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THE VALUE OF THE ECOSYSTEM SERVICE POLLINATION WITHIN A SOCIAL-ECOLOGICAL SYSTEM IN HUILA, COLOMBIA

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Abstract

Even though coffee is self-fertile and therefore does not depend on pollination by honeybees, fruit set and coffee quality can be increased by pollination. As a means of ecological intensification of agriculture, it would even result in a more resilient and sustainable social-ecological system.

In Huila, Colombia pollination is not used as an agricultural input for various reasons. Coffee growers are struggling to maintain a profitable business due to constantly low coffee prices and the lack of governmental financial support. As a result, coffee growers apply large quantities of pesticides to minimize the risk of harvest loss. In consequence, beekeepers suffer from high losses among their beehives due to this pesticide overuse in agriculture, leading to mistrust of beekeepers towards farmers and coffee growers in particular.

This mistrust combined with coffee growers' lack of knowledge about the benefits of pollination, prevents the leasing of beehives between these actors. However, this practice would have advantages for coffee growers, through the potential increase of harvest and improvement of coffee quality, as well as for beekeepers through the diversification of income.

Coffee growers' willingness to pay for pollination depends on the actual increase of coffee harvests: For a 15% increase, farmers would be willing to pay an average of 97.80€, for a 30% increase 166.67€ and for a 50% increase 239.28€. The successful introduction of such a scheme requires two measures: firstly, the education of coffee farmers and, secondly, governmental guidelines regarding types, amount and handling of pesticides. Long-term benefits for consist of the reduced application of pesticides, which increases coffee, honey as well as soil quality. Moreover, beekeepers do not suffer such high bee losses anymore.

Key Words: Pollination, willingness to pay, social-ecological system, Huila, Colombia

Resumen

A pesar de que el café es autofértil y por lo tanto no depende de la polinización de las abejas melíferas, el cuajado y la calidad del café pueden aumentarse mediante la polinización. Empleado como un medio de intensificación ecológica de la agricultura, incluso daría como resultado un socioecosistema más resistente y sostenible.

En Huila, Colombia, la polinización no se utiliza como insumo agrícola por varias razones. Los caficultores apenas mantienen un negocio rentable debido a los constantemente precios bajos del café y la falta de apoyo financiero gubernamental. Como resultado, los productores de café aplican grandes cantidades de pesticidas para minimizar el riesgo de perder su cosecha. En consecuencia, los apicultores sufren grandes pérdidas entre sus colmenas debido al uso excesivo de estos pesticidas y esto lleva a una desconfianza de los apicultores hacia los agricultores y caficultores en particular.

Esta desconfianza, combinada con la falta de conocimiento de los caficultores sobre los beneficios de la polinización, impide el arrendamiento de colmenas entre estos actores. Sin embargo, esta práctica tendría ventajas para los productores de café, a través del potencial aumento de la cosecha y la mejora de la calidad del café, así como para los apicultores a través de la diversificación de los ingresos.

La disposición de los caficultores para pagar la polinización se muestra en dependencia del aumento de las cosechas de café: para un aumento del 15% los agricultores estarían dispuestos a pagar un promedio de 97.80€, para un aumento del 30% de 166.67€ y para un 50% un total de 239.28€. La introducción exitosa de dicho esquema requiere dos medidas. En primer lugar, la educación de los caficultores y, en segundo lugar, las directrices gubernamentales sobre tipos, cantidad y manejo de pesticidas. Los beneficios a largo plazo consisten en la reducción de la aplicación de pesticidas, que aumenta la calidad del café, suelo y de la miel. Además, los apicultores ya no sufren pérdidas tan altas de abejas.

Palabras claves: Polinización, disposición a pagar, socioecosistema, Huila, Colombia

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List of abbreviations

ASOAPIS	Asociación de apicultores del municipio de Garzón
ASAP	Asociación de apicultores del Pitalito
CPAA	Cadena Productiva de las Abejas y la Apicultura
COP	Colombian Peso
CICES	Common International Classification of Ecosystem Services
CVM	Contingent valuation method
COOCENTRAL	Cooperativa Central de Caficultores del Huila
COAPI	Cooperativa Integral de Apicultores del Huila
CORPOICA	Corporación Colombiana de Investigación Agropecuaria
ES	Ecosystem service
EU	European Union
FLO	Fairtrade Labelling Organizations International
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
masl	Meters above sea level
MEA	Millennium Ecosystem Assessment
MADR	Ministerio de Agricultura y Desarrollo Rural
UNAL	National University of Colombia
PES	Payment for ecosystem services
SES	Social-ecological system

1 Introduction

Pollination is the transfer of pollen, which contains the male gametes (Ollerton, 2017) from the anther of a flower to the stigma of the same or another flower of the same species (Tandon & Ram, 2010; Partap, 2011; Shivanna & Tandon, 2014; Abrol, 2015; Amaya-Márquez, 2016; IPBES, 2016). It is regarded as one of nature's most crucial ecosystem services (ESs) (Costanza et al., 1997; Millennium Ecosystem Assessment, 2003; Klein et al., 2007; Allsopp et al., 2008; Potts et al., 2010; Eilers et al., 2011; Gonzalez-Varo et al., 2013). ESs are the manners, either directly or indirectly, in which humankind benefits from the ecosystem functions provided by nature and the interactions between its organisms, therefore leading to an increase in human well-being (Costanza et al., 1997; Klein et al., 2007; Millennium Ecosystem Assessment, 2003; Allsopp et al., 2008; Leemans, 2009).

In 2005, the total economic value of pollination services amounted to 153 billion€ (Gallai et al., 2009; cited in Potts et al., 2010; Abrol, 2012; Melathopoulos et al., 2015), equaling 9.5% of the total value of the global agricultural food production (Potts et al., 2010; Abrol, 2012). The most valuable food products within this valuation were fruits and vegetables (both valued at 50 billion€). It is also noteworthy that crops which do not depend on pollination were valued at 151€ per ton, while pollinated crops were valued at an estimated 761€ per ton, which represents a five-fold increase in price (Gallai et al., 2009). On a global scale, 60% of agricultural production corresponds to crops that do not require pollination, while only 35% are pollination-dependent crops (5% of production were not evaluated) (Klein et al., 2007). Nevertheless, there has been a steady increase in the cultivation of pollination-dependent crops over the last 40 years (Potts et al., 2010).

Pollination provides various contributions to human well-being, including the preservation of the functioning of ecosystems and biodiversity and acting as a global agricultural input (Mburu et al., 2006; Chapin et al., 2009; Gallai et al., 2009; Potts et al., 2010; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Sanchez-Bayo & Goka, 2014; Ratamäki et al., 2015; Potts et al., 2016; Ollerton, 2017). Ultimately, this enables food security (Mburu et al., 2006; Allsopp et al., 2008; Partap, 2011; Abrol, 2012; Van der Sluijs & Vaage, 2016) and ecosystem resilience (Partap, 2011; Zulka & Götzl, 2015; Amaya-Márquez, 2016; Baptiste et al., 2016; Bonilla Gómez, 2016; Potts et al., 2016). Moreover, beekeeping represents an additional source of income especially for rural households (Corporación Colombiana de Investigación Agropecuaria [CORPOICA], 2012; IPBES, 2016; Potts et al., 2016). Hence, the vanishing of pollination would entail ecological and social risks. Ecologically, biodiversity and climate would be in jeopardy, and on the social side, food security, and rural development would be affected (Ratamäki et al., 2015).

Pollination services are threatened (Klein et al., 2007) mainly due to land use change and agricultural intensification (Freitas et al,. 2009; Potts et al., 2010; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Bravo-Monroy et al., 2015; Hanley et al., 2015; TEEB, 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016; Fajardo et al., 2017; Kovács-Hostyánszki et al, 2017), pesticide overuse (Klein et al., 2007; Potts et al., 2010; Abrol, 2015; Hanley et al., 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al, 2017), the introduction of invasive species (Freitas et al,. 2009; Potts et al., 2010; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Hanley et al., 2015; Medina Flores et al., 2015; IPBES, 2016; Morstensen & Ellis, 2016; Van der Sluijs & Vaage, 2016), and climate change (Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Hanley et al., 2015; Zulka & Götzl, 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016). With species disappearing "both [the] known and unknown benefits they provide" (Gascon et al., 2015: R431) are lost. A decrease in pollinator populations would deteriorate the global fruit production and reproduction of plants as well as their genetic variety (Chapin et al., 2009).

Therefore, a recently observed decrease in the prevalence of plants as well as the wild and domesticated pollinators they depend on is worrisome (Ricketts et al., 2004; Gallai et al., 2009; Potts et al., 2010; Partap, 2011; Vanbergen & Insect Pollinators Initiative, 2013; Melathopoulos et al., 2015). Their disappearance potentially entails negative environmental and economic fallouts (Potts et al., 2010; Vanbergen & Insect Pollinators Initiative, 2013), affecting both ecosystems and society (IPBES, 2016). Even though some areas, such as Asia, Africa and Latin America, lack local information concerning pollinators, a general decline is also presumed in these areas (IPBES, 2016). This decrease includes abundance and variety of species, with some already being endangered (Gallai et al., 2009; Eilers et al., 2011; Van der Sluijs & Vaage, 2016). The affected flora consists of cultivated crops and wild flowers, since both rely on pollination. A decrease in these two groups further diminishes food sources for pollinating species, possibly exacerbating the decline in pollinators (Potts et al., 2010).

These interrelations between the social and ecological spheres are easier to analyze within a social-ecological system (SES). SESs are based on the axiom that society and ecosystems are closely intertwined since, in order to survive, mankind relies on ecosystems and the services they provide, while, in turn, mankind transforms ecosystems when exploiting them (Chapin et al., 2009; Folke et al., 2010; Small et al., 2017; Leviston et al., 2018). The system's continuity depends to a large degree on its resilience, which describes the system's ability to maintain its current state in spite of disruptions (Holling, 1973; Walker et al., 2004; Chapin et al., 2009; Meadows & Wright, 2009; Folke et al., 2010; Hobman & Walker, 2015). In the case of this thesis, the SES consists in the Huilan beekeepers' and coffee growers' interrelations among themselves as well as in their interactions with their environment.

Huila is a topographically and climatically diverse (Gobernación del Huila, 2017, A) department in the South American country Colombia and it is located in the nation's southeast (Sociedad Geográfica de Colombia, n. d.). It is Colombia's main coffee producing department, with a contribution of 17% of national production in 2016 (Evaluaciones Agropecuarias Municipales, n. d., A). This equals almost half of Huila's primary crop production (Evaluaciones Agropecuarias Municipales, n. d., B). However, coffee prices are currently constantly low (Ministerio de Agricultura y Desarrollo Rural, 2018, B). Colombian coffee production is characterized by small-scale farms (Bravo-Monroy et al., 2015), which usually implies an increased dependence on coffee prices (Ngo et al., 2011). Beekeeping in Colombia is also usually practiced in the form of family businesses (CORPOICA, 2012). In the case of honey production, Huila occupies the second place among Colombia's departments, contributing 10.26% of the national production (Zambrano Canizales, 2016; Ministerio de Agricultura y Desarrollo Rural, 2018, A), equaling 358 tons in 2017 with an increasing tendency. However, prices in the major honey producing departments tend to be lower than in non-producing departments (Ministerio de Agricultura y Desarrollo Rural, 2018, A). Besides the production of honey and pollen other bee products include wax, royal jelly, queen bees or drones (CORPOICA, 2012; Acosta Leal et al., 2017; Ministerio de Agricultura y Desarrollo Rural, 2018, A).

Even though *Coffea arabica* Linnaeus is self-fertile, which means it does not depend on pollination, productivity as well as quality can be raised substantially by cross-pollination (Raw & Free, 1977; Manrique & Thimann, 2002; Roubik, 2002; Klein et al., 2003; Rickett et al., 2004; Cepeda-Valencia et al., 2014; Bravo-Monroy et al., 2015; Acosta Leal et al., 2017), even though different studies have determined yield increases between 4-54% (Raw & Free, 1977; Manrique & Thimann, 2002; Roubik, 2002; Klein et al., 2003; Rickett et al., 2004; Ngo et al., 2011; Bravo-Monroy et al., 2015; Acosta Leal et al., 2017). Another effect of cross-pollination is the reduction of the occurrence of so-called peaberries (Ricketts et al., 2004), which are small, deformed seeds of a lower quality (Ricketts et al., 2004; Ngo et al., 2011; Bonilla Gómez, 2016), which stem from a lack of pollination (Raw & Free, 1977; Ngo et al., 2011). Bees are the main pollinators of coffee flowers (Klein et al., 2003; Ngo et al., 2011; Cepeda-Valencia et al., 2014; Acosta Leal et al., 2017; Ollerton, 2017), even though a more diverse pollinator community can increase the stability of the provision of pollination, due to complementing species (Ricketts et al., 2004).

For this thesis, in order to estimate the value of pollination services within the studied SES, a thorough literature review will be conducted. During the field work in Huila, surveys with beekeepers and coffee growers will be conducted to inform the analysis and to gauge the willingness to pay (WTP). Additionally, expert interviews will be used in order to contextualize the survey findings.

In the following, the central concepts of pollination (Chapter 1.1), with an emphasis on the benefits of pollination (Chapter 1.1.1), the threats to pollination (Chapter 1.1.3), and pollination's effect on coffee production and quality (Chapter 1.1.4) will be presented. This is followed by an introduction to SESs (Chapter 1.2) and the economic valuation of ESs (Chapter 1.3), focusing on frameworks (Chapter 1.3.1), methods (Chapter 1.3.2) and previous studies regarding the economic value of the pollination of coffee (Chapter 1.3.3). Moreover, Chapter 1.3.4 introduces the study site and its characteristics. This theoretical introduction is followed by a justification and a presentation of the thesis's objective and research questions (Chapter 2). Subsequently, Chapter 3 describes the method applied in this thesis. In the ensuing Chapter 4, the results, in accordance with the research questions from Chapter 2.3, will be depicted. These results include an analysis of social and ecological processes studied within the SES (Chapter 4.1.1), an investigation of anthropogenic influences on the SES (Chapter 4.1.2), a study of the main threats to pollination within the SES (Chapter 4.1.3), and the SES's impact on human well-being (Chapter 4.1.4). Subsequently, Chapter 4.2 will present the economic valuation, in form of willingness-to-pay (WTP) for pollination services, and recommendations on how to foster the SES's resilience will be given (Chapter 5.2). This is followed by the two-piece discussion, which, in the first part, discusses the method itself (Chapter 5.1) and, in the second part, the results (Chapter 5.2). The thesis will finish with a conclusion and an outlook (Chapter 6).

1.1 Pollination

Pollination is crucial for genetic recombination, gene flow and simultaneously the necessary condition for producing seeds (Tandon & Ram, 2010; Partap, 2011; Shivanna & Tandon, 2014). Plants depend on biotic and abiotic means to be successfully pollinated. Approximately 75-90% of plants rely on biotic pollination (Tandon & Ram, 2010; Abrol, 2012; Shivanna & Tandon, 2014), also known as zoophily and being provided by animals, whereas 10% use abiotic means, mainly wind (anemophily) and sometimes water (hydrophily) (Tandon & Ram, 2010; Shivanna & Tandon, 2014; Amaya-Márquez, 2016). Some plants apply mixed strategies (ambophily), e.g. zoophily in combination with anemophily. Yet, these plants remain currently understudied (Ollerton, 2017). In the case of zoophily the suitability of different pollinating species is influenced by the species' abundance and the following two qualitative factors: the species' physical suitability and distance to the next flower visited. Pollinator biodiversity varies in accordance to biogeographic circumstances, as e.g. latitude. For instance, the tropics are more biodiverse, even though bees as the major pollinating species are most diverse in the Mediterranean or comparable regions (Ollerton, 2017). Various pollinating species exist, e.g. insects, birds or bats, but bees, primarily *Apis mellifera* Linnaeus 1758, are the most efficient and economical group (Klein et al., 2007; Partap, 2011).

In contrast, self-fertilization does not require any pollinating agent, but rather occurs when one plant maintains both male and female gametes (Barrett, 2002). On the one hand, self-pollination entails risks, such as inbreeding depression and decreasing genetic variety (Ollerton, 2017). On the other hand, it also offers various short-term advantages, including facilitated colonization and reproductive assurance, since no mating partner is required (Wright et al., 2013).

Additionally, also artificial methods of pollination exist, which have been found to be less efficient than natural pollination. Artificial methods include hand pollination, where pollen is recollected and transferred to another flower by hand, and pollen dusting, where this process occurs mechanically. Whereas the former has at least an equal effectiveness compared to natural pollination, the latter leads to a decrease in fruit production and fruit quality. When contemplating the application of hand pollination, one also has to consider the substantial personnel cost it entails (Allsopp et al., 2008), likely leading to increased prices of the final product (Baptiste et al., 2016).

1.1.1 Pollination and human well-being

Human well-being is highly influenced by contexts and situations, comprised of "local social and personal factors such as geography, ecology, age, gender, and culture" (Leemans, 2009: 57). It is composed of five elements: (1) security, including security of the individual itself and its belongings; (2) basic material minimum for a good life, including the means to gain a livelihood, alimentation, shelter, etc.; (3) health, including physical strength and access to clean water and air; (4) social relations, including social security, mutual respect and the ability to provide for others. These four lead to the fifth factor, (5) freedom and choice, enabling persons to have control over their lives. All of these factors are interrelated in a way that they positively or negatively enhance each other (Millennium Ecosystem Assessment, 2003; Leemans, 2009; Hamann et al., 2016; Leviston et al., 2018).

Humans derive their well-being from ecosystems and ESs (Millennium Ecosystem Assessment, 2003; Ricketts et al., 2004; Haines-Young & Potschin, 2010; Gascon et al., 2015; Bonilla Gómez, 2016; Hamann et al., 2016; Small et al., 2017; Leviston et al., 2018), even though these services are determined by society and are based on respective societal needs and activities (Haines-Young & Potschin, 2010; Small et al., 2017). These benefits can be either material, such as the supply of food (Haines-Young & Potschin, 2010; Hamann et al., 2016; Potts et al., 2016), construction materials (Potts et al., 2016), wood (Haines-Young & Potschin, 2010), potable water (Haines-Young & Potschin, 2010; Hamann et al., 2016), medicine (Haines-Young & Potschin, 2010; Potts et al., 2016) or even musical instruments (Potts et al., 2016). All of the aforementioned benefits generate economic values in contrast to the following, less obvious ones which prevent damages and would otherwise result in additional costs to society (Choi et al., 2017). These benefits usually refer to regulatory functions, such as the protection "from flooding or other hazards like soil erosion, land-slips and tsunamis" (Haines-Young & Potschin, 2010: 110), which are partly also mentioned by Hamann et al. (2016). Furthermore, pollination adds to cultural well-being, e.g. via spiritual values (Haines-Young & Potschin, 2010; Hamann et al., 2016), recreation (Haines-Young & Potschin, 2010; Hamann et al., 2016; Potts et al., 2016), or by simply enjoying nature (Haines-Young & Potschin, 2010; Potts et al., 2016). Moreover, pollinators and their effects might serve "as sources of inspiration for art, music, literature, religion, traditions, technology and education" (Potts et al., 2016: 2). ES contribute to human well-being in a myriad ways. On the one hand, some facilitate human survival; on the other hand more cultural values are included (Small et al., 2017).

ESs are directly or indirectly affected by any change in ecosystems (Leemans, 2009; Costanza et al., 2014; Hamann et al., 2016). The provision of crucial ESs are possibly in jeopardy due to the current global environmental change (Hamann et al., 2016) and given that the future well-being requires a sustainable and conscience lifestyle of today's generation to maintain ecosystems and their services (Leemans, 2009). Therefore, it is important to analyze the underlying SES to understand the relationship between ecosystems and society, and how resources are used (Hamann et al., 2016). More specifically, possible thresholds within ecosystems have to be identified in order to prevent unwanted regime shifts. Moreover, pressures leading up to these thresholds need to be understood in order to prevent harmful actions against ecosystems' processes and structures (Haines-Young & Potschin, 2010).

Pollination, specifically its contribution to food safety, is a well-studied example of an ES contributing to human well-being. This can be depicted by means of a cascade model (Figure 1), which describes how ecosystems and their components ultimately provide a value to human well-being. As such it becomes obvious, that pollination depends on functioning ecosystems providing nesting and foraging resources, which, in turn, lead to a sufficient amount of pollinators. Pollinator abundance, as a ES, connects the ecosystems with human well-being, since they create a benefit, namely a growth in agricultural yield, which then again results in a value, namely the value of heightened yield (Ratamäki et al., 2015).

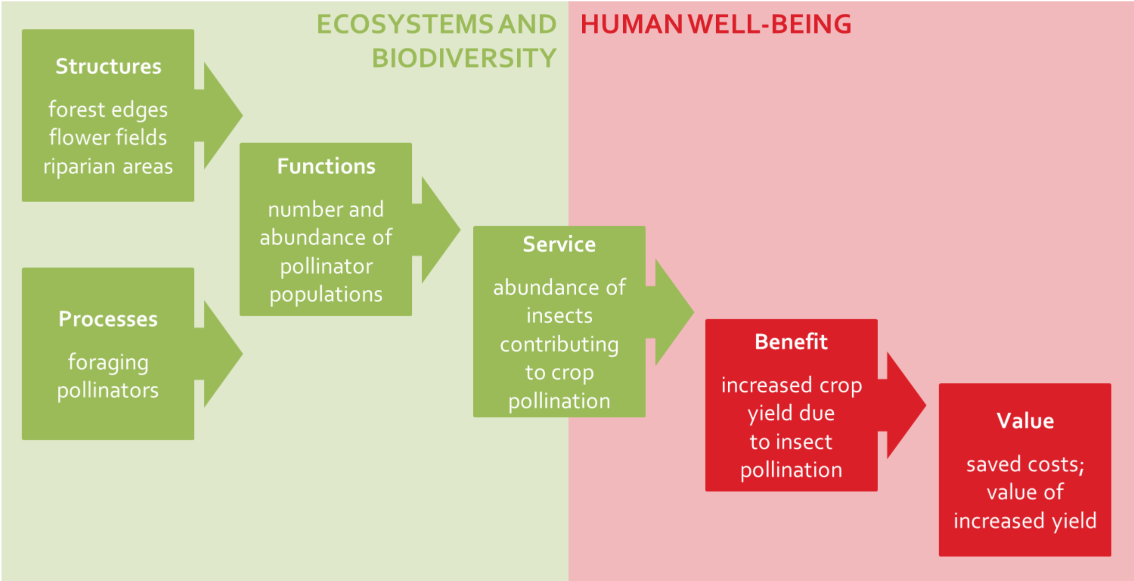


Figure 1: Cascade model depicting pollination's influence on human well-being. Source: Based on Ratamäki et al., 2015.

Similar diagrams, representing the sequence of creating human well-being from ES, exist for example in Haines-Young & Potschin (2010) and Small et al. (2017).

Bees provide a variety of direct and indirect benefits and values, which connects them inseparably with human well-being (Potts et al., 2016). Benefits include pollination (Nates-Parra & González, 2000; CORPOICA, 2012), food production (Nates-Parra & González, 2000), preservation of ecosystem stability and biodiversity (Nates-Parra & González, 2000; Potts et al., 2016), its inherent cultural value (Potts et al., 2016), and the production of goods, which are ultimately used for medicine and cosmetics (Nates-Parra & González, 2000). Further benefits include the production of beekeeping products, most notably honey (CORPOICA, 2012; Potts et al., 2016), which has various medical properties such as being antagonistic to bacteria, fungi and diabetes (Potts et al., 2016). From a social viewpoint, beekeeping and honey-hunting practices supply rural households with an additional source of income (CORPOICA, 2012; IPBES, 2016; Potts et al., 2016) and support livelihoods and lessen poverty, especially in rural settings. Advantages consist of the practice's cost efficiency, flexibility in time and location, as well as the reference to culture because of the inclusion of traditional knowledge. Moreover, most of the traditional cash crops (e.g., coffee and almonds) rely on pollination. They provide 1.4 billion jobs, especially among poor, rural communities, among which 70% work in agriculture. Generally, crops relying on pollination by animals draw higher prices (Potts et al., 2016), which indicates pollination's immense economic value (Ricketts et al., 2004).

Figure 2 depicts the complex interplay between nature and society in a simplified form, in this case focused on pollination. The elements mentioned in this figure interact in terms of time and space (IPBES, 2016).

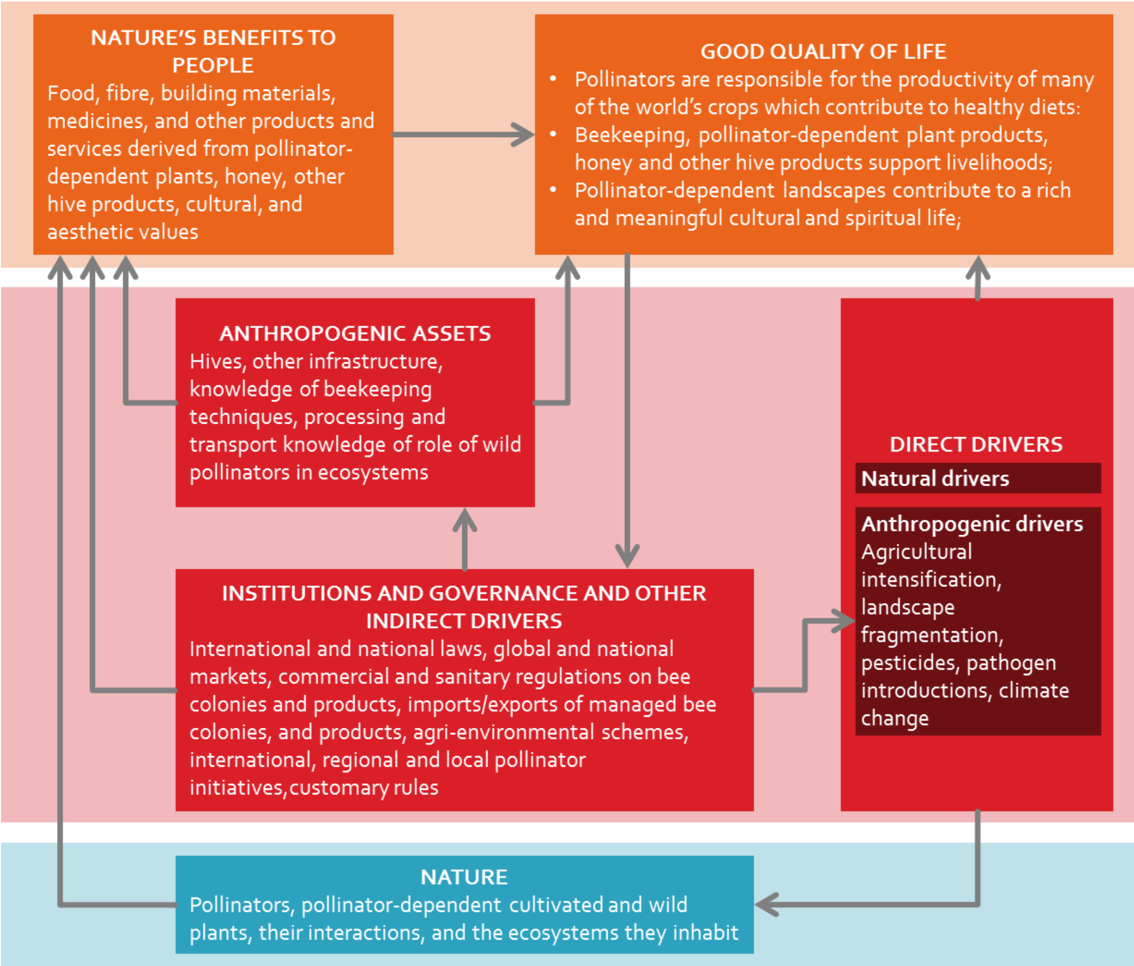


Figure 2: Relationships between nature and society with a focus on pollination services. Source: Based on IPBES, 2016.

1.1.2 Benefits and importance of pollination

The importance of pollination itself is not only apparent in its role in preserving the functioning of ecosystems but also in its relevance for agriculture (Mburu et al., 2006; Chapin et al., 2009; Gallai et al., 2009; Potts et al., 2010; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Sanchez-Bayo & Goka, 2014; Ratamäki et al., 2015; Potts et al., 2016; Ollerton, 2017). The majority of flowering species depend on biotic pollination (Tandon & Ram, 2010; Abrol, 2012; Shivanna & Tandon 2014), them namely being all plants that are not water-, wind- or self-pollinated (Chapin et al., 2009).

Insect pollination has two main advantages. Firstly, it positively affects fruit crops resulting in increased productivity and quality (Partap, 2011; Abrol, 2015; Acosta Leal et al., 2017), even in self-pollinating crops (Allsopp et al., 2008; Acosta Leal et al., 2017). Secondly, insect pollination indirectly protects the plants from pests, since the flowers close faster when pollinated (Abrol, 2012). Moreover, pollinators compete with pest transmitting insects for food (CORPOICA, 2012). Furthermore, pollination maintains biodiversity and, thus, ensures the survival of species (Partap, 2011; Abrol, 2012; Potts et al., 2016; Van der Sluijs &

Vaage, 2016). The diversity of species to which pollination contributes, leads to increased ecosystem resilience, stabilizing them against perturbations (Partap, 2011; Zulka & Götzl, 2015; Van der Sluijs & Vaage, 2016). At the same time, pollination provides mutual benefits to pollinators and pollinated plant species (Klein et al., 2007; Partap, 2011; Gonzalez-Varo et al., 2013; Amaya-Márquez, 2016): pollinators benefit by maintaining nectar or pollen for nutrition purposes, while pollinated species are enabled to reproduce (Partap, 2011; CORPOICA, 2012; Amaya-Márquez, 2016; IPBES, 2016). Hence, both parties depend on one another for survival. This mutualism also favors biodiversity (Amaya-Márquez, 2016).

A decrease in pollinator populations would have a negative effect on fruit production, plant reproduction, and on plants' genetic variety (Chapin et al., 2009), resulting in food insecurity (Potts et al., 2010; Eilers et al., 2011; Vanbergen & Insect Pollinators Initiative, 2013). Furthermore, biodiversity, agricultural output (Potts et al., 2010; Partap, 2011; Vanbergen & Insect Pollinators Initiative, 2013), and human well-being in general (Potts et al., 2010; Abrol, 2012; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014) would be negatively influenced. This cascade of negative effects begins with the lack of fruits and seeds and leads to the deterioration of ecosystems (Cepeda-Valencia et al., 2014).

1.1.2.1 Contribution to agricultural production and food security

Pollination represents an agricultural production practice for crops, which is applied worldwide (Mburu et al., 2006; Chapin et al., 2009; Gallai et al., 2009; Baptiste et al., 2016). In agriculture, a lack of pollination leads to decreased fruit production and therefore a declined yield (Partap, 2011). Many commercial fruit and vegetable crops, e.g. apples, cherries, cabbage or broccoli require pollination but even in species that do not rely on pollination, it can increase quantity and quality of the yield (Allsopp et al., 2008; Partap, 2011). This applies to approximately 75% "of globally important crop types, including most fruits, seeds and nuts and several high-value commodity crops such as coffee, cocoa and oilseed rape" (Potts et al., 2016: 1). Therefore, their importance regarding the provision of diet diversity (Abrol, 2012) ,food security and for increasing human welfare becomes obvious (Partap, 2011; Van der Sluijs & Vaage, 2016).

1.1.2.1.1 Food security

The 1996 World Food Summit defines food security as a state in which "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." (FAO, 2003: 28). This state should be achieved on various levels, such as on a household, national and global scale (FAO, 2003). The provision of food security on a global scale is a necessary requirement in order to provide food security on a local level, even though it does not guarantee it. If food is insufficient on a global level, some regions will inevitably suffer from starvation (Chapell & LaValle, 2011). In order to achieve global food security, three prerequisites have to be fulfilled. First, food has to be available. In case of shortages, rising prices might prevent poorer families from obtaining sufficient food. Second, the food available has to meet the consumer's preferences and nutritional demands. This translates to a variety of the food available, which also caters to e.g. infants' or elderlies' needs. Third, food has to be safe, which considers the expiration date, pollution and the fulfillment of nutritional aspects (Comstock, 2014). These aspects of "availability, accessibility and utilization [...] focus on nutritional well-being, stability, and sustainability" (Van der Sluijs & Vaage, 2016: 76).

Worldwide, approximately 815 million people were undernourished in 2016, representing an almost 5% increase compared to the preceding year. The worldwide prevalence of undernourishment has been steadily declining from 14.7% in 2000, but recently began to increment again, rising from 10.6% in 2015 to a projected 11% in 2016 (FAO et al., 2017). Figure 3 shows the current undernourishment prevalence.

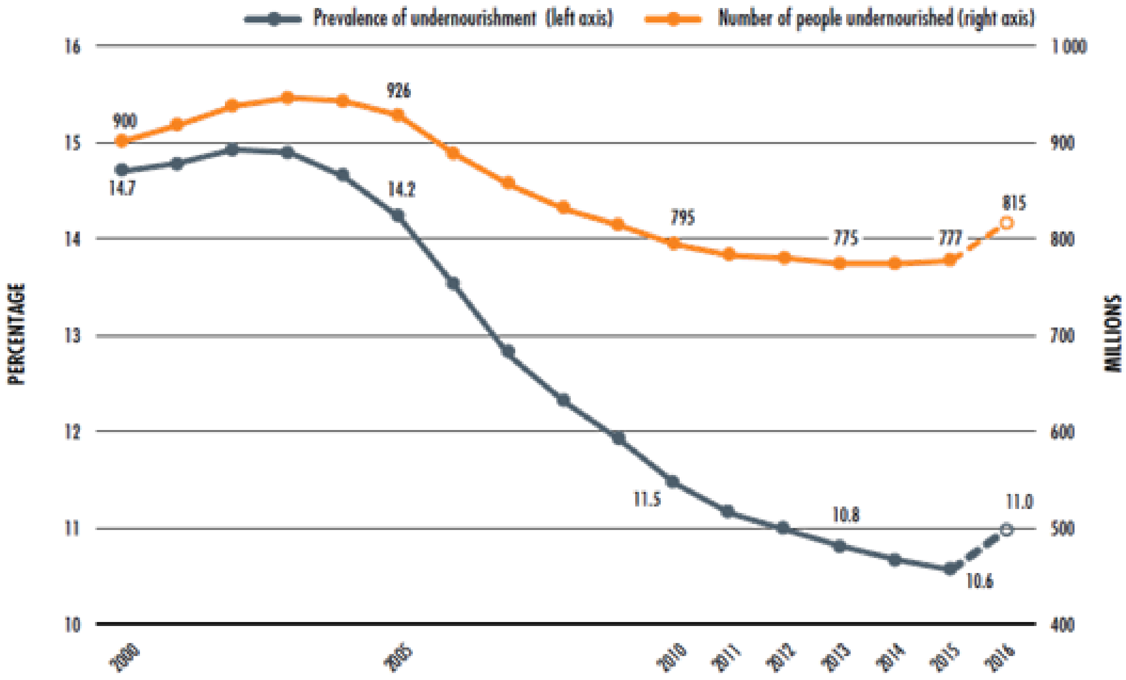


Figure 3: Global prevalence and number of undernourished people, 2000–2016. Figures for 2016 are projected estimates. Source: FAO et al., 2017.

1.1.2.1.2 Interrelations between pollination and food security

Pollination allows genes to flow among several cultivated crop as well as wild species. This consequently enables the fertilization of plants and therefore facilitates seed and fruit development (Partap, 2011; Van der Sluijs & Vaage, 2016). Pollinators maintain biodiversity and thus protect plants which are required for food security, especially to rural households. As already mentioned, many agricultural crops depend on pollination in order to reproduce and vice versa. Consequently, both rely upon each other for survival (Abrol, 2012). Globally, there are about 300 commercial crop varieties, of which 84% rely on pollination by insects, mainly provided by honeybees (*A. mellifera*) (Allsopp et al., 2008).

This translates to roughly one-third of the world's food production (Allsopp et al., 2008; Baptiste et al., 2016), i.e. fruits, vegetables, or animal feedstuff and thus represent a critical part of human diets (Allsopp et al., 2008; Abrol, 2012; Van der Sluijs & Vaage, 2016). Hence, pollination contributes highly to global food security and cannot be reduced to mere honey production (Mburu et al., 2006). Global staple foods, i.e. maize, rice and wheat, are anemophilous (Partap, 2011). Even though these provide the major share of calories in the human diet (Eilers et al., 2011; Klein et al., 2007), humans highly rely on pollinated crops, such as vegetables and fruits, for their micronutrient intake (Chapin et al. 2009; Eilers et al., 2011; Klatt et al, 2014; Van der Sluijs & Vaage, 2016).

Pollinated crops provide approximately 40% of nutrients in the human diet, whereas 2 billion people lack sufficient intake of these necessary micronutrients. This phenomenon, also known as the hidden hunger, is mainly prevalent in developing countries (Eilers et al., 2011; Van der Sluijs & Vaage, 2016) and would supposedly increase in case of on-going pollinator loss (Van der Sluijs & Vaage, 2016). Fruits and vegetables, of which in 2011 1.5 million tons were consumed (Klatt et al., 2014), supply indispensable vitamins, antioxidants and fiber (Klatt et al., 2014; Potts et al., 2016). Pollinated crops provide 98% of available vitamin C, over 70 % of vitamin A, and 55 % of folate. Animal sources of calcium and iron are more readily bioavailable for humans, but their production is environmentally inefficient and costly. Consequently, vegetable sources are crucial for the provision of micronutrients and the corresponding crops' yield can usually be increased by pollination (Eilers et al., 2014).

In consequence of the recent pollinator decrease (Gallai et al., 2009; Partap, 2011; Van der Sluijs & Vaage, 2016), the current difficulties of providing a nutritious alimentation on a global scale might aggravate in the future (Eilers et al., 2011), due to "products [becoming] scarcer in the near future, leading to a general depletion in the supply of essential nutrients and further limiting availability to people in the developing world due to increasing prices" (Klatt et al., 2014: 6). An assessment of the effects stemming from a decrease in pollinator populations regarding food security and health is complex (Eilers et al., 2014) and requires an in-depth knowledge of pollinator species and their possible responses to changes in their environment (Klein et al., 2007). Nevertheless, developing countries are probably more prone to suffer repercussions due to the already existing food insecurity as well as consequences of climate change and demographic change (Eilers et al., 2014). Although the current staple foods are mainly wind-pollinated and thus do not rely on animals for reproduction, the human diet would suffer not only nutritional but also cultural losses in case of a decrease in pollination services (Klein et al., 2007). Especially the production of the three categories with the highest economic per-ton-value, fruits, vegetables and stimulants, would not be able to satisfy the current demand (Gallai et al., 2009). Potts et al. (2010) estimated that a complete disappearance of pollinators would result in a decline of current production standards "of -12% for fruits and

-6% for vegetables" (Potts et al., 2010: 347). This pollinator decrease is especially alarming since it occurs in a period of growing crop pollinator demand (Eilers et al., 2011; Lautenbach et al., 2012). The acreage of crops relying on zoophily has augmented three-fold during the last 45 years (Baptiste et al., 2016). Moreover, a parallel decrease in pollinating and plant species is probable (Klein et al., 2007).

In conclusion, pollination is necessary for providing a healthy, nutritious and balanced alimentation to the growing world population (Klein et al., 2007; Abrol, 2012; Potts et al., 2016; Van der Sluijs & Vaage, 2016). Other relevant aspects that have to be considered in the context of food security and food access include "poverty, gender inequity, racism, and lack of political will" (Chapell & LaValle, 2011: 4).

1.1.2.2 Contribution to the preservation of biodiversity and ecosystems

Biodiversity, or biological diversity, is defined as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Secretariat of the Convention on Biological Diversity, 2005: 89).

Pollination plays a crucial role in plant reproduction and thus helps to maintain their diversity as well as that of associated species (Bonilla Gómez, 2016; Ollerton, 2017), which makes them a fundamental part of existing food webs. Moreover, this enables evolution within plant and pollinating species (Baptiste et al., 2016; Ollerton, 2017). Many plants produce fruits and grains which in turn feed wild animals. This entails that with a lack of pollinators and a consequential inability to reproduce, food webs would disrupt (Baptiste et al., 2016). Furthermore, pollinators "indirectly [support] a vast array of other organisms, including yeasts and other microbes in nectar, fungal diseases of flowers, cleptoparasitic insect species and other parasites, specialist predators and herbivores, fruit- and seed-eating animals, and so forth" (Ollerton, 2017: 370). Hence, pollination is indispensable in preserving ecosystem functioning and structure (Amaya-Márquez, 2016; Baptiste et al., 2016; Potts et al., 2016). Of the 352.000 flowering plant species existing worldwide, 85% rely on pollination; in tropical regions even 94% (Baptiste et al., 2016), so that their reproduction would be hampered by pollinator decreases. Furthermore, studies heavily suggest that declines among pollinators and plants are interrelated (Potts et al., 2016).

The survival of ecosystems is fundamental to human well-being and its future (Amaya-Márquez, 2016), since the ES society relies on stems from biodiversity which in turn is crucial to ecosystem functioning (Bonilla Gómez, 2016). Thus, Colombia being one of the few mega biodiverse countries should sustain its biodiversity (Amaya-Márquez, 2016). However, biodiversity is rapidly lost due to human population growth as well as resource consumption (Gascon et al., 2015).

1.1.3 Threats to pollination

Hazards to pollinating species are mainly man-made or at least induced by human economic activities, as e.g. climate change (Freitas et al., 2009; Hanley et al., 2015; IPBES, 2016). The drivers consist of "interrelated growth in the global human population, economic wealth, globalised trade and technological developments" (Kovács-Hostyánszki, et al., 2017: 673), which have led to a utilization of natural resources in an unsustainable manner (Vanbergen & Insect Pollinators Initiative, 2013). These pressures, only some of which are known (Baptiste et al., 2016), interact at different scales, either enhancing or opposing themselves (Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013)The following hazards are frequently mentioned in relevant literature as the main causes for declines in pollinator populations:

(1) *Land use change and agricultural intensification* (Freitas et al,. 2009; Potts et al., 2010; Lautenbach et al., 2012; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Bravo-Monroy et al., 2015; Hanley et al., 2015; TEEB, 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016; Fajardo et al., 2017; Kovács-Hostyánszki et al, 2017; Ollerton, 2017)

(2) *Pesticide overuse* (Klein et al., 2007; Potts et al., 2010; Lautenbach et al., 2012; Abrol, 2015; Hanley et al., 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al, 2017; Ollerton, 2017)

(3) *Introduction of invasive species* (Freitas et al,. 2009; Potts et al., 2010; Lautenbach et al., 2012; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Hanley et al., 2015; Medina Flores et al., 2015; IPBES, 2016; Morstensen & Ellis, 2016; Van der Sluijs & Vaage, 2016)

(4) *Climate change* (Lautenbach et al., 2012; Gonzalez-Varo et al., 2013; Vanbergen & Insect Pollinators Initiative, 2013; Cepeda-Valencia et al., 2014; Hanley et al., 2015; Zulka & Götzl, 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016; Ollerton, 2017)

Further hazards, although less ubiquitous, include: Colony Collapse Disorder (Abrol, 2012; Van der Sluijs & Vaage, 2016); pathogens (Potts et al., 2010; Lautenbach et al., 2012; Gonzalez-Varo et al., 2013; Hanley et al. 2015; IPBES, 2016; Vanbergen & Insect Pollinators Initiative, 2013; Van der Sluijs & Vaage, 2016) and parasites (Potts et al., 2010; Vanbergen & Insect Pollinators Initiative, 2013; Hanley et al. 2015); heavy metals (Freitas et al,. 2009); expansion of pests (Klein et al., 2007; Potts et al., 2010); decreasing market prices for managed honeybees' products and services (Klein et al., 2007); pollution (Potts et al., 2010; Lautenbach et al., 2012; IPBES, 2016; Van der Sluijs & Vaage, 2016); nitrogen deposition (Hanley et al., 2015; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017); unsustainable honey harvests (Freitas et al., 2009); growth in infrastructure such as roads and consequently motorized traffic, as well as nocturnal light contamination (Van der Sluijs & Vaage, 2016).

1.1.3.1 Land use change and agricultural intensification

Nowadays the vegetative cover has been adapted to human needs in "approximately 53% of the Earth's terrestrial surface" (Kovács-Hostyánszki et al., 2017: 674). This has led to a decline in wild pollinating species due to the extinction of flowering plants necessary for alimentation or nesting. These anthropogenic influences possibly alter gene flows within pollinator species with unknown long-term effects on their coping capacities and potentially jeopardize the survival of plant species reliant on pollination (Kovács-Hostyánszki et al., 2017). Deforestation and the clearing of grasslands occur for firewood and charcoal consumption, establishing meadows for livestock (Freitas et al., 2009) and expanding agriculture (Partap, 2011), with the Neotropics and Southeast Asia being affected the most by deforestation (Freitas et al., 2009; Partap, 2011).

Land-use change leads to a "habitat loss, fragmentation, degradation and resource diversity" (Potts et al., 2010: 348), which results in transformations of landscapes, the structure of communities and habitat diversity (Gonzalez-Varo et al., 2013). This might also lead to the isolation of populations (Gonzalez-Varo et al., 2013). This causes a loss of nesting and feeding sources (Freitas et al., 2009; Partap, 2011) as a result of decreasing diversity and abundancy of wild flowers (Van der Sluijs & Vaage, 2016) and having destructive effects on pollinating species (Klein et al., 2007; Potts et al., 2010; IPBES, 2016; Van der Sluijs & Vaage, 2016). The decrease in abundance and diversity of pollination species (Potts et al., 2010; Gonzalez-Varo et al., 2013; Kovács-Hostyánszki et al., 2017) reshapes plant-pollinator interactions and affects resistance of pollinator and plant species (Gonzalez-Varo et al., 2013; Kovács-Hostyánszki et al., 2017), ultimately hampering plant's sexual reproduction (Gonzalez-Varo et al., 2013). Usually, habitat loss or degradation has stronger impacts on specialized pollinator species (Hanley et al., 2015). In many cases, habitat destruction or degradation is the result of agricultural intensification (Van der Sluijs & Vaage, 2016; Fajardo et al., 2017).

Typically, land-use change and agricultural intensification go hand in hand with "the highest levels of intensification generally [occurring] in the most altered landscapes" (Gonzalez-Varo et al., 2013: 525). In South America the intensification and spread of agriculture have been identified as a main hazard to pollinators, since they cause deforestation and thus lead to a general decline in the diversity of flora and fauna, threatening plant species necessary for nesting and alimentation and killing pollinators by using agrochemicals and soil ploughing (Freitas et al., 2009). Agricultural expansion degrades natural habitats while its intensification diminishes the quality and diversity of ecosystems (Potts et al., 2010; Kovács-Hostyánszki et al., 2017).

Practices which are typical for the conventional intensification of agriculture include the increased application of agrochemicals (Potts et al., 2010; IPBES, 2016) as well as exhaustive mowing, which results in a decrease in pollinator abundance and diversity, altering communities locally and regionally (IPBES, 2016). Other characteristics are simplified crop rotations, bigger farms (Potts et al., 2010), and monocultures (Potts et al., 2010; Partap, 2011; Hanley et al., 2015; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017). Especially monocultures, characterized by the cultivation of only one or a few crops simultaneously, harmonize agroecosystems (Kovács-Hostyánszki et al., 2017) and therefore further lessens diversity of pollinators' food sources (Partap, 2011; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017).

Another driver in the loss of nesting and feeding sources by altering composition and abundance of flowering plants is the use of nitrogen in fertilizers (Hanley et al., 2015; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017) polluting air and water (Van der Sluijs & Vaage, 2016). The nitrogen stems from synthetic fertilizers and livestock (Hanley et al., 2015; Van der Sluijs & Vaage, 2016). Reactive nitrogen remains in the atmosphere, "deposits and accumulates in soils, including soils of nature areas" (Van der Sluijs & Vaage, 2016: 81) and eventually alters interactions within ecosystems, such as plant-pollinator networks (Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017).

1.1.3.2 Pesticide overuse

The intensification of agriculture, which began in the 1960s and nowadays is practiced extensively, is characterized by a heavy use of agrochemicals, such as insecticides, herbicides, fungicides and chemical fertilizers (Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017). Pesticide is the general term for "chemicals designed to kill or inhibit the growth of unwanted organisms" (Gossett, 2013: 1) and among the major groups are insecticides, which target insects, herbicides, which target weeds, and fungicides, which target fungi. The main problematic regarding pesticides is that it is toxic not only for the pest transmitters it is aimed at but also to pollinators and even humans (Gossett, 2013).

The increasing use of pesticides in agriculture in order to protect crops from pests and diseases contaminates nectar and pollen which in turn negatively affects bee populations (Abrol, 2015), resulting in a general decrease in pollinators (Gonzalez-Varo et al., 2013; Gossett, 2013). Insecticides often have lethal or sub-lethal impacts on pollinating species (Potts et al., 2010; IPBES, 2016; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017). Naturally, insecticides can poison pollinators, resulting in death (Potts et al., 2010). But the sub-lethal effects are considered to be even more dangerous (Freitas et al., 2009), leading to alterations in pollinator abundance and diversity (Potts et al., 2010; Kovács-Hostyánszki et al., 2017). These sub-lethal impacts are often indistinct and hard to perceive, but in the case of social bees can affect the whole colony. Therefore, insecticides are often assumed to be the most detrimental agrochemical for bees (Freitas et al., 2009). The danger in this chronic toxicity also lies in the fact, that the longer the exposure lasts, the lower the level to achieve lethal effect (Van der Sluijs & Vaage, 2016). The toxicity of pesticides is influenced by both, toxicity itself and exposure (IPBES, 2016; Kovács-Hostyánszki et al., 2017).

Traditional insecticides were mainly replaced by neonicotinoids at the beginning of the 1990s, because of their "substantially lower acute toxicity to humans, birds and mammals" (Van der Sluijs & Vaage, 2016: 82). But recently it is assumed that they greatly contribute to pollinator decline and disorders (Potts et al., 2010; Van der Sluijs & Vaage, 2016). There are two ways, how pollinators are affected. First, the plants absorb the neonicotinoids while growing and thus becoming toxic to insects. Second, the neonicotinoids residues remain in soil and water, afterwards spreading by surface water, so that pollinators might be susceptible to their uptake while foraging (Van der Sluijs & Vaage, 2016). A long-term exposure to low doses of neonicotinoids causes sub-lethal effects, which change pollinator physiology and behavior, such as "flight behaviour, navigation, brood development and impairs individual and social grooming" (Van der Sluijs & Vaage, 2016: 82).

Herbicides have an indirect impact on pollinators by decreasing floral resources, which provide them with alimentation (Potts et al., 2010; Gonzalez-Varo et al., 2013; IPBES, 2016; Van der Sluijs & Vaage, 2016; Kovács-Hostyánszki et al., 2017).

The excessive use of herbicides, pesticides and fungicides may interfere with the survival of honeybee colonies (Klein et al., 2007; Hanley et al., 2015). However, field studies come to contradicting results regarding the long-term sub-lethal effects on populations (IPBES, 2016).

1.1.3.3 Introduction of invasive species

The threats posed by the introduction of invasive species will be analyzed separately for fauna and flora.

Fauna: Worldwide pollinating species, especially bees, have been introduced to foreign habitats, either deliberately for pollination purposes or unintentionally. The ecological impact of these introductions depends on the local circumstances, i.e. the introduced species' behavior or the abundance of native pollinators (Ollerton, 2017). Exotic pollinators compete with native species for food and other resources and might transfer pathogens or parasites (Potts et al., 2010; Partap, 2011; Hanley et al., 2015), which might lead to the replacement of native species (Hanley et al., 2015). Invasive pollinating species can alter native plant-pollinator networks (Freitas et al., 2009). The impact invasive species (plants or pollinators) have on these networks depends on its characteristics and ecological and evolutionary conditions and can either be neutral, negative or positive. One possibility would be the influx of predatory species, negatively affecting pollinator abundancy (IPBES, 2016). Managed populations, commonly European honeybee *A. mellifera* or bumblebees *Bombus* spp., spread very fast, spatially as well as temporally (Gonzalez-Varo et al., 2013). This inhibits the risk of damaging wild and agricultural flowering plants (IPBES, 2016).

Flora: Generally, invasive plant species can have a negative impact on native pollinators, when they compete with or replace native flowering plants. Plants relying on pollination and which might be more rewarding to native pollinators represent the exception (Gonzalez-Varo et al., 2013; Hanley et al., 2015). These species usually integrate easily into existing plant-pollinator networks (Potts et al., 2010; Gonzalez-Varo et al., 2013), serving as additional food sources (Potts et al., 2010). However, introduced plant species usually require much time in order to spread (Gonzalez-Varo et al., 2013). The introduction of "managed honeybees can reduce both fecundity and progeny performance through pollen limitation and inbreeding depression" (Gonzalez-Varo et al., 2013: 525).

1.1.3.4 Climate change

Climate change is yet another hazard resulting in habitat loss (Van der Sluijs & Vaage, 2016). It leads to regional climatic changes in certain seasons or a year or to local, atypical weather events (Gonzalez-Varo et al., 2013). This also alters plant-pollinator interactions due to spatial and temporal discrepancies (Potts et al., 2010; Gonzalez-Varo et al., 2013). These indirect effects via interactions with other species remain understudied (Potts et al., 2010). Possible manifestations of climate change are deviations in flowering seasons, resulting in mismatches with pollinators' foraging season (Gonzalez-Varo et al., 2013; Hanley et al., 2015; IPBES, 2016; Van der Sluijs & Vaage, 2016) or variations in species' ranges (Gonzalez-Varo et al., 2013; Hanley et al., 2015; IPBES, 2016). Alterations can arise at various scales, namely at individual (e.g. shift in foraging habits), population (e.g. genetic evolutionary adaptation), species (e.g. species decline owed to altered climate conditions) or community (e.g. shifts in interactions between pollinators) levels (Potts et al., 2010).

Additional consequences might still be detected in the future, due to ecosystems' slow responses to climate change (IPBES, 2016). Usually, more generalist plant-pollinator interactions are less vulnerable to climate change (Gonzalez-Varo et al., 2013; Van der Sluijs & Vaage, 2016). In general, global warming causes a pole-wards move of global climate zones (Van der Sluijs & Vaage, 2016), possibly expanding the cultivation of some crops but also leading to the abandonment of others (Hanley et al., 2015). Pollinating species also tend to move to higher altitudes or latitudes, which are more temperate (Potts et al., 2016).

Throughout the Neotropics the frequency and intensity of extreme weather events, such as "droughts, floods, large-scale bushfires and hurricanes" (Freitas et al., 2009: 340), increases presumably due to climate change. The effects are difficult to estimate, but could change distribution and abundance of flowering plants, also impacting the apifauna (Freitas et al., 2009).

1.1.3.5 Interactions between hazards

The afore-mentioned drivers of pollinator loss exhibit interrelations among them and may occur simultaneously (Potts et al., 2010; IPBES, 2016; Van der Sluijs & Vaage, 2016). If more than one applies, the overall pressure enhances (IPBES, 2016). However, studies considering these interactions are rare (Gonzalez-Varo et al., 2013). On the other hand, such synergistic effects are useful in explaining current pollinator declines (Potts et al., 2010) and often the decline of one pressure automatically decreases the overall pressure (Gonzalez-Varo et al., 2013).

Examples for such synergistic effects are the introduction of alien species, whose impacts are exacerbated by concurrent emergence of land-use change, climate change or pathogens (IPBES, 2016). Climate change in turn favors the expansion of pathogens and pests (Potts et al., 2010), as well as land-use change (Potts et al., 2010) and agricultural intensification, with increased infection rates and severity of pests (Gonzalez-Varo et al., 2013). Land-use change and agricultural intensification also aggravate each other's negative impact on pollinators (Gonzalez-Varo et al., 2013). Partap (2011) points out the interrelations between agricultural intensification, especially monocultures and the treatment with agrochemicals, as well as land-use change resulting in habitat loss, leading to shrinkage of food sources.

Nevertheless, many interactions, such as climate change and land-use change, remain unstudied (Gonzalez-Varo et al., 2013).

Moreover, "indirect drivers (demographic, socio-economic, institutional and technological) are producing environmental pressures (direct drivers)" (IPBES, 2016: 28) with impacts on plant-pollinator networks. Specifically, all of these indirect drivers are results of human activities, stemming from population and economic growth, development of international trade and technical inventions, which impact "climate, land cover and management intensity, ecosystem nutrient balance and biogeographical distribution of species" (IPBES, 2016: 28-29). These environmental pressures represent a hazard to humans and their livelihoods, due to a decrease in crop yield and quality and the loss of traditions and cultural practices (IPBES, 2016).

1.1.4 Pollination of coffee

Even though *C. arabica* is highly self-fertile, productivity (fruit set as well as berry weight) as well as quality can be raised substantially by cross-pollination (Raw & Free, 1977; Manrique & Thimann, 2002; Roubik, 2002; Klein et al., 2003; Rickett et al., 2004; Olschewski et al., 2006; Cepeda-Valencia et al., 2014; Bravo-Monroy et al., 2015; Acosta Leal et al., 2017), according to a study from Colombia by 10-40% (Bravo-Monroy et al., 2015), others reported an increase in fruit set in *C. arabica* of even 54%, others in turn a 10%, 4% or 17% increase (Klein et al., 2003). Other authors determined a fruit set increased by 16% (Acosta Leal et al., 2017). In the study conducted by Klein et al. (2003) in Indonesia cross-pollination by wind and insects increased fruit set by 12.3%. Two studies of *C. arabica* 'Caturra' determined an increase in ripened grains of 13.6% (Amaral, 1972 as cited in Manrique & Thimann, 2002 and Ngo et al., 2011) and 52% (Raw & Free, 1977), due to pollination by honeybees. The first study was conducted in Brazil and the second in Jamaica (Raw & Free, 1977; Ngo et al., 2011). Another study from Costa Rica determined a yield increase of 15-

50% in 'Caturra' variety (Rickett et al., 2004). Manrique & Thimann (2002) have found in their study of *C. arabica* 'Catimor' in Venezuela that pollination leads to a rise of 4.7% of mature grains, with an increased yield weight of 15.6% (when wet) and 9.75% (when dry). Roubik (2002) found a 50% increase in coffee yield facilitated by honeybees, with ripe berries being heavier and abundance per flower increased by 49%. Pollination by honeybees generally led to a weight gain of averagely 7%, if pollinated exclusively by African honeybees even by 25%. Thus the africanization of honeybees has presumably led to a general increase of coffee production in Latin America. For example in Colombia, the average yield per hectare amounted to 5,920 kg in the period of 1961-1980. In the period from 1981-2001 however, a period in which honeybees were already Africanized, average production augmented to 7,740 kg per hectare. Furthermore, pollination reduces the occurrence of so-called peaberries (Ricketts et al., 2004; Olschewski et al., 2006) by 27% (Ricketts et al., 2004), which are small, deformed seeds (Ricketts et al., 2004; Ngo et al., 2011; Bonilla Gómez, 2016) resulting from insufficient pollination, when "only one of the two ovules in a coffee flower develops into a bean" (Raw & Free, 1977: 366; see also Olschewski et al., 2006; Ngo et al., 2011). These are supposedly of a poorer quality, due to problems they cause when roasting the coffee beans evenly (Ricketts et al., 2004). There exists however, a small specialized market for peaberry coffee (Ricketts et al., 2004; Ngo et al., 2011). The coffee's quality can also be improved by pollination (Cepeda-Valencia et al., 2014; Bonilla Gómez, 2016; Acosta Leal et al., 2017), due to an increase in degree Brix, indicating a higher amount of sugars, which enhances the coffee's flavor (Cepeda-Valencia et al., 2014). Coffee's self-pollination capacity amounts to 50% on average (Ollerton, 2017). This is why in Colombia pollination was never considered as a limiting production factor (Cepeda-Valencia et al., 2014).

Biotic pollination of coffee is mainly supplied by bees (managed honeybees as well as wild ones) (Klein et al., 2003; Ngo et al., 2011; Cepeda-Valencia et al., 2014; Acosta Leal et al., 2017; Ollerton, 2017), which in one sole visit are able to pollinate both of the coffee flower's ovules. Considering global production levels, this translates to 22 trillion flowers which need to be pollinated (Ollerton, 2017). Honeybees are frequent visitors of coffee flowers (Raw & Free, 1977; Roubik, 2002; Klein et al., 2003; Ricketts et al., 2004; Cepeda-Valencia et al., 2014; Imbach et al., 2017), mainly in search of nectar (Manrique & Thimann, 2002; Ngo et al., 2011; Acosta Leal et al., 2017), but also pollen (Acosta Leal et al., 2017). But also native bees, i.e. stingless bees (tribe *Meliponini*), are frequent visitors of coffee plants (Ricketts et al., 2004; Ngo et al., 2011; Cepeda-Valencia et al., 2014; Bonilla Gómez, 2016; Acosta Leal et al., 2017; Imbach et al., 2017). In a study conducted in Cundinamarca, Colombia the species visiting most frequently were the meliponine *Paratrigona eutaeniata* and *A. mellifera*, even though in total 13 species from three families were observes (Cepeda-Valencia et al., 2014). Pollination efficiency can be influenced by the variety of visiting bee species (Ricketts et al., 2004; Olschewski et al., 2006; Ngo et al., 2011; Cepeda-Valencia et al., 2014) and distance to forests (Amaral, 1972 as cited in Manrique & Thimann, 2002;

Roubik, 2002; Ricketts et al., 2004; Olschewski et al., 2006; Cepeda-Valencia et al., 2014; Bonilla Gómez, 2016). A more diverse pollinator community "may provide greater and more stable pollination services through complementary foraging behaviors, greater pollination efficiencies, and broader climate tolerances, as well as asynchronous population dynamics" (Ricketts et al., 2004: 12580). Wind pollination is negligible for coffee, due to the pollen's stickiness and heaviness (Ngo et al., 2011).

These findings indicate that *C. arabica* might be amphicarpic (Raw & Free, 1977; Manrique & Thimann, 2002; Klein et al., 2003), viz. producing flowers which rely on zoophily and others with are autogamous (Raw & Free, 1977; Klein et al., 2003).

Such high production increases due to pollination obviously also favor the coffee farmers' income (Ngo et al., 2011).

1.2 Social-ecological systems

Current changes, ecological as well as social ones, are all profoundly interrelated and can therefore be seen as SESs, adopting a human-in-nature perspective. On the one hand, humans rely on services provided by nature, but on the other hand, they strongly influence the functioning and condition of these services (Chapin et al., 2009; Folke et al., 2010; Small et al., 2017; Leviston et al., 2018). SESs are comprised of physical items (e.g. lithosphere, hydrosphere, and biosphere) and influenced by humankind in form of environmental pollution and cities (Chapin et al., 2009; Meadows & Wright, 2009). Hence, they include both, human society as well as ecosystems (Folke et al., 2010). The knowledge of the interconnections between social and ecological systems is fundamental to sustaining both subsystems (Leviston et al., 2018).

A system can be defined as a "set of things [...] interconnected in such a way that they produce their own pattern of behavior over time" (Meadows & Wright, 2009: 2). Usually, this interconnection of system components is established by an information flow (Meadows & Wright, 2009). The social as well as ecological subsystem is "strongly influenced by physical, ecological, economic, and cultural factors" (Chapin et al., 2009: 6), which co-evolve spatially and temporally (Haines-Young & Potschin, 2010). These factors manifest themselves in fast and slow controlling components, which affect both ecological and social subsystems, and that in turn determine human well-being (Chapin et al., 2009; Meadows & Wright, 2009).

Chapin et al. (2009) differentiate three types of variables that shape the SES: exogenous controls, which are external, and slow and fast variables, which are internal. The exogenous control shape the SES's environment and are temporally and spatially stable. Slow and fast variables have a stronger effect on the SES, while slow variable are more permanent and less prone to change than fast variables. The former two are particularly important for long-term sustainability. An exemplary SES with the different variables can be seen in Figure 4.

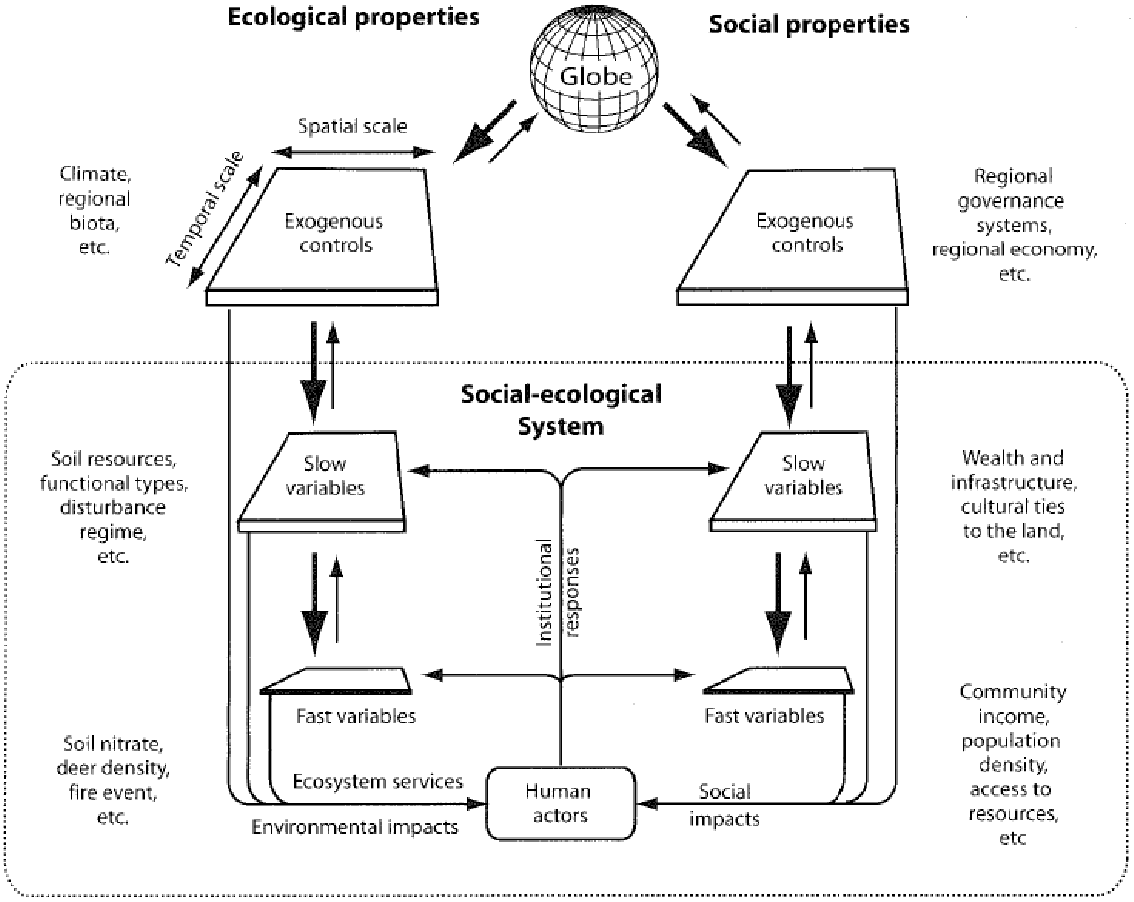


Figure 4: Depiction of an exemplary SES.
Source: Chapin et al., 2009.

Three central, interrelated concepts exist: resilience, adaptability and transformability.

Resilience not only applies to systems, but can also refer to a person or a group and hence is applied in "engineering, economics, environmental science, psychology, and sociology" (Hobman & Walker, 2015: 2). A system's resilience refers to its "capacity [...] to absorb a spectrum of shocks or perturbations and still retain and further develop the same fundamental structure, functioning, and feedbacks" (Chapin et al., 2009: 9 as well as Walker et al., 2004: 1) representing, in other words, the system's capacity to maintain its current state regardless of perturbations (Holling, 1973; Chapin et al., 2009; Meadows & Wright, 2009; Folke et al., 2010; Hobman & Walker, 2015) as a continous process (Folke et al., 2010). In the context of SES, resilience is then referred to as social-ecological resilience (Folke et al., 2010; Hobman & Walker, 2015) and considers both nature and society as complementary systems (Folke et al., 2010). It is comprised of two components:

(1) the short-term capacity to maintain the SES's original state when immediate disruptions arise and

(2) the long-term adaptive or transformative capacity in order to preserve SES functioning (Hobman & Walker, 2015).

Resilience is characterized by four key aspects. First, latitude describes the maximal amount of perturbations that a system is able to absorb before surpassing a threshold. Second, resistance outlines how difficult or easy it is to modify the current system. Third, precariousness delineates the system's current distance to a threshold. Fourth, panarchy details the influence of other scales on the system under consideration. One example of panarchy would be global climate change, which can still effect a local SES (Walker et al., 2004).

Adaptability is rather broadly defined as the capacity to adjust to environmental alterations (Chapin et al., 2009), while remaining on the current path (Folke et al., 2010). These alterations can occur in the form of external drivers but also internal processes (Folke et al., 2010; Hobman & Walker, 2015) and refers to the system's capability to socially self-organize and learn (Hobman & Walker, 2015). It also indicates the ability of humans to influence resilience (Walker et al., 2004; Folke et al., 2010), evading the crossing of a threshold or being able to return to a more desirable state. There exist four strategies to do this, analog to the four key aspects of resilience as presented in the preceding paragraph (Folke et al., 2010).

Transformability on the other hand describes a system's capacity to cross thresholds and thus creating a completely new system when the former one becomes ecologically, economically or socially unsustainable (Walker et al., 2004; Folke et al., 2010; Hobman & Walker, 2015). That means that the systems adopt new paths (Folke et al., 2010). Moreover, transformations should be created gradually and on a small scale, in order to make them easier to control and usually also cheaper. Due to "the interlinked and cross-scale nature of SESs" (Hobman & Walker, 2015: 4), these small-scale and gradual changes still lead to large-scale resilience (Folke et al., 2010; Hobman & Walker, 2015). Examples of transformative changes among society include the emergence of cities or industrial revolution (Walker et al., 2004).

Furthermore, resilience describes the SES's capacity of not surpassing thresholds (Folke et al., 2010; Farley & Voinov, 2016). Thresholds are defined as "sudden large, nonlinear, changes in a property of a system as a consequence of smooth and continuous change in a variable which affects it" (Farley & Voinov, 2016: 390) and are often also called tipping points. When contemplating SESs, one has to consider socio-economic thresholds to the same degree as ecological ones (Farley & Voinov, 2016).

The production of all economic products requires raw materials and produces waste as a by-product. Consequently, economic growth is limited, since the Earth's resources are limited. Moreover, economic growth might jeopardizes the ES humans depend on for their survival and may lead to the crossing of socio-ecological thresholds. Passing ecological or social thresholds should be avoided, even though this might be difficult to fulfill, since they are often antagonistic: A reduction of a social variable can lead to the crossing of an ecological threshold and vice versa. Furthermore, the existence of thresholds as well as the consequences of surpassing them oftentimes remains unclear (Farley & Voinov, 2016).

When valuing SESs, their spatially and timely dynamics have to be considered. This dynamics are based on the interaction of ecological and social drivers at various scales and different speeds. Additionally, the SES and the interactions within them have to be understood very well (Small et al., 2017).

1.3 Economic valuation of ecosystem services

For all production processes, society depends on natural resources. Thus, changes in their availability and quality have a direct impact on their costs and human welfare (Costanza et al., 1997; Villegas-Palacio et al., 2016). However, depending on the use of ESs, they can provide not only economic values, but also natural resources or just enhance human well-being, which may also depend on the beneficiary (Small et al., 2017). In the last 20 years, numerous efforts have been made in order to estimate the ecosystems' worth, in the hope that the visualization of their worth will lead to a more sustainable handling of them (Gascon et al., 2015). It can be argued that ecosystems hold a certain worth since "they maintain life on Earth and the services needed to satisfy human material and nonmaterial needs [and contain] ecological, sociocultural, or intrinsic values to the existence of ecosystems and species" (Millennium Ecosystem Assessment, 2003: 128), even though most ES are not exchanged in the market (Costanza et al., 2014; Gascon et al., 2015). Besides theoretical and practical issues (Costanza et al., 1997), the subjectivity of valuing ES increases the difficulty in realizing monetary estimations (Allsopp et al., 2008), which is influenced by factors such as individual education and ideology and the lack of the necessary information.

The relevance of ESs has first been acknowledged by economists in the 18th century (Gascon et al., 2015). The first explicit mention of the term ES occurred at the beginning of the 1980s (Haines-Young & Potschin, 2010; Costanza et al., 2017), at a time in which interest in ecology was surging. In the same period the transdisciplinary area of ecological economic emerged, which from the first moment on considered ESs as a central research issue. The publication of corresponding research has since increased steadily (Costanza et al., 2017). However, research has been focused on provisioning and regulating ES while at the same time neglecting cultural services, since these are non-material and harder to valuate (Small et al., 2017). Moreover, most of existing studies have an illustrative character and aimed to raise awareness (Hanley et al., 2015).

1.3.1 Classification systems of ecosystem services

In order to value ESs, they usually have to be categorized or described first, for which different frameworks are available (Czúcz et al., 2018). These classification systems are used for economic valuation, scientific research, and policymaking (Costanza et al., 2017). Two of these frameworks, the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB) have contributed substantially to the increased awareness regarding the benefits ESs provide (Lautenbach et al., 2012). The three main classification systems, namely MEA, TEEB, and Common International Classification of Ecosystem Services (CICES), only show minor differences, which will be introduced in the following.

1.3.1.1 Millennium Ecosystem Assessment

The MEA "was the first comprehensive global assessment of the implications of ecosystem change for people" (Haines-Young & Potschin, 2010: 111), which was called for by the United Nations in 2000. It was found that 60% of the ESs that were assessed were handled unsustainably, leading to their degradation (Haines-Young & Potschin, 2010) and ultimately resulting in jeopardy of human well-being (Small et al., 2017). It provides a framework for assessing the economic value of ecosystems and their relevance to human well-being (Millennium Ecosystem Assessment, 2003; Small et al., 2017) and to maintaining the Earth's functioning (Costanza et al., 1997). The MEA aims to increase human well-being by analyzing the impact of current and future changes in ESs and how to mitigate negative consequences of these changes (Leemans, 2009). It introduced the distinction of four types of ESs, which are depicted in Figure 5:

(1) supporting (e.g. nutrient and water cycles, food production, soil formation),
(2) provisioning (e.g. food, fresh water, fuel, natural medicines, and ornamental resources),
(3) regulating (e.g. regulation of air quality, climate and water, erosion control, pollination), and
(4) cultural (e.g. recreation, aesthetical, educational, spiritual or religious values) services (Millennium Ecosystem Assessment, 2003; Mburu et al., 2006; Leemans, 2009; Haines-Young & Potschin, 2010; TEEB, 2010; Steward et al., 2014; Zulka & Götzl, 2015).

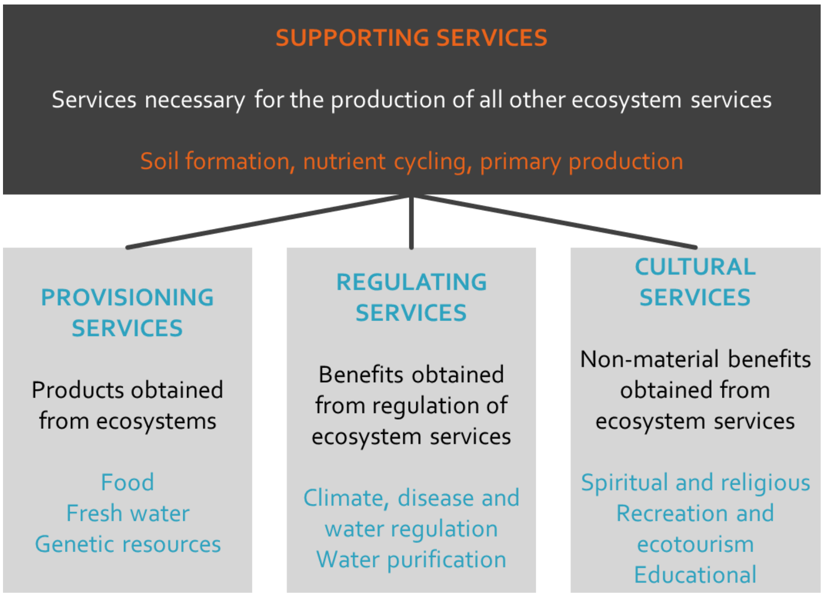


Figure 5: Classification of ES.
Source: Based on Millennium Ecosystem Assessment, 2003 & Leemans, 2009.

Changes in provisioning ESs have immediate consequences on human well-being (Millennium Ecosystem Assessment, 2003), whereas supporting services occupy a special position, because their relation to human well-being differs from the other service classes (Haines-Young & Potschin, 2010). Alterations usually have a more subtle, long-term effects (Millennium Ecosystem Assessment, 2003), due to the fact that they affect humans only indirectly, while they are responsible for the functioning of other services via a complex system of interrelations (Haines-Young & Potschin, 2010). Furthermore, the provision of provisioning, regulating, and cultural services all depend on the successful functioning of supporting services (Millennium Ecosystem Assessment, 2003). Pollination is usually classified as a regulation service (Millennium Ecosystem Assessment, 2003; Mburu et al., 2006; TEEB, 2010; Chagnon et al., 2015; Costanza et al., 2017), but sometimes also as a supporting service (Chagnon et al., 2015).

1.3.1.2 The Economics of Ecosystems and Biodiversity

The TEEB emerged from a G8+5 meeting. The G8 nations include Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States and the 5 refers to the five emerging economies, namely Brazil, China, India, Mexico and South Africa. In their 2007 summit, these nations called for an assessment of biodiversity's global economic benefit as well as the cost of biodiversity conservation versus biodiversity loss (TEEB, 2010).

It addresses the visibility of biodiversity's and ES's value and differentiates between economic, social and ecological benefits and values, while various values can be assigned to a benefit. Three values are distinguished: ecological, socio-cultural, and economic values.

(1) Ecological values include the ecosystem's capacity (resilience, health and integrity) to preserve life and are thus critical to human survival.

(2) Socio-cultural values refer to the cultural contextualization and construction of ES and comprise underlying values, which influence the people's attitude towards the world and their decision-making. Socio-cultural values include intrinsic values, which is the value of mere existence of an ES, instrumental values, which represent a direct contribution to human well-being, and relational values, which describe how humankind relates to nature.

(3) Economic values describe the monetary values of ES (Small et al., 2017).

The TEEB enables well-thought and sustainable decision-making regarding ecological resources, due to the provision of information concerning their benefits, the revelation of cost-effective measures of managing biodiversity, emphasizing the imperativeness to take actions and the creation of policy incentives (TEEB, 2010).

1.3.1.3 Common International Classification of Ecosystem Services

The CICES is based on the pioneering work of MEA and TEEB and was applied by different European Union (EU) initiatives. It is relatively detailed and presents a higher amount of ES categories in comparison to the aforementioned frameworks, assorted in different hierarchical levels (Czúcz et al., 2018), which pursue a taxonomical approach (Haines-Young & Potschin, 2018; Czúcz et al., 2018). This structure was inspired by the MEA, but aims to enhance its practicability. Still it maintains the major categorization, the so-called sections (Czúcz et al., 2018), namely provisioning, regulation and maintenance, and cultural. Follow the more specific categories called divisions, groups, and classes (Haines-Young & Potschin, 2018; Czúcz et al., 2018) as depicted in Figure 6. Provisioning services include all nutritional, material and energetic outputs harnessed by humankind. Regulation and maintenance refers to all the manners in which humankind interferes with ecosystems and vice versa. Cultural services are non-material affecting mental or intellectual well-being. The so-called supporting services, as introduced in the MEA, are not part of the CICES framework, since it focuses on more direct links (Czúcz et al., 2018) or rather final ecosystem services (Haines-Young & Potschin, 2018; Czúcz et al., 2018).

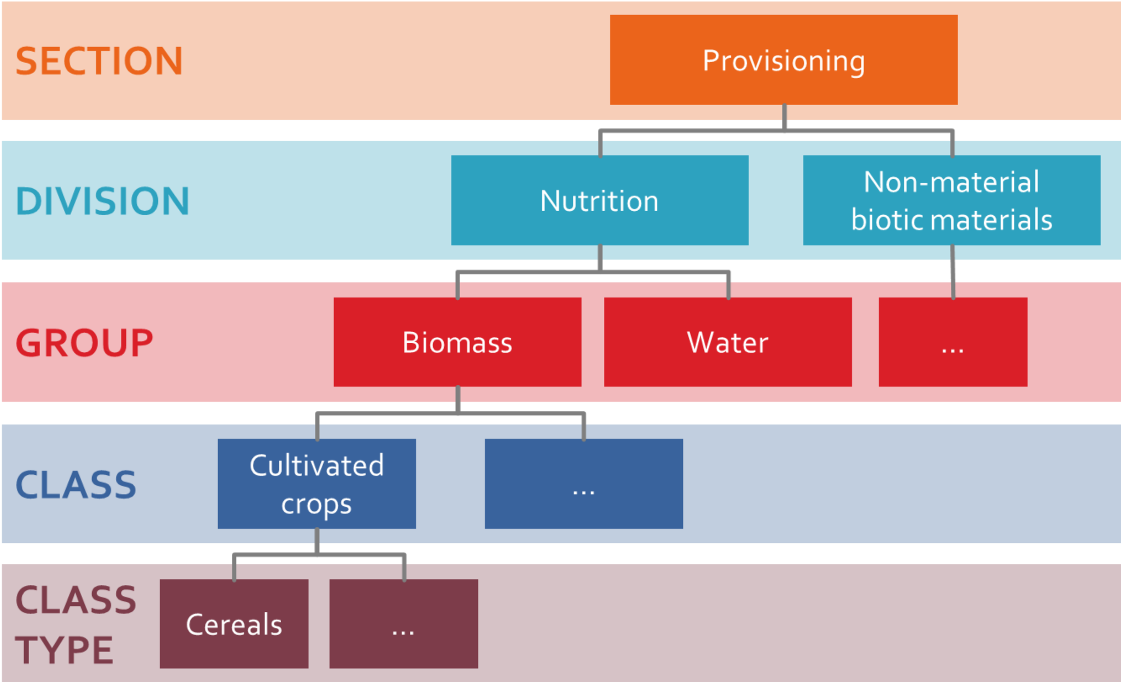


Figure 6: Hierarchy in CICES framework.
Source: Based on Czúcz et al., 2018

1.3.2 Methods of economic valuation of ecosystem services

The first studies valuing the benefits of pollination used proxies, such as the total value of crops which benefit from pollination or the rent for beehives, in order to estimate the value of pollination. More recent studies determined the dependence ratio, which identifies the degree of production loss in case of a lack of pollination. In this case, pollination is considered as only an additional input in crop production in a simplified production function. The data required is usually collected via field research regarding pollination's effect on crop production. Other studies were conducted on a per-hectare-basis. These yield analysis considered market quality, crop variety, storage life and producer benefits. The results are then extrapolated to a greater scale. The studies calculating pollination's effect on consumer welfare are another enhancement of the dependence ratio. These ascertain the loss of consumer surplus via econometric techniques. The consumer surplus describes the difference between the actual price of a certain good and the consumers' maximal WTP for this good. Other studies again estimate pollination value via the cost of replacing it artificially (Hanley et al., 2015).

According to the total economic value framework, as introduced by the MEA and delineated in Figure 7, the use derived from ES can be categorized into two groups: use values (consisting in direct use value; indirect use value; and option value) and non-use values, requiring different valuation methods (Millennium Ecosystem Assessment, 2003).

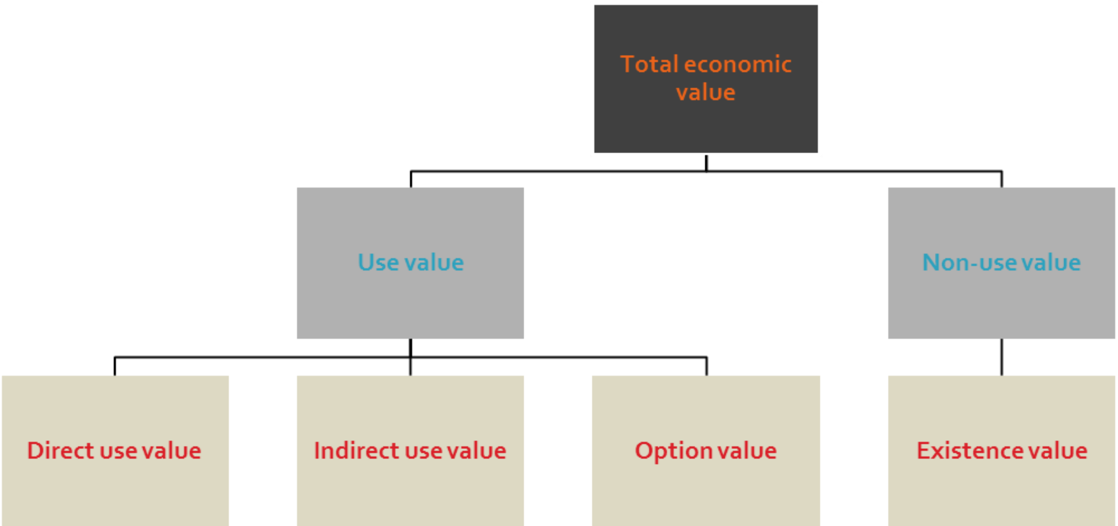


Figure 7: Total economic value framework.
Source: Millennium Ecosystem Assessment, 2003.

Use values represent the entire value humans derive directly or indirectly from ES for their consumption or the manufacturing of goods. Direct use values are services directly used by humankind, whereas indirect use values apply to services that are not consumed directly but rather are processed further (Millennium Ecosystem Assessment, 2003). Option values concern ES that currently are not used, but might still be useful in the future (Millennium Ecosystem Assessment, 2003; Gascon et al., 2015). Non-use values, on the other hand, consist of existence values, which are described as services that are neither used today nor in the future, but still hold intrinsic values (Millennium Ecosystem Assessment, 2003). Principally, pollination represents an indirect use value, due to its relevance to agriculture and ecosystem maintenance, which in turn positively affects human well-being (Mburu et al., 2006).

The actual valuation is based on the concepts of society's WTP or willingness to accept changes in its well-being, derived from welfare economics (Millennium Ecosystem Assessment, 2003; Hanley et al., 2015; Costanza et al., 2017). It derives from the theory of "utility maximisation where rational actors maximise their expected utility given their income constraints" (Angell et al., 2018: 27). WTP applies to the case that the affected person is not the owner of the resource from which he benefits or service levels increase. In the case of willingness-to-accept the person benefitting from a service is the owner of the corresponding resource or service levels decrease (Millennium Ecosystem Assessment, 2003). The various related methods are illustrated in Figure 8 and described below.

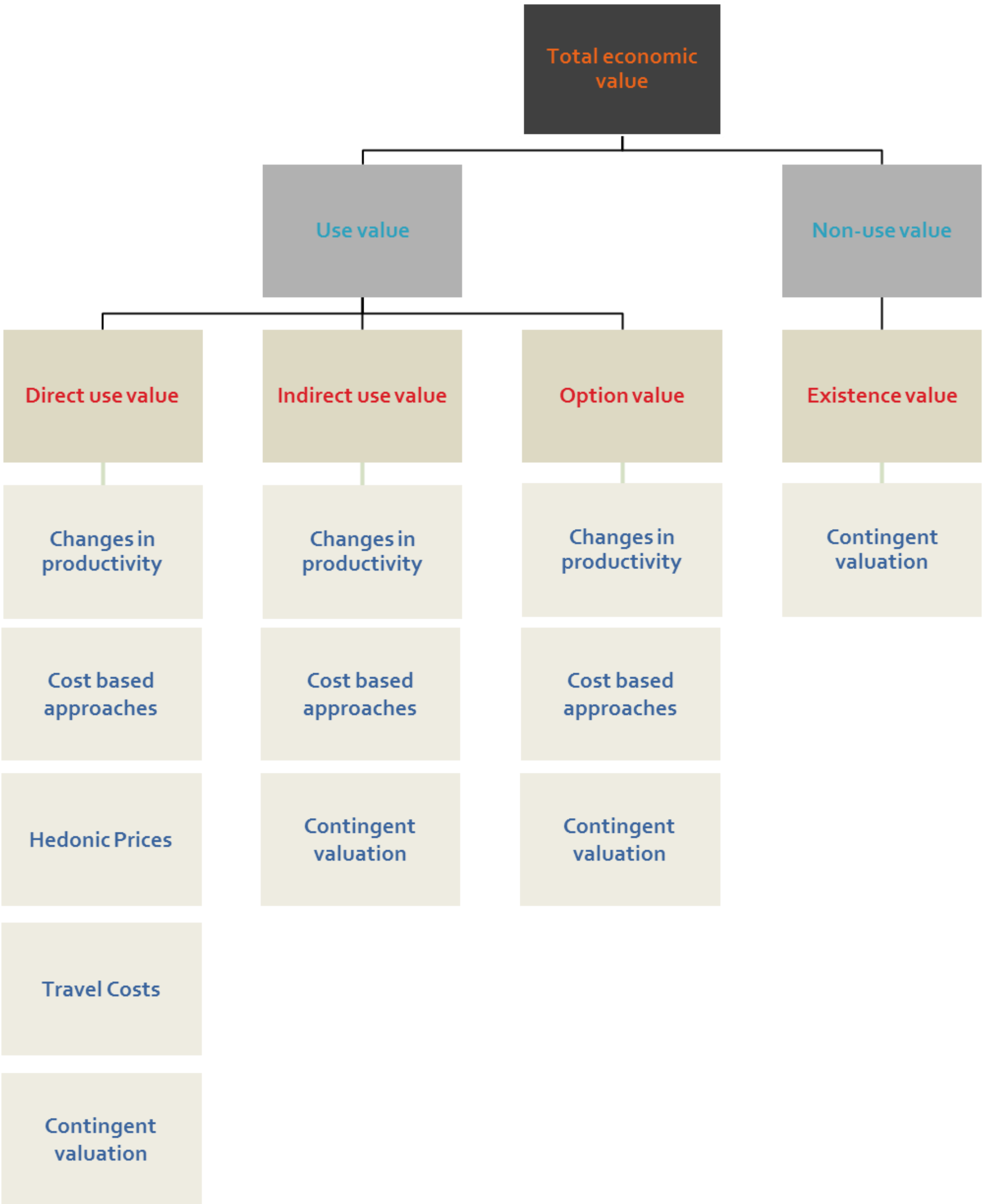


Figure 8: Total economic value framework and related methods.
Source: Based on Millennium Ecosystem Assessment, 2003; McKinney, 2009 & TEEB, 2010.

There are various methods to estimate the monetary value of ES (Millennium Ecosystem Assessment, 2003; Mburu et al., 2006; Akhtar et al., 2017; Angell et al., 2018). The valuation of private goods is relatively uncomplicated since they are exchanged in the market and therefore society's WTP can be directly observed (Mburu et al., 2006; de Melo Travassos et al., 2018). Public goods however are not traded in the market; hence their value has to be estimated by consumers' indirectly observed behavior (Mburu et al., 2006; Angell et al., 2018), creating hypothetical markets (de Melo Travassos et al., 2018). All methods use either revealed or stated preference approaches. The former is based on an analysis of observed consumer behavior whereas the latter involves active choices of customers in a hypothetical market (Angell et al., 2018). One method are cost-based methods, such as preventive costs or costs of replacement. Preventive costs are actions that aim to maintain an ES so that costs for their disappearance are void. Costs of replacement are the costs of replacing a vanished or strained ES (Mburu et al., 2006). Techniques using hypothetical markets include the travel cost and the hedonic pricing method (Comisión Nacional del Agua, 2008; de Melo Travassos et al., 2018). The travel cost method estimates the ES's value by people's willingness to travel to a recreational site. The hedonic pricing method is based on the premise that a certain good is determined by its characteristics. Therefore, its value can be derived from the change in society's WTP if these characteristics change (Comisión Nacional del Agua, 2008). The last group of valuation methods concerns artificial markets (Comisión Nacional del Agua, 2008; Hanley et al., 2015) and include direct approaches such as choice experiments, including the contingent valuation method (CVM) and choice modelling, which apply surveys to estimate the respondents' WTP for a certain ES (Mburu et al., 2006; Angell et al., 2018; de Melo Travassos et al., 2018). In the case of CVMs, interviewees have to specifically state how much they would be willing to pay for public goods (Mburu et al., 2006; Hanley et al., 2015; Akhtar et al., 2017), whereas in choice modelling they only state preferences regarding certain ES and their characteristics (Mburu et al., 2006). These methods of stated preference are assumed to be the only method feasible for estimating pollinators' values (Hanley et al., 2015).

1.3.3 Previous studies of economic valuation of coffee pollination

The popularization of economic valuation has led to the elaboration of various studies regarding the economic value of pollinators (Bos et al., 2007), especially in an agricultural context (Bos et al., 2007; Hanley et al., 2015). Some of these have focused on the economic impact of pollinator loss. Studies focusing on the economic benefits derived from pollinators however should include all the processes provided by ecosystem which are required for pollination (Bos et al., 2007). In the case of pollination, not all benefits are included in the market (Hanley et al., 2015; Potts et al., 2016). Hence no economic indicators exist, so that land management decisions, which depend on these indicators and market forces, might antagonize pollination benefits. The monetary valuation of these benefits lead to a more informed decision-making process. The elaboration of such valuations demands a transdisciplinary approach, e.g. multi-criteria cost-benefit analysis (Potts et al., 2016). Pollinators' economic value depends on the economic benefits they provide and consequentially is prone to change (Hanley et al., 2015).

Two global assessments of the value of pollination, not only to coffee but in general, have been conducted by Costanza et al. (1997) and Gallai et al. (2009). The former estimated the global value pollination's yearly global value at 117 billion US$. This estimate was based on previous research which applied various methods mostly derived from WTP. The latter estimated that pollination's global total economic value equals 153 billion €, which represented 9.5% of total food production. South America's share amounted to 11.6 billion€. The global loss of consumer surplus would be 190-310 billion€.

Ricketts et al. (2004) have valued pollination on a farm in Costa Rica at 62,000 US$ per year during 2000-2003, which represented 7% or the farm's total income. Pollination was provided via two forest fragments close to the farm. The authors however suggest that this value is an underestimation of the actual value. The study referred to *C. arabica* 'Caturra' and even though no honeybees were managed nearby, Africanized honeybees were still plentiful in the region.

Olschewski et al. (2006) realized a study in Ecuador, a tropical region which has been highly transformed by humans, in which they analyzed the impact of nearby forests on fruit set and berry weight and its economic impact. The authors found that proximity to forests increased fruit set and berry weight of the coffee plants and thus heightens gross revenue. More specifically, "at a maximum distance of 1500 m, yields and gross revenues declined by 45%, whereas net revenues were reduced by 93%" (Olschewski et al., 2006: 11).

Veddeler et al. (2008) also researched the economic impact of pollination on coffee production in Ecuador. In order to do so, they studied the 'Caturra' variety, which is cultivated in a traditional manner using highly shaded agroforestry. Neither agrochemicals nor fertilizers are applied and nor are bees rented for pollination services. The most dominant bee species they observed was the Africanized honeybee. The authors found that a fourfold increase of bee visits led to a surge of 816% in coffee farmers' net revenue, e.g. if the bee density was 20, the value per hectare equaled 6 US$. If 80 bees visited, the value per hectare grew to 55.1 US$.

1.3.4 Payments for ecosystem services

Payments for ecosystem or environmental services (PES) provide economic incentives for ecosystem management (Wunder, 2005; Wunder, 2008; Farley & Costanza, 2010; Costanza et al., 2017). These contain "direct, contractual and conditional payments to local landholders and users in return for adopting practices that secure ecosystem conservation and restoration" (Wunder, 2005: 1). Thus, PES can potentially alter behavior which is environmentally damaging and improve rural livelihoods due to additional payments to them (Tacconi, 2012). Payments are realized by at least one buyer benefitting from the previously precisely defined ES. The ES provider, at least one, receives this voluntary payment under the condition to preserve the ES (Wunder, 2005). Farley & Costanza (2010) argue that such a voluntary payment is only suitable for private goods, while public goods might require involuntary payments, i.e. via taxation. However, the payment, which can be monetary or non-monetary, can also be made via an intermediary (Wunder, 2005). Moreover, the ES's conservation has to be monitored, which is legally supervised and enforced in developed countries. In developing countries, however, the necessary governance to do so lacks (Wunder, 2005). Nevertheless, governmental interference is not necessarily required (Farley & Costanza, 2010). Measuring the ES for monitoring purposes is potentially problematic. Ordinarily, they are measured using a proxy (Tacconi, 2012).

In order to introduce a PES scheme, the ES has to be clearly defined at an appropriate scale, as well as interrelations with connected ES analyzed. Next, suitable regions and ES providers have to be selected, framework parameters (i.e. penalties and rewards) have to be determined and a monitoring scheme has to be developed (Tacconi, 2012). The simplest form of PES schemes are so-called self-organized or private payment programs, which are usually initiated by the ES buyers or an intermediary institution, for instance a non-governmental organization. They are normally established on a small to medium scale (Wunder, 2008). Such programs are also called user-financed and the service buyers are congruent to the service users. User-financed programs are usually voluntary for both service buyers and providers, which enables the flexible entry and leaving of contracts (Wunder et al., 2008). Moreover, user-financed programs commonly involve just one ES buyer and a single ES, even though external funding during the set-up is frequently used. Generally, user-financed PES programs are more probable to succeed, due to the direct involvement of the affected parties (Wunder et al., 2008). On the other hand, more complex, public payment, government-financed PES schemes generally span a greater area or various ESs (Wunder, 2008) and engage national governments , who function as a ES buyer on behalf of the actual users (Wunder, 2008; Wunder et al., 2008). Since they frequently feature additional objectives, i.e. poverty alleviation or regional development, they are prone to lose sight of their actual environmental objective (Wunder, 2008). Government-financed programs are usually obligatory to ES buyers. However, in some cases distinction by financing can be blurry, when payments by both governments and services users are involved in the same program (Wunder et al., 2008). The introduction of a PES scheme might face various challenges. These can be categorized as economical, i.e. if the PES is not sufficiently attractive to stop the environmentally harmful behavior, institutional, i.e. land access rights, or informational, i.e. massive costs for ES baseline assessment during set-up phase, obstacles (Wunder, 2008).

Usually, PES concerns four types of ESs, namely the carbon storage and sequestration, biodiversity or watershed protection, or landscape aesthetics (Wunder, 2005). However, fundamental ESs that cannot be substituted, such as ESs underpinning biodiversity, should be prioritized (Farley & Costanza, 2010).

1.4 Description of study site

Huila is a department in southeastern Colombia (Map 1 and Map 2), spanning a total of 19,890 km^2. According to the national census from 2005, the department has a population of 1,001,476 inhabitants. Its capital, Neiva, is located in the department's northwest (Sociedad Geográfica de Colombia, n. d.). Topographically, Huila is comprised of the Magdalena River Valley which is enclosed by two mountain ranges, namely the Central Andes and the Eastern Ranges, running parallel to the north. This topographic variety is mirrored by climate (Gobernación del Huila, 2017, A).

Map 1: Location of Colombia in the world.
Source: Worldatlas, 2018.

Map 2: Location of Huila within Colombia.
Source: Shadowfox, n. d.

The main economic activities consist in agriculture and livestock (Gobernación del Huila, 2017, B), with the main crops being coffee, rice, banana, beans and corn (Evaluaciones Agropecuarias Municipales, n. d., B). Other economic sectors are the exploitation of oil and commerce (Gobernación del Huila, 2017, B). These generated a departmental gross domestic product (GDP) of 4.16 billion€ in 2014, which represents an increase of 4.6% compared to 2013 (Departamento Administrativo Nacional de Estadística, 2016).

In 2017, 35.7% of Huila's population lived in poverty, and 11.2% even in extreme poverty. In comparison, on a national scale, 26.9% of all Colombians are poor, while 7.4% are extremely poor (Departamento Administrativo Nacional de Estadística, 2018).

1.4.1 Coffee production

Coffee is one of the world's major commodities and it employs 25 million people directly and provides 125 million additional indirect jobs (Ricketts et al., 2004; Ngo et al., 2011), mostly in tropical and biodiverse countries (Klein et al., 2003; Ricketts et al., 2004; Ngo et al., 2011). According to the 2017/2018 forecast, global coffee production amounts to 9,594,000 kg in contrast to a consumption of 9,510,000 kg (United States Department of Agriculture, 2017). Most of the coffee growers (approximately 70%) only have small farms, which makes them highly dependent on the coffee prices (Ngo et al., 2011).

The main species cultivated are *C. arabica* (arabica coffee) and *C. canephora* Pierre ex. Froehner (robusta coffee), which account for 66% or rather 34% of the global market, even though around 103 species exist (Ngo et al., 2011). Arabica coffee is generally considered to be of a higher quality (Ricketts et al., 2004; Ngo et al., 2011) and originates from Ethiopian rainforests around 850 A.D. The coffee plants prefer altitudes between 1,000-2,800 m, annual rainfall between 1,200-1,800 mm and an optimal temperature between 18-21 °C. The plants can reach heights of 3-12 meters, usually with a single trunk and almost horizontal branches (Ngo et al., 2011) which in the case of *C. arabica* can bear 2-12 flowers each (Klein et al., 2003). The flowers are white and have five petals (Klein et al., 2003; Ngo et al., 2011) and an intense scent (Manrique & Thimann, 2002; Klein et al., 2003), which if pollinated quickly wither in 1-2 days and if not remain open a maximum of 5 days (Ngo et al., 2011; Acosta Leal et al., 2017).

Picture 1: Flower of coffee plant in the municipality of Garzón, Huila. March 18th, 2018.

Source: Own photograph.

Pollination can occur between dawn and noon. Subsequently about 20-40% of the flowers develop into fruits during the next 7-10 months (Ngo et al., 2011; Acosta Leal et al., 2017). The coffee fruit normally grows from two ovules and is rather fleshy with a hard nut inside (Ngo et al., 2011). The coffee cultivation with shade improves the coffee's flavor. But nowadays it is more common to cultivate it without shade (so-called sun coffee) in order to increase yields. Since shade trees are felled this leads to monocultures, which decreases the bees' foraging and nesting possibilities (Roubik, 2002).

Globally, both coffee production and consumption are expected to rise at 1.2% annually until 2030 while annual consumption will reach 1.1 kg per person (Ngo et al., 2011). In Colombia however, the acreage has decreased by 5% during the last four years, while production stagnated. Productivity could be increased due to an extensive renewal program in which 737,000 hectares were renovated between 2010 and 2017. Of the 72,000 hectares of acreage replaced in 2017, 12,848 corresponded to Huila (Ministerio de Agricultura y Desarrollo Rural, 2018, B). Furthermore, this renewal program has increased the density as well as rust resistance of coffee plants because of a change in variety, while at the same time rejuvenating plants. This has led to a decrease in average age of 8 years: formerly 15 to now 7 years. Due to this, an almost 30% growth in harvests occurred during the last decade (United States Department of Agriculture, December 2017).

Colombia is characterized by small-scale coffee production (Bravo-Monroy et al., 2015). In 2016 Colombia's coffee production (measured as green coffee) amounted to a total of 853,920 tons (Evaluaciones Agropecuarias Municipales, n. d., A), with Huila contributing 145,154 tons (Evaluaciones Agropecuarias Municipales, n. d., B). Huila's coffee production can be seen in Figure 9.

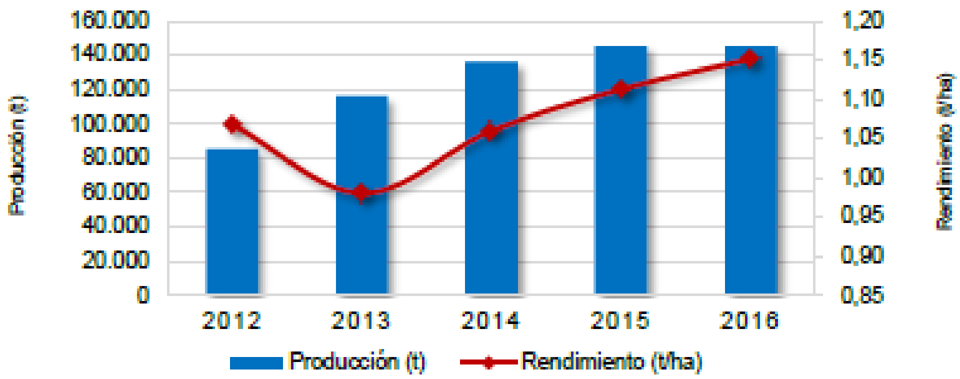


Figure 9: Coffee production (t) and yield (t/ha) in Huila, Colombia between 2012-2016. Source: Evaluaciones Agropecuarias Municipales, n. d., B.

The 2017 harvest was valued at 2.22 million€, which represents an increase of 6.62% compared to preceding year. Still, Colombia is suffering from the low coffee prices. In 2017 they were between 212.22€ and 224.01€ per sack of 60 kg, which hardly covers production costs (Ministerio de Agricultura y Desarrollo Rural, 2018, B).

Most of national production (769,860 tons) was exported (International Coffee Organization, n. d.), which represents around 88% of national coffee production. At the same time, imports become necessary to cater to national demand (Ministerio de Agricultura y Desarrollo Rural, 2018, B). In 2017, almost half of Colombia's coffee exports were to the US, even though in total coffee exports were made to 120 countries. Other major destination countries were Japan, the EU, especially Germany, and Canada (United States Department of Agriculture, December 2017; Ministerio de Agricultura y Desarrollo Rural, 2018, B). The exports in 2017 amounted to 2,807 million US$ (Ministerio de Agricultura y Desarrollo Rural, 2018, B). Exports are expected to stall at the same level in 2018 (United States Department of Agriculture, December 2017).

Huila is the major coffee producing department in Colombia. In 2016, Huila's production accounted for 17% of the country's total output (Evaluaciones Agropecuarias Municipales, n. d., A), as can be observed in Figure 10.

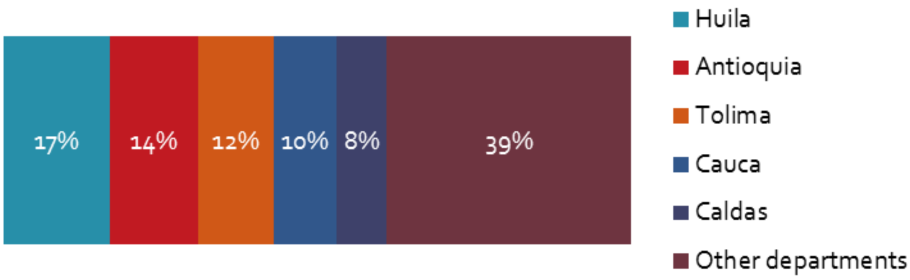


Figure 10: Principal coffee producing departments in Colombia in 2014.
Source: Base don Evaluaciones Agropecuarias Municipales, n. d., A.

Almost half of Huila's overall primary crop production is coffee (47%). The municipality within Huila producing most coffee is Pitalito, producing 18,440 tons, followed by Acevedo (14,049), La Plata (10,885), and Garzón (9,177) (Evaluaciones Agropecuarias Municipales, n. d., B).

1.4.2 Beekeeping

In Colombia, approximately 3,000 persons are occupied as beekeepers (Zambrano Canizales, 2016), mainly in form of family businesses (CORPOICA, 2012) Honeybees produce honey, which is almost 80% sugar, mainly from the nectar they recollect from flowers. Pollen can be found as a fine powder, which the bees agglutinate. Its color depends on the flower of origin (Acosta Leal et al., 2017). The main honey producers are the departments of Córdoba (10.61%), Huila (10.29%), Antioquia (10.19%), Bolívar (9.74%) and Sucre (9.16%). Pollen is mainly yielded in Boyacá (40%) and Cundinamarca (35%) (Zambrano Canizales, 2016; Ministerio de Agricultura y Desarrollo Rural, 2018, A). In 2017, the 110,689 beehives in Colombia produced 3,542 tons of honey, which is expected to increase even further during 2018, with a production of 3,893 tons (and 114,509 beehives). Huila produced 358 tons of honey in 2017 and is estimated to increase production to 391 tons in 2018. Generally, apiculture has the potential to grow, with estimates even calculating a capacity of a million beehives (Ministerio de Agricultura y Desarrollo Rural, 2018, A). Additionally, 120-140 tons of pollen were produced (Zambrano Canizales, 2016; Ministerio de Agricultura y Desarrollo Rural, 2018, A).

The majority of Colombia's production is consumed locally. Of the 3,228 tons of honey which were produced in 2016, only 38 tons were exported and even an additional 286 tons were imported. This represents a total national consumption of 3,476 tons or 67 grams per person per year. The honey prices within Colombia's main honey-producing departments, such as Huila, have been lower than in other areas, with a kilo valuing between 2.65€ and 3.54€. Globally, there are close to 100 million beehives producing 1,800,000 tons, in both cases China occupies the first rank. 11% of the global production originates from Latin America, with Mexico and Argentina contributing almost 50% of the honey. In 2016, the global honey exportations amounted to 2,034,227,000 US$ and the major importers during the last years were the US, Germany and France (Ministerio de Agricultura y Desarrollo Rural, 2018, A).

The services honeybees provide include pollination, their use as indicator species and apitourism (Ministerio de Agricultura y Desarrollo Rural, 2018, A). The products provided by honeybees can be divided into three groups (Ministerio de Agricultura y Desarrollo Rural, 2018, A; Acosta Leal et al., 2017): First, the production of biological material, such as queen bees, drone larvae or complete colonies. Second, goods created by secretion (using their glans), such as wax, apitoxins (the honeybees' venom), royal jelly (CORPOICA, 2012; Acosta Leal et al., 2017; Ministerio de Agricultura y Desarrollo Rural, 2018, A). This group of products is usually low-price and is treated as commodities (Ministerio de Agricultura y Desarrollo Rural, 2018, A). Third are transformed goods, as for example honey, pollen or propolis (CORPOICA, 2012; Acosta Leal et al., 2017; Ministerio de Agricultura y Desarrollo Rural, 2018, A). The characteristics and the quality of these products differ according to the hive's location, so that prices can differentiate based on the added value. Value may be added via the product's origin, certificates, as e.g. fair trade, or transformation as is the case e.g. with mead, a wine produced from honey. Another side effect which results in a good provided by apiculture is the jobs the sector creates. Aside from the 3.000 beekeepers in Colombia, another 3.000 additional direct jobs and about to 6.000 seasonal jobs during the harvest season are provided (Ministerio de Agricultura y Desarrollo Rural, 2018, A).

In Colombia, the mean honey production is 32 kg per year per colony, which among other factors depends on the apiary's altitude, and the production of pollen, which mainly occurs at heights above 2,600 masl. and amounts to 35 kg per year per colony (Ministerio de Agricultura y Desarrollo Rural, 2018, A). Production, however, depends on various factors such as climate, especially temperature, rainy or dry seasons, wind or light conditions or abundance and type of flowers, which should be bee-friendly and in turn also depend on the climate (CORPOICA, 2012; Ministerio de Agricultura y Desarrollo Rural, 2018, A). Other aspects which should be considered when setting up an apiary (Picture 2) include accessibility, soil conditions and security of the site (CORPOICA, 2012).

Picture 2: Exemplary apiary in the municipality of Garzón, Huila. May 1st, 2018. Source: Own photograph.

Since 1979, the main bee species used in Colombian apiculture is a hybrid, denominated as *africanizada*, which resulted from an uncontrolled crossbreed between the European and the African honeybee (*A. mellifera scutellata* Lepeletier 1836) (CORPOICA, 2012; Ministerio de Agricultura y Desarrollo Rural, 2018, A). The Africanized honeybee (Picture 3) currently worked with in Huila is more aggressive than the European honeybee.

Picture 3: Africanized honeybees in Garzón, Huila. May 1st, 2018.
Source: Own photograph.

Within the hives, three classes of bees exist: the queen bee, worker bees and drones, which all cater to different needs. The queen bee is responsible for reproduction; in the tropics she lays 800-1.200 eggs per day on average. Worker bees represent the biggest fraction within the hive, but are smaller than the other types of bees (CORPOICA, 2012).

2 Justification, objective and research questions

This chapter identifies knowledge gaps of the existing research while also introducing the thesis' objective, which will be fulfilled by answering three research questions.

2.1 Justification

Various ESs are common goods, what means that they are not traded on the market (Costanza et al., 2014; Gascon et al., 2015), while still holding a value (Costanza et al., 2014; Costanza et al., 2017). This lack of assigning a value to ESs has led to the degradation and even loss of biodiversity and ecosystems. This deterioration threatens the well-being of hundreds of millions of humans, especially poorer, rural households which usually depend higher on certain ESs as income sources (TEEB, 2010). Beekeeping provides highly to income security of many rural families (IPBES, 2016). More specifically the dimensions of security, health and income are affected (TEEB, 2010). However, there has been a recent increase of studies valuing ESs, initiated by a reframing of the human-nature relationship by society. This paradigm shift is crucial in establishing sustainable development, recognizing the importance of ESs to society's future well-being (Costanza et al., 2014). Nevertheless, the majority of existing studies on the valuation of pollination focus on developed countries, such as the United Kingdom, United States of America (USA) or Australia (Mburu et al., 2006; Hanley et al., 2015; Breeze et al., 2016), while studies in developing countries are lacking (Hanley et al., 2015; Breeze et al., 2016; Perez-Verdin et al., 2016). Further, existing studies are often inaccurate (Mburu et al., 2006; Allsopp et al., 2008), due to the reliance on assumptions (Allsopp et al., 2008), the lack of a commonly agreed-upon framework for the valuation, the great variety of methods (Mburu et al., 2006; Melathopoulos et al., 2015) and the availability of the necessary data (Melathopoulos et al., 2015).

In 2009, it was estimated that the dependence of agricultural Colombia's GDP on pollination amounted to 7.6-10%, indicating the agricultural sector's vulnerability. Benefits provided by pollination differ however at a subnational scale. In Figure 11 it can be observed that in Huila (indicated by the orange frame; 64-700 US$ per hectare) the monetary value of pollination lies well above the national average (<32 US$ per hectare; Lautenbach et al., 2012).

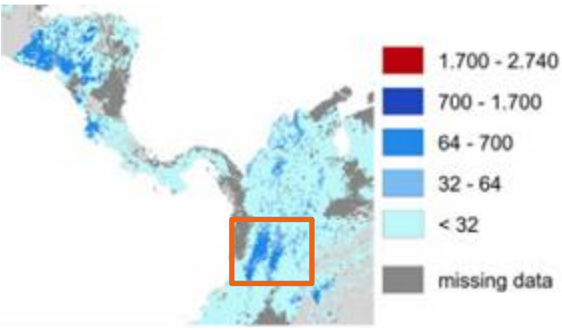


Figure 11: Pollination benefits (in US$ per hectare) for coffee in the year 2000. Source: Lautenbach et al., 2012.

In 2016, coffee cultivation contributed 0.25 billion€ to Huila's departmental GDP, which is equivalent to 6.09% of the total GDP. Moreover, the production of other agricultural crops supplied another 4.23% and forestry and timber extraction another 0.16% (Departamento Administrativo Nacional de Estadística, 2016), which highlights the economic dependence on pollination. Due to constantly low coffee prices however, many coffee growers are already abandoning coffee cultivation in order to produce more profitable crops (Olschewski et al., 2006).

2.2 Objective

This thesis aims to value the relevance of pollination as an ES in a social, ecological and economic context in Huila, Colombia and based thereon to give recommendations on how to foster resilience of the SES.

2.3 Research questions

I. Which factors constitute the SES analyzed in this thesis?
   i. Which are the social and ecological processes within the system?
   ii. Which anthropogenic influences can be observed and what is the historical background of the SES?
   iii. Which are the main threats to the SES?
   iv. How do changes in the SES influence human well-being?

II. How much are coffee growers willing to pay for pollination services?

III. How can the SES's resilience be increased in order to preserve it?

3 Methods

The set of methods applied in this thesis is derived from the work of Villegas-Palacio et al. (2016). This approach originally consists of three phases (Figure 12).

First, in the so-called characterization phase, key actors are defined and information is obtained using ethnographic techniques. This phase aims to identify the relationship between community and ecosystem and determines "the socio-cultural values placed on the ecosystem and characterizes the cultural, institutional, economic and political system" (Villegas-Palacio et al., 2016: 300).

In the second phase, the ecological and socio-cultural evaluation takes place, which includes "the characterization of drivers of change in the region, the consequences of the changes on the ecosystems processes, and their implications on the welfare of human communities" (Villegas-Palacio et al., 2016: 300). Ecological valuations are based on the ecosystem's relevant biophysical components and their relationships and transformations, whereas social-cultural valuations consider a given society's notions vis-à-vis resources and their use as well as traditions (ibid.).

In the third step, the economic valuation is realized, choosing the suited method and conducting surveys. The economic valuation analyzes "how a change in the natural system changes the welfare of society and the trade-offs society faces regarding environmental quality" (Villegas-Palacio et al., 2016: 306). This approach, which encourages the local community's participation in the valuation process, has led to an empowerment of the communities involved. It also incorporates ecological, economic and social-cultural valuations, which combined give a realistic estimate of the ES under study (ibid.).

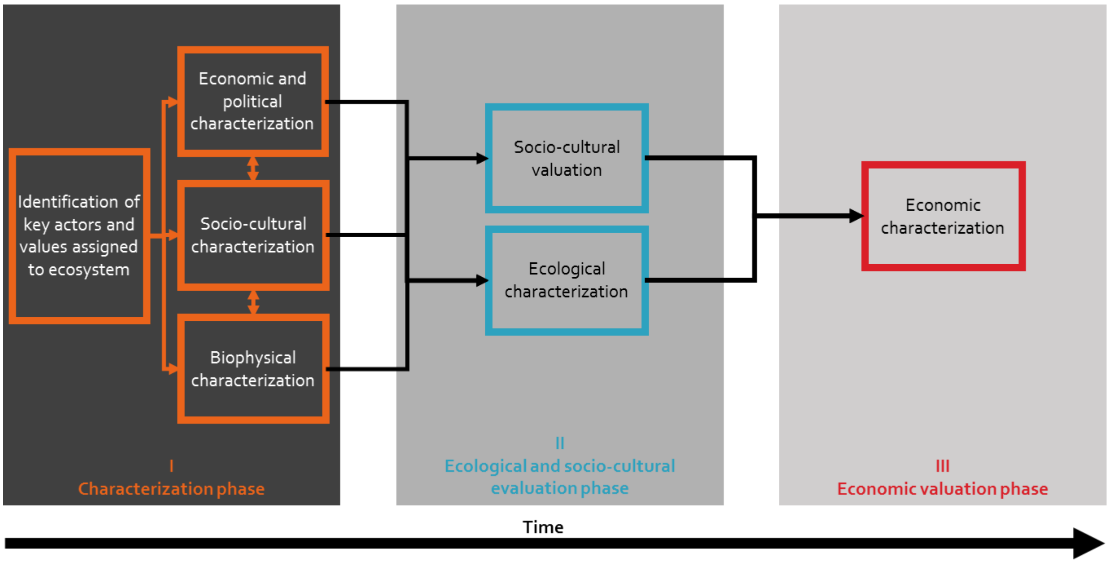


Figure 12: Methodological framework for economic valuation as introduced. Source: Based on Villegas-Palacio et al., 2016.

This approach (Figure 12) has been adapted in order to better fit the requirements as well as temporal and personal restraints of this thesis. It still consists in three consecutive phases, whose content has been modified to better match the research questions (Figure 13). The first two phases aim to answer the first research question including the sub-questions. During the first phase, a preliminary SES will be developed based on social and ecological factors identified during a literature review, which in the second phase will be adjusted according to the local circumstances. The relevant information will be deducted from the surveys and interviews. The second phase also aims to answer the second research question regarding the coffee growers' WTP. Thus, the third phase answers the third research question concerning recommendations for increasing the SES's resilience.

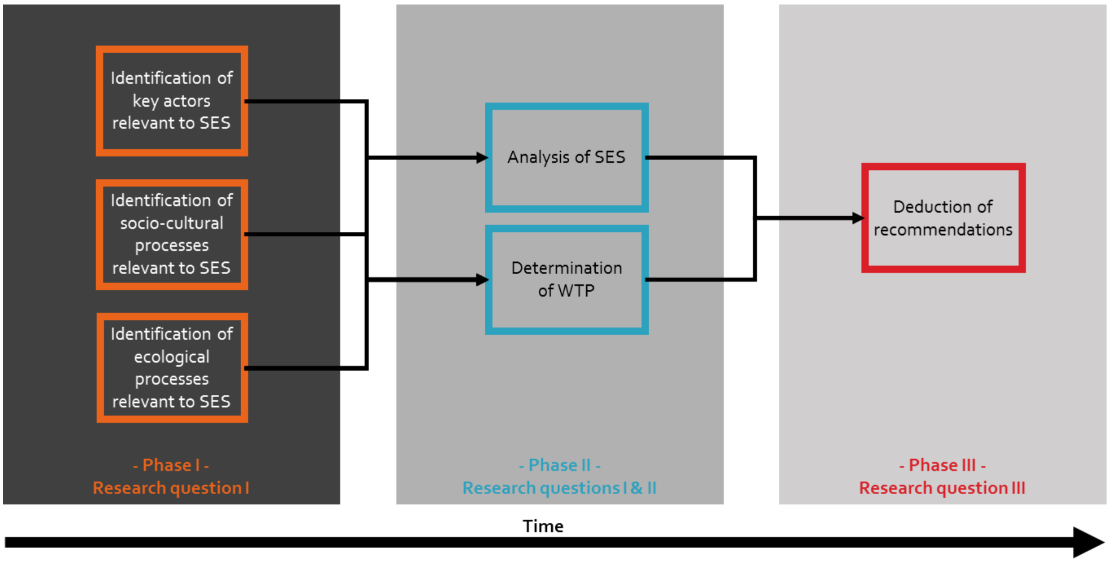


Figure 13: Method applied in this thesis.
Source: Own elaboration based on Villegas-Palacio et al., 2016.

Phase I: In the first phase the SES will be drafted, based on a thorough literature review. In order to do so, relevant socio-cultural and ecological processes will be identified. These factors will also contribute to the design of the interview and survey questions. Moreover, key actors of the SES will be identified via a stakeholder analysis. A stakeholder can be defined as an individual or a group, which has an interest in and can actively influence a project or is affected by the outcome (Gilstein, 2013; Eskerod & Larsen, 2017). The active participation can occur in form of material or non-material support (Siddiki & Goel, 2015; Eskerod & Larsen, 2017). The amount of this support as well as their viewpoints can also be very distinct (Siddiki & Goel, 2015). Consequently, the stakeholder analysis aims to identify the relevant stakeholders and to assess their possible impact (Grimble & Chan, 1995; Gilstein, 2013; Siddiki & Goel, 2015), as well as their motives and interrelations (Gilstein, 2013; Siddiki & Goel, 2015). This phase took place prior to the departure to Colombia, where the field work will be realized between February 28th and May 25th, 2018.

Phase II: In the subsequent second phase, which matches with the stay in Huila, the socio-cultural and ecological processes defined in the first phase were verified via surveys among beekeepers and coffee growers in Huila as well as expert interviews. As a result, three diagrams based on the SES introduced by Chapin et al. (2009) were elaborated. However, the SES in this thesis only distinguishes between exogenous controls and variables within the SES. Or rather, the variables within the SES will not be categorized as slow and fast variables as suggested by Chapin et al. (2009). The depictions of the SES in Huila reflect the beekeepers' point of view (Figure 18), the coffee growers' point of view (Figure 19), and the last one combined the two anterior SESs into one holistic one (Figure 20).

The surveys aim to identify the perception of pollinators, social, economic and market characteristics, main traits of and central threats to the SES as well as the actors' willingness to pay (WTP) for pollination services in different scenarios. These different methods include face-to-face or telephone interviews and online or offline questionnaires (Zhang et al., 2017). The surveys will be conducted face-to-face (Everett, 2013; Angell et al., 2018; Xie et al., 2018) wherever possible to increase trust between the interviewer and the respondents, who never met before filling in the questionnaire.

The surveys (Annexes A and B) were conducted among 19 beekeepers (March 27th to May 11th, 2018) and 25 coffee growers (April 16th to April 20th, 2018) and consists of four categories. This structure is identical for coffee growers and beekeepers; only the questions within the categories are adapted for each group:

(1) Questions regarding basic data, such as the respondent's name, sex and age, as well as the location of his apiary or coffee farm and the date on which the questionnaire was filled in.

(2) Questions regarding the social factors, i.e. for how long the person has worked as a beekeeper or coffee grower, if he has other income sources, if he receives governmental support, etc.

(3) Questions regarding the ecological factors, i.e. which bee species or coffee variety he works with, the occurrence of bee diseases or coffee plagues, the application of chemicals (medication for bees or fertilizer and pesticides for coffee plants), etc.

(4) Questions regarding the economic factors, i.e. how high annual production is and how high average prices during the last year were, as well as their WTP for pollination, etc.

As can be seen in Figure 14, pollination represents an indirect use value, which is often used for regulating services (Mburu et al., 2006; TEEB, 2010). Pollination does not directly benefit society, but rather via the agricultural production and preservation of biodiversity and ecosystem functioning. The method applied in order to estimate WTP will be CVM. The WTP will be determined via the afore-mentioned questionnaires and the according questions are part of the questionnaire's fourth category. The WTP serves as a proxy for the value of pollination. CVM is oftentimes employed when valuing non-market resources in environmental impact or cost-benefit assessments and aims to determine its value by means of applying a stated preference approach (Everett, 2013; Choi et al., 2017; Lim et al., 2017; Angell et al., 2018). This method is suitable in order to determine WTP for a non-market good, whenever the interviewee directly benefits from the ES studied (Hanley et al., 2015). CVM always concerns hypothetical markets (an den Berg et al., 2017). It is derived from the concepts of WTP or willingness to accept (Everett, 2013; Angell et al., 2018; de Melo Travassos et al., 2018; Xie et al., 2018). The benefits of the CVM is that it generates reliable data (Lim et al., 2017), which indicates the respondent's preference's strength and direction (Akhtar et al., 2017). Nevertheless, results are considerable influenced by region and time (Xie et al., 2018).

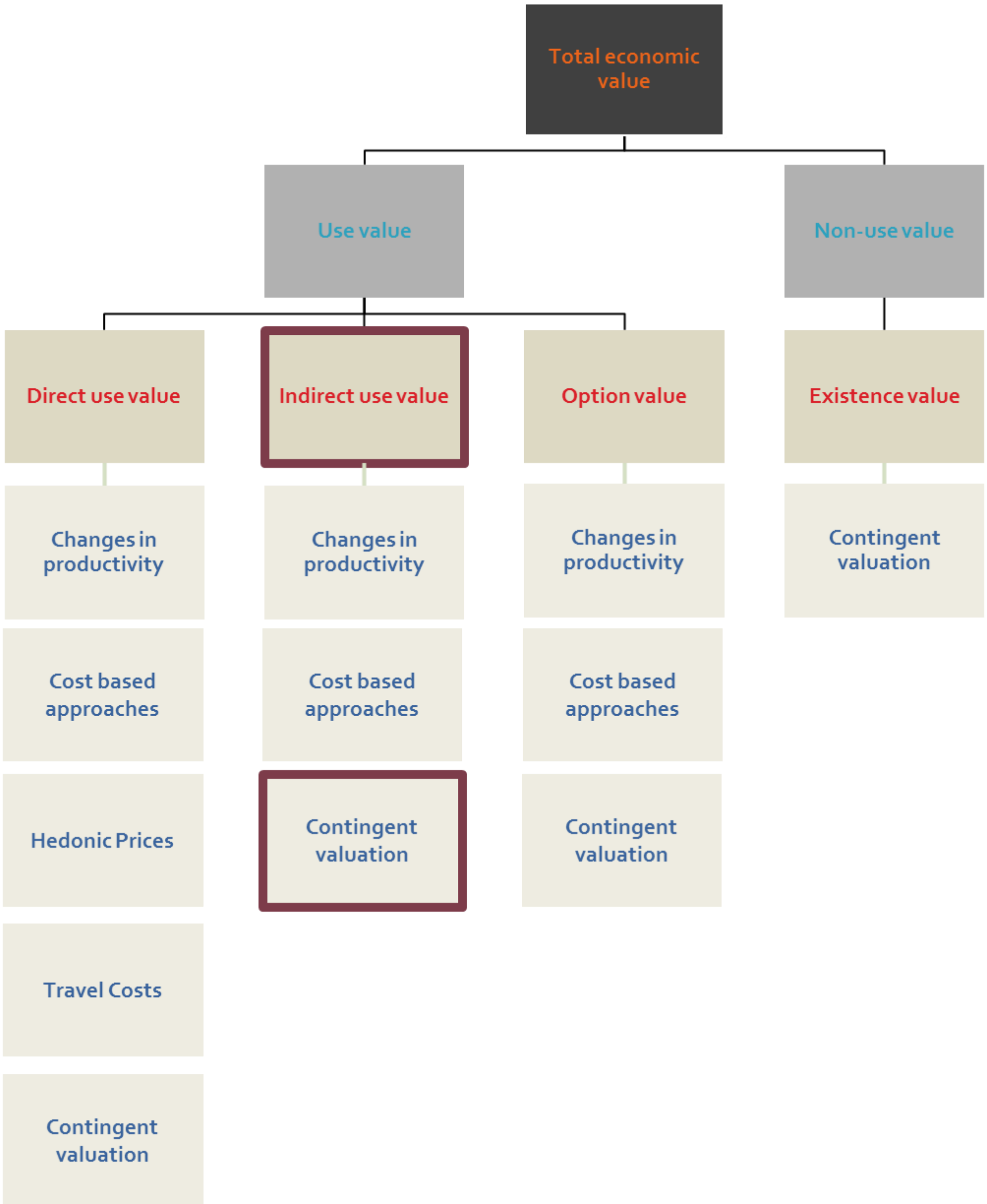


Figure 14: Classification of value estimated and method applied.
Source: Based on Millennium Ecosystem Assessment, 2003; McKinney, 2009 & TEEB, 2010.

The means by which WTP will be estimated in this thesis are open-ended question (de Melo Travassos et al., 2018). Other sources however do not encourage the use of open-ended questions (Everett, 2013; Lim et al., 2017), since it might lead to an overestimation of WTP (Lim et al., 2017). The according question was phrased as clear, concrete and realistic as possible (an den Berg et al., 2017; de Melo Travassos et al., 2018) in order to elicit WTP when changes in an ES, in this case pollination, occur (de Melo Travassos et al., 2018). Krupnick (2006) recommends the use of supporting questions in surveys, such as the following: (1) regarding demographics or the economic situation; (2) regarding specific behavior or (3) characteristics relevant to the study, i.e. certifications; (4) regarding prior knowledge; (5) regarding the understanding of the decisive factors; (6) debriefing questions; as well as (7) regarding the respondent's attitude towards the survey object. The first four categories are included in the questionnaire.

In order to contextualize the surveys' findings, two to three expert interviews will be conducted. Interviews are defined as "verbal interchanges where one person, the interviewer, attempts to elicit information from another person" (Longhurst, 2003: 145). Semi-structured interviews are characterized by the fact that the interviewer already knows which information he wants to obtain before conducting the interview and predefines questions to obtain qualitative data. Still, the interview is flexible to some degree as issues detected during the conversation can be further investigated, even if not previously included in the questionnaire. Other interview forms are structured or unstructured interviews (Longhurst, 2003; Fylan, 2005). In the case of structured interviews, the interviewer elaborates a questionnaire which he applies with all the interviewees in the same manner and order. Unstructured interviews, on the other hand, do not require the formulation of questions beforehand, and only the topic is defined (Longhurst, 2003; Fylan, 2005). Normally, this type of interviews is more influenced by the interviewee, while structured interviews are dominated by the interviewer and semi-structured interviews are more similar to conversations (Longhurst, 2003). Due to their flexibility in questioning, semi-structured interviews are especially suited to detect motives of the interviewees (Fylan, 2005). The interviews conducted as part of this thesis will be semi-structured ones, in order to maintain the flexibility to explore each expert's focus while still following a common theme and covering all the important points. The questionnaire used for the interviews focused on the perception of the benefits and threats of bees. Moreover, it covered an assessment of the preliminary SES developed in phase I, its components and its impact on human well-being as well as the value of pollination in an ecological, economic and sociocultural dimension. The translated questionnaire can be found in Annex C.

Three semi-structured interviews were conducted. The first one on March 23rd, 2018, with Francisco Arturo F. A. Silva Aldana, personal interview, March 23, 2018, the legal representative and founder of Apisred, and apicultural company based in Neiva and operating in Huila. The second one on April 4th, 2018, Dr. rer. nat. Rodulfo Ospina-Tórres and Guiomar Nates Parra. Both are investigators at the National University of Colombia (UNAL) in Bogota and affiliated with the *Bee Research Laboratory* [Laboratorio de Investigaciones en Abejas]. And finally, the third one with Giovanny Andres G. A. Vargas Bautista, personal interview, May 21, 2018, an investigator focused on apiculture at the *Apicultural Group National University* [Grupo Apícola Universidad Nacional] which is also based at the UNAL in Bogota.

Phase III: Based on the findings of the first two phases, recommendations in order to increase the SES's resilience will be derived. These will also be backed by relevant literature. Here also comes into effect the stakeholder analysis from Phase I. The key actors affected by these recommendations will be briefly analyzed. In terms of time, this phase might overlap with the second phase and thus begin during the field work in Colombia or after returning to Germany.

Generally, WTP and other economic data will be collected in Colombian Pesos (COP), the local currency. For a better understanding within the thesis, these will be converted to Euros. In order to do so, the historic exchange rate from April 20th, 2018 will be used, according to which 1€ equals 3,392.70800 COP (https://de.exchange-rates.org/history/COP/EUR/T; accessed August 8th, 2018).

4 Results

Beekeepers: The 19 beekeepers surveyed between March 27th and May 11th, 2018, were based in the municipalities of Algeciras, Rivera, Neiva, Garzón, Pitalito, San Agustín and Santa María. Thereof, one survey was realized via phone and nine by Asociación de apicultores del municipio de Garzón (ASOAPIS) based in Garzón. The other nine interviews were realized face-to-face by the author. Of the 19 beekeepers, 10 were from the municipality of Garzón, in each case two from Neiva, San Agustín, and Pitalito, and one from Algeciras, Rivera and Santa María. The apiary's (Picture 2) location of only nine beekeepers could be determined.

These were at an average altitude of 1,046 m, with a standard deviation of 314 m. The lowest apiary was located at 449 above sea level (masl) and the highest at 1,425 masl. Of the beekeepers surveyed only one was female. Two were 30-40, four 40-50, five 50-60, and eight were older than 60. The beekeepers had an overall average of 27.8 years of experience as beekeeper, with a standard deviation of 16.8 years. The minimum experience was 9 years and the maximum 63 years. Moreover, eight beekeepers indicated that they rely on beekeeping as their sole source of income, while eleven stated that they have additional sources of income, among them livestock, electric engineering, the recollection of rural swarms, agriculture, pension, a stationary, and poultry. Almost a third, more precisely six beekeepers, received governmental support, even though not always as part of their apicultural occupation. In some cases it was non-monetary support in research or trainings, other times a governmental program which aims to diminish rural poverty, or sometimes support for the company or association. In one case, in San Agustín, the whole association was only founded in order to participate in a call for governmental support. 17 beekeepers formed part of an association, while two did not. Some did not specify with which they are associated, whereas others were even associated with two. Eight were linked to ASOAPIS, five to Cooperativa Integral de Apicultores del Huila (COAPI), three with Asociación de apicultores del Pitalito (ASAP) and one with APIMACO. ASOAPIS, ASAP and APIMACO are local associations in Garzón, Pitalito and San Agustín respectively, while COAPI is a regional association spanning all of Huila. Benefits these associations offered included trainings, technical assistance, marketing, and generally help. Two beekeepers stated that they do not receive any benefits at all. Most beekeepers questioned sell their products locally (12) or regionally (10), some nationally (5), and one internationally, mainly to the US. Ten beekeepers hold a certification, namely *negocio verde*, a national certification from the Ministry of Environment and Sustainable Development for economic activities with a positive environmental impact, and one was certified by the Alexander von Humboldt Biological Resources Research Institute. All 19 beekeepers handled the Africanized bee, and ten beekeepers also the stingless meliponine *Tetragonisca angustula* Illiger 1806. One beekeeper had bees from the native *Euglossini* (euglossine tribe) and one imported European honeybees (*A. mellifera*). Some also had native bees, specifically *Melipona eburnea* Friese (boca de sapo) and *Melipona favosa* Fabricius 1798. Moreover, ten beekeepers reported that they also see native bees in or around their apiaries. The number of colonies of the Africanized bees the beekeepers owned varied greatly: The average amounted to 43.78 colonies, with a standard deviation of 34.12 colonies and a minimum of four and a maximum of 150 colonies. However, various beekeepers lamented their high losses of bees (Picture 4). One beekeeper said he lost three complete apiaries, equaling 120 colonies, during the last year, while another lost 35 of his 50 colonies during the same time. Both resided in Garzón. In San Agustín, one beekeeper told that he lost five of his 23 colonies and the beekeeper from Santa María lost 110. Unfortunately, no official data regarding the loss of bee colonies could be found in order to contextualize these findings.

Picture 4: Dead bees in the municipality of Pitalito, Huila. May 8th, 2018.
Source: Own photograph.

The majority (13) of beekeepers said that no disease occurred during the last year, while five mentioned *Varroa* and one poisoning, whose source could not be definitely defined. However, ten beekeepers stated that a colony collapse disorder took place during the last year, cause mainly by fumigation (in nine cases), which was related to the cultivation of lulo (*Solanum quitoense*), coffee and corn, and also to climate change, scarce blooming, and carelessness. None of the beekeepers used medications, only three gave the bees vitamins from time to time. The apiaries were always located close to forests and other flower sources. Knowledge about bees' benefits and threats were rather prevalent among the beekeepers interviewed. Table 1 summarizes this question's results.

Table 1: Perception of bees' benefits and threats among beekeepers in the department of Huila (n= 19).

Source: Own elaboration based on surveys conducted.

Benefits	#	Threats	#
Preservation of biodiversity	17	Use of pesticides	19
Increase of agricultural productivity	17	Change in land uses, i.e. deforestation	18
Maintenance of ecosystem	17	Agricultural intensification, i.e. monocultures	15
Pollination	19	Introduction of invasive species	13
Contribution to food security	18	Habitat destruction and degradation	19
		Climate change	16

Additional benefits mentioned by the beekeepers were medicine (namely apitoxins, propolis, and pollen), supplementary income sources for beekeepers, leading to a better life, human survival, and cosmetics. The theft of beehives, overexploitation by humans, human ignorance, and water pollution by agriculture were named as further threats. But also the introduction of invasive species was specified more by giving examples, such as the Asian hornet (*Vespa velutina*), as well as the accompanying introduction of diseases, bacteria and the resulting rivalry for food and nesting resources. All but one of the beekeepers produced honey and propolis, twelve produced pollen, 11 nucleus, which are small beehives, ten royal jelly, eight bee wax, two bee queens, and only one was producing mead, mead (honey-wine), complete beehives, *propomieles*, and apitoxins. But often, the bee wax and nucleus were produced for self-consumption, for example to offset colony losses. Also the propolis and honey-beer were produced for self-consumption. All beekeepers were satisfied with the quality of the products they produced. Of the 17 beekeepers who answered the question about the profitability of their apicultural activities, all said that they were profitable.

Coffee growers: Furthermore, 25 coffee growers from the Garzón municipality were interviewed in person from April 16th to April 20th, 2018. All of the coffee growers interviewed were associated with Cooperativa Central de Caficultores del Huila (COOCENTRAL), a cooperative spanning seven municipalities in central Huila with around 4,000 associates (COOCENTRAL, n. d.). The coffee growers perceived the technical support, subsidies and loans, reduced price volatility, and trainings as benefits this cooperative offers. Only one coffee grower questioned stated that the cooperative does not propose any benefit. All farmers interviewed had their farms in the municipality of Garzón with altitudes between 749 m and 1,803 m. 17 were male and 8 female with an average of almost 27 years in the cultivation of coffee, even though many considered themselves coffee growers since forever. One coffee grower was 20-30, four 30-40, five 40-50, nine 50-60, and six had more than 60 years.

When comparing the age distribution between coffee growers and beekeepers, it becomes apparent that the beekeepers generally tend to be older than coffee growers (Table 2). Almost half of the beekeepers (42%) are older than 60, while none was 20-30. On the other hand, most coffee growers were 50-60 (36%). Nevertheless, also in this case the lack of younger generations is noteworthy. Only a fifth (20%) was younger than 40. For comparison, about a tenth (11%) of beekeepers was younger than 40 and only a third (31%) younger than 50.

Table 2: Comparison of age distribution between coffee growers (n=25) and beekeepers (n=19). Source: Own elaboration.

AGE DISTRIBUTION					
	20-30	30-40	40-50	50-60	60+
Coffee growers	1 4%	4 16%	5 20%	9 36%	6 24%
Beekeepers	0 0%	2 11%	4 21%	5 26%	8 42%

19 stated that they have further income sources, while 6 did not have. Of the 19 with additional incomes, 16 cultivated additional crops, most commonly banana, which often was intercropped with the coffee, but also yucca, avocado, corn, and various citrus fruits (Picture 5). Intercropping is an agricultural practice that describes the simultaneous and spatially congruent cultivation of at least two crops in order to maximize crop productivity. Other advantages include erosion and pest control (Ouma & Jeruto, 2010). Some also cultivated other crops, but without intercropping them. These crops included onions and cacao.

Picture 5: Coffee intercropped with banana, yucca, corn and a citrus tree in the municipality of Garzón, Huila. April 16th, 2018.
Source: Own photograph.

Non-agricultural income sources included livestock, dairy, chickens and in one case the work as primary school teacher. None of the coffee growers received governmental support. But all coffee growers were equipped with at least one certification: Since COOCENTRAL as an organization holds a Fairtrade Labelling Organizations International (FLO) certification, every associated coffee grower is certified as well. Some coffee growers held as much as six certificates, among them Rainforest Alliance, UTZ, 4C, Starbucks C.A.F.E. practices and café femenino. Figure 15 illustrates the amount of coffee growers holding each of the certificates mentioned before.

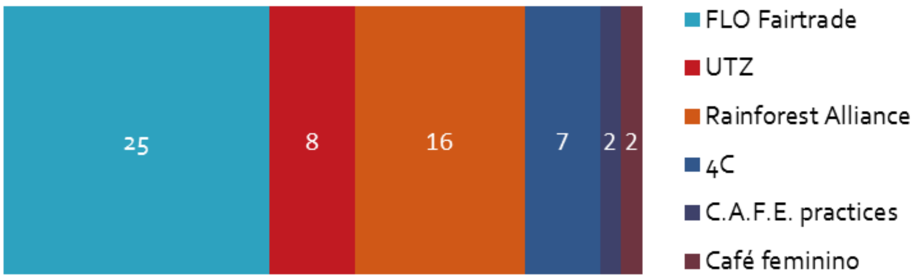


Figure 15: Certifications held by coffee growers interviewed (n = 25).
Source: Own elaboration based on surveys conducted.

The coffee farmers exclusively cultivate *C. arabica*, which was found in form of four varieties in the coffee farms visited: *C. arabica* 'Caturra', *C. arabica* 'Castillo', *C. arabica*

'Colombia', and *C. arabica* 'Catimor'. Usually, the coffee growers questioned cultivated different varieties on their farmlands, so that 63% had variety 'Caturra', 67% had 'Castillo', 50% had 'Colombia' and 17% had 'Catimor'. Figure 16 shows the distribution of coffee varieties among the coffee growers questioned.

Figure 16: Coffee varieties cultivated among Huilan coffee growers interviewed (n = 25). Source: Own elaboration.

The majority (24) of the coffee growers were the owner of the farm they worked on, only in one case it belonged to the father. These farms had an average size of 7.95 hectares, with a standard deviation of 11.74 hectares, with the smallest being 1 hectare and the biggest 60 hectares. In average, 55% of this was dedicated to the cultivation of coffee. On average there were 21,075coffee plants per farm with a standard deviation of 38,895.35, the minimum being 3,500 and the maximum 200,000 plants. The majority, 20 out of 25 coffee growers, sold all of their coffee to COOCENTRAL. Two sold their coffee to another coffee cooperation aside from COOCENTRAL, and the other three sold theirs independently either regionally or nationally. All coffee growers sold their coffee in form of beans, usually fermented and dried (85%). Moreover, all of the coffee growers asked used fertilizer, usually ever 3-4 months. Only 1 out of the 25 coffee growers said that his plants do not suffer from any plague or disease. The others had mostly problems with *Hemileia vastatrix* Berk. & Broome (coffee leaf rust) and *Hypothenemus hampei* Ferrari, 1867 (coffee borer beetle), which concerned 14 and 15 cases respectively. In two additional cases, not further identified ants were found among the coffee plants' roots. Due to this, 18 coffee growers used pesticides in different intervals and in different moments, while eight controlled the coffee borer beetle manually. The pesticides were applied between 1 to 4 times per year, sometimes only when deemed necessary, and application took place sometimes after each harvest, in October, not while there were fruits, before using fertilizer, before or after flowering and in one case even while flowering, even though a special pesticide was used. 23 coffee growers observed *A. mellifera scutellata* among their coffee cultivations and 20 *T. angustula*. Three even had hives of the latter at home. One coffee grower said he even sometimes saw *Euglossini*. Most of the coffee growers are fairly aware about the benefits bees bring, while being a bit ignorant about the threats they face, as can be seen in Table 3. Nevertheless, all coffee growers questioned were conscious, that pesticides threaten honeybees.

Table 3: Perception of bees' benefits and threats among coffee growers in the department of Huila (n= 25).

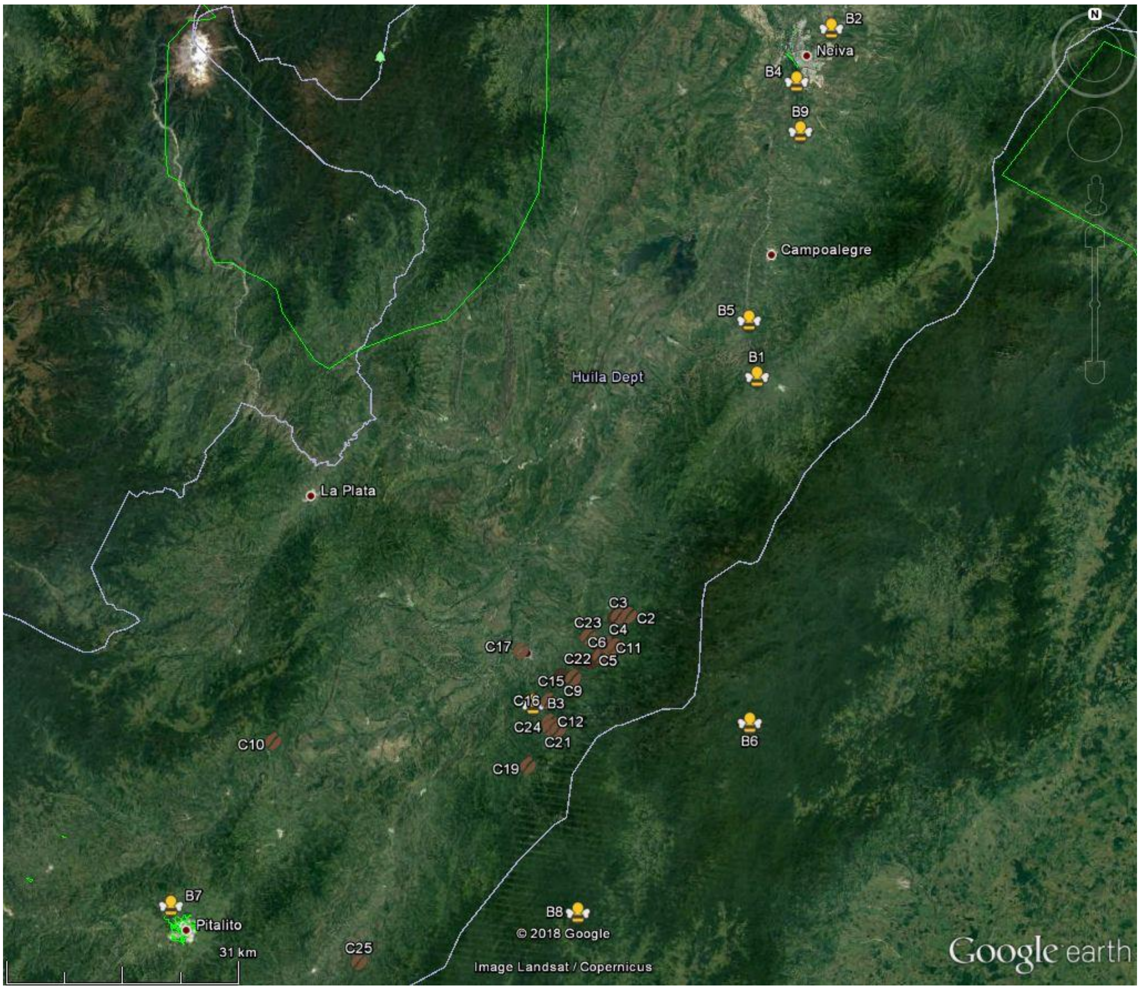
Source: Own elaboration based on surveys conducted.

Benefits	#	Threats	#
Preservation of biodiversity	24	Use of pesticides	25
Increase of agricultural productivity	22	Change in land uses, i.e. deforestation	21
Maintenance of ecosystem	23	Agricultural intensification, i.e. monocultures	7
Pollination	24	Introduction of invasive species	8
Contribution to food security	24	Habitat destruction and degradation	18
		Climate change	13

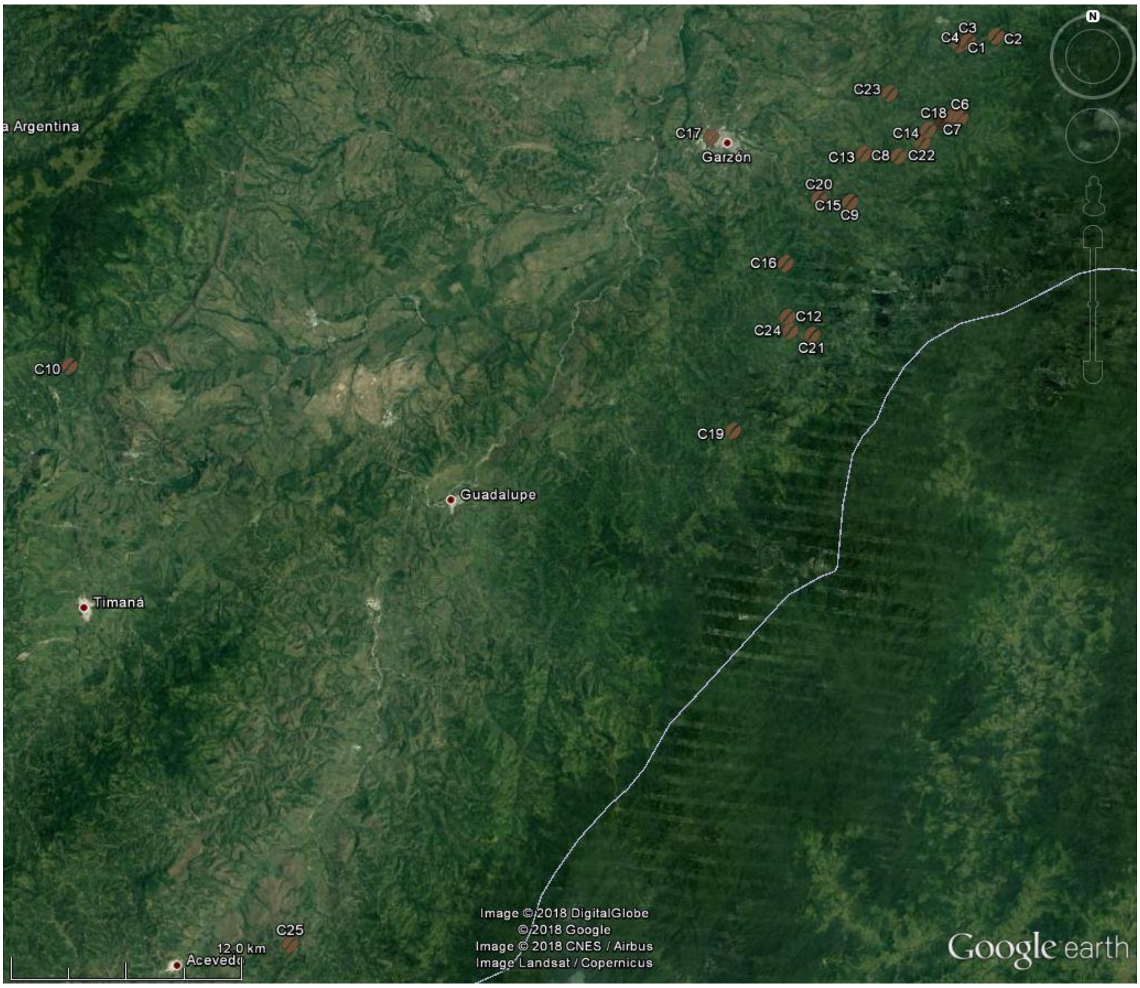
Additional benefits named included the production of honey and pollen, which contribute to human health. Regarding the threats the coffee grower mentioned also natural enemies, humans, and transgenic crops.

The surveyed coffee growers produced an average of 8,557.5 kg of coffee per year, with a standard deviation of 18,955.70 kg and a minimum of 1,300 kg and a maximum of 100,000 kg annually. In selling their coffee, the coffee growers obtained an average price of 1.86€/kg, with a standard deviation of 0.48€/kg. Selling prices differ due to the certifications held and the volatility of national prices which depend on international prices and the COP/US$ exchange rate. This resulted in a minimum price of 0.68€/kg and a maximum of 2.68€/kg. Thereupon, 14 coffee growers stated that the cultivation of coffee is still profitable for them, while for eleven it is not. One coffee grower identified the problem that coffee prices were too low, while costs for agricultural inputs stayed the same. He even had to abandon the 'Caturra' variety, which is the best in his opinion, because of coffee leaf rust. That is why he was not satisfied with the quality of his coffee, while two others criticized the prices' volatility. But after all, 23 coffee farmers were content with the quality of the coffee they produced while two were not.

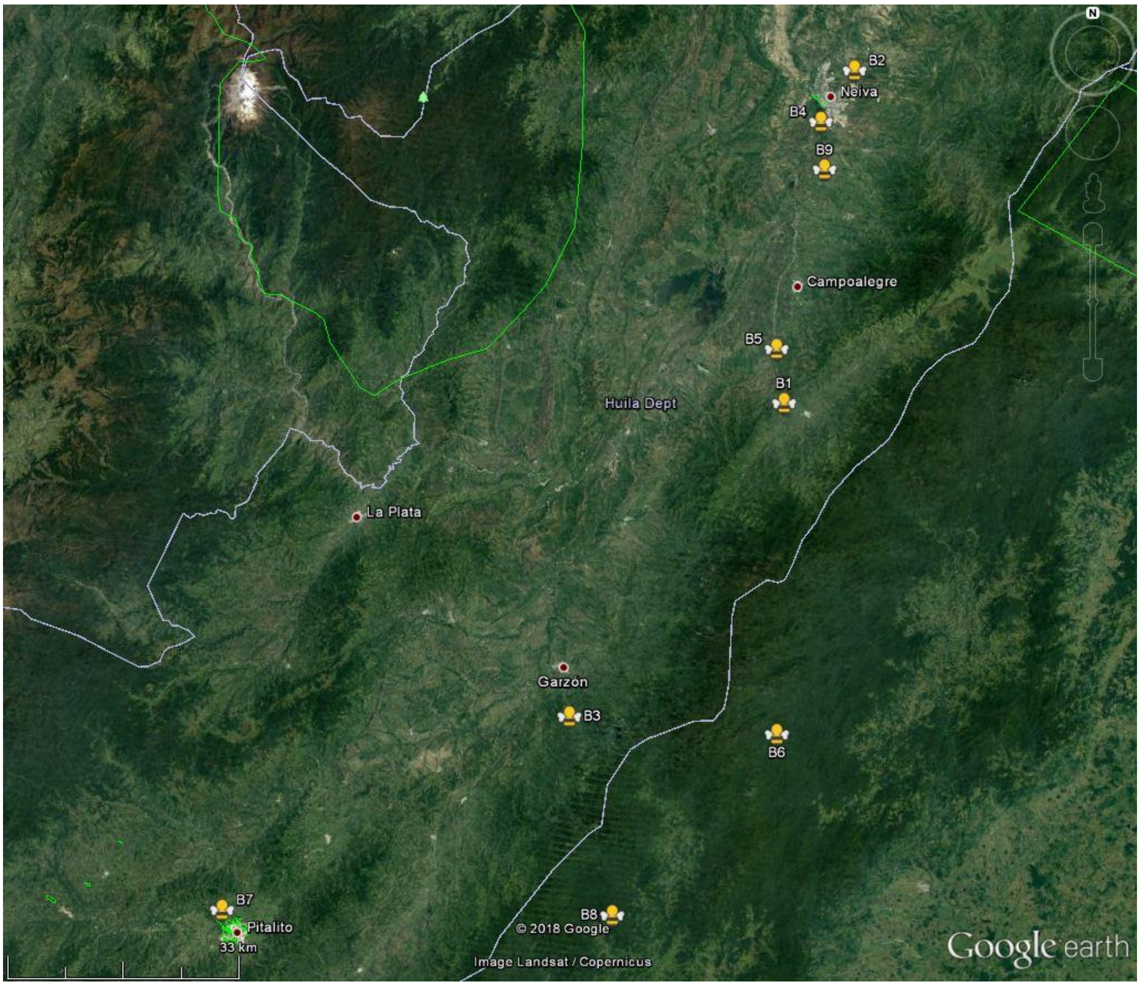
Map 3 depicts the spatial distribution of the coffee farms and apiaries where interviews were conducted. It includes 25 coffee farms and nine apiaries, the others were not visited. In one case, two interviews were realized on the same farm, because father and son both worked on this farm on distinct fields. Apiaries are represented by a small bee icon and coffee farms by a coffee bean icon. Additionally, two more detailed maps, one for coffee growers (Map 4) and one for beekeepers (Map 5), were elaborated. For the coordinates of the coffee farms and apiaries, please see Annex D.



Map 3: Map of Huila including locations of apiaries (n=9) and coffee farms (n= 25). Source: Google Earth. 2018. A.



Map 4: Map of southern Huila including locations coffee farms (n= 25).
Source: Google Earth. 2018. B.



Map 5: Map of Huila including locations of apiaries (n=9).
Source: Google Earth. 2018. B.

4.1 Analysis of the social-ecological system

In this chapter, the SES will be introduced and analyzed, focusing on the system's social and ecological processes, anthropogenic alterations, main threats and its impact on human well-being. This analysis is the foundation for the recommendations on how to increase the SES's resilience later on (Chapter 5.2).

4.1.1 Social and ecological processes within the social-ecological system

Whereas in the first subchapter, the general context is spanned, the second subchapter depicts the SES and its fundamental processes and actors.

4.1.1.1 Interrelations between pollination and other ecosystem services

Besides pollination's social impact via the production of sustainable commodities (CORPOICA, 2012), it is indirectly linked to other ecological processes (Figure 17). However, studies regarding the links of pollination and other ecological factors are non-existent in Central and South America (Garibaldi et al., 2018).

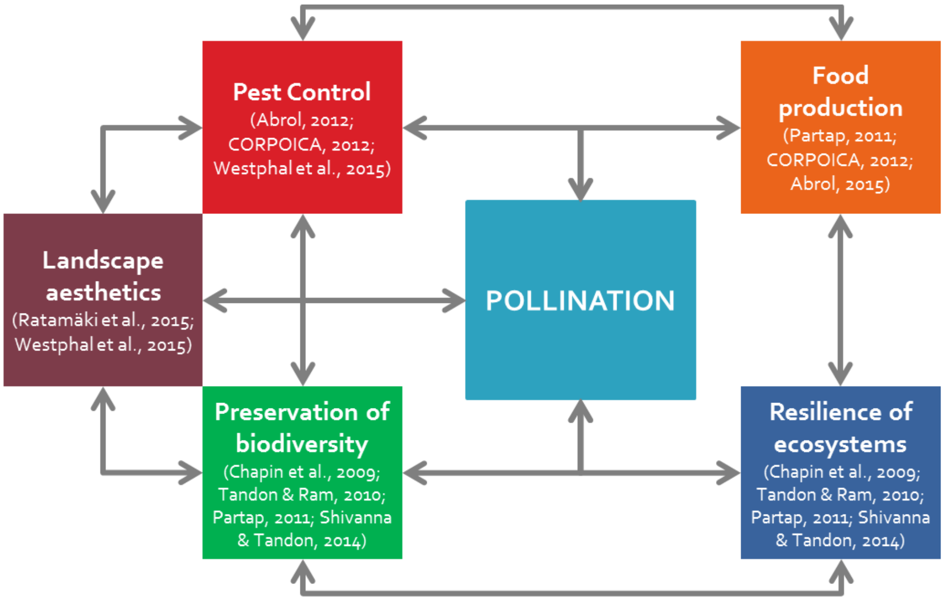


Figure 17: Interrelations between pollination and other relevant ecological processes. Source: Own elaboration.

Pest control: In the case of pollinator abundance plants are less likely infected by pests. In case of a sufficient number of pollinators, the time in which flowers are open and waiting to be pollinated is significantly reduced which in turn declines the probability of pest infection (Abrol, 2012). Furthermore, pollinators compete with other plant-eating insects, which may transmit plagues, for food (CORPOICA, 2012). Moreover, the absence of pests results in an increased agricultural production and food supply (Zulka & Götzl, 2015; Garibaldi et al., 2018), leading to the second point of pollination's contribution to food production.

Food Production: Successful pollination is the prerequisite for seed and fruit production in plants (Tandon & Ram, 2010; Partap, 2011; Shivanna & Tandon, 2014; Van der Sluijs & Vaage, 2016), which affects 75 to 90% of all flowering plants (Tandon & Ram, 2010; Abrol, 2012; Shivanna & Tandon 2014). Thus, pollination helps in establishing food security (Mburu et al., 2006; Steward et al., 2014). Pollination is especially important in battling Hidden Hunger (Chapin et al. 2009; Eilers et al., 2011; Klatt et al, 2014; Van der Sluijs & Vaage, 2016). This describes the state in which people lack sufficient intake of the necessary micronutrients, which are mainly provided by pollinated crops (Eilers et al., 2011; Van der Sluijs & Vaage, 2016). Moreover, insect pollination positively affects fruit crops resulting in heightened productivity and quality (Partap, 2011; CORPOICA, 2012; Abrol, 2015; Acosta Leal et al., 2017; Garibaldi et al., 2018), even in self-fruitful crops (Allsopp et al., 2008; Acosta Leal et al., 2017).

Preservation of biodiversity: Pollination is indispensable for plant reproduction as well as plants' genetic variety (Chapin et al., 2009; Tandon & Ram, 2010; Partap, 2011; Shivanna & Tandon, 2014). Pollination by insects and the generated gene flow prevent inbreeding depression, which leads to a decreased ability to survive and a reduction in productivity and health (Fernando, 2013). Furthermore, pollination maintains the biodiversity and thus ensures the survival of plants species (Abrol, 2012; Ratamäki et al., 2015). Biodiversity is a fundamental contributor to human well-being, providing "various ES, including material (e.g. food, fibers, timber), regulating (e.g. pest regulation, pollination, and nutrient cycling), and non-material (e.g. health, aesthetic, spiritual, education, or recreation)" (Garibaldi et al., 2018: 38).

Resilience of ecosystems: The diversity of species to which pollination contributes, "protects ecosystem functions against failure under altered conditions" (Zulka & Götzl, 2015: 170). This diversity of species in turn depends on the successful reproduction of plant species, which is provided by pollination services (Chapin et al., 2009; Tandon & Ram, 2010; Partap, 2011; Shivanna & Tandon, 2014).

In addition, there also exist linkages between pollination and landscape aesthetics (Ratamäki et al., 2015; Westphal et al., 2015).

4.1.1.2 Description of the social-ecological system

In the following, the three SESs, the first focusing on beekeepers (Figure 18), the second one on coffee growers (Figure 19), and the third one combining the two preceding ones into a holistic SES (Figure 20), are depicted. All three describe the current situation, particularly the present actors' activities. The SESs include exogenous controls and variables within the SES, classified into the social and ecological spheres.

Beekeeper SES: The actors that form part of the SES from the beekeepers' point of view include individual beekeepers, as well as beekeeper associations and companies, in the present case COAPI, ASAP, ASOAPIS, APIMACO and Apisred, and the Productive Chain of Bees and Beekeeping [CPAA; Cadena Productiva de las Abejas y la Apicultura]. Beekeeping associations and companies organize the commercialization of beekeeping-related products and the provision of trainings to beekeepers (Apisred, 2018). The CPAA is a consulting entity to the Ministry of Agriculture and Rural Development [MADR; Ministerio de Agricultura y Desarrollo Rural] and aims to increase the beekeeping sector's productivity (CPAA, n.d.) as well as to improve sustainability in the whole supply chain and increase final product quality (Ministerio de Agricultura y Desarrollo Rural, n.d.).

These actors are surrounded by the system's ecological and social properties. Exogenous controls in the ecological sphere include the local climate, climate change, regional flora and fauna, and proximity to natural forests, all of which influence beekeeping within the SES. Social exogenous controls consist of governmental support and legislation and the regional economy, since these create the circumstances of the actors' possible actions. All of the aforementioned controls affect the SES from the outside.

Ecological variables within the SES are comprised of diversity and abundance of pollinators and flowering plants, the occurrence of bee diseases, pest control, food production and the resilience of ecosystems. These endogenous variables affect beekeeping directly. Beekeeping in Colombia has a high potential, due to the country's high biodiversity which provides for continuous food sources throughout the year. Furthermore, plants produce more pollen than in other regions, which allows for pollen production during the whole year (G. A. Vargas Bautista, personal interview, May 21, 2018).

The corresponding actors' responses are the conservation of biodiversity and ecosystems which is provided via pollination as a side effect of the actors' beekeeping activity. Social variables include habitat destruction, pesticide overuse, the introduction of exotic species, the dependency on beekeeping as sole source of income, and the prices of apicultural products. The actors' response involves certifications, namely as *negocio verde*.

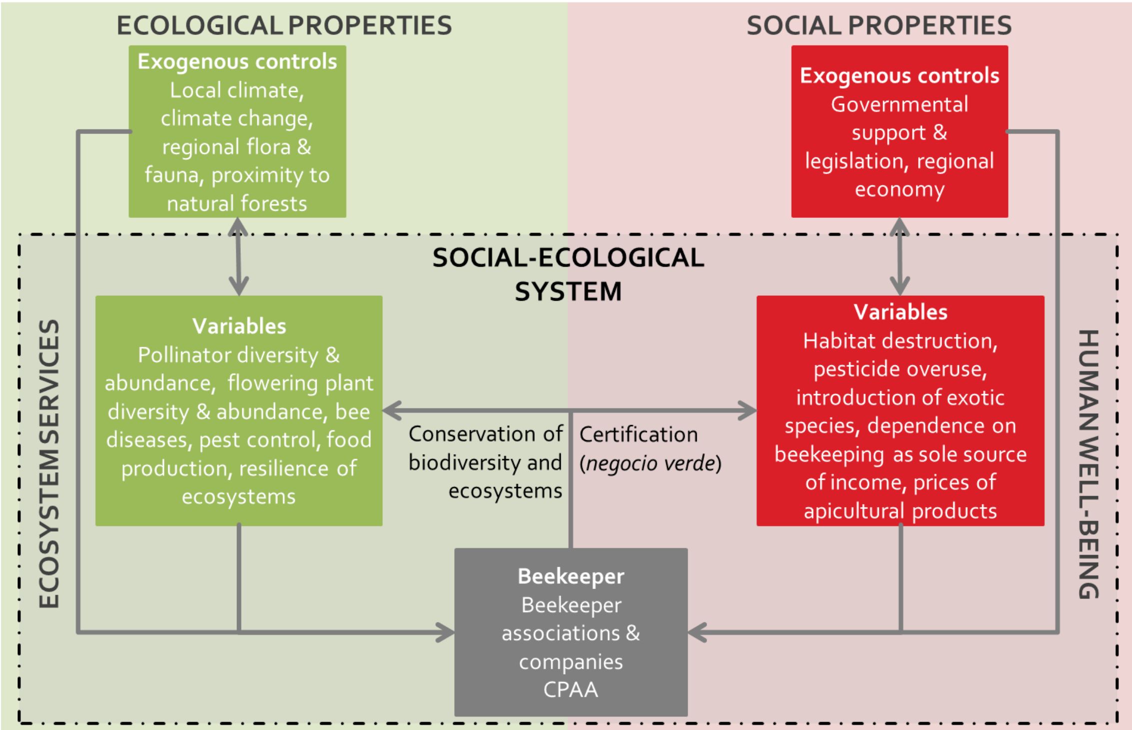


Figure 18: SES from beekeepers' point of view.
Source: Own elaboration.

Coffee grower SES: The actors in the SES from the coffee growers' point of view include individual coffee growers, as well as coffee grower cooperatives and associations, most notably COOCENTRAL. The main governmental actors are the MADR as well as the local government of Huila [Gobernación del Huila]. The MADR partly funds initiatives and projects via the National Federation of Coffee Growers [Federación Nacional de Cafeteros de Colombia], technical consultancy and the renewal of coffee crops (Ministerio de Agricultura y Desarrollo Rural, 2018, B). In accordance with the ministry, the local government of Huila offers support to the Huilan coffee industry (Gobernación del Huila, 2017, C). The National Federation of Coffee Growers of Colombia aims to improve living conditions for coffee growers by means of social, productive, environmental, educational and infrastructural development (Federación Nacional de Cafeteros de Colombia, n.d., B). In order to do so, it is affiliated with cooperatives in whole Colombia, such as COOCENTRAL

(Federación Nacional de Cafeteros de Colombia, n.d., C). COOCENTRAL, as a local coffee cooperative, aims to be a locally, nationally and internationally model cooperative with values of profitability and social and environmental responsibility (COOCENTRAL, n.d.). The cooperatives' agronomists regularly visit the coffee farms in order to give recommendations regarding farm management. These recommendations also include advice on amount and type of agrochemicals to be used. However, organic farm management is not encouraged by COOCENTRAL. Moreover, they organize and execute certification workshops.

Ecological exogenous controls include the local climate and climate change. Social exogenous controls include governmental support and legislation and the regional economy. All of the aforementioned exogenous controls, both ecological and social, affect the cultivation of coffee as part of the system. Ecological variables within the SES are comprised of pest abundance (particularly *H. hampei* and *H. vastatrix*), pollinator abundance and effectivity as well as soil fertility. The corresponding actors' response is the type of farm management, which mainly consists in a traditional farm management. Social variables include agricultural intensification, the introduction of exotic species, the dependence on coffee as a sole source of income, as well as national and international coffee prices. The actors' response involves coffee certifications, which are numerously offered by COOCENTRAL.

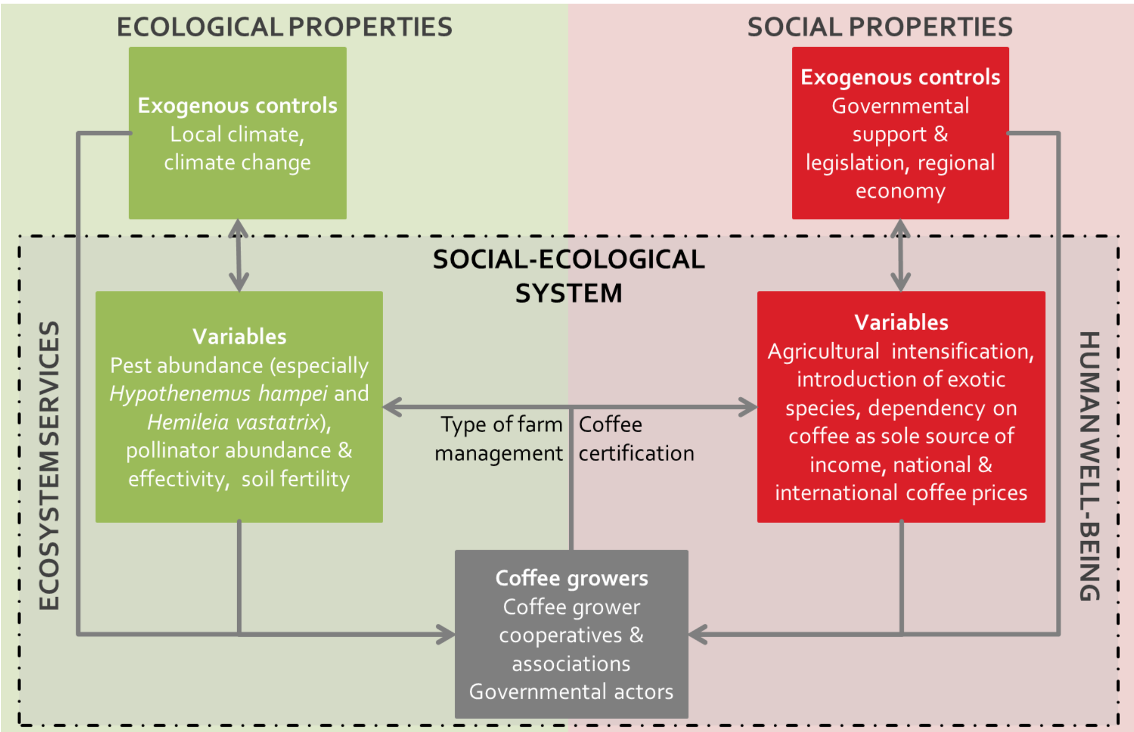


Figure 19: SES from coffee growers' point of view.
Source: Own elaboration.

Combined SES: Naturally, all the factors, actors, exogenous controls, variables, and responses summarize the situation described in the preceding two SES. Hence, the actors of the combined SES consist of the aforementioned ones: local associations, companies and cooperatives of beekeepers and coffee growers as well as governmental actors, primarily the MADR and CPAA.

The exogenous controls also coincide with the ones mentioned previously and involve local climate, climate change, regional flora and fauna, proximity to natural forests, governmental support and legislation, and regional economy. Regional flora and fauna, for instance, impinge on the foraging sources of honeybees and possibly results in competition with other bee species. Moreover, the proximity to forests influences the provision of pollination services for coffee crops whereas the regional economy shapes coffee and honey markets. Ecological variables within the SES include pollinator abundance and effectivity, pest abundance (especially *H. hampei* and *H. vastatrix*), pest control, bee diseases, flowering season, flower diversity and abundance, food production, resilience of ecosystems, and soil fertility.

However, beekeeping in Colombia has a competitive advantage in regard to bee diseases. More precisely, many diseases occurring on a global level, such as *Varroa*, do not affect the Africanized bee (G. A. Vargas Bautista, personal interview, May 21, 2018). The majority of beekeepers (13) answered that their bees do not suffer from any diseases and only five observed *Varroa* among their bees. One beekeeper explained that a great part of Colombian honeybees actually have *Varroa*, but it does not affect them. Beekeepers and coffee growers are affected by climatic conditions, such as rainy or flowering season (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018).

The social variables in turn are comprised of habitat destruction, pesticide overuse, agricultural intensification, introduction of exotic species, dependence on a sole source of income, and coffee and apicultural prices. These variables are also affected by the beekeepers' and generally society's fear of the Africanized honeybee (G. A. Vargas Bautista, personal interview, May 21, 2018). The dependence on a sole source of income leads to an immense pressure on coffee growers, which greatly dictates their actions. Similarly, beekeepers are affected by market pressures, particularly the high prevalence of honey falsification. A norm regarding honey quality even exists, but is not respected. Consequentially altered honey can even be found in supermarkets (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018).

Responses include the conservation of biodiversity and ecosystem by means of pollination, type of farm management, and certifications. An additional response consists of the pollination of coffee crops which affects the yield and quality of the coffee produced.

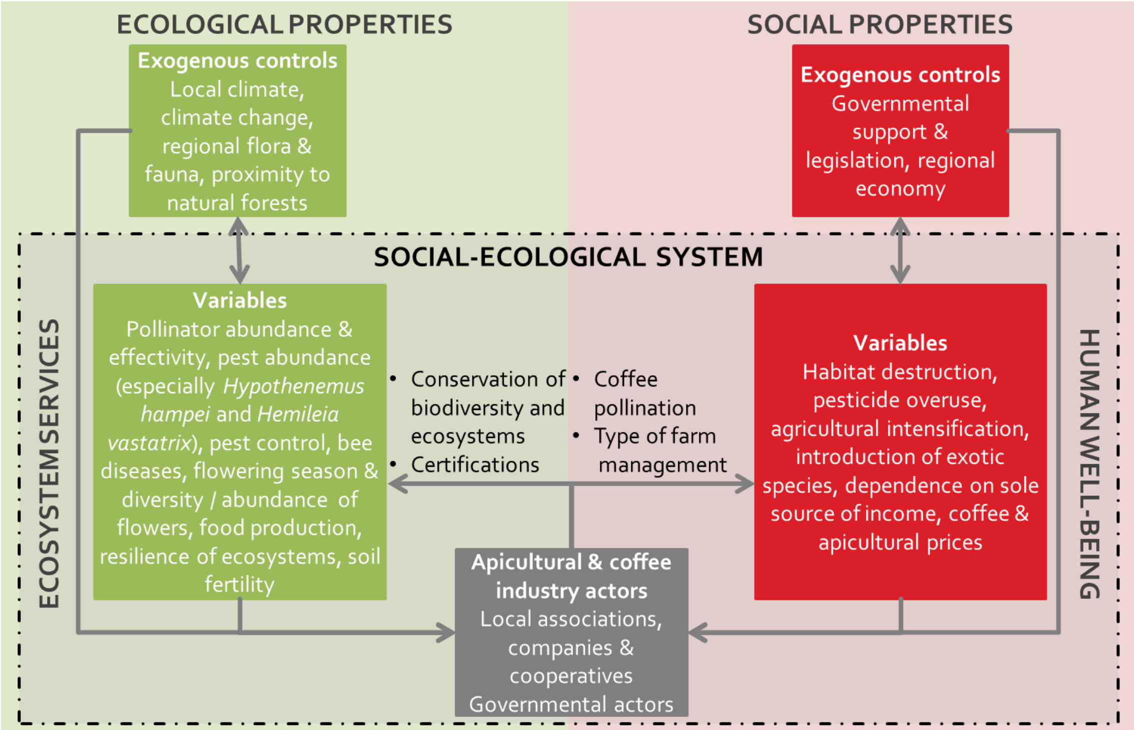


Figure 20: Combined SES from beekeepers' and coffee growers' point of view.
Source: Own elaboration.

4.1.2 The social-ecological system's history and anthropogenic influences

How coffee plants of *C. arabica* got from tropical Africa to Colombia remains unclear, with one theory suspecting its entry via Venezuela, others suspect via Central America. Coffee cultivation in Colombia, however, was first mentioned in 1735, when priests started to plant coffee in their monastery in Popayán, from where it quickly spread to other parts of the country (Diaz, 1997). However, it took until 1835 until it was first cultivated commercially in the departments of Norte de Santander and Santander in Western Colombia (Diaz, 1997; Federación Nacional de Cafeteros de Colombia, n. d., A). It arrived in Huila around 1900 (Federación Nacional de Cafeteros de Colombia, n. d., A). The coffee's spreading was boosted by the construction of railways (Diaz, 1997).

Apis mellifera originated in Asia and since more than 9,000 years humankind exploits its honey. Later, however, this species has been distributed in Australia, Europe, North and South America (Nates-Parra & González, 2000). *Apis mellifera* was introduced to Latin America between the 16th and 18th century by European conquerors (Freitas et al., 2009; Lopez-Maldonado & Athayde, 2015; F. A. Silva Aldana, personal interview, March 23, 2018). First the conquerors introduced *A. mellifera carnica* Pollmann 1879 (Carniolan honeybee), which they knew how to manage, and afterwards *A. mellifera iberica* Engel 1999 (Spanish bee). In this case, social benefits were created by beekeeping and honey harvesting (Freitas et al., 2009). The introduction of the Western honeybee has been "the most abundant and impactful of these introductions" (Ollerton, 2017: 361). Previously, Colombians worked with native stingless bees, among others *T. angustula* (Picture 6), *M. eburnea* (Picture 7), *M. favosa* and *Scaptotrigona spec.*, which were their only manner of obtaining sweetener.

Picture 6: Tetragonisca angustula in Neiva, Huila. April 13th, 2018.
Source: Own photograph.

Picture 7: Melipona eburnea in Neiva, Huila. March 22nd, 2018.
Source: Own photograph.

However, the Spanish conquerors demonized those native bees, which led to their replacement by *A. spec.* (F. A. Silva Aldana, personal interview, March 23, 2018). Furthermore, in 1956 the African *A. mellifera scutellata* was introduced to Brazil, from which it spread and africanized almost the whole American continent (Freitas et al., 2009; Lopez-Maldonado & Athayde, 2015; Medina Flores et al., 2015; Morstensen & Ellis, 2016; G. A. Vargas Bautista, personal interview, May 21, 2018). The first appearance of the africanized hybrid in Colombia occurred in 1979 (CORPOICA, 2012). Hence, *A. spec.* is actually a non-native, invasive species in Colombia. Usually, *A. spec.* has bigger colonies than native bees, which gives them more time to forage and maintain their hives. This in turn leads to different foraging times compared to native bees, which means that they might be complementing each other (G. A. Vargas Bautista, personal interview, May 21, 2018). Nowadays, *A. mellifera* and exotic bumblebees are the main concerns in the Neotropics (Freitas et al., 2009).

Of the 20,000 bee species worldwide, only 5% are social bees. Of the 600 species identified in Colombia around 240 are social (Ministerio de Agricultura y Desarrollo Rural, 2018 A). Another source states that more than 90% of Colombia's wild bees are solitary bees. *Meliponini* represent the only exception (Nates-Parra & González, 2000). In Colombia around 120 native species of stingless bees exist, which are organized in 14 genera and nine subgenera and occur mainly at heights between 500 and 1,500 masl. In the Neotropics a total of 400 social species is expected to exist. At the same time, *Meliponini* represent the only native social bees which reproduce via swarming. The *Meliponini* represent important social and cultural values and some cultural groups engaged in meliponiculture, the breeding of stingless bees, for alimentation, ornamental or medicinal means or just representing symbolic or cosmogonic values. Hence they are part of Colombia's biological and cultural heritage. The species used nowadays in meliponiculture however differs from the traditional one (Nates-Parra & Rosso-Londoño, 2013).

In their study Nates-Parra & Rosso-Londoño (2013) located five genera of *Meliponini* in Huila, with *T. angustula*, commonly known as angelita, being the most abundant one. Moreover, *Meliponini*'s cultural significance is demonstrated by the variety of local denominations of its species. These denominations can be based on the bees' appearance, behavior, use or ecology.

Colombia's native bees are suffering from human impacts with the main drivers being deforestation, grazing land, the Africanized bee and the irrational exploitation of bees (Nates-Parra & González, 2000). Moreover, the native bees remain greatly unprotected (G. A. Vargas Bautista, personal interview, May 21, 2018).

4.1.3 Main threats to pollination within the social-ecological system

Based on the interviews and surveys, six threats to the SES have been identified and will be briefly analyzed.

Pesticide use: The application of pesticides as an agricultural input, especially their use in coffee and lulo (*S. quitoense*), has been greatly emphasized in all three interviews (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; F. A. Silva Aldana, personal interview, March 23, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018; personal conversations with beekeepers as part of the survey). Of the 25 coffee growers participating in the survey, 18 stated that they regularly use pesticides. They were applied 1-4 times per year, even though not all coffee growers recalled the name of the pesticide they usually use. In order to control the coffee borer beetle, six coffee growers applied Lorsban™, whereas another six coffee growers controlled the beetle manually. The coffee leaf rust was fought using ALTO® 100 (3 coffee growers) and Amistar ZTRA® (2 coffee growers). The statement that pesticides which are prohibited in other parts of the world are still being used in Colombia (F. A. Silva Aldana, personal interview, March 23, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018), could not be confirmed. Nevertheless, only three pesticides were named by the coffee growers. A brief review of these follows.

The first pesticide mentioned by the coffee growers is Lorsban™, whose active substance is chlorpyrifos (Dow AgroSciences de Colombia S.A., 2013). Chlorpyrifos was originally developed as a neurotoxin during the Second World War. Afterwards it was adjusted to be used as a pesticide and it functions by attacking the insects' nervous system. In the developed world, restrictions regarding the application of chlorpyrifos are becoming more common (Trasande, 2017). For instance, even though it was approved by the EU in 2006 and was authorized by 20 member states, it remains prohibited in Germany (European Commission, n. d., A). Chlorpyrifos has been found to be extremely toxic to honeybees (Christensen et al., 2009; Sanchez-Bayo & Goka, 2014). It is a neonicotinoid and a so-called systemic pesticide. For honeybees especially the long-time exposure is problematic. They ingest chlorpyrifos via pollen, where it is also highly prevalent. The contact risk was determined to be 8.3–12.9% (Sanchez-Bayo & Goka, 2014).

The second pesticide is ALTO® 100 with an active substance called cyproconazole (Syngenta S.A., n.d., A). It was admitted in the EU in 2011 and is authorized in the majority of member states including Germany (European Commission, n. d., B). The threshold of residues allowed in the EU is 50 ng/g (Wiest et al., 2011; Juan-Borrás et al., 2016). A global study found cyproconazole residues in 11% of honey samples with a maximum concentration of 4 ng/g. Further residues were found in 1% of pollen samples with a maximum concentration of 22 ng/g. Nevertheless, no residues could be found in honeybees (Wiest et al., 2011). Neither could another study on a global level detect the threshold's crossing (Juan-Borrás et al., 2016).

The third pesticide mentioned is Amistar ZTRA®, which has two active substances: cyproconazole and azoxystrobin (Syngenta S.A, n.d., B). For information regarding cyproconazole see the preceding paragraph. Azoxystrobin was approved by the EU in 2012 and is authorized in all member states (European Commission, n. d., C). Furthermore, it has been found to be almost nontoxic to honeybees (United States Environmental Protection Agency, 1997).

Vargas Bautista remarked during his interview, that pesticides are not always applied as they should be. For instance the actual concentration of the pesticide might differ from project recommendations which in turn might result in the resistance of the fungus, so that higher doses of pesticides are required. In the end, these then bioaccumulate in the food, breed and reserves within the beehive (G. A. Vargas Bautista, personal interview, May 21, 2018). The reason for increasing losses of bees remains unclear (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). In 2017 i.e. a total of 16,500 hives were lost in Colombia. In Huila, 250 were lost in Pitalito alone and 250 in Timaná due to poisoning presumably by pesticides (F. A. Silva Aldana, personal interview, March 23, 2018). Generally, beehive losses could be caused by various factors, such as bee diseases, the use of pesticides or natural triggers. However, according to the interviewees the application of pesticides is forbidden during flowering in Colombia, even though this is not respected. The reason for such an aggressive use of pesticides is the pressure which coffee growers, especially small-scale farmers, are subjected to. Coffee is often their only source of income, so if their crops are harmed in any way, in the worst case they will end up without income. Moreover, there are no governmental subsidies or support in the cases of harvest loss. Hence, the coffee growers perceive insects as a threat to their crops, which they want to protect them from via the massive use of pesticides. Furthermore, most do not receive neutral consultancy on how to sustainably manage their farms (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Besides killing insects, birds and other pollinators, the exhaustive use of pesticides also affects the products which in the end are consumed by humans (F. A. Silva Aldana, personal interview, March 23, 2018).

Monocultures: Monocultures were identified as another threat in two interviews. Historically, coffee was intercropped with fruit plants (i.e. *Inga edulis* (guamo), *Psidium guajava* (guava) or *Tamarindus indica* (tamarind)) (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018). Moreover, the fruit trees increased income for coffee growers as well as food sources for bees (G. A. Vargas Bautista, personal interview, May 21, 2018) in addition to creating a better balanced agroecosystem (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). These shade trees provided several ESs, such as nitrogen fixation, the prevention of soil erosion, and pest avoidance via nesting pest predators, namely birds and bats (Jha & Vandermeer, 2010). In contrast to historical cultivation, nowadays coffee is cultivated without shade and in a dense manner (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Of the 25 coffee growers interviewed, 19 said they would intercrop. The degree of intercropping differs however, since some used a variety of fruit trees to intercrop, while others only plant banana trees. Banana trees were by far the most common species used for intercropping, used by 14 coffee growers, sometimes exclusively. Other species included yucca, cacao, corn, avocado, and orange.

Deforestation: Natural areas have been changed into agricultural ones. These are the areas in which a lot of pesticides are primarily used, which in turn negatively affect bees (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Currently half of Colombia's surface is covered by forests. This corresponds to approximately 59 million hectares. Nevertheless, in the period from 1990 to 2010 5.4 million hectares were lost. In Colombia, deforestation increases the risk of the occurrence of extreme weather events, leads to increased sedimentation of rivers and watersheds and to a loss of biodiversity, as well as an increase in water supply (García, 2014). The main causes consist in the advance of the agricultural frontier, but also livestock breeding, the cultivation of illegal crops, illegal logging, forest fires, mining, infrastructure construction and population growth (García, 2014; Sistema de Información Ambiental de Colombia, 2017). In 2016, an area of 178.597 hectares were deforested, which constitutes a 44% increase compared to 2015 (124.035 ha). In the same year, deforestation in Huila amounted to 354 hectares (Instituto de Hidrología, Meteorología y Estudios Ambientales, n. d.). Generally, the deforestation rate in Colombia is 143,502 hectares per year since 2010, even though it slightly declined during 2012-2013 (Instituto de Hidrología, Meteorología y Estudios Ambientales, 2014).

Climate change: Climate change leads to changes in flowering seasons, while historically seasons have been very stable (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Coffee cultivation areas and bee habitats will geographically shift due to climate change, affecting coffee production directly and indirectly. Direct effects manifest themselves in alterations of rainfall, temperature and extreme weather events, while indirect effects concern pollination. This will lead to global repercussions among rural livelihoods. In Latin America, coffee cultivation areas will decrease between 73-88% until 2050. Areas still suitable for coffee cultivation in the future will lie largely within current ones and only 12-30% will be in areas currently not suitable. These additional areas usually develop at greater altitudes, since these compensate the raised temperatures. This circumstance favors Colombia among other countries. However, bee abundance is predicted to diminish by 65% and a rise will only occur in 4-5% of Latin America (Imbach et al., 2017).

Introduction of exotic species: The lack of regulation regarding the introduction of foreign bee species has also been mentioned as a threat (G. A. Vargas Bautista, personal interview, May 21, 2018).

Ignorance about the benefits bees provide (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; F. A. Silva Aldana, personal interview, March 23, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018). Just recently, due to the massive bee deaths which have also been communicated via radio, press and television, awareness begins to rise (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; F. A.

Silva Aldana, personal interview, March 23, 2018). Previously, only few farmers and indigenous communities knew about pollination, even though this knowledge was intuitional and not formalized. Special attention received angelita bees (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018).

4.1.4 The social-ecological system' impact on human well-being

The threats analyzed in the preceding chapter might all pose a risk to human well-being, which will be explained in further detail below.

Pesticide use and deforestation lead to the loss of pollinating species, both *A. mellifera* and native bees, which in turn decreases coffee yield, due to the lack of pollination. This would pose a threat to the beekeepers' and coffee growers' income. On the one hand, beekeepers often rely on the bees as their sole source of income and replacing them continuously is expensive. Coffee growers on the other hand would have to apply more costly fertilizers in order to maintain current production levels. A bee loss also jeopardizes the SES's resilience. Monocultures also generate pollinator as well as income losses, a decline in landscape aesthetics, a deterioration of biodiversity and ecosystems and eventually also reduce the SES's resilience. Monocultures limit pollinators' foraging and nesting sites and narrows down coffee growers' income sources. Climate change results in a timely mismatch between plants' flowering season and thus disrupts plant-pollinator networks. Another effect might be spatial mismatches when coffee cultivation areas expand upslope. This will presumably degrade biodiversity and ecosystems as well as decline landscape aesthetics. The introduction of exotic species possibly drives away native species if they compete for foraging and nesting sites. If pollinator diversity diminishes, this in turn could decrease SES resilience. The coffee growers' ignorance about bees' benefits decreases social-ecological resilience, since it prevents them from recognizing pollination as a production input nor will they protect honeybees. On the contrary, coffee growers are even scared of the Africanized honeybees. Such behavior might lead to an exacerbated pollinator loss with all the negative consequences that can be observed currently.

As indicated in the preceding paragraph, the risks to human well-being result in a ripple effect: If one factor of human well-being decreases it usually negatively affects other factors as well. For instance, a loss of bees will inevitably signify an income loss for beekeepers. But moreover, it will lead to a decline of coffee crop pollination and thus also in a reduction of coffee yield, resulting also in an income loss for coffee growers. Additionally, the loss of pollination services will presumably lead to a rising use of other inputs, such as pesticides or artificial fertilizers (Garibaldi et al., 2018). Obviously, this in turn decreases the SES's resilience, due to the fact that the SES will not be able to absorb disruptions well. For example, with an already limited number of pollinators, the loss of another bee group will have more devastating consequences than in a system with a high pollinator variety. Furthermore, a decline in pollination also influences biodiversity and ecosystem functioning, since a great amount of wild plants also requires pollination to reproduce. Hence, forests might disappear not only due to deforestation but also the lack of pollination, successively exacerbating pollinator loss. Moreover, this also degrades landscape aesthetics since numerous wild flowers also require pollination for reproduction. The disruption of plant-pollinator networks as a result of changing flowering seasons would also harm biodiversity, ecosystems and consequentially landscape aesthetics.

These factors of human well-being can be classified according to the five categories introduced in chapter 1.1.1. However, in some cases one factor corresponds to various categories simultaneously. Security, the first category, includes the changes in flowering seasons and disruptions of plant-pollinator networks, since this might result in difficulties regarding food security. Moreover, income loss of the key actors also is likely to endanger the security of their belongings. The loss of pollination species and incomes for beekeepers and coffee growers as well as a decrease in coffee pollination and coffee yield compromise the basic material minimum required for a good live. The loss of beehives for instance deprives beekeepers of their means to gain a livelihood, especially if it is their sole or main source of income. The deterioration of biodiversity and ecosystems and the subsequent decline in landscape aesthetics threaten ecosystem health whose decline negatively affects human well-being since it might restraint access to clean water and air. The last category, freedom and choice, contains the loss of pollinating species, since these would drastically restrict the beekeepers' freedom of choice of the field they work in and the income loss affects various other decision-making options. Additionally, a reduction in the SES's resilience, the changes in flowering seasons and disruptions of plant-pollinator networks as well as the deterioration of biodiversity and ecosystems would subject beekeepers and coffee growers to the ecosystem's influence.

Possible anthropogenic responses in order to mitigate the mentioned threats and contain the possible negative impact on human well-being have been clustered into three groups. The first one regarding coffee farm management aims to replace pesticides by adapting biotic pest control. Another measure would be the publication of governmental guidelines in order to reduce pesticide use (Potts et al., 2016). This would help to protect honeybees and other pollinators by restricting pesticide use and at the same time reduce coffee growers' spending on agrochemicals. Moreover, the crops cultivated on coffee farms could be diversified in order to abolish monocultures, which would also diversify income sources for coffee growers and thus limit their dependence on only one crop, while at the same time making coffee cultivation more sustainable and pollinator-friendly. The second group concerns pollinator management. As a first step, bees should be considered in relevant laws in order to protect them, which could also target coffee growers' ignorance about the benefits provided by bees and generally lead to an improved protection of bees. Also, the introduction of foreign bee species could be regulated. Furthermore, bees' exposition to pesticides should be reduced. This could be achieved with a decline in pesticide application. The third and last group involves the conservation of biodiversity and ecosystems. Correspondingly, bees' habitats should be conserved or restored where possible. This could be facilitated by governmental support. Additionally, methods to cope with climate change have to be developed, since it will alter coffee cultivation areas and plant-pollinator networks. All of these responses would ultimately increase the system's social-ecological resilience.

Values that can be deduced by beekeepers and coffee growers include socio-cultural and ecological ones. However, the perception of values is subjective and might differ from person to person (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Socio-cultural values include income security and diversification. Beekeepers benefit from a more diversified production, i.e. not only honey but also pollen etc. Moreover, coffee growers benefit from an increased coffee yield and quality due to pollination services. (G. A. Vargas Bautista, personal interview, May 21, 2018). For indigenous tribes, additional values consist in medicinal, artisanal and ritual uses (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). These values however were considered insignificant for the SES studied. Ecologically, the main value is pollination (G. A. Vargas Bautista, personal interview, May 21, 2018), crucial to both human and plant survival (F. A. Silva Aldana, personal interview, March 23, 2018). Moreover it conserves all ecosystems, natural as well as agroecosystems (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). One specific example named was the conservation of forests (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018) and páramos, which are fundamental for provisioning clean water (G. A. Vargas Bautista, personal interview, May 21, 2018). In the end, this allows them to make life choices freely, without external pressures. All of the interrelations explained above can be observed in a summarized manner in Figure 21.

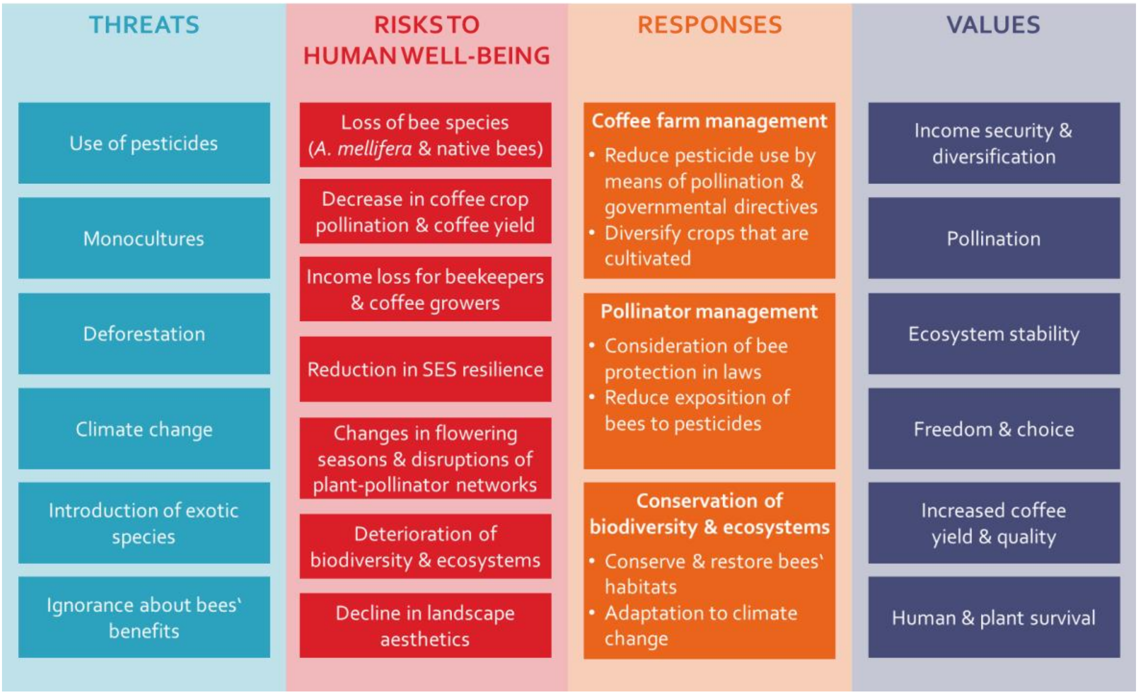


Figure 21: Interactions between threats, human well-being, possible responses and values within the SES.

Source: Own elaboration based on Potts et al., 2016.

4.2 Willingness to pay for pollination services

Only ten of the 19 beekeepers asked answered the question of how much they would charge or in two cases have charged in the past, in order to lease their bees to coffee growers (Table 4). Generally, concerns regarding the fumigation of coffee or other nearby crops, the difficult transport through mountainous areas or the risk of theft of the hives were expressed by the beekeepers, which currently impede the introduction of such a practice. The two beekeepers who have leased their hives in the past charged 2.95€ and 11.79€ per hive per month, even though this does not seem to be a reasonable price to them. In their opinion, a more justified price would be 23.58€ - 29.47€ per hive per month. Two other beekeepers responded that they would also charge at least 29.47€ per hive per month, while they would sell them at 117.90€ - 147.37€ per hive. Another beekeeper said he would demand 53.05€, while yet another would charge a total of 88.42€ - 117.90€ per season and an additional 58.95€ for transport. Another reply indicated the willingness to charge 8.84€ - 11.79€ per hive per month, not including transportation costs. The other two beekeepers answered giving a percentage: One said he would demand 1-2% of the harvest's profit and the other aligned his response to the situation in Brazil or Argentina, where it is common to pay 2% of the yield per hive. Still, this price did seem too low to him. The beekeepers' answers equal an average of 1.75% of yield profits or otherwise a charge of 55.27€ per hive per month.

Table 4: Beekeepers' answers regarding the renting of beehives to coffee growers (n = 19). Source: Own elaboration.

	How much do you charge for leasing your hives?	Do you think that this is an appropriate price?	What would be an appropriate price in your opinion?
1	11.79€/hive/month	No, because of the risk of the bees' death or theft	23.58€ - 29.47€/hive/month
2	Depends on the transportation costs	No	
3	2.95€/hive/month	No, because of the risk that the coffee grower uses pesticides	29.47€/hive/month
4			53.05€/hive/season
5	In for example Brazil or Argentina one pays 2% per hive of the value of harvest in accordance with the production	No, because the coffee growers only want to benefit themselves, while they kill the hives and there does not exist any governmental support for these cases	
6			1-2% of the harvest's profit
7			For sale: 117.90€ - 147.37€/hive For rent: min. 29.47€/colony/month
8			For sale: 117.90€ - 147.37€/hive For rent: min. 29.47€/colony/month
9		I would not do it due to the risk of the application of pesticides	8.84€ - 11.79€/hive/month, not including transportation costs
10			58.95€ for transport 88.42€ - 117.90€ per season

Also the 25 coffee growers were asked how much they were willing to pay for the service of pollination, if they could increase their production by either 15%, 30% or 50% by means of pollination. One said that he would not pay at all and another indicated that he would only be willing to pay for pollination if harvest would be increased by 50%. Eleven coffee growers stated their WTP in monetary terms and the other 13 in a percentage related to additional profits. The average paid for a 15% increase would be 97.80€ or 6% of the increased harvest's profit, for a 30% increase 166.67€ or 10% of the additional profit, and for an 50% increase 239.28€ or 21%. Still, the consciousness regarding pollination's benefits are lacking in order to implement such a practice of renting beehives. Rather, the coffee growers are afraid of being stung by the aggressive Africanized honeybees.

Table 5 depicts the survey results. The percentages (15%, 30% and 50%) indicate the yield increase hypothetically gained by pollination. The bold numbers in the rows (1-25) depict the coffee growers. WTP was either indicated in form of a total price (originally in COP, but here in€) or as a percentage of increase of harvest resulting from pollination.

Table 5: Coffee growers' WTP for pollination services (n = 25).
Source: Own elaboration.

	If hypothetically you were able to increase your productivity in terms of an increased yield by means of pollination, how much would you be willing to pay to a beekeeper for renting his hives for pollination services? For practical reasons, we assume that pollination were the only relevant variable for production.					
	1	**2**	**3**	**4**	**5**	**6**
15%	294.75€	294.75€	29.47€	56.00€	14.74€	56.00€
30%	442.12€	589.50€	58.95€	112.00€	29.47€	112.00€
50%	589.50€	884.25€	103.16€	176.85€	29.47€	176.85€
	7	**8**	**9**	**10**	**11**	**12**
15%	58.95€	5.89€	7.5%	7%	147.37€	5%
30%	117.90€	8.84€	10%	15%	156.22€	10%
50%	176.85€	14.74€	20%	25%	170.95€	17.5%
	13	**14**	**15**	**16**	**17**	**18**
15%	58.95€	0%	1%	5%	3.%	58.95€
30%	117.90€	0%	15%	10%	6%	88.42€
50%	162.11€	50%	20%	20%	7.5%	147.37€
	19	**20**	**21**	**22**	**23**	**24**
15%	0€	5%	5%	5%	7.5%	10%
30%	0€	10%	0%	10%	15%	20%
50%	0€	20%	0%	25%	25%	30%
	25					
15%	10%					
30%	12%					
50%	15%					

5 Discussion

5.1 Discussion of method

Discussion of method applied in thesis: The valuation of ESs is highly context-dependent, so that the method applied may differ from study to study (TEEB, 2010; Mburu et al., 2006; Melathopoulos et al., 2015). Moreover, not all of the methods introduced in Chapter 1.3.2 are applicable in this thesis. More specifically, neither the dependence ratio, nor yield analysis, nor consumer surplus could be applied. The main causes were time restraints as well as the lack of sufficient data for the study site. For instance, the dependence ratio requires information regarding pollination's effect on coffee production, but the know-how on how to scientifically carry out a corresponding investigation was not available. Moreover, the main flowering season did not coincide with the on-site field work in Huila, so that during this period the coffee plants were expected to only flower sporadically. Furthermore, a consumer surplus study would have also demanded detailed information regarding demand, exports and imports. Such information could not be located for the study site.

For the actual valuation, there exists a variety of survey methodologies and their application may influence the respondents' answers, even though studies on this issue are inconsistent (Zhang et al., 2017). The intention was to conduct all surveys face-to-face, which are supposed to give more representative results than telephone or online questionnaires. However, in one case this was not possible and the survey was realized by phone. Telephone surveys presumably represent an adequate alternative to face-to-face surveys (Szolnoli & Hoffmann, 2013). Moreover, since this only concerned one interview out of 44, or rather 2.3% of all questionnaires, the possibly existing effect caused by the use of this survey method can be neglected.

The questionnaires were carefully phrased and structured, including five out of seven types of support questions suggested by Krupnick (2006). The other two question types did not seem to provide any considerable value added to the questionnaire or the results. Hence, neither questions regarding the respondent's attitude towards pollination nor debriefing questions were included. When uncertainties arose during the survey, these were clarified immediately. However, no mentionable uncertainties emerged; the only more complicated question regarding the WTP was explained extensively and the respondent was asked to confirm his understanding of this specific question's parameters. Questions regarding the respondent's attitude were also deemed unnecessary and rather redundant with the questions regarding prior knowledge. Moreover, attitude could be derived from other answers as well as the accompanying conversations.

In a more comprehensive study, the amount of survey participants could be increased, especially since in the present case some respondents did not answer all of the questions. Thus, a bigger sample size would be recommended for the future to increase representativeness of the data. Perhaps, this could be implemented in cooperation with a Colombian institution which already does similar research. Possible institutions include the CPAA or a university. The UNAL for instance also investigates pollination's economic value in a variety of crops. Moreover, the questionnaire should be pre-tested with a sample group in order to review its adequacy and comprehensibility. This may prevent the questionnaire's adaptation after already having begun with the survey while at the same time improving it.

Chapin et al. (2009) consider exogenous controls as well as slow and fast variables within the SES. In contrast, the SES developed as part of this thesis only includes external factors in form of exogenous controls and internal factors, called variables. It was found that neither could slow and fast variables be clearly distinguished nor was this distinction relevant in the analysis of the SES. Hence, this simplification of the model is not expected to have any major impact on the analysis' quality.

Discussion of economic valuation: Economic valuation itself has been widely criticized (Olschewski, 2017) and even called "morally contentious" (Farley & Voinov, 2016: 392). Gascon et al. (2015), for instance, claim that due to their complexity valuations will never be complete. According to Small et al. (2017), the mismatched scales of organization of society and ecosystems contribute to this complexity. Moreover, in many cases considerable knowledge gaps exist, for example regarding the biophysical provision of ecosystem functions or thresholds and reversibility (Olschewski, 2017). This in turn results in "considerable doubt over the precision, reliability, usefulness and interpretation of such figures" (Hanley et al., 2015: 124). Another point of criticism is the inconsistent methodology (Farley & Voinov, 2016; Olschewski, 2017) and the questionable scalability of results (Farley & Voinov, 2016; Costanza et al., 2018). Moreover, the anthropogenic focus of valuations might emphasize materialism and economic ecosystem management too strongly (Small et al., 2017).

More specifically, economic valuation is often seen as a commoditization of nature. McCauly (2006) argues that nature is invaluable due to its intrinsic value, cultural and evolutionary importance, and aesthetics. Thus, the impression might arise that nature's conservation is only worthwhile if it is profitable enough (McCauly, 2006). The application of terms like use or value of nature has been met with criticism, particularly because uses might be indirect and values are primarily associated with monetary values (Small et al., 2017).

Besides, economic and socio-cultural valuations are strongly subjective and therefore influenced by the group of participants consulted during the valuation process (Villegas-Palacio et al., 2016). The respondents value ESs based on their character as well as their background (Small et al., 2017), thus the values strongly depends on individual preferences (Olschewski, 2017). Time and place of the valuation also highly affect valuation (Haines-Young & Potschin, 2010; Olschewski, 2017).

Discussion of CVM: One point frequently criticized is that the respondent might not know or understand well enough the ES they are asked to value (de Melo Travassos et al., 2018). Moreover, the results might be influenced by question design (Everett, 2013). Furthermore, budget restraints may interfere with WTP (de Melo Travassos et al., 2018). Respondents' might also strategically over- or underestimate their WTP. Especially if they assume they will never actually have to pay for these services in the future, they tend to exaggerate their WTP (Olschewski, 2017). Similar to the criticism of economic valuation, personal preferences and attitudes may influence the WTP revealed via the contingent valuation (Choi et al., 2017). Particularly in the case of pollination, additional production inputs have to be considered when interpreting CVM results. Thus, results cannot be generalized unrestrictedly (Olschewski, 2017).

5.2 Recommendations for fostering the social-ecological system's resilience

Even though various human responses have been named in Chapters 4.1.1.2 and 4.1.4, this chapter focuses on the use of pollination as an input to coffee cultivation. This can be achieved by means of managed bees, usually *A. mellifera*, or wild pollination by native bees (Ratamäki et al., 2015). This thesis' main recommendation consists in the beekeepers leasing their beehives to coffee growers for pollination services. This practice would result in a more resilient SES. Resilience highly depends on pollinator abundance and diversity as well as the redundancy in plant-pollinator networks (Haines-Young & Potschin, 2010; Potts et al., 2016; Garibaldi et al., 2018). Coffee can be pollinated by a variety of bee species, even though *A. mellifera* seemed to be the most frequent visitor of coffee flowers (Klein et al., 2003; Ngo et al., 2011; Cepeda-Valencia et al., 2014; Acosta Leal et al., 2017; Ollerton, 2017). The intercropping with fruit trees further enhances the plant-pollinator network, by providing nesting sites for bees (Klein et al., 2003; Jha & Vandermeer, 2010) as well as expanding food sources for bees (Klein et al., 2003; Jha & Vandermeer, 2010; Acosta Leal et al., 2017). Additionally, it would diversify the coffee growers' sources of income. Intercropping is recommended as a complementary measure to the renting of beehives, since it would increase wild pollination simultaneously. The resulting increase in plant and pollinator diversity further increases the SES's resilience, since the dependence on just one pollinating species decreases redundancy in the plant-pollinator network and, thus, the system's capacity to absorb disturbances. One example is the increased resilience to climate change (Garibaldi et al., 2018). The same applies to the bees' dependence on coffee as a sole food source. Intercropping offers numerous other benefits. Particularly relevant for coffee cultivation is the enhanced soil fertility due to the increased presence of humus (Ouma & Jeruto, 2010).

Moreover, the SES in the future scenarios will be able to balance the social and ecological subsystems more equally, providing income stability for both beekeepers and coffee growers, while reducing the use of pesticides and, hence, protecting bees and the coffee cultivation's impact on the surrounding environment. The application of this practice might result in lower income for coffee growers compared to the status quo. Nevertheless, the status quo's sustainability and capacity to offer long-term benefits is unclear (Garibaldi et al., 2018). Other options to increase coffee productivity include an expansion of the cultivation area or increasing the crops' density. However, these measures have been found to be unsustainable (Roubik, 2002).

Actually, the practice of using pollination as an agricultural input in coffee cultivation is not new. It was recommended already 1977 to locate beehives in the coffee fields during flowering in order to increase coffee yield (Raw & Free, 1977). Before the honeybees' Africanization in Colombia the pollination of coffee crops was actively promoted by the National Federation of Coffee Growers (Federación Nacional de Cafeteros) as well as the government (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018). Hence, the effect of pollination on coffee was common knowledge (G. A. Vargas Bautista, personal interview, May 21, 2018) and almost all coffee growers also had a few beehives (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Due to the honeybees' Africanization, coffee growers began to be afraid of the bees and did not want to continue working with them (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018).

Status quo: Currently, large quantities of pesticides are applied by coffee farmers (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018; F. A. Silva Aldana, personal interview, March 23, 2018; G. A. Vargas Bautista, personal interview, May 21, 2018). This enables an effective pest control, while causing immense expenses for coffee growers, due to the pesticides' high prices (personal conversations with coffee growers as part of the survey). Obviously, this results in a resistant coffee production and thus a stable income for coffee growers, when neglecting the volatility of coffee prices. For beekeepers however, this represents an unfavorable situation, since they suffer from high losses among their colonies (F. A. Silva Aldana, personal interview, March 23, 2018; personal conversations with beekeepers as part of the survey). This in turn reduces their income, since they either have to continuously replace the lost colonies or else have to keep working with a reduced number of colonies, resulting in a declined production.

In conclusion, the status quo favors the coffee growers over beekeepers. The SES's resilience is undermined by the high amount of pesticides applied. This has repercussions in the ecological subsystem by diminishing bee abundance and diversity which ultimately endangers the provision of pollination services (Ollerton, 2017). Moreover, pests usually develop resistances over time, so that the amount of pesticides applied has to be constantly augmented, resulting in growing expenses for coffee growers (Zhang et al., 2007). Furthermore, the social subsystem is affected by the fact that beekeepers and coffee growers usually both depend on a sole source of income, which is diminished by the high expenses for agrochemicals for coffee growers and bee replacement costs for beekeepers. Moreover, the status quo not only endangers biodiversity but also human health (Zhang et al., 2007; Garibaldi et al., 2018). Human long-term exposure to pesticides can result in "immune-suppression, hormone disruption, diminished intelligence, reproductive abnormalities, or cancer" (Garibaldi et al., 2018: 44). Additionally, such high-input farming practices become increasingly detached from their natural surroundings, but instead depend to a greater extent on price volatility (ibid.).

Future scenario: These defects could be mitigated, if coffee growers considered pollination as a production input and collocated beehives among their crops during flowering season. This practice for yield enhancement has also been endorsed in literature (Raw & Free, 1977; Klein et al., 2003; CORPOICA, 2012; Potts et al., 2016). For the Colombian states of Tolima and Cundinamarca, two beehives per hectare of coffee crops were recommended by CORPOICA (2012). Hence, this future scenario would involve a decreased use or even abolishment of pesticides but rather the pollination of coffee plants in order to intensify production ecologically and prevent pest infection biologically. The short- as well as long-term effects of this scenario will be estimated in the following.

In the short-term, the reduced pesticide use will lead to an increase of pest infections. However, coffee growers can save high expenses for pesticides. Nevertheless, coffee production will decrease due to higher pest prevalence and will consequently result in lower incomes for coffee growers. It remains debatable if these saved expenses would offset the economic loss caused by yield losses. Beekeepers will not lose such high quantities of bees anymore (provided that use pesticides as agreed beforehand, or not use them at all), resulting in a higher productivity and thus a higher income. Additionally, this scenario represents an income diversification for beekeepers, since renting fees represent additional income source. Hence, this scenario is more favorable to beekeepers than coffee growers. The SES's resilience stays low, due to an increase in pest prevalence and beekeepers and coffee growers remain dependent on a sole source of income.

In the long-term, pest infections of the coffee crops can be controlled in a biotic manner via a various species of natural predators, such as wasps, flies, mantis, ladybugs, spiders, and birds, which benefit from the increased biodiversity (Zhang et al., 2007). This means that coffee growers still do not have to buy expensive pesticides, while improving the coffee's quantity and quality. Increased quality might even result in higher selling prices, as well as a possible certification as organic or sustainable coffee. The beekeepers can also increase the quality of their products since they are now pesticide free, which might also result in higher prices. In conclusion, this scenario is beneficial to both, coffee growers and beekeepers and also represents a resilient SES.

The status quo and future scenarios are summarized in Table 6, where the status quo is delineated in orange and the future scenarios in blue.

Table 6: Description of the SES' status quo as well as the recommendations' short- and long-term consequences.

Source: Own elaboration

			Pollination			
	Pesticides	$	Short-term	$	Long-term	$
Pest control	↑	↓	↓	↑	↑	↑
Coffee growers	↑	↑	↓	↓	↑	↑
Beekeepers	↓	↓	↑	↑	↑	↑
SES resilience	↓		↓		↑	

↑	Positive effect
↓	Negative effect

Prerequisites: However, before such a scheme can be reintroduced, certain prerequisites have to be considered. First, the beekeepers' mistrust towards coffee growers has to be mediated. This means that the amount of pesticides applied has to be reduced or its use has to even be banished (Klein et al., 2003; Acosta Leal et al., 2017). In order to achieve this, the government could issue official guidelines in order to regulate pesticide use, for example the prohibition of pesticide application during the flowering season. Additionally, trainings regarding responsible pesticide use could be implemented by a neutral institution (Potts et al., 2016). Second, the coffee growers have to be educated regarding the benefits of pollination to their crops (G. A. Vargas Bautista, personal interview, May 21, 2018) so that they would actively participate in such a scheme. Third, reluctance to enter into such a scheme could presumably be decreased when reducing the risks for coffee growers and beekeepers. Thus, the beekeepers and coffee growers participating should be offered some type of security. Coffee growers, especially small ones, should be protected against short-term production losses. Furthermore, beekeepers need assurance against bee losses due to illegitimate pesticide application. This could be achieved via a governmental initiative, which gives financial support to coffee growers and serves as an ombudsman in case of bee losses. If these losses occurred because pesticides were applied irresponsibly, coffee growers could be forced to compensate them

Affected stakeholders: Various stakeholders would be affected by implementing such a scheme. On a national level, these would include various actors at different levels, with distinct interests and different capacities to influence the scheme. Nevertheless, all of these actors would have to interact cross-functionally and cross-scale, or at least would be affected by the implementation of this thesis's recommendations.

In the future scenario the MADR could (1) publish guidelines on diligent pesticide use, (2) promote ecological intensification of coffee cultivation by means of pollination and

(3) offer financial support for coffee growers during the transition. The second activity could be realized in collaboration with the Ministry of Environment [Ministerio del Medio Ambiente] and universities, where agronomy and comparable courses are taught. The local government of Huila could assume the same actions as the ministry, simply on a local level: (1) publish guidelines on diligent pesticide use, (2) promote coffee cultivation's ecological intensification via pollination and (3) offer financial support for coffee growers during the transition. The National Federation of Coffee Growers of Colombia [Federación Nacional de Cafeteros de Colombia] aims to improve living conditions for coffee growers via a social, productive, environmental, educational and infrastructural development (Federación Nacional de Cafeteros de Colombia, n.d., B). In order to so, it is affiliated with cooperatives all over Colombia, such as COOCENTRAL (Federación Nacional de Cafeteros de Colombia, n.d., C). As a neutral instance, in the future scenario the federation could (1) provide trainings regarding the responsible use of pesticides, (2) educate coffee growers concerning the benefits of pollination to their coffee crops and (3) promote the governmental guidelines of considerate pesticide use. The coffee growers' education could be realized in collaboration with beekeeping associations and companies. In the future scenario, COOCENTRAL could (1) provide technical consultancy to the coffee growers in order to decrease pesticide use and (2) promote ecological intensification via pollination as well as responsible pesticide use.

In the future scenario, beekeeping associations and companies, such as COAPI, ASOAPIS, ASAP APIMACO, and Apisred S.A.S., could take charge of the (1) provision of educating the coffee growers in cooperation with the National Federation of Coffee Growers, as well as (2) offer technical consultancy on factors relevant for renting beehives.

The beekeepers and coffee growers as individuals will be affected in various manners by the future scenario. Beekeepers are involved by (1) opening up an additional source of income, (2) the end of massive bee deaths, (3) an improved quality of their product and (4) the possibility to certificate their products as organic. Coffee growers are concerned via (1) the decreased expenses for pesticides, (2) a more sustainable farm management, (3) the possibility to certificate as organic coffee and moreover, if intercropping is applied, (4) a reduced dependence on one sole crop as income. The consumers are primarily affected by the improved quality of coffee and beekeeping products in the future scenario.

Table 7 summarizes the stakeholders that would be affected by the recommendations presented above.

Table 7: Overview of the stakeholders involved in or affected by the recommendations' application.
Source: Own elaboration.

SCALE	STAKEHOLDERS Government - Cooperatives & associations - Companies - Individuals
National	• MADR • CPAA • National Federation of Coffee Growers of Colombia
Regional	• Government of Huila • COAPI • Consumers
Local	• COOCENTRAL • ASOAPIS • ASAP • APIMACO • Apisred S.A.S. • Individual beekeepers and coffee growers

5.3 Discussion of results

In order to further increase the SES's resilience, meliponiculture could be promoted more strongly to expand pollinator diversity. For instance, the honey from angelitas is well-known for medicinal uses in case of eye diseases (R. Ospina-Tórres & G. Nates Parra, personal interview, April 4, 2018). Such a high reputation for a product might result in decent prices, even though no data regarding sales prices for native bee honey could be found. Nevertheless, Colombia generally has a high potential for organic production (G. A. Vargas Bautista, personal interview, May 21, 2018).

Moreover, coffee and honey could possibly be certified as organic products. Generally, product certifications for beekeeping products are non-existent in Colombia (personal conversations with beekeepers as part of the survey). This also favors honey falsifications, which are very common, and in turn increases consumers' mistrust. Nevertheless, the recommendation's future scenario creates favorable conditions for the introduction of such a certification. For instance, one could be created in order to guarantee a certain quality level of honey and to impede falsifications and an additional certificate for organic honey. Certified organic honey could possibly facilitate greater exports to northern countries, such as the USA or the EU, in contrast to the current focus on local consumptions. Such certifications would have to be issued by a neutral and widely trusted institution. However, no studies regarding possible impact on prices, markets etc. could be found. The coffee growers in the SES, on the other hand, already disposed of numerous certifications, even though none was certified as organic (Table 8).

Table 8: Percentage of coffe growers (n=25) holding coffee certificates. Source: Own elaboration.

FLO Fairtrade	UTZ	Rainforest Alliance	4C	C.A.F.E. practices	Café feminino
100%	32%	64%	28%	8%	8%

The economic benefit of organic certifications is disputed. Ibanez & Blackman (2016) reviewed numerous relevant studies and conclude that even though environmentally favorable, economic benefits for Colombian coffee growers are questionable, although such certifications have the potential to improve coffee growers' profits via improved access to markets and price premiums. One case study the authors mentioned determined that certified organic coffee growers in Uganda obtained 75% higher net revenues when compared to uncertified growers. Another study found that income increases decidedly depend on the impact on yields. Moreover, even though higher prices for organic coffee offset the lower yields, the considerable certification costs have to be deliberated.

In order to promote ecological intensification of the coffee cultivation as introduced in Chapter 5.2, the MADR and local government could offer incentives, such as initiating a PES program. However, the introduction of such a program would require a more precise valuation of ES (Costanza et al., 2018). Nevertheless, a preliminary PES scheme regarding the payment for pollination will briefly be presented (Figure 22).

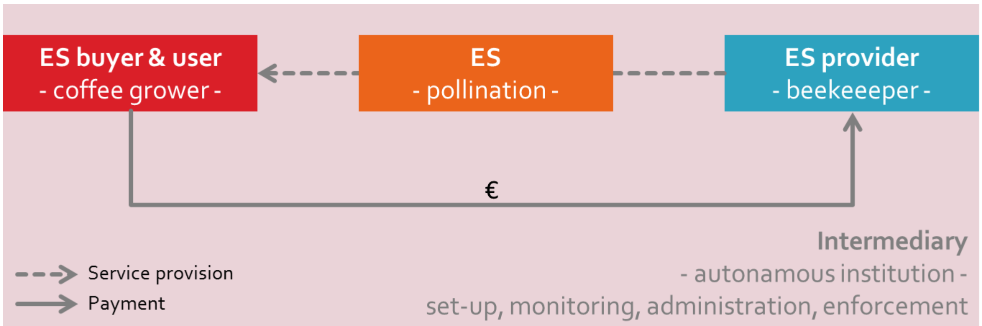


Figure 22: Possible PES scheme for pollination services. Source: Own elaboration.

It consists in a simple self-organized, user-financed organization, which seems appropriate due to the program's local scope. This slim organization, with only few stakeholders and intermediaries, results in relatively low costs. Nevertheless, during the program's set-up higher costs are expected to arise, due to high expenses for contract negotiations, baseline assessments, and the program design. Afterwards, costs still occur for monitoring, administration, and contract enforcement, but to a somewhat lesser amount than during the program set-up. Hence, PES programs can be difficult to finance, especially small-scale, user-financed PES (Wunder, 2008). The intermediary could be congruent to the ombudsman mentioned in Chapter 5.2. A suggestion for a possible institution is the local government in Huila or an autonomous entity related to the local government. This institution would be responsible for initiating and monitoring the program. The measurement of pollination for monitoring purposes can be derived from current production levels and the actual payment would correspond to the production increases in comparison to the baseline production. The payment's height as part of the PES program could be deducted from the WTP estimated in the present thesis.

Wunder (2005) suggested five criteria for PES programs, of which the here presented scheme fulfills the majority. It represents a voluntary payment by at least one ES buyer, namely a coffee grower, from at least one ES provider, specifically a beekeeper. The ES would have to be defined clearly in the contracts, which cannot be assessed at the present moment, which also applies to the conditionality.

Further considerations regarding the PES program would include how the program will be funded and if ecological coffee farming could or should be integrated into the PES program as a second ES. Furthermore, a more detailed feasibility study should be undertaken. As part of that study, it could be analyzed if the funding via the yield increase would be sufficient, since the SES involves mainly small-scale farmers with limited financial resources.

This thesis' recommendations focus on small-scale farmers, since these represent the majority of Colombian coffee farmers. The average coffee cultivation area among all 25 coffee growers amounted to 4.4 hectares with a standard deviation of 5.6 hectares. The smallest farm had one intercropped hectare of coffee, while the largest one cultivated 30 hectares. This was also reflected in the number of coffee plants per farm, which averaged at 21,075. However, the standard deviation was relatively high (38,895.35), the minimum being 3,500 and the maximum 200,000 plants. The reason for this high difference was a statistical outlier, who cultivated 200,000 crops on 30 hectares. When correcting the data by eliminating this outlier, the results become more homogenous (Table 9). Afterwards the average coffee cultivation area equaled 3.3 hectares with a standard deviation of 2.1 hectares. On average, each coffee grower cultivated 13,295.7 coffee crops with a standard deviation of 8,707.62 crops. The maximum now lays considerably lower at 35,000 coffee plants. Hence, the dominance of small-scale coffee growers in the SES becomes apparent. Furthermore, this justifies why the one outlier was not considered in the recommendations.

Table 9: Comparison of the original (n=25) and modified data (n=24) regarding coffee cultivation area and amount of coffee plants.

Source: Own elaboration.

	ORIGINAL DATA (n=25)		CORRECTED DATA (n=24)	
	Coffee cultivation area (ha)	Amount of coffee plants (per farm)	Coffee cultivation area (ha)	Amount of coffee plants (per farm)
Average	4.40	21,075	3.34	13,295.65
Standard deviation	5.60	38,895.35	2.05	87,07.62
Minimum	1	3,500	1	3,500
Maximum	30	200,000	10	35,000

Generally, the robustness of the data collected is uncertain. For instance, many beekeepers and coffee growers were not sure about their yearly production or selling prices, neither about the type and frequency in which they apply pesticides. Nevertheless, this thesis' primarily aims to raise interest in and awareness of the local SES, for which a low precision is sufficient (Costanza et al., 2017).

This is also reflected in an apparent discrepancy between coffee growers' WTP for pollination and the amount charged by beekeepers: The beekeepers would charge an average of 55.27€ per hive per month, while coffee growers' WTP amounted to 97.80€ for a 15% increase in yield, 166.67€ for a 40% increase, and 239.28€ for a 30% increase. Thus, WTP seems to be considerably higher than what beekeepers would charge. Nevertheless, when comparing the actual renting cost per coffee farm, which was assumed with the average cost of 55.27€ per beehive per month and two hives per hectare (CORPOICA, 2012), the data becomes more comparable (Table 10). Moreover, relative WTP (stated as percentage of additional profit), was converted to total values based on current production and revenue. However, inconsistencies remain. Now, WTP tends to be lower than what the beekeepers would charge. Only in very few cases (8% of the cases) do the WTP and renting costs coincide approximately (± 10% difference).

Table 10: Comparison of coffee growers' WTP and renting costs charged by beekeepers. Source: Own elaboration.

#	Coffee cultivation area (ha)	Beehive renting cost (€)	Coffee growers' WTP (€)		#	Coffee cultivation area (ha)	Beehive renting cost (€)	Coffee growers' WTP (€)	
1	2	221.08€	15%	294.75€	**14**	2.5	276.35€	15%	0.00€
			30%	442.12€				30%	0.00€
			50%	589.50€				50%	1,105.31€
2	1	110.54€	15%	294.75€	**15**	4	442.16€	15%	169.78€
			30%	589.50€				30%	509.33€
			50%	884.25€				50%	1,131.84€
3	1.4	154.76€	15%	29.47€	**16**	1.5	165.81€	15%	17.93€
			30%	58.95€				30%	71.73€
			50%	103.16€				50%	239.10€
4	4	442.16€	15%	56.00€	**17**	3	331.62€	15%	37.14€
			30%	112.00€				30%	127.33€
			50%	176.85€				50%	265.27€
5	2	221.08€	15%	14.74€	**18**	2	221.08€	15%	58.95€
			30%	29.47€				30%	88.42€
			50%	29.47€				50%	147.37€
6	1.4	154.76€	15%	56.00€	**19**	4.5	497.43€	15%	0.00€
			30%	112.00€				30%	0.00€
			50%	176.85€				50%	0.00€
7	1.75	193.45€	15%	58.95€	**20**	30	3.316.20€	15%	1,326.37€
			30%	117.90€				30%	5,305.50€
			50%	176.85€				50%	17,684.99€
8	1.5	165.81€	15%	5.89€	**21**	3.5	386.89€	15%	36.36€
			30%	8.84€				30%	0.00€
			50%	14.74€				50%	0.00€
9	3	331.62€	15%	191.66€	**22**	4	442.16€	15%	20.43€
			30%	511.10€				30%	81.70€
			50%	1.703.65€				50%	340.44€
10	10	1.105.40€	15%	268.63€	**23**	6	663.24€	15%	20.39€
			30%	1.151.29€				30%	81.54€
			50%	3.198.04€				50%	226.51€
11	5	552.70€	15%	147.37€	**24**	3	331.62€	15%	212.22€
			30%	156.22€				30%	848.88€
			50%	170.95€				50%	2,122.20€
12	5.5	607.97€	15%	165.35€	**25**	6	663.24€	15%	289.68€
			30%	661.42€				30%	695.23€
			50%	1.929.14€				50%	1,448.40€
13	1.5	165.81€	15%	58.95€					
			30%	117.90€					
			50%	162.11€					

Moreover, in some cases it was difficult to locate official data for the Colombian apiculture. This data could have used as reference values in the SES's analysis, i.e. the amount of beehives lost. One interviewee also mentioned that the few studies that have been conducted in Colombia are usually not published afterwards (G. A. Vargas Bautista, personal interview, May 21, 2018). Thus, this thesis' findings could not be compared to relevant studies.

As a suggestion for further research, cases in which a comparable scheme is applied, i.e. in the USA, could be reviewed in order to determine advantages and disadvantages as well as the economic impact. However, the transferability might be insufficient due to other circumstances. An in-depth stakeholder analysis might be required in order to estimate the recommendations' feasibility. Moreover, regional studies regarding pollination's impact on coffee yield are recommended, since the range of existing studies is enormous and might be influenced by local factors. Such a study could help to quantify the yield increase, identify the most effective and abundant pollinator as well as possible complementary effects between them. These studies should also include native bees. Moreover, the interrelations between production inputs in regard to pollination should be further investigated. Generally, the links between pollination and other ESs in Huila remains understudied.

6 Conclusions

The SES studied in this thesis consists of coffee growers and beekeepers in the Colombian department Huila, as well as the interrelations among each other and their environment.

Exogenous controls, which affect the SES from the outside, consist of (1) ecological ones, more specifically local climate, climate change, regional flora and fauna, proximity to natural forests, as well as (2) social ones, namely governmental support and legislation, and regional economy. Ecological variables within the system included pollinator abundance and effectivity, pest abundance (especially *H. hampei* and *H. vastatrix*), pest control, bee diseases, flowering season, diversity and abundance of flowers, food production, resilience of ecosystems, and soil fertility, affecting the provision of pollination services as well as coffee cultivation and beekeeping. Socially, the aforementioned factors are shaped by habitat destruction, pesticide overuse, agricultural intensification, introduction of exotic species, dependence on a sole source of income, and coffee and apicultural prices.

Over time, humans have drastically transformed the SES. For instance, neither honeybees nor coffee plants are natural but have been introduced to Colombia. However, beekeeping has a long history on Colombian territory. Before the introduction of *A. mellifera* during the Spanish conquest, the so-called meliponiculture, especially with the angelitas (*T. angustula*), was practiced. The introduction of European honeybees and the Africanization of Colombian bees after 1979 have led to severe alterations in the SES, such as the abandonment of meliponiculture.

Currently, the exposure to various threats possibly puts the SES in jeopardy. The main threat is the extensive use of pesticides. Moreover, the following threats have been identified: monocultures, deforestation, climate change, the introduction of exotic species and ignorance about the benefits bees provide. Not only pose they a risk to the SES's resilience, but also to human well-being.

Thus, a reduction of pesticide application is strongly encouraged. In order to do so, coffee growers would first need to know about the benefits pollination provides for their crops, specifically increasing fruit set and quality while decreasing the occurrence of peaberries. However, current practices possibly endanger four out of five categories of human well-being: security, basic material minimum required for a good live, health, as well as freedom and choice. Ultimately, mere human and plant survival are at stake.

Coffee growers' WTP for pollination changed according to the assumed yield increase. Average WTP for a 15% increase was estimated at 97.80€ or 6% of the increased yield's profit, for a 30% increase 166.67€ or 10% of the additional profit, and for a 50% increase 239.28€ or 21% of the additional profit. Beekeepers on the other hand would charge 55.27€/hive/month or 1.75% of additional yield profits. Moreover, pollination not only provides an economic value to the actors, but also social and ecological ones. The social value mainly consists of the provision of income security and diversification due to beekeeping practices. Ecologically the value consists of the maintenance of natural and agroecosystems.

In order to maintain these values and to increase the resilience of the SES, this thesis recommends intensifying the coffee cultivation by means of pollination, ideally in combination with the intercropping of coffee crops with other fruit trees. Theoretically, such a scheme seems possible, since coffee growers would be willing to pay for the renting of beehives. However, certain prerequisites have to be fulfilled, most notably a drastic reduction of pesticide use in the coffee cultivation. The SES's resilience would increase, due to a growth of bee abundance and diversity. Moreover, coffee growers and beekeepers would both be able to exploit new sources of income, while acting more sustainably and protecting the local environment.

In conclusion, this thesis' objective was fulfilled for both sub-targets: pollination's value was determined in the form of coffee growers' WTP for pollination services, but also ecological and social values and recommendations were given on how to increase the SES's resilience.

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Annexes

Annex A. Survey conducted with beekeepers

QUESTIONNAIRE FOR BEEKEEPERS

Date: ____________________ Municipality: ____________________

Coordinates: ____________________________________ Height: ____________________

Name of interviewee: ____________________________ ☐ F ☐ M

Age: ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ 60+

SOCIAL FACTORS
1. For how many years have you been a beekeeper?
___ years
2. Do you have other sources of income?
☐ No ☐ Yes. Please specify: ____________________
3. Do you receive governmental support for the beekeeping?
☐ No ☐ Yes. Please specify: ____________________
4. Are you part of a beekeeper association?
☐ No ☐ Yes. Please specify: ____________________ Why? What advantages does it offer? ____________________
5. In what type of market do you sell your products?
☐ Local: ___% Please specify: ____________________ ☐ Regional: ___% Please specify: ____________________ ☐ National: ___% Please specify: ____________________ ☐ International: ___% Please specify: ____________________
6. Do you have any certification for your products?
☐ No ☐ Yes. Please specify: ____________________ Why? What advantages does it offer? ____________________

ECOLOGICAL FACTORS
7. What species of bees do you work with? Multiple selection possible.
☐ *Apis mellifera* (European honeybee) ☐ *Apis mellifera scutellata* (African honeybee) ☐ *Euglossini* (orchid bees) ☐ *Tetragonisca angustula* (Angelita) ☐ Other. Please specify: ______
8. What other species of bees can you observe in your environment? Multiple selection possible.
☐ *Apis mellifera* (European honeybee) ☐ *Apis mellifera scutellata* (African honeybee) ☐ *Euglossini* (orchid bees) ☐ *Tetragonisca angustula* (Angelita) ☐ Other. Please specify: ______
9. Of how many bees does each of your hives consist of?
☐ 0 – 20.000 bees ☐ 20.000 – 30.000 bees ☐ 30.000 – 40.000 bees ☐ 40.000 – 60.000 bees
10. How many colonies do you have?
____ colonies
11. In the past year, did you observe the following diseases among your bees?
☐ *Varroa* ☐ American foulbrood ☐ European foulbrood ☐ *Nosema* ☐ Other. Please specify: ______
12. Did a colony collapse disorder ever occur in your hives?
☐ No ☐ Yes. Please specify the moment and impact: ______
13. Do you use medications in the hives?
☐ No ☐ Yes. Please specify which one: ______ Please specify the frequency of use: ______ Please specify the annual amount applied: ______
14. Are there forests near your apiary?
☐ No ☐ Yes. Please specify the distance: ______
15. Are there flowers near your apiary?
☐ No ☐ Yes. Please specify the distance: ______

16. Which services do you think honeybees provide? Multiple selection possible.

☐ Preservation of biodiversity
☐ Increase of agricultural productivity
☐ Maintenance of ecosystems
☐ Pollination
☐ Contribution to food security
☐ Other. Please specify: ______________________________

17. What do you think which threats bees are facing? Multiple selection possible.

☐ Use of pesticides
☐ Change in land uses, i.e. deforestation
☐ Agricultural intensification, i.e. monocultures
☐ Introduction of invasive species
☐ Destruction and degradation of habitats
☐ Climate change
☐ Other. Please specify: ______________________________

ECONOMIC FACTORS

18. Which products do you produce?

☐ Honey
☐ Pollen
☐ Propolis
☐ Royal jelly
☐ Nucleus
☐ Other. Please specify: ______________________________

19. . How much do you produce annually?

☐ Honey: ___ kg
☐ Pollen: ___ kg
☐ Propolis: ___ kg
☐ Royal jelly: ___ g
☐ Nucleus: ___
☐ Other. Please specify: ______________________________

20. Are you satisfied with the quality of your products?

☐ No. Please specify: ______________________________
☐ Yes. Please specify: ______________________________

21. What is the average price at which you sold your products during the last year?

☐ Honey: ___ COP/kg
☐ Pollen: ___ COP/kg
☐ Propolis: ___ COP/kg
☐ Royal jelly: ___ COP/g
☐ Nucleus: ___
☐ Other. Please specify: ______________________________

22. Is your apicultural activity profitable?
☐ No ☐ Yes
23. Do you rent beehives / bees to farmers (directed pollination)?
☐ No ☐ Yes. Please specify: ____
24. How much do you charge for leasing your hives?
___ COP/hive
25. Do you think that this is an appropriate price?
☐ No. Please specify why not: ____ ☐ Yes
26. What would be an appropriate price in your opinion?
___ COP/hive

Annex B. Survey conducted with coffee growers

QUESTIONNAIRE FOR COFFEE GROWERS

Date: ____________________

Farm: ____________________________________Municipality: _________________________

Coordinates: _____________________________________ Height: _______________________

Name of interviewee: ____________________________ ☐ F ☐ M

Age: ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ 60+

SOCIAL FACTORS
1. For how many years have you been a coffee grower?
___ years
2. Do you have other sources of income?
☐ No ☐ Yes. Please specify: ____________________
3. Do you receive governmental support for the cultivation of coffee?
☐ No ☐ Yes. Please specify: ____________________
4. Are you part of a coffee grower association?
☐ No ☐ Yes. Please specify: ____________________ Why? What advantages does it offer? ____________________
5. Do you have any of the following certifications?
☐ FLO Fairtrade ☐ UTZ ☐ Rainforest Alliance ☐ 4c ☐ Other. Please specify: ____________________
6. Do you own the farm where you grow?
☐ No ☐ Yes
7. How big is the farm?
___ hectares
8. How many hectares correspond to coffee cultivation?
___ hectares
9. In what type of market do you sell your products?
☐ Local: ___ % Please specify: ____________________ ☐ Regional: ___ % Please specify: ____________________ ☐ National: ___ % Please specify: ____________________ ☐ International: ___ % Please specify: ____________________
10. How do you sell your coffee?

☐ In grain: ___ %

☐ Roasted: ___ %

☐ Grounded: ___ %

☐ Other. Please specify: ______________________________

ECOLOGICAL FACTORS

11. Which coffee species are you cultivating? Multiple selection possible.

☐ *Coffea arabica* 'caturra'

☐ *Coffea arabica* 'catimor'

☐ *Coffea arabica* 'colombia'

☐ *Coffea arabica* 'castillo'

☐ Other. Please specify: ______________________________

12. ¿In what months does your coffee usually flower?

☐ January	☐ February	☐ March	☐ April
☐ May	☐ June	☐ July	☐ August
☐ September	☐ October	☐ November	☐ December

13. Do you use fertilizers in your coffee plants?

☐ No

☐ Yes. Please specify which one: ______________________________

Please specify the frequency of use: ______________________________

Please specify the annual amount applied: ______________________________

14. Do your plants suffer from some type of pest?

☐ No

☐ Yes. Please specify which one: ______________________________

15. Do you use pesticides in your coffee plants?

☐ No

☐ Yes. Please specify which one: ______________________________

Please specify the frequency of use: ______________________________

Please specify the annual amount applied: ______________________________

16. What form of agricultural management do you apply on your farm?

☐ Traditional

☐ Organic

☐ Intercropping

☐ Terrazing

☐ Use of compost as fertilizer

☐ Other. Please specify:______________________________

17. Do you collaborate with beekeepers who provide you with hives for pollinating your coffee crops (managed pollination)?

☐ No

☐ Yes. Please specify with whom: ______________________________

18. Which bee species can you observe among your coffee plants? Multiple selection possible.

☐ *Apis mellifera scutellata* (African honeybee)

https://es.wikipedia.org/wiki/Apis_mellifera_scutellata#/media/File:Apis_mellifera_scutellata.jpg

☐ *Euglossini* (orchid bees)

https://de.wikipedia.org/wiki/Prachtbienen#/media/File:Male_Euglossa_sp.jpg

☐ *Tetragonisca angustula* (Angelita)

https://es.wikipedia.org/wiki/Tetragonisca_angustula#/media/File:Abelha-jatai.jpg

☐ Other. Please specify: ______________________________

19. Which services do you think honeybees provide? Multiple selection possible.

☐ Preservation of biodiversity
☐ Increase of agricultural productivity
☐ Maintenance of ecosystems
☐ Pollination
☐ Contribution to food security
☐ Other. Please specify: ______________________________

20. What do you think which threats bees are facing? Multiple selection possible.

☐ Use of pesticides
☐ Change in land uses, i.e. deforestation
☐ Agricultural intensification, i.e. monocultures
☐ Introduction of invasive species
☐ Destruction and degradation of habitats
☐ Climate change
☐ Other. Please specify: ______________________________

ECONOMIC FACTORS

21. . How much coffee do you produce annually?

_______ kg

22. What is the average price at which you sold your coffee during the last year?

_______ COP/kg

23. In your personal case, is your coffee cultivation profitable?

☐ No
☐ Yes

24. Are you satisfied with your coffee's quality?

☐ No. Please specify: ______________________________
☐ Yes. Please specify: ______________________________

25. If hypothetically you were able to increase your productivity in terms of an increased yield by means of pollination, how much would you be willing to pay to a beekeeper for renting his hives for pollination services? For practical reasons, we assume that pollination were the only relevant variable for production.
If the yield were to increase by 15%:______ COP/hive If the yield were to increase by 30%: ______ COP/ hive If the yield were to increase by 50%: ______ COP/ hive

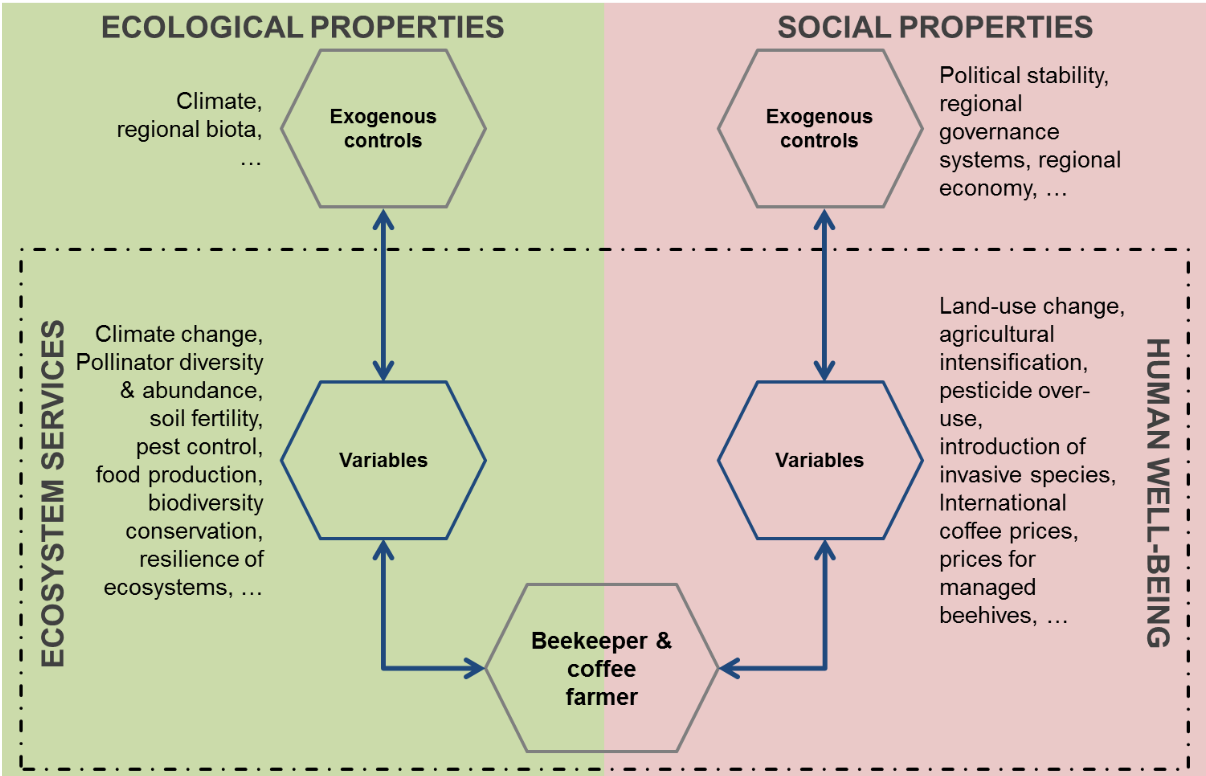
Annex C. Interview questions

EXPERT INTERVIEW

Date: ______________ Name of interviewee: __________________________________

Institution: ____________________________________ Position: ________________________

1. How do Colombians perceive the honeybees' importance?
2. Do the Colombians know about the honeybees' relevance and the threats they face?
3. What are the most pressing risks for honeybees in the Colombian context?
4. How can society benefit from honeybees and the ecosystem services they provide and increase their welfare?
5. In your opinion, which ecological factors determine the interactions between the beekeeping and coffee growing industry and their actors?
6. In your opinion, which social factors determine the interactions between the beekeeping and coffee growing industry and their actors?

7. Do you consider the selected sociological and ecological factors in the socio-ecological system presented below to be correct?


8. What are the socio-cultural, ecological and economic values of pollination?

Annex D. Coordinates of apiaries and coffee farms

APIARIES				
ID	Beekeeper name	Municipality	Coordinates N	W
B1	Ramon Ruiz	Algeciras	2,53679	75,3435
B2	Horacio Ortiz Chávarro	Neiva	2,96952	75,2498
B3	Alberto Plata Antía	Garzón	2,13339	75,62
B4	Alfredo Collazos Ortiz	Neiva	2,90269	75,2936
B5	Juan Carlos Alvares Dávila	Garzón	2,1040	75,3528
B6	Amparo Campos Vidarte	Garzón	2,1118	75,3541
B7	Luis Hernando Fajardo	Pitalito	1,88361	76,0679
B8	Gerardo España	Pitalito	1,87742	76,07040
B9	Francisco Arturo Silva	Rivera	2,84063	75,2892

COFFEE FARMS				
ID	Farm name	Municipality	Coordinates N	W
C1	La Fortuna	Garzón	2,23999	75,51868
C2	Nueva Floresta	Garzón	2,24309	75,50266
C3	El Progreso	Garzón	2,24129	75,51492
C4	Miranda	Garzón	2,24129	75,51492
C5	Los Sauces	Garzón	2,20302	75,52745
C6	Las Cruces	Garzón	2,20460	75,51924
C7	El Hueco	Garzón	2,20541	75,52261
C8	Filadelfia	Garzón	2,18702	75,54803
C9	La Violeta	Garzón	2,16551	75,57066
C10	El Rosal	Garzón	2,08848	75,93845
C11	Evenecer	Garzón	2,20652	75,52855
C12	Bella Vista	Garzón	2,11157	75,60004
C13	Villa Consuela	Garzón	2,18815	75,56423
C14	El Socorro	Garzón	2,19919	75,53423
C15	El Mirador	Garzón	2,16551	75,57066
C16	La Tolda	Garzón	2,13698	75,60070
C17	La Esperanza	Garzón	2,19822	75,63533
C18	El Recuerdo	Garzón	2,20522	75,52128
C19	Las Palmeras	Garzón	2,05784	75,62623
C20	Lucitiana	Garzón	2,16765	75,58501
C21	Barcelona	Garzón	2,10285	75,58881
C22	Los Pinos	Garzón	2,19324	75,53695
C23	La Polita	Garzón	2,21649	75,55215
C24	La Fortuna	Garzón	2,10493	75,59893
C25	Buenos Aires	Garzón	1,81655	75,83393