforestry systems that included shade trees had slightly less mammalian diversity than forests (Caudill et al., 2015). However, shaded systems had a significantly higher degree of species diversity and abundance compared to un-shaded systems, indicating that mammals "benefited from increased canopy cover" and vegetative complexity (Caudill et al., 2015, p. 91). Similar to these findings from Thrupp (2000), Somarriba et al. (2004), and Caudill et al. (2015), Participant C noted "a flow of animals" through their agroforestry system, as well as numerous species of birds that fed on the fruit trees scattered between coffee plants. The findings from this study further reinforce the literature on the role of landscape diversity, and the ecosystem services provided by numerous landscape components, in bolstering social-ecological resilience.

5.3. Sustainable Use of Resources

Mijatović et al. (2013) identified the sustainable use of resources as an indicator of resilience because of the ecosystem services that conserving and protecting soil and water provide to production systems. Dollinger and Jose (2018) posit healthy soil as arguably the most important resource for the functioning and provisioning of ecosystem services by both natural and agroecosystems. Healthy soil is defined by the United States Department of Agriculture as "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans" (n.d., para. 2). Participants in this study focused on building soil health through a variety of approaches that also worked to deliver vital ecosystem services. According to the literature, the four main ecosystem services provided by healthy soil are plant production, regulation of water quality, contributions to human health, and climate change mitigation (Lehmann et al., 2020).

One of the most common strategies utilized by participants in this study to increase soil health was a focus on reducing soil erosion. Topsoil, the microorganism and organic matter-rich upper layer of soil (Altieri, 2018), is being eroded at a much faster rate than it can be replenished, largely due to industrial agricultural practices (White, 2020). Globally, topsoil erosion is occurring at a rate of about one inch per decade; while less than half an inch of soil can take between 20 and 1,000 years to form (Horrigan et al., 2002; White, 2020). Industrial practices that mechanically, chemically, or physically disturb the soil, including tilling and the application of chemical fertilizers and pesticides, all contribute to erosion, and as a result, negatively impact soil health (White, 2020).

Erosion is a chief contributor to land degradation due to the negative impact it has on soil fertility and the water retention capacity of soil—which also intensifies the risk of both flooding and drought (Dudai et al., 2006). Additionally, Chen et al. (2017) assert that erosion can lead to the sedimentation of rivers and the deterioration of water quality. These impacts make reducing soil erosion crucial to fostering social-ecological resilience. To minimize soil erosion, participants in this study employed a variety of practices and strategies that have been identified as particularly effective in the literature. These strategies included planting *Chrysopogon nigritanus* L. (vetiver grass) and utilizing terraces.

Multiple participants in this study utilized vetiver grass in their production systems for the explicit purpose of preventing erosion. Vetiver grass has been employed extensively around the world for soil and water conservation purposes, as well as slope stabilization, due to its quick-growing root system and resulting resistance to drought and dislodgement from strong water flows (Dudai et al., 2006). In Chattogram, Bangladesh, Aziz and Islam (2023) found that vetiver grass reduced erosion on slopes by 94-97% under high-intensity artificially simulated rainfall. This finding highlights the potentially vital role of vetiver grass considering the projected impacts of climate change, including future scenarios of intense precipitation in many areas of Costa Rica (World Bank Group, 2021a).

In addition to planting vetiver grass, some participants in this study utilized terraces to reduce soil erosion. Terraces work by transforming slopes into sequences of flat surfaces, expanding the area of cultivable land while also conserving soil and water (Deng et al., 2021). The flat surfaces created by terracing aid in minimizing surface runoff (Hillel, 2005). Surface runoff leads to significant erosion on slopes and occurs when the rate of rainwater reaching the soil surface exceeds the rate at which rainwater can infiltrate the soil (Hillel, 2005). In a critical review on the effects of terracing in China, Chen et al. (2017) found that terraces were effective in reducing surface runoff by just under 49%. The results from Chen et al.'s study on terracing, as well as from Aziz and Islam's (2023) research on vetiver grass, support the experiences described by producers in this study who found these approaches to be effective in managing soil erosion.

Another commonly practiced approach to resource conservation among participants in this study was rainwater harvesting (RWH). RWH generally involves the collection of "rainstorm-generated runoff from a particular area," for example rooftops or ground surfaces, "in order to provide water for human, animal, or crop use" (Hillel, 2005, p. 264). Participants in this study described practicing RWH for use during dry seasons, as a safety net during instances of unanticipated drought, and to conserve potable water. In addition to the uses described by participants, Kertolli et al. (2024) also found RWH to be beneficial in offering farmers in Morocco an alternative to expensive external sources, namely municipal water supplies. As mentioned previously, agriculture is responsible for almost 70% of freshwater withdrawals globally (Harron & Matthew, 2022). In Costa Rica specifically, agriculture accounted for 73% of surface and groundwater withdrawals in 2014 and 2015 (Esquivel-Hernández et al., 2018). Considering that climate change is negatively impacting the reliability of precipitation patterns, condensing the amount of rain that historically fell over a long period to increasingly short periods (Ertop et al., 2023), efforts to increase water security in agricultural production, including through RWH, are extremely important to ensuring social-ecological resilience.

5.4. Innovation in Management Practices

Transitioning toward resilient agricultural production requires innovation (Bennett et al., 2014). This is particularly true considering both the long-standing and unprecedented challenges facing agriculture today, including market fluctuations, seasonal variations, availability of inputs, decreased populations of pollinators, and climate change (Labeyrie et al., 2024). These challenges have the potential to disrupt production. However, they also have the potential to create opportunities “for doing new things, for innovation, and for development” (Folke, 2006, p. 253). Many participants in this study embraced innovative management practices to respond to various challenges. For example, Participants D, E, and F began making biofertilizers using unavoidable by-products from their production systems. Participant D was motivated by the high cost and limited availability of organic fertilizers in Costa Rica. Making their own biofertilizers aided each of these producers in reducing their expenses, and also contributed to the creation of increasingly circular production systems, a goal explicitly mentioned by Participants D and E. Circular agriculture involves certain basic ideas, including minimizing “resource input and waste, emission, and energy leakage” through the creation of enduring systems which slow and close “material and energy loops” (Geissdoerfer et al., 2017, p. 759). Creating biofertilizers with typically discarded farm-system by-products closes a nutrient loop that was disrupted by industrial agriculture and its dependence on external inputs, including synthetic fertilizers (Rauw et al., 2023).

Innovation within agricultural production requires both traditional and new knowledge (Aksoy & Öz, 2020). Mijatović et al. (2013, p. 102) established in their review of case studies from the Global South that producers who managed systems for increased agricultural biodiversity often relied on a “dynamic process of continuous innovation” based on a combination of new information and traditional knowledge. The authors found that while local knowledge regarding crop, seed, animal, soil, and water management was particularly important for strengthening resilience, there were some occasions in which traditional practices were insufficient for maintaining production under evolving conditions (Mijatović et al., 2013). In these instances, producers either abandoned, adjusted, or combined traditional practices with novel methods through processes of innovation (Mijatović et al., 2013). In this study, multiple participants reported utilizing local landraces alongside hybrid seeds, demonstrating a willingness to embrace innovative production systems which incorporated both traditional and new technologies.

Numerous other studies have documented similar findings highlighting the linking of new and traditional practices. For example, in a case study of home gardens in the Iberian Peninsula, Reyes-García et al. (2014, p. 228) found a positive association between "traditional and modern agricultural knowledge." Specifically, the authors showed that gardeners who held knowledge regarding landraces were also knowledgeable about commercial crop varieties (Reyes-García et al., 2014). Similarly, in Northwestern Patagonia, Eyssartier et al. (2011) demonstrated that members of a rural agricultural community maintained traditional practices including gathering medicinal plants, while also adopting new technologies to respond to changing social and ecological contexts, such as the inclusion of exotic plants and the use of greenhouses to grow them.

Among the most important and pervasive challenges producers face is climate change, which was mentioned by eight participants in this study as being a major barrier to social-ecological resilience. Because over half of the participants in this study mentioned climate change as a pressing challenge, strategies must be developed to ensure producers in Costa Rica are supported in adapting to the changes in their regions. Zilberman et al. (2018) posit distinguishing innovations for climate-resilient agricultural practices based on their form. For example, technological innovations are related to machinery and inputs, whereas institutional innovations include the formation of new networks, organizations, and trade arrangements (Zilberman et al., 2018). Managerial innovations refer to altering management practices, including adopting crop rotations, improving pruning techniques, and utilizing integrated pest management, which is a holistic approach to fighting pests and diseases that works to minimize the use of synthetic pesticides (Stenberg, 2017; Zilberman et al., 2018).

Two participants in this study reported adopting managerial innovations to increase their resilience to climate change: one altered their pruning techniques to adapt to consistently higher temperatures, and the other adjusted the crops they planted to better suit the changing climatic conditions in their region. These examples highlight the important role of innovative practices in mediating the impacts of climate change on agroecosystems, leading to increased social-ecological resilience. An important avenue for future research could include a comparative study on the effectiveness of managerial innovations in relation to technological and institutional innovations. Such a study would provide insight into the best ways to support producers in Costa Rica in responding to the relatively new and severe challenge associated with climate change.

5.5. Local Networks and Institutions

5.5.1. Local Networks

The sharing of agricultural information, resources, and insights among producers through local community networks is an essential component of resilience (Mijatović et al., 2013). Numerous participants in this study discussed relying on other producers in their communities for three main purposes: first, to access inputs, specifically seeds; second, to exchange information; and third, to form connections. Accessing seeds through local community connections is discussed in-depth in section 5.6 with the indicator 'Availability and Exchange of Seeds and Livestock.'

In terms of exchanging information, Mijatović et al. (2013) assert that the facilitation of information and knowledge dissemination among and between communities through the existence of local networks is essential for strengthening the resilience of production systems. Rockenbauch and Sakdapolrak (2017) completed a systematic review related to social networks and their contributions to resilience and found social networks to be an essential part of facilitating learning between farmers, particularly in the dissemination of information regarding innovative practices and approaches. Rockenbauch and Sakdapolrak (2017, p. 9) also referred to social networks as "pipes of information exchange" that are necessary for adapting to changing conditions.

The importance of sharing information, knowledge, and experiences was a recurring theme among participants in this study, particularly concerning responses to climate change. For example, Participant K discussed the importance of sharing information related to addressing and responding to climate change with other producers in their community. Participant K described being motivated not only by the possibility of helping to foster resilience among their neighbours but also of encouraging others to adopt practices which work to mitigate the impacts of climate change. Eise et al. (2021) demonstrated similar findings related to information and knowledge dissemination within networks in their study centred on coffee farmers in Risaralda, Colombia. The authors showed that community connections between family, friends, and neighbours played a central role in the exchange of climate change-related knowledge among producers (Eise et al., 2021). It is interesting to note that Eise et al. (2014) identified a lack of connection to formal institutions as one explanation for producers' reliance on their close community connections for information related to climate change. In this study, producers reported relatively strong connections to formal governmental and private institutions, yet still stressed the importance of community in the exchange of climate change information. This finding indicates the importance of informal networks in the dissemination of knowledge, particularly regarding climate change, regardless of whether or not formal institutions have a strong presence in the community.

As mentioned previously, participants in this study reported receiving numerous cultural ecosystem services from their production systems. Among these services was the formation of close connections and the feeling of being part of a community. McMillan and Chavis (1986, p. 9) defined a sense of community as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together." The experiences of producers in this study paralleled this definition: respondents used phrases including "we're very united," "they're excellent people," and "we look out for each other" in reference to other producers in their communities and the relationships they shared. Similar findings have been reported in urban agricultural settings. For example, Kim et al. (2023) demonstrated a significant increase in the sense of community among participants who were involved in urban gardening activities compared to those who were not. The relationship between feeling a sense of community and resilience has been explored in the literature under the concept of 'community resilience.' Magis (2010, p. 402) defined community resilience as "the existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise." Rapaport et al. (2018) determined robust social relationships and a strong sense of community to be an accurate predictor of community resilience, particularly in rural areas. The results of this study and the descriptions of close community relations by many of the participants further support evidence from the literature regarding the importance of a strong sense of community to resilience.

Not all participants in this study, however, benefited from strong social ties. Gender emerged as an important factor which impacted how and if producers in this study formed solid and lasting community connections. In East Africa, Zebrowski et al. (2018) established that women were more likely than men to form strong ties with other community members. The authors also found that women shared learning experiences within their social networks more often than men did (Zebrowski et al., 2018). This finding is consistent with the experience of one woman coffee producer in this study who described forming strong personal and professional connections with other women coffee producers in her area. However, Zebrowski et al.'s (2018) findings contrast with the experiences described by two other women participants who found their gender to be a barrier to forming community connections. Interestingly, one of these participants described being the only woman producer in her community, while the other noted often being the only woman at the training sessions she attended. One conclusion that can be drawn from this insight is that women are more likely to benefit from the advantages of forming strong community connections when there are other women producers with whom they can connect.

5.5.2. Institutions

Institutions are defined as "systems of established and prevalent social rules that structure social interactions" (Hodgson, 2006, p. 2). Using this definition, institutions could refer to any rule or norm that governs human behaviour and interaction, including language, organizations, money, cultural customs, and policies (Herrera-Murillo et al., 2021; Hodgson, 2006). For this research, institutions will refer specifically to formal private and governmental organizations.

Institutions are an important feature in the promotion of innovation within resilient agricultural systems (Bennett et al., 2014). Institutions can work to promote innovation by giving time and resources to experiments, fostering opportunities for bottom-up ideas, learning from results, and establishing opportunities for ideas to connect across communities (Bennett et al., 2014). The role of institutions in fostering innovation is demonstrated by Haque et al. (2024) through their research in a coastal agricultural community in Bangladesh. The authors found that local institutions were essential for "various partnership-building processes and actions" which worked to promote agricultural innovation and adaptation to climate-related risks (Haque et al., 2024, p. 17). The institutions referred to in Haque et al.'s (2024) study employed bottom-up and community-led approaches to innovation and adaptation, leading to direct benefits for producers and the empowerment of local communities.

Numerous participants in this study recounted a similar experience with institutions. Participant A, for example, described the support they received from various private and governmental institutions on a project which aimed to shorten complex cacao supply chains by connecting local producers directly with international markets. As a result of this project, cacao producers involved in the program received various benefits, including better prices for their products. In support of Participant A's experience, a report co-authored by the FAO and the Bureau for the Appraisal of Social Impacts for Citizen Information (BASIC) found that organized small-holder farmers who benefited from connections to supportive institutions not only tended to produce "high(er) quality and high(er) yield varieties" of cacao, they also achieved higher incomes when compared to non-organized smallholder producers (2024, p. 13).

In the same way that institutions can foster innovation through the promotion of bottom-up ideas, they can also act as a barrier to resilience-building through the implementation of top-down approaches. Chhetri et al. (2012) described an example of this from Nepal in the 1970s, where, at the time, national agricultural research and development was funded chiefly by large international institutions. The initiatives implemented by these institutions centred on the introduction of new varieties with inflexible conditions for growth, largely failing to consider local climates and the concerns of Nepali farmers (Chhetri et al., 2012). As a result, these new varieties were not widely adopted and an opportunity to bolster social-ecological resilience and improve the lives of producers was missed (Chhetri et al., 2012). This example not only emphasizes the power that institutions have in influencing producer resilience, it also demonstrates how important it is that institutions centre producer autonomy by supporting bottom-up innovations which directly address the specific needs of producers.

Outside of innovation, institutions also function as important supports for producers, particularly during disturbances. Rice et al. (2023) found that producers throughout Guatemala who were connected to an agroecological organization were better insulated from economic shocks resulting from the COVID-19 pandemic. Additionally, in eastern Uganda, Okuku Oloo and Omondi (2017) found that local institutions were effective in reducing community vulnerability to the impacts of climate change. The authors noted that the primary role of local institutions in their case study was to promote diverse livelihood options, provide context-appropriate educational opportunities, and connect producers with other private, governmental, or non-governmental organizations (Okuku Oloo & Omondi, 2017). These findings are similar to the results from this study, which showed that producers often relied on support from institutions for access to infrastructure and resources, training opportunities, and connections to other institutions with additional resources to respond to challenges, particularly climate change.

5.6. Availability and Exchange of Seeds and Livestock

Building resilient production systems requires that producers have access to local species and varieties that are already adapted to the conditions of their region, as well as new varieties that may be better suited for future conditions under climate change (Acevedo et al., 2020). Mijatović et al. (2013) posit the existence of community seed banks, nurseries, local markets, and formal and informal seed exchange networks as effective methods for measuring this indicator. Producers in this study reported activity in each of these domains, indicating participation in robust systems for acquiring production inputs.

Regarding informal networks, a majority of participants in this study reported accessing seeds or livestock in part through community connections with other local producers. This practice aligns with van Noordwijk et al.'s (2021) findings, which suggest that because the impacts of climate change will materialize largely as climate shifts, nearby systems often contain genetic diversity suitable to address local climate problems. Additionally, research from Ethiopia by Seboka and Deressa (1999, p. 250) emphasized that farmers benefited "a great deal from social networks" in the context of acquiring seeds. In particular, the authors found that the relationships among community members were based on trust and mutual interdependence and were especially valuable to producers concerning the adoption of new varieties, and in times of drought and social unrest (Seboka & Deressa, 1999). Consistent with these findings, participants in this study highlighted the importance of community connections in acquiring seeds. For example, one producer described engaging in community seed exchanges through relationships based on reciprocity, while another participant discussed exchanging seeds within their network during instances of unpredictable weather. These results support Seboka and Deressa's (1999) findings and indicate that producers will continue to rely on strong relationships with other local producers in their responses to future challenges, particularly climate change. Further support for the resilience-building potential of these networks is evident in a study by Porcuna-Ferrer et al. (2020), which found that in the western highlands of Guatemala, community management of seeds for local use bolstered social-ecological resilience through:

i) promoting innovation;
ii) encouraging the adoption of agroecological practices, thereby conserving on-farm biodiversity;
iii) increasing access to and exchange of information within communities; and
iv) creating opportunities for community self-organization (Porcuna-Ferrer et al., 2020).

Each of these benefits highlights the resilience-enhancing potential of community-based seed management systems, findings that the results of this study also support.

Additionally, two producers in this study described accessing production inputs through inheritance. The connection between accessing seeds and livestock through inheritance and social-ecological resilience has not been widely studied and offers a crucial avenue for further investigation. For instance, in a case study from the Sahel region of Senegal, Labeyrie et al. (2023) found that seed varieties passed down through generations tended to be from landraces, meaning they were highly adapted to their local regions. This finding suggests that inputs acquired through inheritance may provide producers with a greater capacity for resilience; however, this resilience may also be weakened by climate change and resulting shifting climatic conditions. One additional significant finding from Labeyrie et al.'s (2023) study was that men inherited seeds more often than women, indicating that gendered norms influenced women's access to inputs. In this study, both a woman and a man reported receiving inputs through inheritance, offering insight into potentially shifting conventions around daughters and inheritance in Costa Rica. Future studies should examine whether women are increasingly receiving production inputs through inheritance, as this could indicate a trend toward increasing equity in access to resources.

5.7. Gender

Gender is an important indicator of resilience because of the contributions that women's "concerns, views, and knowledge" make to the effectiveness of resilience-strengthening practices (Mijatović et al., 2013, p. 103). One way to measure gender equality in the context of social-ecological resilience is by looking at women's access to agricultural information and resources (Mijatović et al., 2013). In this study, three out of six women said they felt as though they had equal access to agricultural information and resources compared to the men in their communities. It is essential to note, however, that two of these women felt this was true for themselves but stressed that many other women in their communities still lacked appropriate access to both information and resources related to agricultural production. This finding adds nuance to the literature, which generally reports that women often do not have equal access to agricultural inputs, labour, equipment, technologies, extension services, and opportunities for skill development (Achandi et al., 2018; Anderson et al., 2021; Nnadi et al., 2023). As Arora-Jonsson (2011) noted, it is important to avoid generalizing women as one homogenous group. The literature has shown that women tend to be more vulnerable to the impacts of climate change compared to men, a problem that is essential to address (Eastin, 2018; Glazebrook, 2017; Goh, 2012); still, there are other factors which contribute to vulnerability and resilience which should be considered in conjunction with gender. For example, in this study, education emerged as an important element which positively influenced resilience by bolstering two women participants' access to agricultural information and resources.

Both of these producers noted that receiving a formal education allowed them to access the means necessary for their production systems to succeed. One woman producer in particular emphasized that receiving a university education was the primary reason she felt she had an equal opportunity to access agricultural information and resources. Currently, there is a lack of research regarding the specific relationship between post-secondary education and increased access among women producers. Filling this gap with further investigation into this relationship is an important future step in the refinement of gender as an indicator of social-ecological resilience. Recent research shows that education and literacy are important aspects of well-being for women in various other domains, including those related to accessing health-related information and opportunities. For example, Xavier et al. (2024, p. 2) found that literate women in western Rwanda were twice as likely to consume a sufficiently diverse diet, which is associated with beneficial health outcomes including “a reduced risk of micronutrient deficiencies, improved maternal health, and enhanced child development,” compared to illiterate women. Xavier et al.’s (2024) findings indicated that educated women likely benefitted from increased access to healthcare services, leading to greater awareness of diverse food options. Regarding resilience to climate change, Jordan (2019) demonstrated that many women in southwestern Bangladesh saw increased education as a means for limiting vulnerability to climate events including cyclones. This perceived increase in resilience was a result of the impact of education levels on girls’ marriage prospects (Jordan, 2019). According to participants in Jordan’s (2019) study, if a woman was well-educated, she was more likely to marry a man who lived in an area less susceptible to extreme weather events. The findings from Xavier et al. (2024) and Jordan (2019) support this study’s results in proposing that educated women tend to have greater opportunities to increase their resilience, either through access to information or through bettering their circumstances.

Another significant finding that emerged from this study is the important role of institutions in supporting women's participation in agricultural activities. As discussed in section 5.5.2, institutions have the potential to help or hinder resilience through either support for bottom-up or top-down approaches to innovation. The same is true in the context of gender. Two participants in this study discussed the deficiencies of institutions which seek to support women's access to agricultural information and resources without accounting for the contexts within which many women live and work. For example, as discussed earlier in this paper, gender equality is a central component of the agroecological transition necessary for strengthening the resilience of agroecosystems. Gender is also a feature in the High Level Panel of Experts on Food Security and Nutrition's 13 principles of agroecology, under principle nine, 'social values and diets' (2019). Despite the emphasis placed on gender in agroecological spaces, certain institutions founded around these principles still operate in ways that harm and exclude women. Pickering (2024) found instances in Peru where agroecological organizations offered programs that restricted participation based on educational requirements and land ownership. Interestingly, one participant in this study specifically discussed landownership as a major contributor to gender inequality in Costa Rica, and in Latin America broadly. The observations made by this participant are confirmed in the literature, which shows that women in Latin America own less land than men, and when they do own land, it is often a smaller plot and of lower quality (Deere & Leon, 2003). The World Bank Group (2020) also found the same inequality in land ownership in Costa Rica specifically and added that women often receive less financial support for their farms than men do.

5.8. Autonomy

When producers have agency regarding what land management and agricultural practices they adopt, they are better able to choose methods of production which correspond to their specific needs as well as the resources available to them (Mijatović et al., 2013). Over half of the participants in this study felt they had autonomy regarding the management strategies and practices they employed, and in some cases, the preceding indicators played an important role in fostering this autonomy. For example, autonomy can be highly dependent on a producer's ability to access and maintain agricultural biodiversity, including different varieties (Mijatović et al., 2013).

Much of the current literature on the relationship between producer autonomy and agricultural biodiversity is concentrated on the individual-level factors that impact producer decision-making, including education, age, gender, and income, as well as producers' attitudes, values, and perceptions of risk related to adopting new species and varieties (Blesh et al., 2023). This perspective reveals important information regarding autonomy in the context of sociodemographic characteristics; however, it also ignores the larger-scale political and economic factors that impact how producers access agricultural biodiversity, including the important role of institutions (Blesh et al., 2023). For multiple participants in this study, institutions were a vital component in developing the system they desired and therefore played an important role in furthering their autonomy.

In Participant A's experience, institutions played an invaluable role in advancing their agency and aiding their access to agricultural biodiversity. In some cases, though, institutions act as a barrier to producer autonomy. For example, in the Central Coast region of California, Stuart and Gillon (2013) found that food safety concerns resulting from an outbreak of *E. coli* in

Spinacia oleracea L. (spinach) in 2006 led to the implementation of food safety standards by private companies that encouraged the reduction of biodiversity. If producers did not meet the rigorous standards set by these institutions, including reducing the presence of wildlife and any habitat that might shelter wildlife, they risked having their crops rejected or losing their production contracts (Stuart & Gillon, 2013). Through the process of responding to health and safety risks, the institutions involved in Stuart and Gillion's (2013) research limited producer agency by restricting the land management practices those producers could implement. This example, taken with the experiences of participants in this study, demonstrates the role that institutions can play in either promoting or acting as a barrier to producer autonomy by influencing access to agricultural biodiversity.

Bennett et al. (2014, p. 69) note that diversity aids in bolstering autonomy by preventing producers from "getting locked into traps that are set by having one solution available." Increased diversity within production systems can also create greater opportunities for "diverse alternate livelihoods" which subsequently expand adaptation options for individuals and families, resulting in increased resilience over time (Bhattarai et al., 2015, p. 129). This was the case for Participant B in this study, as they were looking to capitalize on the diversity of their production system by creating and implementing agritourism opportunities. Participant B described being motivated by the idea of creating a long-term and sustainable economic system, and the benefits that would have on their autonomy. Participant B's experience builds on research by Schneider and Niederle (2010) which found that among Brazilian family farmers, having a diversity of livelihood options was a condition of autonomy. Specifically, Schneider and Niederle (2010) established that a diversity of livelihood options allowed producers to develop strategies that aided them in building resilience to the challenges associated with their production systems, including seasonal changes, the impacts of climate change, and possible market failures or losses in income (Schneider & Niederle, 2010).

The examples above demonstrate the essential role of producer autonomy in developing and building social-ecological resilience. Conversely, limited autonomy and decision-making power may act as a barrier to resilience. For example, Participant I described feeling as though their autonomy was restricted because they rented the pastureland where they raised dairy cattle. From an economic perspective, Han et al. (2021) found that renting agricultural land directly improved on-farm income for families in rural China, positively impacting economic aspects of resilience. Therefore, future research is needed to understand the trade-offs between the economic benefits of renting farmland and the restrictions to autonomy experienced by producers as a result of renting.

For Participant I, their social-ecological resilience was hindered by renting pastureland because they were not able to adopt certain resilience-building practices, including reincorporating wastewater back into their system. Wastewater reuse from dairy cattle production has the potential to be an important method for climate change adaptation in the face of water shortages (Herrera-Murillo et al., 2021). Additionally, wastewater reuse may also provide advantages to crop growth through the provisioning of nutrients—this, however, is heavily dependent on the type of wastewater treatment utilized (Herrera-Murillo et al., 2021). Regardless, renting land limited the opportunities available to Participant I and as a result limited their autonomy as well.

5.9. Implications for the Management of Agroecosystems

Properly managed agroecosystems provide valuable ecosystem services that contribute to both human well-being and resilience. In this study, these ecosystem services included:

provisioning services in the form of food, fuel, and fodder; regulating services such as carbon sequestration, soil fertility improvement, pollination, and pest, water, and wind regulation; cultural services including beautification, recreation, fostering a sense of community, education, and agritourism; and supporting services, for instance, nutrient cycling and soil and habitat formation. While the agroecosystems managed by participants in this study contributed substantially and in numerous ways to human well-being, they were also, like all agroecosystems, directly impacted by climate change, biodiversity loss, and social inequality. These challenges, described as proximal drivers in the conceptual framework, along with the ways producers experienced them, were mediated and shaped by various forces. These forces are referred to as distal drivers and include the eight indicators of resilience considered in this discussion: species and varietal diversity, landscape diversity, sustainable use of resources, innovation in management practices, local networks and institutions, availability and exchange of seeds and livestock, gender, and autonomy.

These distal drivers both aided and detracted from producers' social-ecological resilience. In most cases, they were effective in helping producers to mediate the impacts of the proximal drivers. For instance, high varietal diversity, the sustainable management of soil and water resources, innovation using both traditional and modern practices and knowledge, and the use and exchange of local seeds each helped producers reduce many of the negative impacts associated with climate change. Likewise, high species diversity and landscape heterogeneity, as well as heightened producer autonomy, all aided in conserving on and off-farm biodiversity. Finally, support from institutions and the formation of close community connections through local networks aided in the exchange and dissemination of knowledge among producers, benefiting social aspects of resilience.

In other instances though, these distal drivers acted as barriers to building resilience. For example, participants in this study utilized varietal diversity as a defence against pests, diseases, and climate-related disturbances. However, access to varietal diversity through institutions also hindered adaptation and resilience due to the long and resource-intensive nature of the process. Similarly, institutions were found to have the capacity to foster innovation, but also reduce autonomy and negatively impact women producers. Lastly, with respect to local networks, some participants' gender prevented them from forming connections with other producers, leading to greater social inequality.

The findings from this study have resulted in several key implications for the future management of agroecosystems. For one, the ecosystem services provided to production systems and people by landscape heterogeneity, particularly from scattered trees and shrubs, forest patches, and agroforestry systems, make a compelling case for the prioritization of the inclusion of these landscape components across agricultural lands. Additionally, practices including employing vetiver grass to hold soil in place, building terraces into sloped land, and utilizing rainwater harvesting techniques are all management strategies identified in this study that served to increase resilience. However, these strategies are also particularly location-specific. Therefore, instead of offering strict guidelines for soil and water management, these strategies may be taken as inspiration to encourage soil and water conservation in ways that are appropriate to local ecological and social contexts. In a similar manner, the innovations described by participants in this study also offer inspiration for pathways to increasing resilience utilizing creativity and whatever resources are available. This is evidenced in the three producers who each employed a unique byproduct from their production systems to make their own biofertilizers, and in the process created increasingly circular production systems.

A reoccurring theme in this study has been the value that producers received from sharing information, resources, and ideas with other producers within their networks, particularly in response to changing climatic conditions. In the future, as the impacts of climate change progress, the facilitation of strong, trust-based relationships will become increasingly vital as a tool for producers to share adaptation strategies and resources. This research has shown that gender influences how social ties are formed. As a result, in male-dominated settings, steps should be taken to ensure the meaningful inclusion of women to guarantee equitable access to the benefits resulting from local networks. For one producer in this study, this looked like connecting formally and informally with other women producers in her area. In other contexts, this may look like addressing the root causes of gender inequality in communities.

6. Conclusion

The severity of the various challenges impacting agricultural production, including climate change, biodiversity loss, and social inequality, indicate the need for strategies focused on increasing the resilience of production systems. They also signal a need for an effective indicator framework for measuring resilience. As social-ecological systems, agroecosystems are not compatible with either strictly social or ecological indicators of resilience. They require measures that adequately account for the robust connections and interdependence between humans and ecosystems. They require a focus on social *and* ecological resilience together.

The purpose of this research has been to explore how producers strengthen the social-ecological resilience of their production systems, with a specific focus on producers in Costa Rica's Central Valley and Northern Zone. This study revealed how these producers experienced and perceived aspects of their production systems which have been identified in the literature to contribute to resilience. Three objectives framed this research. These objectives included: identifying the strategies and practices producers employed to build social-ecological resilience; examining the barriers that limited producers' resilience; and utilizing insights from this research to support the literature on indicators of social-ecological resilience in the context of agriculture.

Rural communities have long advocated for the development of local resilience-building strategies to improve livelihoods and aid in adapting to changing conditions. Indicator frameworks, such as the one applied in this study, provide a base from which to begin understanding resilience. However, location-specific context is required to adequately examine and identify both the viable approaches and barriers to resilience that exist in local communities. By focusing research on locally relevant agricultural practices and the conditions that affect them, this study worked to understand social-ecological resilience for producers in two regions of Costa Rica based on what they experienced and how they experienced it.

6.1. Key Contributions

Costa Rica is an important leader globally in supporting ecosystem-based adaptations to climate change and biodiversity conservation. Because Costa Rica is already esteemed for its progress toward climate-resilient and biodiversity-rich food systems, I originally questioned the benefit that would come from further research into maximizing this resilience, as opposed to conducting research in a location where less attention is paid to adaptation. However, by contributing to an understanding of how to maximize the social-ecological resilience of producers in a country which already prioritizes this aim, there is a greater chance of optimizing these systems. This research also offers valuable lessons for other regions and highlights the need for context-specific resilience-building strategies that can be adapted based on local needs and conditions. Additionally, like all places, Costa Rica has the potential to expand their efforts to increase the resilience of their agricultural producers. For instance, there are still various commonplace practices which contribute to climate change and biodiversity loss, including many massive areas of monocultures and high rates of agrochemical use. Additionally, unequal opportunities for women producers and a lack of access to resources and information in rural communities both contribute to social inequality and negatively impact producer resilience in Costa Rica.

The results of this study centred on the data collected from interviews primarily concerning eight indicators of social-ecological resilience. The discussion section then focused on analyzing how participants described using species and varietal diversity and landscape heterogeneity in their production systems, as well as the associated impacts. It also analyzed how producers conserved and protected soil and water resources, what strategies they used to access seeds and livestock, what innovative management practices they adopted to address challenges, what local networks and institutions they were connected to, the role women producers felt their gender played in their ability to build resilience, and finally, to what degree producers felt they had autonomy over their production systems. In the discussion surrounding these findings, I reviewed key pieces of data from interviews with producers and examined them in the context of the literature and the conceptual framework that guided this study.

One key finding from this study was the impact of the numerous ecosystem services producers received from integrating high landscape diversity into their production systems. The majority of ecosystem services reported by producers resulted from scattered trees and shrubs, forest patches, and agroforestry land use components, and many were related to biodiversity conservation. This finding is significant as it contributes to a growing acknowledgement in the literature of the crucial role of agricultural lands in achieving conservation goals. Another significant finding includes the importance of investing in community-based input management systems as a way to support collective action and knowledge dissemination in communities. This investment is indispensable as a mechanism for enhancing practices that support producer access to seeds with traits that are resilient to their local climate or to future climatic conditions. Additionally, the results of this study add new insights into the power of social networks to facilitate the co-creation and sharing of information. The findings from this study also point to the importance of being creative in seeking opportunities for innovation and development. This research could assist institutions in finding actionable ways to promote innovation by fostering opportunities for bottom-up ideas and establishing methods to connect ideas across communities.

This study is valuable to governments in the context of their role in incentivizing mechanisms to enhance resilience and diversity within agricultural production systems. Costa Rica already promotes biodiversity conservation and innovation through its Payment for Ecosystem Services (PES) program. However, it was also noted that women have fewer opportunities to participate in these programs. The findings from this study indicate how imperative it is that governments and organizations find avenues for increasing women's participation in resilience-building in agriculture, without unintentionally causing harm to women or their families.

This research aims to be of use to producers in Central and Northern Costa Rica, as well as other similar locations. The discussion in this study is one form of knowledge dissemination identified in the literature to be an important aspect of innovation. Although practices in agroecological systems must be tailored to particular situations and environments, the findings from this research can act as inspiration for producers in other areas to experiment with diversity, form networks, and investigate new practices or re-establish traditional ones. There is a great deal to learn from the experiences of participants in this study regarding how to approach enhancing resilience in other sectors and geographical areas. For example, taking inspiration from the many participants in this study who practiced rainwater harvesting will be an important consideration for agricultural producers in most areas, as well as various other sectors that rely on water, as climate change continues to alter precipitation patterns. For agroecological systems to be viewed as a viable alternative to industrial agriculture, it is essential to present and discuss desirable examples. It is therefore crucial to show the potential for resilience-building strategies to uphold and safeguard livelihoods that are fulfilling and that provide people with a sense of pride while also operating within the biophysical limits of ecosystems.

6.2. Recommendations for Further Research

In addition to the key points addressed above, the contributions of this study include highlighting areas that would benefit from further investigation. This research is intended to provide a reference for larger studies in the future. From this position, this study provides a basis from which more in-depth research can develop to expand on the dataset and widen the scope of each indicator's contributions to social-ecological resilience in agriculture. Measuring resilience is inherently difficult. Aspects of resilience can and are likely to change over time; a system may be resilient when indicators are measured but less so in the future. Therefore, this research sets the foundation for future long-term investigations into how best to support and enhance social-ecological resilience in agricultural systems.

This study revealed that producers relied on a wide diversity of species and varieties to build resilience in their production systems. Future studies should examine both the quantitative and qualitative value of the crop species and varieties included in production systems. Additionally, current research indicates that mixed-breed cattle herds may improve reproduction and milk production. However, further research is needed to understand the technical and economic impacts of breed diversity in herds to confirm the benefits to resilience and address this gap in the literature.

Despite the importance of gender equality to agroecology, research shows that many agroecological organizations do not adequately support their women members. Addressing and exploring the different possibilities and opportunities for the meaningful inclusion of women in organizations, while focusing on strategies that break down gendered barriers to accessing these resources and information, is an important opening for future research. Additionally, the literature indicates that education is an important factor in influencing women's resilience in the context of health and decreasing vulnerability to extreme climate events. This study found that education also played a vital role in bolstering the resilience of women in the agriculture sector. Future research is needed into the various socio-economic characteristics that influence how women respond to the challenges impacting agricultural production in order to improve and refine gender as an indicator of social-ecological resilience.

Strategies and practices which uplift producers and rural communities must be prioritized in future investigations. To promote and maintain the social-ecological resilience of agricultural production systems in the context of several key challenges, researchers, governments, private institutions, and producers must work collectively to implement the beneficial strategies identified in this study. These approaches include prioritizing inclusive and community-driven strategies that mix traditional and modern knowledge and emphasize gender equality. This study sets the foundation for future exploration into local and context-specific strategies for building the social-ecological resilience of agricultural production systems, to ultimately ensure a viable, sustainable, and robust future for food production.

References

Acevedo, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., Bizikova, L., Isaacs, K., Ghezzi-Kopel, K., & Porciello, J. (2020). A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nature Plants*, *6*(10), 1231–1241. https://doi.org/10.1038/s41477-020-00783-z

Acevedo-Osorio, Á., & Chohan, J. K. (2020). Agroecology as social movement and practice in Cabrera's peasant reserve zone, Colombia. *Agroecology and Sustainable Food Systems*, *44*(3), 331–351. https://doi.org/10.1080/21683565.2019.1623359

Achandi, E. L., Mujawamariya, G., Agboh-Noameshie, A. R., Gebremariam, S., Rahalivavololona, N., & Rodenburg, J. (2018). Women's access to agricultural technologies in rice production and processing hubs: A comparative analysis of Ethiopia, Madagascar and Tanzania. *Journal of Rural Studies*, *60*, 188–198. https://doi.org/10.1016/j.jrurstud.2018.03.011

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, *24*(3), 347–364. https://doi.org/10.1191/030913200701540465

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-Ecological Resilience to Coastal Disasters. *Science*, *309*(5737), 1036–1039. https://doi.org/10.1126/science.1112122

Agroecology Info Pool. (2019). *Agroecology Info Pool*. https://www.agroecology-pool.org/13aeprinciples/

Aksoy, Z., & Öz, Ö. (2020). Protection of traditional agricultural knowledge and rethinking agricultural research from farmers' perspective: A case from Turkey. *Journal of Rural Studies*, *80*, 291–301. https://doi.org/10.1016/j.jrurstud.2020.09.017

Alcamo, J. (Ed.). (2003). *Ecosystems and human well-being: A framework for assessment*. Island Press.

Alharahsheh, H., & Pius, A. (2019). A Review of key paradigms: Positivism VS interpretivism. *Global Academic Journal of Humanities and Social Sciences*, *2*(3). https://doi.org/10.36348/gajhss.2020.v02i03.001

Almeyda Zambrano, A. M., Broadbent, E. N., & Durham, W. H. (2010). Social and environmental effects of ecotourism in the Osa Peninsula of Costa Rica: The Lapa Rios case. *Journal of Ecotourism*, *9*(1), 62–83. https://doi.org/10.1080/14724040902953076

Alshenqeeti, H. (2014). Interviewing as a Data Collection Method: A Critical Review. *English Linguistics Research*, *3*(1), Article 1. https://doi.org/10.5430/elr.v3n1p39

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment*, *74*(1), 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6

Altieri, M. A. (2018). *Agroecology: The science of sustainable agriculture* (2nd ed). CRC Press.

Altieri, M. A., & Nicholls, C. I. (2002). The simplification of traditional vineyard based agroforests in northwestern Portugal: Some ecological implications. *Agroforestry Systems*, *56*(3), 185–191. https://doi.org/10.1023/A:1021366910336

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, *140*(1), 33–45. https://doi.org/10.1007/s10584-013-0909-y

Altieri, M. A., & Toledo, V. M. (2011). The agroecological revolution in Latin America: Rescuing nature, ensuring food sovereignty and empowering peasants. *The Journal of Peasant Studies*, *38*(3), 587–612. https://doi.org/10.1080/03066150.2011.582947

Anderson, C. L., Reynolds, Travis. W., Biscaye, P., Patwardhan, V., & Schmidt, C. (2021). Economic Benefits of Empowering Women in Agriculture: Assumptions and Evidence. *The Journal of Development Studies*, *57*(2), 193–208. https://doi.org/10.1080/00220388.2020.1769071

Andrén, O., & Kätterer, T. (2008). Agriculture Systems. In S. E. Jørgensen & B. D. Fath (Eds.), *Encyclopedia of Ecology* (pp. 96–101). Academic Press. https://doi.org/10.1016/B978-008045405-4.00313-X

Arora-Jonsson, S. (2011). Virtue and vulnerability: Discourses on women, gender and climate change. *Global Environmental Change*, *21*(2), 744–751. https://doi.org/10.1016/j.gloenvcha.2011.01.005

Artal-Tur, A., Briones-Peñalver, A. J., Bernal-Conesa, J. A., & Martínez-Salgado, O. (2019). Rural community tourism and sustainable advantages in Nicaragua. *International Journal of Contemporary Hospitality Management*, *31*(6), 2232–2252. https://doi.org/10.1108/IJCHM-05-2018-0429

Assandri, G., Bogliani, G., Pedrini, P., & Brambilla, M. (2018). Beautiful agricultural landscapes promote cultural ecosystem services and biodiversity conservation. *Agriculture, Ecosystems & Environment*, *256*, 200–210. https://doi.org/10.1016/j.agee.2018.01.012

Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014). *Tropical agroforestry*. Springer.

Aziz, S., & Islam, M. S. (2023). Erosion and runoff reduction potential of vetiver grass for hill slopes: A physical model study. *International Journal of Sediment Research*, *38*(1), 49–65. https://doi.org/10.1016/j.ijsrc.2022.08.005

Azungah, T. (2018). Qualitative research: Deductive and inductive approaches to data analysis. *Qualitative Research Journal*, *18*(4), 383–400. https://doi.org/10.1108/QRJ-D-18-00035

Balázsi, Á., Dänhardt, J., Collins, S., Schweiger, O., Settele, J., & Hartel, T. (2021). Understanding cultural ecosystem services related to farmlands: Expert survey in Europe. *Land Use Policy*, *100*, 104900. https://doi.org/10.1016/j.landusepol.2020.104900

Banerjee, O., Cicowiez, M., Vargas, R., Molina-Perez, E., Bagstad, K. J., & Malek, Ž. (2024). The economics of decarbonizing Costa Rica's agriculture, forestry and other land uses sectors. *Ecological Economics*, *218*, 108115. https://doi.org/10.1016/j.ecolecon.2024.108115

Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(25), 6506–6511.

Barriball, K. L., & While, A. (1994). Collecting data using a semi-structured interview: A discussion paper. *Journal of Advanced Nursing*, *19*(2), 328–335. https://doi.org/10.1111/j.1365-2648.1994.tb01088.x

Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., Batello, C., & Tittonell, P. (2020). The 10 Elements of Agroecology: Enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosystems and People*, *16*(1), 230–247. https://doi.org/10.1080/26395916.2020.1808705

Baudron, F., Corbeels, M., Monicat, F., & Giller, K. E. (2009). Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: A review paper based on two case studies. *Biodiversity and Conservation*, *18*(10), 2625–2644. https://doi.org/10.1007/s10531-009-9663-x

Bengochea Paz, D., Henderson, K., & Loreau, M. (2020). Agricultural land use and the sustainability of social-ecological systems. *Ecological Modelling*, *437*, 109312. https://doi.org/10.1016/j.ecolmodel.2020.109312

Bennett, E., Carpenter, S., Gordon, L., Ramankutty, N., Balvanera, P., Campbell, B. M., Cramer, W., Foley, J., Folke, C., Karlberg, L., Liu, J., Lotze-Campen, H., Mueller, N., Peterson, G., Polasky, S., Rockström, J., Scholes, R., & Spierenburg, M. (2014). Toward a More Resilient Agriculture. *Solutions*, *5*(5), 65–75.

Bergen, N., & Labonté, R. (2020). "Everything Is Perfect, and We Have No Problems": Detecting and Limiting Social Desirability Bias in Qualitative Research. *Qualitative Health Research*, *30*(5), 783–792. https://doi.org/10.1177/1049732319889354

Berrouet, L. M., Machado, J., & Villegas-Palacio, C. (2018). Vulnerability of socio—ecological systems: A conceptual Framework. *Ecological Indicators*, *84*, 632–647. https://doi.org/10.1016/j.ecolind.2017.07.051

Beuchelt, T. D., & Badstue, L. (2013). Gender, nutrition- and climate-smart food production: Opportunities and trade-offs. *Food Security*, *5*(5), 709–721. https://doi.org/10.1007/s12571-013-0290-8

Bhattarai, B., Beilin, R., & Ford, R. (2015). Gender, Agrobiodiversity, and Climate Change: A Study of Adaptation Practices in the Nepal Himalayas. *World Development*, *70*, 122–132. https://doi.org/10.1016/j.worlddev.2015.01.003

Blesh, J., Mehrabi, Z., Wittman, H., Kerr, R. B., James, D., Madsen, S., Smith, O. M., Snapp, S., Stratton, A. E., Bakarr, M., Bicksler, A. J., Galt, R., Garibaldi, L. A., Gemmill-Herren, B., Grass, I., Isaac, M. E., John, I., Jones, S. K., Kennedy, C. M., … Kremen, C. (2023).

Against the odds: Network and institutional pathways enabling agricultural diversification. *One Earth*, *6*(5), 479–491. https://doi.org/10.1016/j.oneear.2023.03.004

Borron, S. (2006). *Building resilience for an unpredictable future*. Food and Agriculture Organization. http://www.fao.org/tempref/docrep/fao/009/ah617e/ah617e.pdf

Bracken, P., Burgess, P. J., & Girkin, N. T. (2023). Opportunities for enhancing the climate resilience of coffee production through improved crop, soil and water management. *Agroecology and Sustainable Food Systems*, *47*(8), 1125–1157. https://doi.org/10.1080/21683565.2023.2225438

Brandle, J. R., Takle, E., & Zhou, X. (2021). Windbreak Practices. In H. E. "Gene" Garrett, S. Jose, & M. A. Gold (Eds.), *ASA, CSSA, and SSSA Books* (1st ed., pp. 89–126). Wiley. https://doi.org/10.1002/9780891183785.ch5

Braun, V., & Clarke, V. (2012). Thematic analysis. In *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological* (pp. 57–71). American Psychological Association. https://doi.org/10.1037/13620-004

Bravo-Peña, F., & Yoder, L. (2024). Agrobiodiversity and smallholder resilience: A scoping review. *Journal of Environmental Management*, *351*, 119882. https://doi.org/10.1016/j.jenvman.2023.119882

Brunetti, I., Tidball, M., & Couvet, D. (2018). Relationship between biodiversity and agricultural production. *Natural Resource Modeling*, *32*(2). https://doi.org/10.1111/nrm.12204

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples.

Journal of Research in Nursing: JRN, *25*(8), 652–661. https://doi.org/10.1177/1744987120927206

Candelo, E., Casalegno, C., Civera, C., & Büchi, G. (2019). A Ticket to Coffee: Stakeholder View and Theoretical Framework of Coffee Tourism Benefits. *Tourism Analysis*, *24*(3), 329–340. https://doi.org/10.3727/108354219X15511864843830

Cardona, O. D., van Aalst, M. K., Birkman, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R. S., Schipper, E. L. F., & Sinh, B. T. (2012). Determinants of risk: Exposure and vulnerability. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 65–108). Cambridge University Press.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, *4*(8), 765–781. https://doi.org/10.1007/s10021-001-0045-9

Castellazzi, M. S., Wood, G. A., Burgess, P. J., Morris, J., Conrad, K. F., & Perry, J. N. (2008). A systematic representation of crop rotations. *Agricultural Systems*, *97*(1), 26–33. https://doi.org/10.1016/j.agsy.2007.10.006

Caudill, S. A., DeClerck, F. J. A., & Husband, T. P. (2015). Connecting sustainable agriculture and wildlife conservation: Does shade coffee provide habitat for mammals? *Agriculture, Ecosystems & Environment*, *199*, 85–93. https://doi.org/10.1016/j.agee.2014.08.023

Chen, D., Wei, W., & Chen, L. (2017). Effects of terracing practices on water erosion control in China: A meta-analysis. *Earth-Science Reviews*, *173*(Complete), 109–121. https://doi.org/10.1016/j.earscirev.2017.08.007

Chhetri, N., Chaudhary, P., Tiwari, P. R., & Yadaw, R. B. (2012). Institutional and technological innovation: Understanding agricultural adaptation to climate change in Nepal. *Applied Geography*, *33*, 142–150. https://doi.org/10.1016/j.apgeog.2011.10.006

Chiffoleau, Y., & Dourian, T. (2020). Sustainable Food Supply Chains: Is Shortening the Answer? A Literature Review for a Research and Innovation Agenda. *Sustainability*, *12*(23), Article 23. https://doi.org/10.3390/su12239831

Cinner, J. E., & Barnes, M. L. (2019). Social Dimensions of Resilience in Social-Ecological Systems. *One Earth*, *1*(1), 51–56. https://doi.org/10.1016/j.oneear.2019.08.003

Cinner, J. E., & Kittinger, J. N. (2015). Linkages between social systems and coral reefs. In C. Mora (Ed.), *Ecology of Fishes on Coral Reefs* (1st ed., pp. 215–220). Cambridge University Press. https://doi.org/10.1017/CBO9781316105412.024

Clapp, J. (2020). *Food* (3rd edition). Polity.

Costa, A., Bommarco, R., Smith, M. E., Bowles, T., Gaudin, A. C. M., Watson, C. A., Alarcón, R., Berti, A., Blecharczyk, A., Calderon, F. J., Culman, S., Deen, W., Drury, C. F., Garcia y Garcia, A., García-Díaz, A., Hernández Plaza, E., Jonczyk, K., Jäck, O., Navarrete Martínez, L., … Vico, G. (2024). Crop rotational diversity can mitigate climate-induced grain yield losses. *Global Change Biology*, *30*(5), e17298. https://doi.org/10.1111/gcb.17298

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services*, *28*(Part A), 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed). SAGE Publications.

Cursach, J., Rita, J., Gómez-Martínez, C., Cardona, C., Capó, M., & Lázaro, A. (2020). The role of landscape composition and heterogeneity on the taxonomical and functional diversity of Mediterranean plant communities in agricultural landscapes. *PLoS ONE*, *15*(9), e0238222. https://doi.org/10.1371/journal.pone.0238222

Decocq, G., Andrieu, E., Brunet, J., Chabrerie, O., De Frenne, P., De Smedt, P., Deconchat, M., Diekmann, M., Ehrmann, S., Giffard, B., Mifsud, E. G., Hansen, K., Hermy, M., Kolb, A., Lenoir, J., Liira, J., Moldan, F., Prokofieva, I., Rosenqvist, L., … Wulf, M. (2016). Ecosystem Services from Small Forest Patches in Agricultural Landscapes. *Current Forestry Reports*, *2*(1), 30–44. https://doi.org/10.1007/s40725-016-0028-x

Deere, C. D., & Leon, M. (2003). The Gender Asset Gap: Land in Latin America. *World Development*, *31*(6), 925–947. https://doi.org/10.1016/S0305-750X(03)00046-9

Deng, C., Zhang, G., Liu, Y., Nie, X., Li, Z., Liu, J., & Zhu, D. (2021). Advantages and disadvantages of terracing: A comprehensive review. *International Soil and Water Conservation Research*, *9*(3), 344–359. https://doi.org/10.1016/j.iswcr.2021.03.002

DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical Education*, *40*(4), 314–321. https://doi.org/10.1111/j.1365-2929.2006.02418.x

Djihouessi, M. B., Degan, A., Mpo Yekanbessoun, N., Sossou, M., Sossa, F., Adanguidi, J., & Aina, M. P. (2022). Inventory of agroecosystem services and perceptions of potential implications due to climate change: A case study from Benin in West Africa. *Environmental Impact Assessment Review*, *95*, 106792. https://doi.org/10.1016/j.eiar.2022.106792

Djuwendah, E., Karyani, T., Wulandari, E., & Pradono, P. (2023). Community-Based Agro-Ecotourism Sustainability in West Java, Indonesia. *Sustainability*, *15*(13), Article 13. https://doi.org/10.3390/su151310432

Dollinger, J., & Jose, S. (2018). Agroforestry for soil health. *Agroforestry Systems*, *92*(2), 213–219. https://doi.org/10.1007/s10457-018-0223-9

Dudai, N., Putievsky, E., Chaimovitch, D., & Ben-Hur, M. (2006). Growth management of vetiver (Vetiveria zizanioides) under Mediterranean conditions. *Journal of Environmental Management*, *81*(1), 63–71. https://doi.org/10.1016/j.jenvman.2005.10.014

Dudley, N., & Sasha, A. (2017). Agriculture and biodiversity: A review. *Biodiversity*, *18*(2–3), 45–49. https://doi.org/10.1080/14888386.2017.1351892

Dumont, B., Puillet, L., Martin, G., Savietto, D., Aubin, J., Ingrand, S., Niderkorn, V., Steinmetz, L., & Thomas, M. (2020). Incorporating Diversity Into Animal Production Systems Can Increase Their Performance and Strengthen Their Resilience. *Frontiers in Sustainable Food Systems*, *4*. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2020.00109

Dunn, K. M. (2006). Interviewing. In I. Hay (Ed.), *Qualitative research methods in human geography*. Oxford University Press.

Duru, M., Therond, O., & Fares, M. (2015). Designing agroecological transitions; A review. *Agronomy for Sustainable Development*, *35*(4), 1237–1257. https://doi.org/10.1007/s13593-015-0318-x

Eastin, J. (2018). Climate change and gender equality in developing states. *World Development*, *107*, 289–305. https://doi.org/10.1016/j.worlddev.2018.02.021

Echeverri, A., Smith, J. R., MacArthur-Waltz, D., Lauck, K. S., Anderson, C. B., Monge Vargas, R., Alvarado Quesada, I., Wood, S. A., Chaplin-Kramer, R., & Daily, G. C. (2022). Biodiversity and infrastructure interact to drive tourism to and within Costa Rica. *Proceedings of the National Academy of Sciences*, *119*(11), e2107662119. https://doi.org/10.1073/pnas.2107662119

Eise, J., Lambert, N. J., & Wiemer, E. C. (2021). Leveraging communities' network strengths to support climate change adaptation information-sharing: A study with coffee farmers in Risaralda, Colombia. *Climatic Change*, *168*(1–2), 12. https://doi.org/10.1007/s10584-021-03206-w

Ertop, H., Kocięcka, J., Atilgan, A., Liberacki, D., Niemiec, M., & Rolbiecki, R. (2023). The Importance of Rainwater Harvesting and Its Usage Possibilities: Antalya Example (Turkey). *Water*, *15*(12), Article 12. https://doi.org/10.3390/w15122194

Esquivel-Hernández, G., Sánchez-Murillo, R., Birkel, C., & Boll, J. (2018). Climate and water conflicts coevolution from tropical development and hydro-climatic perspectives: A case study of Costa Rica. *JAWRA Journal of the American Water Resources Association*, *54*(2), 451–470.

Eyssartier, C., Ladio, A. H., & Lozada, M. (2011). Horticultural and Gathering Practices Complement Each Other: A Case Study in a Rural Population of Northwestern Patagonia. *Ecology of Food and Nutrition*, *50*(5), 429–451. https://doi.org/10.1080/03670244.2011.604587

Faber, J., & Fonseca, L. M. (2014). How sample size influences research outcomes. *Dental Press Journal of Orthodontics*, *19*(4), 27. https://doi.org/10.1590/2176-9451.19.4.027-029.ebo

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., Sirami, C., Siriwardena, G. M., & Martin, J.-L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters*, *14*(2), 101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

FAO. (n.d.). *Co-creation and sharing of knowledge: Agricultural innovations respond better to local challenges when they are co-created through participatory processes*. Agroecology Knowledge Hub. Retrieved June 26, 2024, from http://www.fao.org/agroecology/knowledge/10-elements/co-creation-knowledge/en/?page=9&ipp=5&tx_dynalist_pi1%5Bpar%5D=YToxOntzOjE6IkwiO3M6MToiMCI7fQ%3D%3D

FAO. (2002). *The State of Food Insecurity in the World*.

FAO. (2013). *Smallholders and Family Farmers* [Dataset]. http://www.fao.org/docrep/018/ar588e/ar588e.pdf

FAO. (2018). *Sustainable food systems: Concept and framework*.

FAO. (2024a). *Building resilience through agrifood systems transformation* (NO371; Regional Conference for Asia and the Pacific (APRC)). https://www.fao.org/3/no371en/no371en.pdf

FAO. (2024b). *Prevalence of moderate and severe food insecurity (%) (3-year average)* [Dataset]. https://www.fao.org/faostat/en/#country/48

FAO. (2024c). *Scaling up Climate Ambition on Land Use and Agriculture through Nationally Determined Contributions and National Adaptation Plans (SCALA)*. https://www.fao.org/in-action/scala/countries/costa-rica/en

FAO & BASIC. (2024). *Comparative study on the distribution of value in European chocolate chains* (p. 20 p.) [Executive Summary]. https://openknowledge.fao.org/handle/20.500.14283/cd0411en

Fifanou, V. G., Ousmane, C., Gauthier, B., & Brice, S. (2011). Traditional agroforestry systems and biodiversity conservation in Benin (West Africa). *Agroforestry Systems*, *82*(1), 1–13. https://doi.org/10.1007/s10457-011-9377-4

Fisher, G. B., & Ryan, P. C. (2006). The Smectite-to-Disordered Kaolinite Transition in a Tropical Soil Chronosequence, Pacific Coast, Costa Rica. *Clays and Clay Minerals*, *54*(5), 571–586. Cambridge Core. https://doi.org/10.1346/CCMN.2006.0540504

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, *16*(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Folke, C., Colding, J., & Berkes, F. (2002). Synthesis: Building resilience and adaptive capacity in social–ecological systems. In C. Folke, F. Berkes, & J. Colding (Eds.), *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change* (pp. 352–387). Cambridge University Press. https://doi.org/10.1017/CBO9780511541957.020

Fontana, A., & Frey, J. H. (2005). The Interview: From Neutral Stance to Political Involvement. In *The Sage handbook of qualitative research, 3rd ed* (pp. 695–727). Sage Publications Ltd.

Fournier, M.-L., Echeverría-Sáenz, S., Mena, F., Arias-Andrés, M., de la Cruz, E., & Ruepert, C. (2018). Risk assessment of agriculture impact on the Frío River watershed and Caño Negro Ramsar wetland, Costa Rica. *Environmental Science and Pollution Research*, *25*(14), 13347–13359. https://doi.org/10.1007/s11356-016-8353-y

Franco, S., Pancino, B., Martella, A., & De Gregorio, T. (2022). Assessing the Presence of a Monoculture: From Definition to Quantification. *Agriculture*, *12*(9), Article 9. https://doi.org/10.3390/agriculture12091506

Frison, E. A., Cherfas, J., & Hodgkin, T. (2011). Agricultural Biodiversity Is Essential for a Sustainable Improvement in Food and Nutrition Security. *Sustainability*, *3*(1), Article 1. https://doi.org/10.3390/su3010238

Gabrielsen, P., & Bosch, P. (2003). Environmental indicators: Typology and use in reporting. *EEA, Copenhagen*, 1–20.

Gatto, M., de Haan, S., Laborte, A., Bonierbale, M., Labarta, R., & Hareau, G. (2021). Trends in Varietal Diversity of Main Staple Crops in Asia and Africa and Implications for Sustainable Food Systems. *Frontiers in Sustainable Food Systems*, *5*. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2021.626714

Gaughan, J., Lacetera, N., Valtorta, S. E., Khalifa, H. H., Hahn, L., & Mader, T. (2009). Response of Domestic Animals to Climate Challenges. In K. L. Ebi, I. Burton, & G. R. McGregor (Eds.), *Biometeorology for Adaptation to Climate Variability and Change* (pp. 131–170). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8921-3_7

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Ghosh-Jerath, S., Kapoor, R., Dhasmana, A., Singh, A., Downs, S., & Ahmed, S. (2022). Effect of COVID-19 Pandemic on Food Systems and Determinants of Resilience in Indigenous

Communities of Jharkhand State, India: A Serial Cross-Sectional Study. *Frontiers in Sustainable Food Systems*, *6*. https://doi.org/10.3389/fsufs.2022.724321

Glazebrook, T. (2017). Women and climate change: A case Study from Northeast Ghana. In *Applied Ethics* (pp. 545–557). Routledge.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5967), 812–818. https://doi.org/10.1126/science.1185383

Goh, A. H. X. (2012). *A Literature Review of the Gender-Differentiated Impacts of Climate Change on Women's and Men's Assets and Well-Being in Developing Countries* (CAPRi Working Paper 106; 0 ed.). International Food Policy Research Institute. https://doi.org/10.2499/CAPRiWP106

Gordon, L. J., Finlayson, C. M., & Falkenmark, M. (2010). Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management*, *97*(4), 512–519. https://doi.org/10.1016/j.agwat.2009.03.017

Goulet, F., Aulagnier, A., & Fouilleux, E. (2023). Moving beyond pesticides: Exploring alternatives for a changing food system. *Environmental Science & Policy*, *147*, 177–187. https://doi.org/10.1016/j.envsci.2023.06.007

Government of Costa Rica. (2018). *National Decarbonization Plan 2018-2050*. https://unfccc.int/documents/204474

Gowdy, J., & Baveye, P. (2019). An Evolutionary Perspective on Industrial and Sustainable Agriculture. In G. Lemaire, P. C. D. F. Carvalho, S. Kronberg, & S. Recous (Eds.), *Agroecosystem Diversity* (pp. 425–433). Academic Press. https://doi.org/10.1016/B978-0-12-811050-8.00027-3

Haan, N. L., Zhang, Y., & Landis, D. A. (2020). Predicting Landscape Configuration Effects on Agricultural Pest Suppression. *Trends in Ecology & Evolution*, *35*(2), 175–186. https://doi.org/10.1016/j.tree.2019.10.003

Hackshaw, A. (2008). Small studies: Strengths and limitations. *European Respiratory Journal*, *32*(5), 1141–1143. https://doi.org/10.1183/09031936.00136408

Halewood, M., Bedmar Villanueva, A., Rasolojaona, J., Andriamahazo, M., Rakotoniaina, N., Bossou, B., Mikpon, T., Vodouhe, R., Fey, L., Drews, A., Kumar, P. L., Rasoanirina, B., Rasoazafindrabe, T., Aigbe, M., Agbahounzo, B., Otieno, G., Garforth, K., Kiene, T., & Nnadozie, K. (2021). Enhancing farmers' agency in the global crop commons through use of biocultural community protocols. *Agriculture and Human Values*, *38*(2), 579–594. https://doi.org/10.1007/s10460-020-10164-z

Han, W., Zhang, Z., Zhang, X., & He, L. (2021). Farmland Rental Participation, Agricultural Productivity, and Household Income: Evidence from Rural China. *Land*, *10*(9). https://doi.org/10.3390/land10090899

Hanneke, R., Asada, Y., Lieberman, L., Neubauer, L. C., & Fagen, M. (2017). *The Scoping Review Method: Mapping the Literature in "Structural Change" Public Health Interventions*. SAGE Publications Ltd. https://doi.org/10.4135/9781473999008

Haque, C. E., Khan, S. A., & Choudhury, M. (2024). Role of multi-level institutions in facilitating innovation and adaptation technologies for reducing climate risk and impact: Evidence from coastal communities of Bangladesh. *International Journal of Disaster Risk Reduction*, *111*, 104669. https://doi.org/10.1016/j.ijdrr.2024.104669

Harron, C. F., & Matthew, R. A. (2022). Prosocial Partnerships – A Scalable Pathway to Sustainable Agricultural Development. In W. Leal Filho, M. Kovaleva, & E. Popkova (Eds.), *Sustainable Agriculture and Food Security* (pp. 35–52). Springer International Publishing. https://doi.org/10.1007/978-3-030-98617-9_3

Harvey, C. A. (2000). Windbreaks enhance seed dispersal into agricultural landscapes in Monteverde, Costa Rica. *Ecological Applications*, *10*(1), 155–173. https://doi.org/10.1890/1051-0761(2000)010[0155:WESDIA]2.0.CO;2

Harvey, C. A., Martínez-Rodríguez, M. R., Cárdenas', J. M., Avelino, J., Rapidel, B., Vignola, R., Donatti, C. I., & Vilchez-Mendoza, S. (2017). The use of Ecosystem-based Adaptation practices by smallholder farmers in Central America. *Agriculture, Ecosystems & Environment*, *246*, 279–290. https://doi.org/10.1016/j.agee.2017.04.018

Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R., & Alpizar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture & Food Security*, *7*(1), 57. https://doi.org/10.1186/s40066-018-0209-x

Haydari, H., Agahi, H., & Geravandi, S. (2023). Social Resilience of Iranian Potato Farmers Against Climate Changes. *Potato Research*. https://doi.org/10.1007/s11540-023-09649-1

Hecht, S. B. (2018). The Evolution of Agroecological Thought. In M. A. Altieri, *Agroecology: The science of sustainable agriculture* (2nd ed., pp. 1–19). CRC Press. https://doi.org/10.1201/9780429495465-1

Hergoualc'h, K., Blanchart, E., Skiba, U., Hénault, C., & Harmand, J.-M. (2012). Changes in carbon stock and greenhouse gas balance in a coffee (Coffea arabica) monoculture versus an agroforestry system with Inga densiflora, in Costa Rica. *Agriculture, Ecosystems & Environment*, *148*, 102–110. https://doi.org/10.1016/j.agee.2011.11.018

Herrera-Murillo, J., Mora-Campos, D., Salas-Jimenez, P., Hidalgo-Gutierrez, M., Soto-Murillo, T., Vargas-Calderon, J., Villalobos-Villalobos, A., & Androvetto-Villalobos, E. (2021). Wastewater Discharge and Reuse Regulation in Costa Rica: An Opportunity for Improvement. *Water*, *13*(19), Article 19. https://doi.org/10.3390/w13192631

Hillel, D. (2005). Water Harvesting. In D. Hillel (Ed.), *Encyclopedia of Soils in the Environment* (pp. 264–270). Elsevier. https://doi.org/10.1016/B0-12-348530-4/00306-4

HLPE. (2019). *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition* (HLPE Report 14). Committee on World Food Security.

Hodgson, G. M. (2006). What Are Institutions? *Journal of Economic Issues*, *40*(1), 1–25. https://doi.org/10.1080/00213624.2006.11506879

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Horrigan, L., Lawrence, R. S., & Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives*, *110*(5), 445–456. https://doi.org/10.1289/ehp.02110445

Huyer, S. (2016). Closing the Gender Gap in Agriculture. *Gender, Technology and Development*, *20*(2), 105–116. https://doi.org/10.1177/0971852416643872

Instituto Nacional de Estadística y Censos. (2024). *Encuesta Nacional de Hogares: Resultados Generales*. https://admin.inec.cr/sites/default/files/2024-10/reenaho2024.pdf.pdf

IPCC. (2019). Summary for Policymakers. In P. R. Shukla, E. C. Buendia, V. Masson-Delmotte, J. Skea, H. O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, … J. Malley (Eds.), *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.

IPCC. (2022). *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157988

IPCC. (2023). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157896

Izaurralde, R. C., Thomson, A. M., Morgan, J. A., Fay, P. A., Polley, H. W., & Hatfield, J. L. (2011). Climate Impacts on Agriculture: Implications for Forage and Rangeland Production. *Agronomy Journal*, *103*(2), 371–381. https://doi.org/10.2134/agronj2010.0304

Jordan, J. C. (2019). Deconstructing resilience: Why gender and power matter in responding to climate stress in Bangladesh. *Climate and Development*, *11*(2), 167–179. https://doi.org/10.1080/17565529.2018.1442790

Kahane, R., Hodgkin, T., Jaenicke, H., Hoogendoorn, C., Hermann, M., (Dyno) Keatinge, J. D. H., d'Arros Hughes, J., Padulosi, S., & Looney, N. (2013). Agrobiodiversity for food security, health and income. *Agronomy for Sustainable Development*, *33*(4), 671–693. https://doi.org/10.1007/s13593-013-0147-8

Kahsay, G. A., Turreira-García, N., Ortiz-Gonzalo, D., Georget, F., & Bosselmann, A. S. (2023). New coffee varieties as a climate adaptation strategy: Empirical evidence from Costa Rica. *World Development Sustainability*, *2*, 100046. https://doi.org/10.1016/j.wds.2023.100046

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Kanianska, R. (2016). Agriculture and Its Impact on Land-Use, Environment, and Ecosystem Services. In A. Almusaed (Ed.), *Landscape Ecology—The Influences of Land Use and Anthropogenic Impacts of Landscape Creation*. IntechOpen. https://doi.org/10.5772/61905

Kaye-Blake, W., Stirrat, K., Smith, M., & Fielke, S. (2019). Testing indicators of resilience for rural communities. *Rural Society*, *28*(2), 161–179. https://doi.org/10.1080/10371656.2019.1658285

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., & Hudson, P. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, *468*(7324), 647–653. https://doi.org/10.1038/nature09575

Keneni, G., Bekele, E., Imtiaz, M., & Dagne, K. (2012). Genetic Vulnerability of Modern Crop Cultivars: Causes, Mechanism and Remedies. *International Journal of Plant Research*, *2*(3), 69–79.

Kertolli, E., Prosperi, P., Harbouze, R., Moussadek, R., Echchgadda, G., & Belhouchette, H. (2024). The water–energy–food–ecosystem nexus in North Africa dryland farming: A multi-criteria analysis of climate-resilient innovations in Morocco. *Agricultural and Food Economics*, *12*(1), 34. https://doi.org/10.1186/s40100-024-00327-5

Kim, H.-R., Oh, W.-S., Kim, J.-G., & Shin, W.-S. (2023). The Influence of Urban Gardening Activities on Participants' Perceived Restorativeness, Resilience, Sense of Community and Stress. *Healthcare*, *11*(12), NA. Gale Academic OneFile.

Knott, E., Rao, A. H., Summers, K., & Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, *2*(1), Article 1. https://doi.org/10.1038/s43586-022-00150-6

Kuyah, S., Öborn, I., & Jonsson, M. (2017). Regulating Ecosystem Services Delivered in Agroforestry Systems. In J. C. Dagar & V. P. Tewari (Eds.), *Agroforestry: Anecdotal to Modern Science* (pp. 797–815). Springer. https://doi.org/10.1007/978-981-10-7650-3_33

Labeyrie, V., Friedman, R. S., Donnet, S., Faye, N. F., Cobelli, O., Baggio, J., Felipe-Lucia, M. R., & Raimond, C. (2023). Linking seed networks and crop diversity contributions to people: A case study in small-scale farming systems in Sahelian Senegal. *Agricultural Systems*, *211*, 103726. https://doi.org/10.1016/j.agsy.2023.103726

Labeyrie, V., Ouadah, S., & Raimond, C. (2024). Social network analysis: Which contributions to the analysis of agricultural systems resilience? *Agricultural Systems*, *215*, 103832. https://doi.org/10.1016/j.agsy.2023.103832

Läderach, P., Ramirez–Villegas, J., Navarro-Racines, C., Zelaya, C., Martinez–Valle, A., & Jarvis, A. (2017). Climate change adaptation of coffee production in space and time. *Climatic Change*, *141*(1), 47–62. https://doi.org/10.1007/s10584-016-1788-9

Larson, R. B. (2019). Controlling social desirability bias. *International Journal of Market Research*, *61*(5), 534–547. https://doi.org/10.1177/1470785318805305

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment*, *1*(10), 544–553. https://doi.org/10.1038/s43017-020-0080-8

Little, M., & Blau, E. (2020). Social adaptation and climate mitigation through agrotourism: A case study of tourism in Mastatal, Costa Rica. *Journal of Ecotourism*, *19*(2), 97–112. https://doi.org/10.1080/14724049.2019.1652305

Little, M., & Sylvester, O. (2022). Agroecological producers shortening food chains during Covid-19: Opportunities and challenges in Costa Rica. *Agriculture and Human Values*, *39*(3), 1133–1140. https://doi.org/10.1007/s10460-022-10298-2

Lynch, J., Cain, M., Frame, D., & Pierrehumbert, R. (2021). Agriculture's Contribution to Climate Change and Role in Mitigation Is Distinct From Predominantly Fossil CO2-Emitting Sectors. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.518039

Magis, K. (2010). Community Resilience: An Indicator of Social Sustainability. *Society & Natural Resources*, *23*(5), 401–416. https://doi.org/10.1080/08941920903305674

Magne, M. A., Thénard, V., & Mihout, S. (2016). Initial insights on the performances and management of dairy cattle herds combining two breeds with contrasting features. *Animal*, *10*(5), 892–901. https://doi.org/10.1017/S1751731115002840

Malak-Rawlikowska, A., Majewski, E., Wąs, A., Borgen, S. O., Csillag, P., Donati, M., Freeman, R., Hoàng, V., Lecoeur, J.-L., Mancini, M. C., Nguyen, A., Saïdi, M., Tocco, B., Török, Á., Veneziani, M., Vittersø, G., & Wavresky, P. (2019). Measuring the Economic, Environmental, and Social Sustainability of Short Food Supply Chains. *Sustainability*, *11*(15), Article 15. https://doi.org/10.3390/su11154004

Martínez-Torres, M. E., & Rosset, P. M. (2014). Diálogo de saberes in La Vía Campesina: Food sovereignty and agroecology. *Journal of Peasant Studies*, *41*(6), 979–997. https://doi.org/10.1080/03066150.2013.872632

Matarrita-Cascante, D., Brennan, M. A., & Luloff, A. E. (2010). Community agency and sustainable tourism development: The case of La Fortuna, Costa Rica. *Journal of Sustainable Tourism*, *18*(6), 735–756. https://doi.org/10.1080/09669581003653526

Mbow, C., Rosenzweig, C., Tubiello, F., Benton, T., Herrero, M., Pradhan, P., Barioni, L., Krishnapillai, M., Liwenga, E., Rivera-Ferre, M., Sapkota, T., & Xu, Y. (2019). *IPCC Special Report on Land and Climate Change. Chapter 5: Food Security*.

Mcmillan, D., & Chavis, D. (1986). Sense of Community: A Definition and Theory. *Journal of Community Psychology*, *14*, 6–23. https://doi.org/10.1002/1520-6629(198601)14:13.0.CO;2-I

MEA. (2005). *Ecosystems and human well-being: Synthesis; a report of the Millennium Ecosystem Assessment*. Island Press.

Merchant, E. V., Fatima, T., Fatima, A., Maiyo, N., Mutuku, V., Keino, S., Simon, J. E., Hoffman, D. J., & Downs, S. M. (2022). The Influence of Food Environments on Food Security Resilience during the COVID-19 Pandemic: An Examination of Urban and Rural Difference in Kenya. *Nutrients*, *14*(14), Article 14. https://doi.org/10.3390/nu14142939

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., Mey, Y. de, Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., … Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656. https://doi.org/10.1016/j.agsy.2019.102656

Mijatović, D., Van Oudenhoven, F., Eyzaguirre, P., & Hodgkin, T. (2013). The role of agricultural biodiversity in strengthening resilience to climate change: Towards an analytical framework. *International Journal of Agricultural Sustainability*, *11*(2), 95–107. https://doi.org/10.1080/14735903.2012.691221

Moon, K., Brewer, T., Januchowski-Hartley, S., Adams, V., & Blackman, D. (2016). A guideline to improve qualitative social science publishing in ecology and conservation journals. *Ecology and Society*, *21*(3). https://doi.org/10.5751/ES-08663-210317

Motha, R. P., & Baier, W. (2005). Impacts of Present and Future Climate Change and Climate Variability on Agriculture in the Temperate Regions: North America. *Climatic Change*, *70*(1), 137–164. https://doi.org/10.1007/s10584-005-5940-1

Mukhlis, I., Rizaludin, M. S., & Hidayah, I. (2022). Understanding Socio-Economic and Environmental Impacts of Agroforestry on Rural Communities. *Forests*, *13*(4), Article 4. https://doi.org/10.3390/f13040556

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology*, *18*(1). https://doi.org/10.1186/s12874-018-0611-x

Murillo, A. (2024, April 22). 'This country is what the world would like to be': Can Costa Rica's environment minister keep its green reputation intact? *The Guardian*. https://www.theguardian.com/global-development/2024/apr/22/sustainable-or-solventcosta-rica-environment-minister-franz-tattenbach-on-balancing-green-credentials-and-growth

Nair, P. K. R. (1985). Classification of agroforestry systems. *Agroforestry Systems*, *3*(2), 97–128. https://doi.org/10.1007/BF00122638

Nair, P. K. R. (1993). *An introduction to agroforestry*. Kluwer Academic Publishers in cooperation with International Centre for Research in Agroforestry.

Neubauer, B. E., Witkop, C. T., & Varpio, L. (2019). How phenomenology can help us learn from the experiences of others. *Perspectives on Medical Education*, *8*(2), 90–97. https://doi.org/10.1007/s40037-019-0509-2

Newbold, T., Hudson, L. N., Phillips, H. R. P., Hill, S. L. L., Contu, S., Lysenko, I., Blandon, A., Butchart, S. H. M., Booth, H. L., Day, J., De Palma, A., Harrison, M. L. K., Kirkpatrick, L., Pynegar, E., Robinson, A., Simpson, J., Mace, G. M., Scharlemann, J. P. W., & Purvis, A. (2014). A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1792), 20141371. https://doi.org/10.1098/rspb.2014.1371

Nguyen, Q., Hoang, M. H., Öborn, I., & van Noordwijk, M. (2013). Multipurpose agroforestry as a climate change resiliency option for farmers: An example of local adaptation in Vietnam. *Climatic Change*, *117*(1–2), 241–257. https://doi.org/10.1007/s10584-012-0550-1

Nnadi, O. I., Lyimo, J., Liwenga, E., & Madukwe, M. C. (2023). Gender Perspectives of Responses to Climate Variability and Change among Farm Households in Southeast Nigeria. *Environmental Management*, *71*(1), 201–213. https://doi.org/10.1007/s00267-022-01748-y

Norris, K. (2008). Agriculture and biodiversity conservation: Opportunity knocks. *Conservation Letters*, *1*(1), 2–11. https://doi.org/10.1111/j.1755-263X.2008.00007.x

Norton, L. R. (2016). Is it time for a socio-ecological revolution in agriculture? *Agriculture, Ecosystems & Environment*, *235*, 13–16. https://doi.org/10.1016/j.agee.2016.10.007

OECD. (2017). *Agricultural Policies in Costa Rica*. Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/agriculture-and-food/agricultural-policies-in-costa-rica_9789264269125-en

OECD. (2020). *OECD Economic Surveys: Costa Rica 2020*. OECD. https://doi.org/10.1787/2e0fea6c-en

OECD. (2023a). *Agricultural Policy Monitoring and Evaluation 2023: Adapting Agriculture to Climate Change*. OECD. https://doi.org/10.1787/b14de474-en

OECD. (2023b). *OECD Economic Surveys: Costa Rica 2023*. OECD. https://doi.org/10.1787/8e8171b0-en

OECD. (2024). *Costa Rica: Overview of the education system*. Education GPS. http://gpseducation.oecd.org

Okuku Oloo, J., & Omondi, P. (2017). Strengthening local institutions as avenues for climate change resilience. *International Journal of Disaster Resilience in the Built Environment*, *8*(5), 573–588. ABI/INFORM Global; Materials Science & Engineering Collection; Politics Collection. https://doi.org/10.1108/IJDRBE-12-2013-0047

Ortiz, A. M. D., Outhwaite, C. L., Dalin, C., & Newbold, T. (2021). A review of the interactions between biodiversity, agriculture, climate change, and international trade: Research and policy priorities. *One Earth*, *4*(1), 88–101. https://doi.org/10.1016/j.oneear.2020.12.008

Owen, G. (2020). What makes climate change adaptation effective? A systematic review of the literature. *Global Environmental Change*, *62*, 102071. https://doi.org/10.1016/j.gloenvcha.2020.102071

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Panpakdee, C., Limnirankul, B., & Kramol, P. (2021). Assessing the Social-ecological Resilience of Organic Farmers in Chiang Mai Province, Thailand. *Forest and Society*, 631–649. https://doi.org/10.24259/fs.v5i2.13268

Parker, L., Bourgoin, C., Martinez-Valle, A., & Läderach, P. (2019). Vulnerability of the agricultural sector to climate change: The development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. *PLOS ONE*, *14*(3), e0213641. https://doi.org/10.1371/journal.pone.0213641

Pascua, P., McMillen, H., Ticktin, T., Vaughan, M., & Winter, K. B. (2017). Beyond services: A process and framework to incorporate cultural, genealogical, place-based, and indigenous relationships in ecosystem service assessments. *Ecosystem Services*, *26*, 465–475. https://doi.org/10.1016/j.ecoser.2017.03.012

Peng, W., & Berry, E. M. (2019). The Concept of Food Security. In P. Ferranti, E. M. Berry, & J. R. Anderson (Eds.), *Encyclopedia of Food Security and Sustainability* (pp. 1–7). Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.22314-7

Pheasey, H., Griffiths, R. A., Matechou, E., & Roberts, D. L. (2023). Motivations and sensitivities surrounding the illegal trade of sea turtles in Costa Rica. *Ecology and Society*, *28*(4). https://doi.org/10.5751/ES-14296-280415

Pickering, C. (2024). Women in agroecology: Inclusion, exclusion, and empowerment in Peru. *Agroecology and Sustainable Food Systems*, *0*(0), 1–23. https://doi.org/10.1080/21683565.2024.2356199

Poland, B. D. (1995). Transcription Quality as an Aspect of Rigor in Qualitative Research. *Qualitative Inquiry*, *1*(3), 290–310. https://doi.org/10.1177/107780049500100302

Polkinghorne, D. E. (1989). Phenomenological Research Methods. In R. S. Valle & S. Halling (Eds.), *Existential-Phenomenological Perspectives in Psychology: Exploring the Breadth of Human Experience* (pp. 41–60). Springer US. https://doi.org/10.1007/978-1-4615-6989-3_3

Pomereda, C. (2003). Costa Rica. In FAO, *WTO Agreement on Agriculture: The Implementation Experience—Developing Country Case Studies*.

Poncet, V., Asten, P. van, Millet, C. P., Vaast, P., & Allinne, C. (2024). Which diversification trajectories make coffee farming more sustainable? *Current Opinion in Environmental Sustainability*, *68*, 101432. https://doi.org/10.1016/j.cosust.2024.101432

Porcuna-Ferrer, A., Fiala, V., Freyer, B., Van Etten, J., Vernooy, R., & Probst, L. (2020). Do community seed banks contribute to the social-ecological resilience of communities? A case-study from western Guatemala. *International Journal of Agricultural Sustainability*, *18*(3), 232–249. https://doi.org/10.1080/14735903.2020.1747199

Porras, I., Barton, D. N., Miranda, M., & Chacón-Cascante, A. (2013). *Learning from 20 years of Payments for Ecosystem Services in Costa Rica*. International Institute for Environment and Development, London.

Power, A. G. (2010). Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2959–2971. https://doi.org/10.1098/rstb.2010.0143

Proesmans, W., Bonte, D., Smagghe, G., Meeus, I., & Verheyen, K. (2019). Importance of forest fragments as pollinator habitat varies with season and guild. *Basic and Applied Ecology*, *34*, 95–107. https://doi.org/10.1016/j.baae.2018.08.004

Quandt, A., Neufeldt, H., & Gorman, K. (2023). Climate change adaptation through agroforestry: Opportunities and gaps. *Current Opinion in Environmental Sustainability*, *60*, 101244. https://doi.org/10.1016/j.cosust.2022.101244

Quesada-Román, A. (2021). Landslide risk index map at the municipal scale for Costa Rica. *International Journal of Disaster Risk Reduction*, *56*, 102144. https://doi.org/10.1016/j.ijdrr.2021.102144

Rapaport, C., Hornik-Lurie, T., Cohen, O., Lahad, M., Leykin, D., & Aharonson-Daniel, L. (2018). The relationship between community type and community resilience. *International Journal of Disaster Risk Reduction*, *31*, 470–477. https://doi.org/10.1016/j.ijdrr.2018.05.020

Rauw, W. M., Gomez-Raya, L., Star, L., Øverland, M., Delezie, E., Grivins, M., Hamann, K. T., Pietropaoli, M., Klaassen, M. T., Klemetsdal, G., Gil, M. G., Torres, O., Dvergedal, H., & Formato, G. (2023). Sustainable development in circular agriculture: An illustrative bee↺legume↺poultry example. *Sustainable Development*, *31*(2), 639–648. https://doi.org/10.1002/sd.2435

Rawe, T., Tank, F., Deering, K., Echols, W., Nierenberg, D., Nink, E., Ahern, C., & Small, S. (2015). *Cultivating equality: Delivering just and sustainable food systems in a changing climate*. https://cgspace.cgiar.org/bitstream/handle/10568/68536/CARE-Food-Tank-CCAFS_Report.pdf

Rawlani, A. K., & Sovacool, B. K. (2011). Building responsiveness to climate change through community based adaptation in Bangladesh. *Mitigation and Adaptation Strategies for Global Change*, *16*(8), 845–863. https://doi.org/10.1007/s11027-011-9298-6

Reyes-García, V., Aceituno-Mata, L., Calvet-Mir, L., Garnatje, T., Gómez-Baggethun, E., Lastra, J. J., Ontillera, R., Parada, M., Rigat, M., Vallès, J., Vila, S., & Pardo-de-Santayana, M. (2014). Resilience of traditional knowledge systems: The case of agricultural knowledge in home gardens of the Iberian Peninsula. *Global Environmental Change*, *24*, 223–231. https://doi.org/10.1016/j.gloenvcha.2013.11.022

Rice, A. M., Einbinder, N., & Calderón, C. I. (2023). 'With agroecology, we can defend ourselves': Examining *campesino* resilience and economic solidarity during pandemic-era economic shock in Guatemala. *Agroecology and Sustainable Food Systems*, *47*(2), 273–305. https://doi.org/10.1080/21683565.2022.2140378

Ricketts, T. H. (2004). Tropical Forest Fragments Enhance Pollinator Activity in Nearby Coffee Crops. *Conservation Biology*, *18*(5), 1262–1271. JSTOR.

Riger, S., & Sigurvinsdottir, R. (2016). Thematic Analysis. In L. Jason & D. Glenwick (Eds.), *Handbook of Methodological Approaches to Community-based Research: Qualitative, Quantitative, and Mixed Methods*. Oxford University Press.

Robertson, G. P., & Swinton, S. M. (2005). Reconciling agricultural productivity and environmental integrity: A grand challenge for agriculture. *Frontiers in Ecology and the Environment*, *3*(1), 38–46. https://doi.org/10.1890/1540-9295(2005)003[0038:RAPAEI]2.0.CO;2

Rockenbauch, T., & Sakdapolrak, P. (2017). Social networks and the resilience of rural communities in the Global South: A critical review and conceptual reflections. *Ecology and Society*, *22*(1). https://www.jstor.org/stable/26270110

Rodríguez Echavarría, T., & Prunier, D. (2020). Extractivismo agrícola, frontera y fuerza de trabajo migrante: La expansión del monocultivo de piña en Costa Rica. *Frontera norte*, *32*, 1–25. https://doi.org/10.33679/rfn.v1i1.1983

Rogers, M. (2023). Coding Qualitative Data. In J. M. Okoko, S. Tunison, & K. D. Walker (Eds.), *Varieties of Qualitative Research Methods: Selected Contextual Perspectives* (pp. 73–78). Springer International Publishing. https://doi.org/10.1007/978-3-031-04394-9_12

Saja, A. M. A., Teo, M., Goonetilleke, A., & Ziyath, A. M. (2018). An inclusive and adaptive framework for measuring social resilience to disasters. *International Journal of Disaster Risk Reduction*, *28*, 862–873. https://doi.org/10.1016/j.ijdrr.2018.02.004

Sandström, V., Kaseva, J., Porkka, M., Kuisma, M., Sakieh, Y., & Kahiluoto, H. (2023). Disparate history of transgressing planetary boundaries for nutrients. *Global Environmental Change*, *78*, 102628. https://doi.org/10.1016/j.gloenvcha.2022.102628

Schneider, S., & Niederle, P. A. (2010). Resistance strategies and diversification of rural livelihoods: The construction of autonomy among Brazilian family farmers. *The Journal of Peasant Studies*, *37*(2), 379–405. https://doi.org/10.1080/03066151003595168

Seboka, B., & Deressa, A. (1999). Validating farmers' indigenous social networks for local seed supply in central rift valley of Ethiopia. *The Journal of Agricultural Education and Extension*, *6*(4), 245–254. https://doi.org/10.1080/13892240085300071

Shaver, I., Chain-Guadarrama, A., Cleary, K. A., Sanfiorenzo, A., Santiago-García, R. J., Finegan, B., Hormel, L., Sibelet, N., Vierling, L. A., Bosque-Pérez, N. A., DeClerck, F., Fagan, M. E., & Waits, L. P. (2015). Coupled social and ecological outcomes of agricultural intensification in Costa Rica and the future of biodiversity conservation in tropical agricultural regions. *Global Environmental Change*, *32*, 74–86. https://doi.org/10.1016/j.gloenvcha.2015.02.006

Sinclair, K., Rawluk, A., Kumar, S., & Curtis, A. (2017). Ways forward for resilience thinking: Lessons from the field for those exploring social-ecological systems in agriculture and natural resource management. *Ecology and Society*, *22*(4). https://doi.org/10.5751/ES-09705-220421

Smith, C., & Oelbermann, M. (2010). Climate Change Perception and Adaptation in a Remote Costa Rican Ag-ricultural Community. *The Open Agriculture Journal*, *4*, 72–79. https://doi.org/10.2174/1874331501004010072

Somarriba, E., Harvey, C. A., Samper, M., Anthony, F., González, J., Staver, C., & Rice, R. A. (2004). Biodiversity Conservation in Neotropical Coffee (Coffea arabica) Plantations. In G. Schroth, G. A. B. da Fonseca, C. A. Harvey, C. Gascon, H. Vasconcelos, & A. N. Izac (Eds.), *Agroforestry and Biodiversity Conservation in Tropical Landscapes*. Island Press.

Squires, A. (2009). Methodological challenges in cross-language qualitative research: A research review. *International Journal of Nursing Studies*, *46*(2), 277–287. https://doi.org/10.1016/j.ijnurstu.2008.08.006

Srinivasa Rao, Ch., Kareemulla, K., Krishnan, P., Murthy, G. R. K., Ramesh, P., Ananthan, P. S., & Joshi, P. K. (2019). Agro-ecosystem based sustainability indicators for climate resilient agriculture in India: A conceptual framework. *Ecological Indicators*, *105*, 621–633. https://doi.org/10.1016/j.ecolind.2018.06.038

Statistics Canada. (2024). *Food security*. https://www160.statcan.gc.ca/prosperity-prosperite/food-security-securite-alimentaire-eng.htm

Stenberg, J. A. (2017). A Conceptual Framework for Integrated Pest Management. *Trends in Plant Science*, *22*(9), 759–769. https://doi.org/10.1016/j.tplants.2017.06.010

Stewart, I. T., Maurer, E. P., Stahl, K., & Joseph, K. (2022). Recent evidence for warmer and drier growing seasons in climate sensitive regions of Central America from multiple global datasets. *International Journal of Climatology*, *42*(3), 1399–1417. https://doi.org/10.1002/joc.7310

Stuart, D., & Gillon, S. (2013). Scaling up to address new challenges to conservation on US farmland. *Themed Issue 1-Guest Editor Romy GreinerThemed Issue 2- Guest Editor Davide Viaggi*, *31*, 223–236. https://doi.org/10.1016/j.landusepol.2012.07.003

Sunderland, T. C. H. (2011). Food security: Why is biodiversity important? *International Forestry Review*, *13*(3), 265–274. https://doi.org/10.1505/146554811798293908

Sundler, A. J., Lindberg, E., Nilsson, C., & Palmér, L. (2019). Qualitative thematic analysis based on descriptive phenomenology. *Nursing Open*, *6*(3), 733–739. https://doi.org/10.1002/nop2.275

Sylvester, O., & Little, M. (2021). "I came all this way to receive training, am I really going to be taught by a woman?" Factors that support and hinder women's participation in agroecology in Costa Rica. *Agroecology and Sustainable Food Systems*, *45*(7), 957–980. https://doi.org/10.1080/21683565.2020.1811830

Tang, Q., Bao, Y., He, X., Zhu, B., & Zhang, X. (2012). Farmer's adaptive strategies on land competition between societal outcomes and agroecosystem conservation in the purple-soiled hilly region, southwestern China. *Journal of Mountain Science*, *9*(1), 77–86. https://doi.org/10.1007/s11629-012-2201-4

Teixeira, H. M., Schulte, R. P. O., Anten, N. P. R., Bosco, L. C., Baartman, J. E. M., Moinet, G. Y. K., & Reidsma, P. (2022). How to quantify the impacts of diversification on sustainability? A review of indicators in coffee systems. *Agronomy for Sustainable Development*, *42*(4), 62. https://doi.org/10.1007/s13593-022-00785-5

Temple, B., & Young, A. (2004). Qualitative Research and Translation Dilemmas. *Qualitative Research*, *4*(2), 161–178. https://doi.org/10.1177/1468794104044430

Thayer, A. W., Vargas, A., Castellanos, A. A., Lafon, C. W., McCarl, B. A., Roelke, D. L., Winemiller, K. O., & Lacher, T. E. (2020). Integrating Agriculture and Ecosystems to Find Suitable Adaptations to Climate Change. *Climate*, *8*(1), Article 1. https://doi.org/10.3390/cli8010010

Thrupp, L. A. (2000). Linking Agricultural Biodiversity and Food Security: The Valuable Role of Agrobiodiversity for Sustainable Agriculture. *International Affairs*, *76*(2), 265–281. https://doi.org/10.1111/1468-2346.00133

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., Levac, D., Ng, C., Sharpe, J. P., Wilson, K., Kenny, M., Warren, R., Wilson, C., Stelfox, H. T., & Straus, S. E. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology*, *16*(15), NA. Gale Academic OneFile.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters*, *8*(8), 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

Tully, K. L., & Lawrence, D. (2012). Canopy and leaf composition drive patterns of nutrient release from pruning residues in a coffee agroforest. *Ecological Applications*, *22*(4), 1330–1344. https://doi.org/10.1890/10-2342.1

UNCC. (n.d.). *Payments for Environmental Services Program: Costa Rica*. https://unfccc.int/climate-action/momentum-for-change/financing-for-climate-friendly-investment/payments-for-environmental-services-program

UNDP. (2024). *Human development summary capturing achievements in the HDI and complementary metrics that take into account gender gaps, inequality, planetary pressures and multidimensional poverty* [Human Development Reports: Costa Rica]. https://hdr.undp.org/data-center/specific-country-data#/countries/CRI

USDA. (n.d.). *Soil Health*. Natural Resources Conservation Service. Retrieved July 25, 2024, from https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

van Noordwijk, M., Coe, R., Sinclair, F. L., Luedeling, E., Bayala, J., Muthuri, C. W., Cooper, P., Kindt, R., Duguma, L., Lamanna, C., & Minang, P. A. (2021). Climate change adaptation in and through agroforestry: Four decades of research initiated by Peter Huxley. *Mitigation and Adaptation Strategies for Global Change*, *26*(5), 18. https://doi.org/10.1007/s11027-021-09954-5 van Oudenhoven, F. J. W. van, Mijatovic, D., & Eyzaguirre, P. B. (2011). Social-ecological indicators of resilience in agrarian and natural landscapes. *Management of Environmental Quality*, *22*(2), 154–173. https://doi.org/10.1108/14777831111113356

Vanloqueren, G., & Baret, P. V. (2009). How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy*, *38*(6), 971–983. https://doi.org/10.1016/j.respol.2009.02.008

Vasileiou, K., Barnett, J., Thorpe, S., & Young, T. (2018). Characterising and justifying sample size sufficiency in interview-based studies: Systematic analysis of qualitative health research over a 15-year period. *BMC Medical Research Methodology*, *18*(1), 148. https://doi.org/10.1186/s12874-018-0594-7

Vernooy, R. (2022). Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. *Agroecology and Sustainable Food Systems*, *46*(6), 877–901. https://doi.org/10.1080/21683565.2022.2076184

Villa, T. C. C., Maxted, N., Scholten, M., & Ford-Lloyd, B. (2005). Defining and identifying crop landraces. *Plant Genetic Resources*, *3*(3), 373–384. https://doi.org/10.1079/PGR200591

Viñals, E., Maneja, R., Rufí-Salís, M., Martí, M., & Puy, N. (2023). Reviewing social-ecological resilience for agroforestry systems under climate change conditions. *Science of The Total Environment*, *869*, 161763. https://doi.org/10.1016/j.scitotenv.2023.161763

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01530-110113

Walker, B., & Salt, D. (2012). Preparing for Practice: The Essence of Resilience Thinking. In B. Walker & D. Salt (Eds.), *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function* (pp. 1–25). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-231-0_1

Wall, D. H., & Nielsen, U. N. (2012). Biodiversity and Ecosystem Services: Is It the Same Below Ground? *Nature Education Knowledge*, *3*(12). https://www.nature.com/scitable/knowledge/library/biodiversity-and-ecosystem-services-is-it-the-96677163/

Walz, R. (2000). Development of Environmental Indicator Systems: Experiences from Germany. *Environmental Management*, *25*(6), 613–623. https://doi.org/10.1007/s002670010048

Weller, S. C., Vickers, B., Bernard, H. R., Blackburn, A. M., Borgatti, S., Gravlee, C. C., & Johnson, J. C. (2018). Open-ended interview questions and saturation. *PLOS ONE*, *13*(6), e0198606. https://doi.org/10.1371/journal.pone.0198606

White, C. (2020). Why Regenerative Agriculture? *The American Journal of Economics and Sociology*, *79*(3), 799–812. https://doi.org/10.1111/ajes.12334

WHO & CBD. (2015). *Connecting global priorities: Biodiversity and human health: a state of knowledge review*. World Health Organization. https://iris.who.int/handle/10665/174012

Wilkinson, C. (2012). Social-ecological resilience: Insights and issues for planning theory. *Planning Theory*, *11*(2), 148–169. https://doi.org/10.1177/1473095211426274

Wintle, B. A., Kujala, H., Whitehead, A., Cameron, A., Veloz, S., Kukkala, A., Moilanen, A., Gordon, A., Lentini, P. E., Cadenhead, N. C. R., & Bekessy, S. A. (2019). Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(3), 909–914. JSTOR.

Wood, S. L., & DeClerck, F. (2015). Ecosystems and human well-being in the Sustainable Development Goals. *Frontiers in Ecology and the Environment*, *13*(3), 123–123. https://doi.org/10.1890/1540-9295-13.3.123

World Bank Group. (2020, October 7). *For Costa Rica, the Future of Forests Hangs in the Gender Balance*. World Bank. https://www.worldbank.org/en/news/feature/2020/10/07/for-costa-rica-the-future-of-forests-hangs-in-the-gender-balance

World Bank Group. (2021a). *Climate Risk Profile: Costa Rica*.

World Bank Group. (2021b). *Costa Rica: Climate Change Overview*. Climate Change Knowledge Portal: For Development Practitioners and Policy Makers. https://climateknowledgeportal.worldbank.org/country/costa-rica

World Bank Group. (2023). *Poverty & Equity Brief: Costa Rica* (Spring 2023 Edition; Latin America & the Caribbean). https://databankfiles.worldbank.org/public/ddpext_download/poverty/987B9C90-CB9F-4D93-AE8C-750588BF00QA/current/Global_POVEQ_CRI.pdf

World Bank Group. (2024). *Poverty & Equity Brief: Costa Rica* (Spring 2024 Edition; Latin America & the Caribbean). https://datacatalogapi.worldbank.org/ddhxext/ResourceDownload?resource_unique_id=DR0092398

World Bank Group, CIAT, & CATIE. (2014). *Supplemental material to Climate-Smart Agriculture in El Salvador* (CSA Country Profiles for Latin America Series). The World Bank Group.

Wu, F., & Butz, W. P. (2004). The Green Revolution. In *The Future of Genetically Modified Crops* (1st ed., pp. 11–38). RAND Corporation. https://www.jstor.org/stable/10.7249/mg161rc.11

Xavier, S. F., Kwizera, P., Umwungerimwiza, Y. D., Reverien, R., Philbert, K., Delice, I. N., & Umugwaneza, M. (2024). Dietary Diversity and Nutritional Status Among Rwandan Women Engaged in Agriculture: A Cross-Sectional Study. *Public Health Challenges*, *3*(3), e214. https://doi.org/10.1002/puh2.214

Young, J. C., Rose, D. C., Mumby, H. S., Benitez-Capistros, F., Derrick, C. J., Finch, T., Garcia, C., Home, C., Marwaha, E., Morgans, C., Parkinson, S., Shah, J., Wilson, K. A., & Mukherjee, N. (2018). A methodological guide to using and reporting on interviews in conservation science research. *Methods in Ecology and Evolution*, *9*(1), 10–19. https://doi.org/10.1111/2041-210X.12828

Zaremba, H., Elias, M., Rietveld, A., & Bergamini, N. (2021). Toward a Feminist Agroecology. *Sustainability*, *13*(20), 11244. https://doi.org/10.3390/su132011244

Zebrowski, W., Lacasse, H., Otieno, G., Reynolds, T., LaValle, N., Baker-Wacks, E., & Klein, E. (2018). *Social seed networks and climate change adaptation in East Africa.* Biodiversity International. https://hdl.handle.net/10568/100211

Zhang, Y. W., McCarl, B. A., & Jones, J. P. H. (2017). An Overview of Mitigation and Adaptation Needs and Strategies for the Livestock Sector. *Climate*, *5*(4), Article 4. https://doi.org/10.3390/cli5040095

Zilberman, D., Lipper, L., McCarthy, N., & Gordon, B. (2018). Innovation in Response to Climate Change. In L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw, & G. Branca (Eds.), *Climate Smart Agriculture* (Vol. 52, pp. 49–74). Springer International Publishing. https://doi.org/10.1007/978-3-319-61194-5_4

Zimmerer, K. S., de Haan, S., Jones, A. D., Creed-Kanashiro, H., Tello, M., Carrasco, M., Meza, K., Plasencia Amaya, F., Cruz-Garcia, G. S., Tubbeh, R., & Jiménez Olivencia, Y. (2019). The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. *Anthropocene*, *25*, 100192. https://doi.org/10.1016/j.ancene.2019.100192

Appendix A: Interview Guide

1. How long have you been farming in this community?
   ¿Cuánto tiempo lleva cultivando en esta comunidad?

2. What motivated you to farm in this community?
   ¿Qué le motivó a cultivar en esta comunidad?

3. What agricultural products do you produce on your farm?
   ¿Qué productos agrícolas produce en su finca?

4. What is the total area of your farm? In acres or hectares.
   ¿Cuál es el área total de su finca? En acres o hectáreas.

5. How do you use the land on your farm?
   ¿Cómo utiliza la tierra en su finca?
   a. For example, how many acres/hectares do you used for production? Are there areas not used for production? Are there forests? Do you use land on your farm for any other purpose or activity?
      Por ejemplo, ¿cuántas acres/hectáreas utiliza para la producción? ¿Hay áreas no utiliza para producción? ¿Hay bosques? ¿Utiliza la tierra de su finca para algún otro propósito o actividad?
   b. If there are forests or other land uses, do they benefit your farm? If yes, in what ways?
      Si hay bosques u otros usos de la tierra, ¿benefician a su finca? En caso afirmativo, ¿de qué manera?

6. Do you cultivate trees, raise livestock, or produce crops on the same unit of land on your farm?
   ¿Cultiva usted árboles, cría ganada, o produce cultivos en la misma unidad de tierra de su finca?

   a. If so, explain why and how.
      En caso afirmativo, explique cómo y por qué.

7. Do you adopt practices on your farm with the goal to conserve resources such as water or soil?
   ¿Adopta prácticas en su finca con el objetivo de conservar recursos como el agua o el suelo?

8. Have you changed your farming practices over time?
   ¿Ha cambiado sus prácticas agrícolas con el tiempo?
   a. If yes, in what ways?
      En caso afirmativo, ¿de qué manera?
   b. Was there a reason for this change?
      ¿Hubo alguna razón por la que hizo este cambio?

9. How many crop varieties (livestock species) do you cultivate on your farm?
   ¿Cuántas variedades de cultivos (especies de ganado) cultiva en su finca?

10. How did you come to decide which crop varieties (livestock species) to produce?
    ¿Cómo llegó a decidir qué variedades de cultivo (especies de ganado) producir?

11. How did you acquire the varieties (species) you currently produce?
    ¿Cómo adquirió las variedades de cultivos (especies de ganado) que cultiva en su finca?

12. How much choice do you feel you have in deciding what to produce on your farm?
    ¿Se siente obligado a cultivar los productos que tiene? ¿Prefiere cultivar otro cultivo? ¿Qué se limita?

13. Would you like to change how you engage in agricultural production?
    ¿Le gustaría cambiar su forma de participar en la producción agrícola?

a. If yes, how?
   En caso afirmativo, ¿cómo?

14. Do you feel there are barriers to adopting production practices you would like to adopt?
    ¿Se siente que existen obstáculos para adoptar prácticas de producción que le gustaría implementar?

15. What do you feel are some of the most difficult challenges you face on your farm?
    ¿Cuáles cree que son algunos de los desafíos más difíciles que enfrenta en su finca?

16. Do you feel connected to other farmers in the area?
    ¿Se siente conectado con otros agricultores de la zona?
    a. If not, why do you feel those connections are not there?
       Si no es así, ¿Por qué cree que esas conexiones o comunicación no existen?
    b. If yes, can you describe what those connections are?
       En caso afirmativo, ¿Puede describir cuáles son esas conexiones?
    c. Do other farmers influence the decisions you make on your farm? If yes, how so?
       ¿Otros agricultores influyen en las decisiones que usted toma en su finca? En caso de que sí, ¿Cómo es eso?

17. Do you have access to networks or local institutions that provide support for you and you farm?
    ¿Tiene acceso a redes o instituciones locales para que le briden apoyo a usted y a su finca?
    a. If yes, what sort of support is provided?
       En caso afirmativo, ¿Qué tipo de apoyo le proporciona?

18. *For women participants only* Do you feel you have equal access to information and resources compared to male farmers?
    ¿Siente usted que tiene igualdad de acceso a la información y recursos relacionados con la agricultura en comparación con los agricultores masculinos?

19. Is there something I missed, or something important you would like to add before we conclude the interview?
    ¿Hay algo que no está incluido o algo importante que le gustaría agregar antes de concluir esta entrevista?

20. Are you interested in receiving information related to the results of this research once it is complete?
    ¿Está interesado en recibir información relacionada con los resultados de esta investigación una vez que esté completa?