Chapter 2

Agricultural SystemS and the Conservation of Biodiversity and Ecosystems in the Tropics

F.F. Goulart, T.K.B. Jacobson, B.Q.C. Zimbres,
R.B. Machado, L.M.S. Aguiar and G.W. Fernandes

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1. Introduction

One quarter of the terrestrial surface is composed of cultural systems, while in the tropics, 70% of the land has already been converted into pastures, agriculture, or a mixture of managed landscapes [1,2]. Agricultural expansion is recognized as the most significant human alteration of the global environment, with the addition of fertilizers in the agricultural sector accounting for high input of nitrogen and phosphorus in terrestrial ecosystems. The conversion of natural ecosystems in agricultural areas has increased fire frequency, and caused profound rupture in nutrient cycles. Furthermore, agricultural expansion has modified landscapes, making them more vulnerable to invasion by exotic species.

In spite of these facts, there is enough evidence that anthropogenic systems managed using agroecological principles can support high levels of biodiversity [3,4], contribute to the maintenance of a healthy environment and its services, as well as depend less on costly external inputs of pollutant pesticides and fertilizers [5]. Therefore, there is a wide range of agricultural management strategies, and they differ greatly on their effect on biodiversity.

Today, agroforestry systems cover more than 16 million hectares, and they involve 1.2 billion people worldwide [6]. Traditional shade-cocoa [7], shade-coffee [3], and agroforestry home-gardens [8] are examples of agricultural systems that retain part of the natural habitat structure and ecosystems properties, providing habitat for rich and diverse fauna and flora including threatened and endemic species. On the other hand, intensive agricultural systems, such as pastures and extensive mono specific plantations, harbour low levels of biodiversity, hamper biological flux, and lead to soil leaching, and nutrient import/export. Intensive agriculture is one of the major drivers of change in some biogeochemical cycles such as nitrogen and phosphorus [9]. This "out of farm" nutrient input changes the coexistence and competition patterns between autotrophic organisms, changing the structure of natural ecosystems. The more intensive the agricultural systems, the less they are capable of harbouring biodiversity, maintaining landscape connectivity, and conserving ecosystems properties and services. Agricultural intensification is a process in which low-input agriculture (such as traditional mixed farming) becomes intensified in terms of input/output level, which in turn impacts negatively the associated biodiversity, and the natural ecological services.

2. Hunger and conservation in the tropics

Two of the most important issues in the political and scientific agendas are biodiversity conservation, and hunger. Of the world's 2 million formally described taxa, between 12% and 52% are threatened with extinction according to IUCN Red List of Endangered Species [10]. For example, 119 out of 273 species of turtles in the world are threatened, and 1,063 out of 4,735 mammal species are threatened [10]. At the same time, solving the hunger problem seems to be another great challenge for humanity. Global food production has increased 168% over the past 42 years. However, there is great inequality in food distribution. Only between 2000 and 2002, 852 million people suffered from malnutrition (96% in developing countries). Although biodiversity loss and hunger are global problems, nowhere are these problems more acute than in the tropical region. There is a clear pattern in the distribution of biodiversity and latitude, i.e. the closer it gets to the Equator, the larger the number of species. The Afrotropical and the Neotropical region account for 49% of the bird, 63% of the amphibian, and 45% of the mammal species of the world [10]. Only in the Neotropical region, more than 10,000 vertebrate species are found [10]. Hence, most world priority sites for biodiversity conservation are concentrated in the tropical region [11]. On the other hand, hunger problem are also much more intense in the tropics, where most underdeveloped countries are situated. South Asia alone accounts for 60% of the undernourished people in the world, and Subsaarian Africa also shows high starvation levels. In the Congo Democratic Republic, more than 60% of the population is unable to acquire sufficient calories to meet their daily caloric requirements. In India, one of the most populous countries, this value lies between 30 and 40% [6].

Because of the high level of biological diversity, and the great famine incidence, it seems clear that trade-off or win-win relationship between biodiversity and agriculture must be exacerbated. Therefore, global scientific and political concerns that address the issues of hunger and biodiversity conservation in the tropical region are necessary.

3. Myths and facts about conservation and agricultural production

Ecologists and biologists have focused their work primarily on 'pristine' or 'untouched' habitats [12,13,14]. This is done under the assumption that human modified ecosystems have virtually null or diminished importance for conservation, and that conservation efforts should go in the direction of establishing human-free reserves as large as possible to avoid species loss. What some ecologists and conservation biologists ignore is the fact that: even supposedly untouched places have actually moderate degree of human intervention [15]. Human-modified ecosystems vary greatly in their quality for biodiversity and maintenance of ecosystems properties. In the 'unaltered' habitat, biodiversity is often restricted to patches embedded in an anthropogenic matrix, which can serve as a conduit or barrier to species movement. Because connectivity is necessary for the long term maintenance of species in patchy landscapes [16], matrix management has deep effects on biodiversity, and functioning of the complex habitat mosaic [17,18]. Finally, human activities can reach far beyond anthropogenic environments, causing changes in several regional processes, hence affecting ecosystems and biodiversity at larger scales.

On the other hand, agricultural sciences are rarely aware of the effect of management on ecological patterns taking place in the agrienvironments and landscapes. The inverse is also true: they are unaware of how ecological patterns taking place in the agrienvironment and of the landscape affect agricultural production. Agribusiness and agricultural scientists generally aim at reaching the highest agricultural yields. There is an implicit assumption that the loss of ecosystems services will be overcome by biotechnological advances. It is common the thinking that if the weather is drier because of climatic alterations, resistant crop will be developed; that if soil is leached, higher fertilizer quantities can be applied; and so on.

A common argument, in which yield-maximization is based, is the poverty and hunger alleviation issue. The mostly accepted ideas are that agricultural managements should increase production at any cost, based on the hunger alleviation argument, and that conservation efforts, although being relevant to society, should never prevent food production from increasing. Facing these persuasive arguments, biological conservation is regarded as low priority, compared to productivist sectors in the stakeholder's agenda.

Even some conservation biologists accept such assumptions, so that they propose that agricultural areas should reach maximum yields in order to reduce the need to convert more natural areas into agricultural systems, but still maintain the production target [19,20]. This theory is called Land Sparing, and predicts that agricultural intensification would reduce deforestation by increasing productivity. This view has been criticized on the theoretical ground [13,14,21], as well as with empirical data from studies at both regional [22], and local scales [23]. For example, the agricultural product demand (mainly meat and soybean) has increased Amazonian ecosystems' conversion rates. Direct forest conversion into agricultural lands in 2003 accounted for 23% of forest and savannah deforestation in the Mato Grosso state of Brazil. While grazing areas remain the main deforestation cause in the Amazon, land conversion for the production of soybean crops for exportation is also leading to high deforestation rates [24].

Figure 1A. shows that, at global levels, food production has been steeply increasing since the sixties [25]. Food production per capita has also increased, although at lower rates, and food prices have been declining with some oscillation. Finally, the number of undernourished people has declined up to the mid 1990s, when it started increasing suddenly. Therefore, at global levels (in which agribusiness operates), the increase in food production per capita *per se* does not guarantee hunger alleviation. Hence even disregarding conservation issues, the argument that food production should increase to nurse the hunger problem, even if conservation policies are underprivileged, is a fallacy and lacks scientific base.

Using basic ecological principles, such as trophic webs, it is possible to maximize food by simply moving down to lower levels of the trophic pyramid. By changing our food habits so that we eat more vegetables and less meat, the quantity of food *per capita* will increase. Therefore, it is more reasonable to use actual food production in a more rational manner, rather than clearing forest for agricultural expansion, or increasing productivity at the cost of biodiversity loss. Another important issue that emerges from the hunger problem is that of food distribution. From 1980 to 2000, the number of obese adults have doubled in the United States [28], and tripled in the United Kingdom [29]. Obesity is growing around the world and affects mostly high income countries, but it is also epidemic of many low income countries. For instance, in some cities of China, 20% of the population is overweight [30]. In some countries in Africa, Latin America, Asia, and the Pacific, there is a double burden of diet-related diseases caused by obesity and undernourishment. Figure 1.B shows the proportion of the population which is overweight in the last years in some countries.

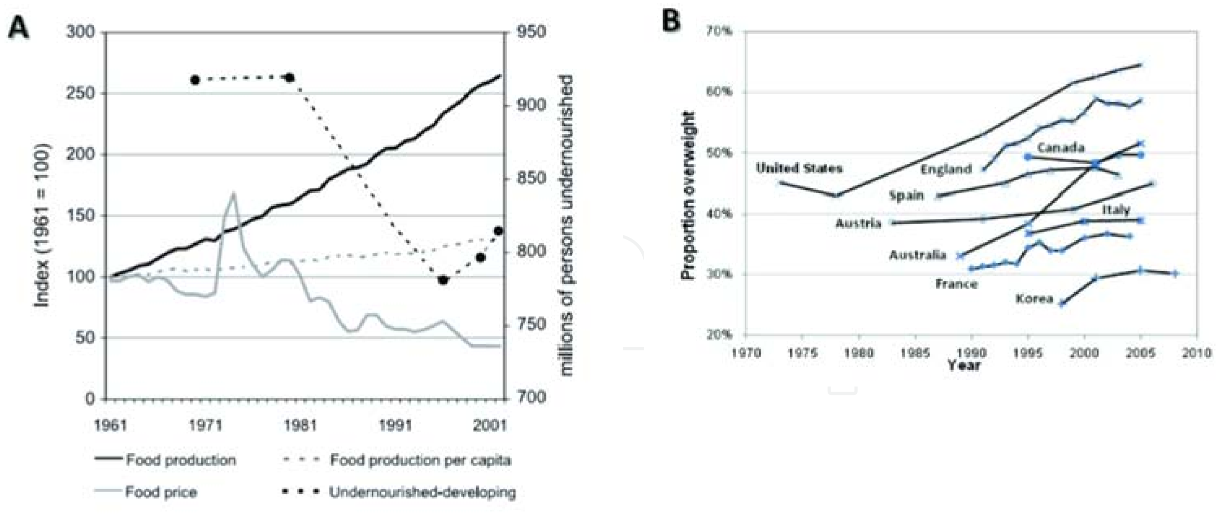

Figure 1. A) Trends in key indicators of world's food production 1961-2002 [26]. (B) Proportion of the population which is overweighed in the last years in some countries [27].

Another wrong aspect of the Land Sparing Theory is that it does not account for some important political and social aspects [8]. For instance, the rural poor comprise 80% of those hungry worldwide [6], and any management that addresses the hunger issue must therefore focus on poor farmers. Studies in Brazil [31], Central America [32], and India [33] showed that agricultural intensification leads to social disasters. In Brazil, agricultural intensification has lead to an increase or to the maintenance of rural poverty levels, and to a drastic increase of poverty in the cities. It has reduced prematurely the labour demand, inflated land prices, expelling small landholders from their lands [31]. In Andra Pradesh, in India, 16,000 farmers committed suicide between 1995 and 1997, mainly because of farm failure. Most failure was caused by conversion of traditional mixed farming systems into monocultures of a high yield variety of cotton, which was highly dependent on external inputs [33]. Hence the assumption that agricultural intensification can solve the problem of hunger and poverty is naïve. Furthermore, the idea that large scale agriculture produces more than at smaller scales is erroneous for most countries [34], as is the idea that organic systems are generally less productive than conventional ones [35,36].

4. Agriculture and biodiversity conservation

Great part of the world's terrestrial surface is in the agrienvironment, so that most of the world's terrestrial biodiversity inhabits the agrienvironment (known as farm biodiversity), or inhabits patches of natural habitat embedded in an agricultural matrix. In the last 40 years, most of these agricultural landscapes have gone through deep changes in farming practices, which have negatively affected farm biodiversity [37,38,39], as well as the metapopulation dynamics of the species inhabiting patches embedded in an agriculture matrix [13,40,21]. "Agricultural intensification" is the general term given to changes in farming practices that have begun after the Green Revolution. Intensification includes pesticides, irrigation systems, machinery, an increase in farm size, and a decrease of spatial and temporal heterogeneity [37].

Concerning agriculture and biodiversity, it is important to distinguish "planned biodiversity" or "agrobiodiversity", which are the species intentionally introduced in the agricultural systems for the proposes of production, from "associated biodiversity" defined as the biological components that exist in an agricultural system by chance, without being actively introduced [41]. From an ecological point of view, it is also useful to distinguish the associated biodiversity that inhabits the agrienvironment (that feeds, reproduces and roosts in it) from species using the agricultural matrix simply for dispersion.

Agricultural intensification leads to declines at the species level, through conversion of mixed crop systems into monocultures, but also at the genetic level though the replacement of highly diverse traditional cultivated varieties for single high-yield varieties [42,43]. This has caused the extinction of many traditional varieties worldwide, leading to homogenization of cultivated species at the genetic level. Because traditional varieties have gone through centuries or millenniums of adaptation and selection, many traditional varieties are much more adaptable and less demanding in terms of external inputs than modern ones.

Moreover, agriculture intensification leads to the widespread use of pesticides, which cause the loss of biodiversity through direct poisoning. The famous Rachel Carson's Silent Spring [44] is a keystone in the environmental cause, and describes the effect of pesticides on birds. Pesticides increase the risk of egg breakage by reducing egg shell thickness [44, 46]. They also cause changes in brain activity of the birds [47]. Consequently, pesticides may not only cause population decline of birds inhabiting agrienvironments, but it may also negatively affect species inhabiting adjoining habitat forest areas [48]. Pesticides exposure associated to trematode infection can cause morphological deformities in amphibians [49]. Another vertebrate species negatively affected by pesticides are human beings. The WHO [51] estimates that 220,000 people die annually because of unintended pesticide poisoning. The majority of cases occur in low-income countries, where knowledge of health risks and safe use of pesticides is limited [6].

Another effect of agricultural intensification on farm biodiversity is the loss of spatial and temporal heterogeneity which seems to be the major cause of farm associated biodiversity decline worldwide [37]. Studies conducted in 'natural landscapes' suggest that spatial heterogeneity increases the number of possible niches in a given habitat [51], as well as the possibility of co-existence among species that share the same niche [52]. Heterogeneity also increases the chance of co-existence of predator-prey dynamics [53]. Bird nest predation rates in homogeneous environments are higher than in heterogeneous ones [55,37]. Also, heterogeneity can affect perceived risks for bird species, so that even if there is no real predation pressure (for instance, because top predators abundance has decreased due of habitat alteration), birds will not establish in homogeneous habitats, where perceived risk is high [55,56]. Therefore agriculture intensification, by affecting predation pressure via habitat homogenization deeply reduces bird diversity associated with agricultural habitats [37,55].

For animals that disperse through the agricultural matrix, heterogeneity can increase matrix permeability to species flux, reducing (re)colonization in patches in agricultural landscapes [37]. Regarding forest birds, individuals face great actual and perceived risk when dispersing in open habitats [57], which suggest that intensification of the agricultural matrix may reduce avian dispersion rates. Hence, agriculture intensification leads to a loss of temporal and spatial heterogeneity among farm plots and regions via homogenization of farming practices [37]. Heterogeneity is a key concept in agroecology, and can go beyond the biological sphere, reaching important aspects of social spheres, such as cultural (diversity of agricultural practices and knowledge in the community), gender (woman participation in farming activities), and individual (individual empowerment in rural communities) levels. Hence, heterogeneity must be a flagship in the management of agricultural landscapes [58].

Following, we exemplify how agricultural practices affect biodiversity in the tropical region, by highlighting the effects of agricultural intensification on biodiversity and production of shade-cocoa (Fig 2.A), shade-coffee (Fig 2.B) and home gardens (Fig 2.C).

Figure 2. Highly diverse agroforestry systems in the Atlantic Forest Hotspot of Brazil. Figure 2.a is a shade-cocoa (*cabruca*) in the south of the Northeast region in the state of Bahia; Fig 2.b is a traditional rustic coffee agroforest in the southeast region in the state of Minas Gerais; and Fig 2.c is a home-garden in the southeast in the state of São Paulo. Photos by F.F. Goulart.

4.1. Shade-cocoa plantations

Shade-cocoa systems are the largest agroforestry system in the world, accounting for 7 million hectares worldwide [6]. Cocoa is planted under a shade canopy in many tropical countries, such as Indonesia [59], Costa Rica [61], Mexico [62], Camerron [63], and Brazil. The cabruca is the local name of traditional rustic shade-cocoa plantations in the state of Bahia, in the northeast Brazil. The system involves growing cocoa under the canopy of native Atlantic Forest. In the 1960s, the Brazilian military government implemented a policy of promoting the intensification of the cabruca to increase production. The program involved the reduction of shade in a way to reduce the incidence of the witches broom fungi (*Moniliophthora perniciosa*), a cocoa pest responsible for the collapse of the productivity in the region. Additionally, the use of fertilizers and pesticides was suggested due to an increase in insect pests in the low-shade management strategy. The government conceded credit loans to farmers who removed trees from the system. This involved the use of arboricides in order to facilitate the 'deforestation' of the high-shade cabruca. Fortunately, many farmers did not adopt the program, while many that obtain the loan did not remove the trees. The reason for this is that fertilizer and insecticide expenditures outweighed the gains of the low-shade management. Also farmers considered that tree removal would increase risk under the condition of price uncertainty.

Today, the rustic cabruca is what was left of the Atlantic Forest in the region, and it harbours high levels of forest biodiversity. High richness of forest ants [64], bats, birds [4], frogs, lizards, ferns [7], and trees have been reported in the cabruca [65]. Furthermore, many threatened species, such as the golden lion tamarin (*Leontopithecus rosalia*), one of the rarest monkeys of the world [66], the golden headed lion tamarin (*Leontopithecus chrysomelas*), the yellow breasted porcupine (*Chaetomys subspinosus*) [67], the white-necked hawk (*Leucopternis lacernulatus*), and the pink-legged graveteiro (*Acrobatornis fonsecai*) [4] live in the cabrucas. This *Acrobatornis* is a mono-specific genus, first described in the cabruca [68], and has never been reported outside of this environment [69]. Because all of these organisms are forest dwelling species, it seems plausible that, if all cabruca were converted into low-shade system, as proposed by the government, these species would be locally extinct. In the case of *Acrobatornis* it is would be globaly extinct, as it is restricted to high shade systems. Hence, if farmers were risk takers, this species would have disappeared without science ever knowing about it, as it was described 30 years after the implementation of the intensification policy. We consider the *cabruca* one of the most biological important agroecosystem in the world.

Faria and coworkers [4,7] found that the richness of species in the rustic agroforestry is even higher than the found in the forest. Despite this great importance of shade plantations for biodiversity conservation, most studies indicate that many forest dwelling species are absent or found at a much lower abundance in the agroforest, compared to the primary forest, suggesting that shade plantations cannot substitute the forest in its ecological function. In a study in Costa Rica, two species of sloths (*Bradypus variegatus* and *Choloepus hoffmannis*) were radio-tracked to understand the use of the agrienvironment by the individuals. The results indicated that the shade-cocoa, the riparian forest, and live fences provided habitat and increased connectivity for these species [70].

Concerning the relationship between biodiversity and cocoa production, a recent study conducted in Sulawesi concluded that, for most taxa (Fig. 3), including endemic species (Fig. 4), there is no correlation between both variables [71]. This suggests that the relationship between conservation importance and yield is not a trade-off, but can be win-win, as high production can be coped with biological conservation. Additionally, authors found no relationship between forest distance and biodiversity, so that that species richness is related to management structure rather than landscape patterns. Therefore Landsparing Theory, which assumes a trade-off between conservation and production [20], cannot be applied to these cocoa systems.

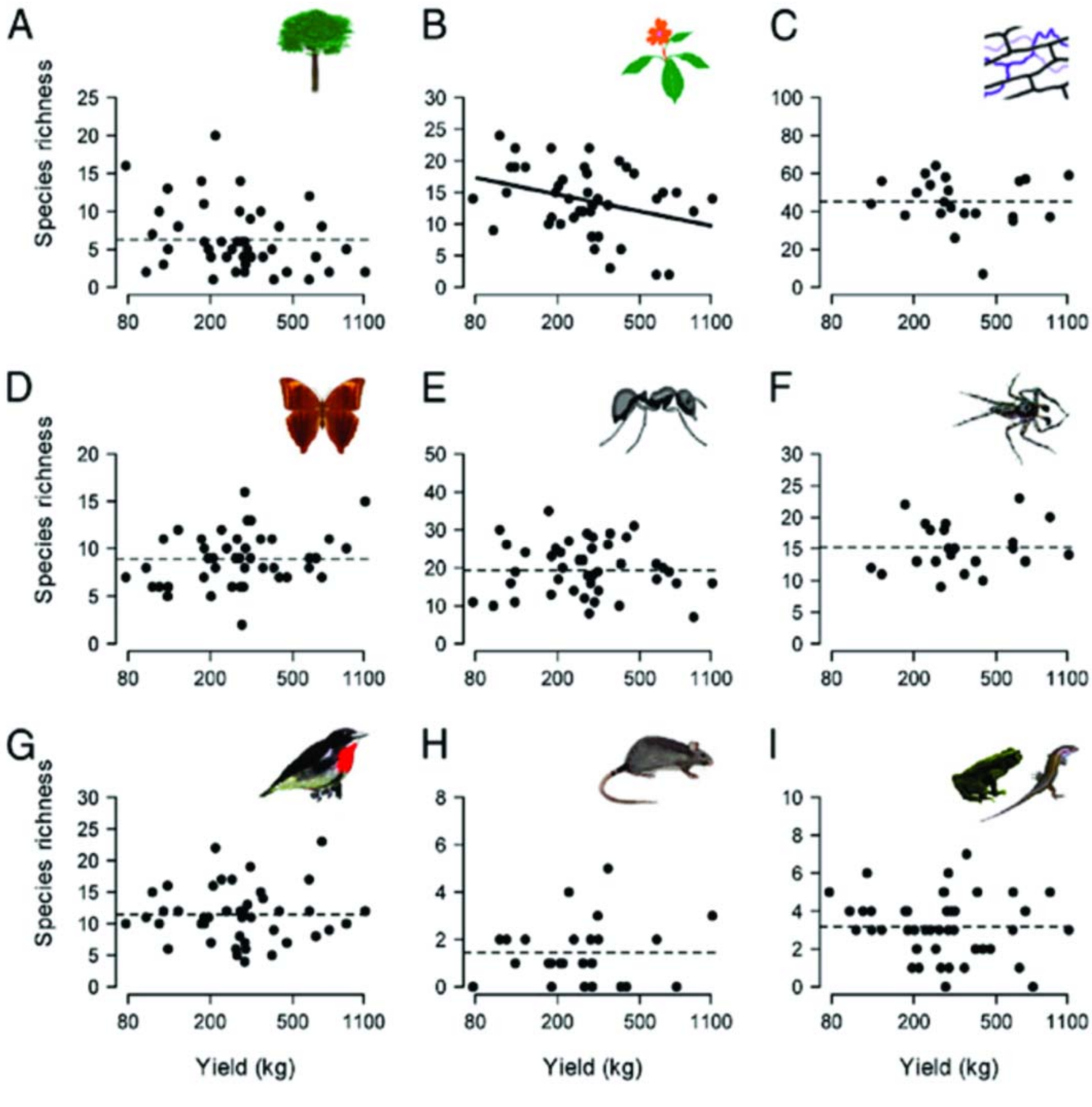

Figure 3. Associated biodiversity in smallholder cacao agroforestry in relation to cacao yeild in Sulawesi, Indonesia, for (A) trees, (B) herbs (C) endophytic fungi, (D) butterflies, (E) ants, (F) spiders, (G) birds, (H) rats, and (I) amphibians and reptiles. Broken lines are intercept-only linear models. Source: [71]

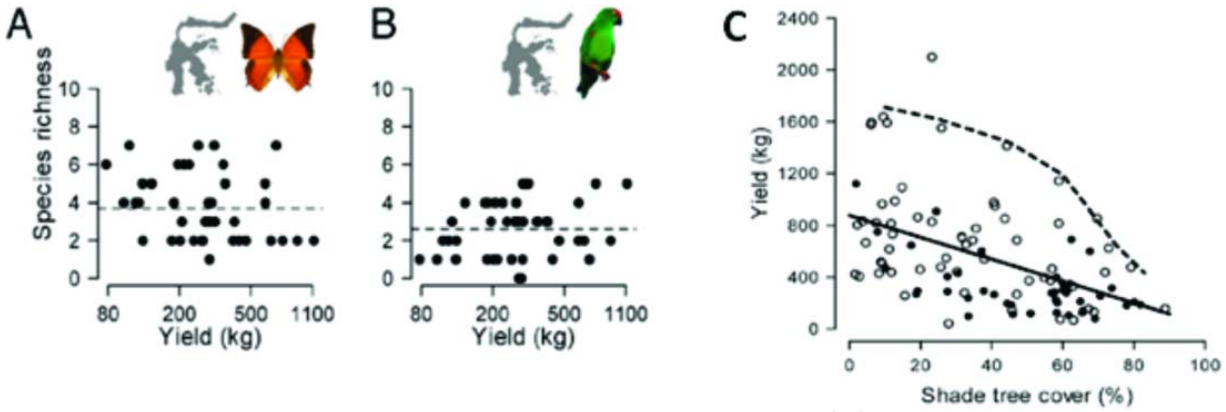

Figure 4. Endemic species richness and cacao yield relationship for (A) butterflies and (B) birds in Sulawesi, and the influence on shade cover on productivity (C). In all figures dashed lines are linear adjust, and in C solid line is the linear adjust and dashed line are maximum son-linear adjust. Broken lines are intercept-only linear models (A, B), and in (C) broken line are the maximum simulated values. Source: [71]

4.2. Shade-coffee systems

Just as in the case of the shade-cocoa, coffee is planted in high-shade rustic agroforestry systems in Mexico [3], Jamaica [72], Guatemala [73] and Brazil [74] among others. In the Mexican systems (probably the most studied agroforest in the world), high richness of species is found [4,75]. The conversion of these systems into sun monocultures, as part of the worldwide intensification policy, has called the attention of ornithologists because many migrant birds used shade plantations in the winter. Consequently, the substitution of high-shaded for sun systems leads to a decline in migrant bird populations. Therefore, conservationist agencies, such as the Smithsonian Bird Migratory Center, the Conservation International, and the Nature Conservancy launched a campaign to conserve this agrienvironment by certifying coffee farms as "bird friendly", or "biodiversity friendly".

High diversity of trees, birds, frogs [75], ants, butterflies [41], orchids [76], bats, dung-beetles [77], bees, and wasps [78] are found in shade-coffee plantations in comparison with sun coffee systems. Birds are the most well known taxa in coffee plantations, as in other agricultural systems [79]. By the year 2006, forty studies had been published in well known international scientific journals on birds in shade-coffee plantations [80]. This review suggests that more than 50 North-American migrant species use shade-coffee plantations. Concerning endangered birds, eight species that use shade-coffee are considered to be threatened at some degree [80]. Some other aspects of bird ecology are worth noting. For example, migrants to show high winter site fidelity (individuals return to the same area in consecutive years) in shade plantations, which suggests that these areas are highly suitable for wintering [81]. Many threatened taxa of mammals are found in shaded-coffee systems in Mexico, such as the tamandua anteater (*Tamandua mexicanus*), the river otter (*Lutra longicaudis*), the mexican porcupine (*Shiggurus mexicanus*), and the margay (*Leopardus wiedii*) [82].

Agriculture intensification acts by reducing both planned and associated biodiversity, and coffee systems are not an exception. For instance, in the southeast of Brazil, traditional coffee farmers cultivated a traditional varieties of coffee (*Moca, Carolina, Cravinho* among others), which is shade tolerant, and has a long productive life cycle (according to farmers, the *Moca* plants can produce for more than a hundred years). In the 1970s, agricultural intensification policies introduced a sun-variety of coffee (locally called *Catuaí*). This variety starts producing at earlier life stages than the traditional varieties, but also stops producing earlier and it is much more dependent on fertilizer and pesticides [74]. The substitution of traditional varieties for modern ones leads to a widespread failure of coffee production in the region, because farmers could not keep up with the high costs of necessary inputs. The result was the conversion of coffee plantations into pastures. Many traditional varieties, as the *Carolina,* are at risk of extinction due to the substitution for the modern varieties. We once heard a statement from a local farmer, saying in a mix of disappointment and anger: "Agronomists have ruined coffee production in the region". Although we believe that the problem lies beyond simple government agriculture agencies' technicians, this is a good example of the misleading efforts of the agriculture intensification programs.

Regarding the pattern of conservation-production of coffee systems, studies conducted in Central America, points out to a trade off. This occurs because the reduction in tree density may, depending on the shade values, decrease biodiversity and increase yields. Species richness and productivity negative relationship can be concave or convex. Convex pattern, means that significant amount biodiversity is present at intermediate levels of biodiversity, while in the concave, trade-off is steep and relatively low levels of biodiversity in systems with intermediate productivity. In the Mexican systems, butterflies show a convex, while ants show a concave pattern (Fig 5).

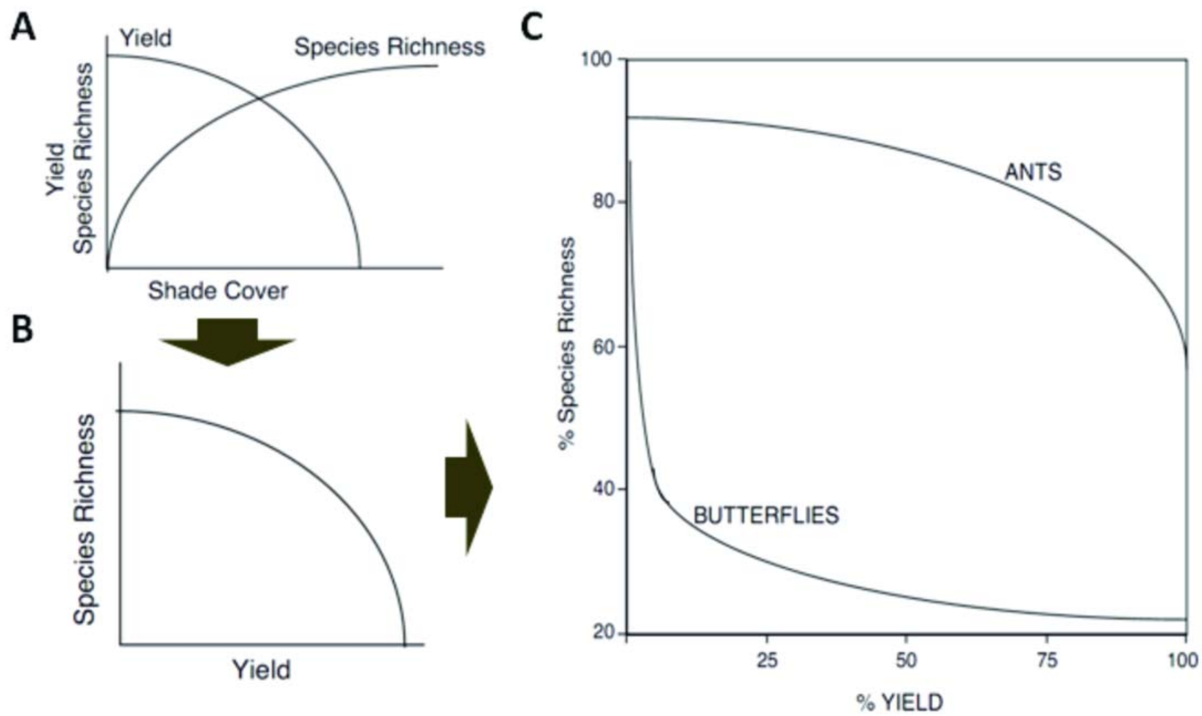

Figure 5. Construction of yield set from the functions of cover (A and B) and the yield-richness relationship for butterflies and ants in coffee systems of Mexico (C). Source: [41]

4.3. Home-gardens and other agricultural systems

Home-gardens are the oldest agroecosystems in the world [84], and may be more than 10,000 years old [85]. These systems are generally characterized by a high heterogeneity within plots and regions. Because home-gardens are a complex mosaic of orchards, live-fences, mixed farming practices (including animal raising), and they vary greatly on their temporal and spatial structure. Another aspect of home-gardens is that they individually occupy a small area, especially in the tropics, so that the management grain (minimal area in which a certain farming practice takes place) is small, and human density is high.

Home-gardens are a pool for agrobiodiversity, work as refuges, preventing the genetic erosion of cultivars, and are considered living gene banks [86]. For example, in the home-gardens of Nepal, twenty crop species have been lost in the last 10 to 15 years, and 11 species are threatened (their use has declined significantly over the last years) [87]. In an arid region of the northeast of Brazil, more than 50 woody plants were reported in 31 home gardens, including many native species [88]. In the tropical lowland forest of Indonesia, in only six traditional home-gardens (locally called *tembwang*), 144 of the tree species were found [89]. In Bangladesh, in 402 home-gardens, Kabir & Webb [90] recorded 419 tree species. Half of these species were native, and six are in the IUCN Red List.

The biodiversity associated with home-gardens is largely unknown. Mardsen and coleagues [91] have conducted bird diversity censuses in home-gardens of New Guinea, finding high richness of species in those systems. In spite of this, many forest species were found in lower numbers or were absent in the gardens. In the Brazilian Atlantic forest hotspot, two works [92, 93] were carried out in the Pontal of Paranapamena agroforestry home-gardens, comparing bird assemblages in pasture, forest, and gardens. Both concluded that agroforestry systems are very important for bird conservation in the region. However, one of them noted a great influence of the distance between gardens and the nearest forest on bird richness and abundance (Fig 6A). Two species of Psittacidae of conservation concern (threatened or near-threatened respectively), *Ara chloroptera* and *Primolius maracana*, were found in home-gardens [92]. Additionally, another study concerning the feeding ecology of frugivorous birds, including *Ara chloroptera*, reported that the feeding activity, and the diversity of food items consumed by this species were greater in home-gardens compared to forest. In spite of it, abundance was higher in the forest compared to gardens. Feeding bouts per abundance (FBPF), which describes the relative amount of feeding activities irrespectively of the frequency of habitat use, was greater in home gardens than in forest (Fig 6B). The study suggested that home-gardens have richer and more abundant food resources, but because they are more intensely disturbed, and perceived predator risk pressure is greater, birds spend less time in this habitat compared to forest [8] (Fig 6B). Figure 7 shows two species feeding in these home-gardens.

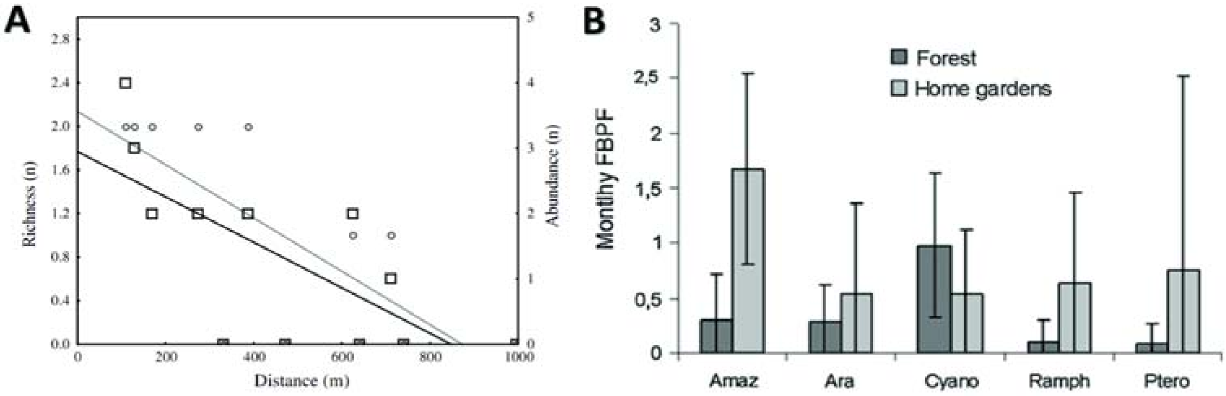

Figure 6. Variation in richness (circles and grey line) and number of individuals (squares and black line) as a function of distance to the closest large forest patch (A) [93], and Feeding bouts per frequency of *Amazona aestiva* (Amaz), *Ara chloroptera* (Ara), *Cyanocorax chrysops* (Cyano), *Ramphasto toco* (Ramph) and *Pterglossus castanotis* (Ptero) in forests and home gardens (B) in the Pontal of Paranapanema, Brazil [8]

Many other tropical agroforestry systems are known to harbour high biodiversity, such as the shade yerba mate [94], and the rubber jungle [95]. Live fences, isolated trees on pastures, and wind breaks also serve as habitat to many species, as well as increase landscape connectivity for many other species [96]. For example, a study conducted in Vera Cruz, Mexico, showed that pasture with isolated trees hosted 35 different orchid species [97]. Another study in the same region found that these systems harboured 58 species of vascular epiphytic and hemiepiphytic forest species [98]. Guevara and Laborde [99] recorded 73 species of bird species visiting four individuals of fig trees (*Ficcus* sp) in pastures of Veracruz. In Australia, isolated paddock trees in New South Wales are used by 31 bird species [99]. In Brazil, *Ara ararauna* has been seen foraging in pastures with high abundance of palms (*Syagrus romazoffiana*). This bird is considered threatened, and its population is declining in some states of Brazil [101]. Other studies show that fig trees (*Ficcus sp*) in pastures near forests are visited by bats [102], and primates [103].

5. Agriculture, biogeochemical cycles, and ecosystem services

Biogeochemical cycles represent the movement of chemical elements within and between several biotic and abiotic entities. These elements can be extracted from mineral sources, the atmosphere, or be recycled through conversion of organic to ionic form, returning to the atmosphere or soil. This cycle is performed by a wide variety of organisms, from a large number of nutrient compartments. The relative abundance of these compartments is specific for each ecosystem type [104]. Any biogeochemistry imbalance between compartments results in diversity loss through bottom-up effects, in which changes in nutrient levels trigger an imbalance in the whole ecosystem's trophic web. Ecosystem fertility is defined as the potential of soil, sediment or aquatic systems to provide nutrients in enough quantity, form or proportion to support optimal plant growth. Soil nutrient flows can be represented by the release of organic matter from microbial communities. However, the chemical balance and the maintenance of ecological processes (mainly carbon, nitrogen, phosphorus, and sulphur cycles) are strongly affected by agricultural and industrial activities.

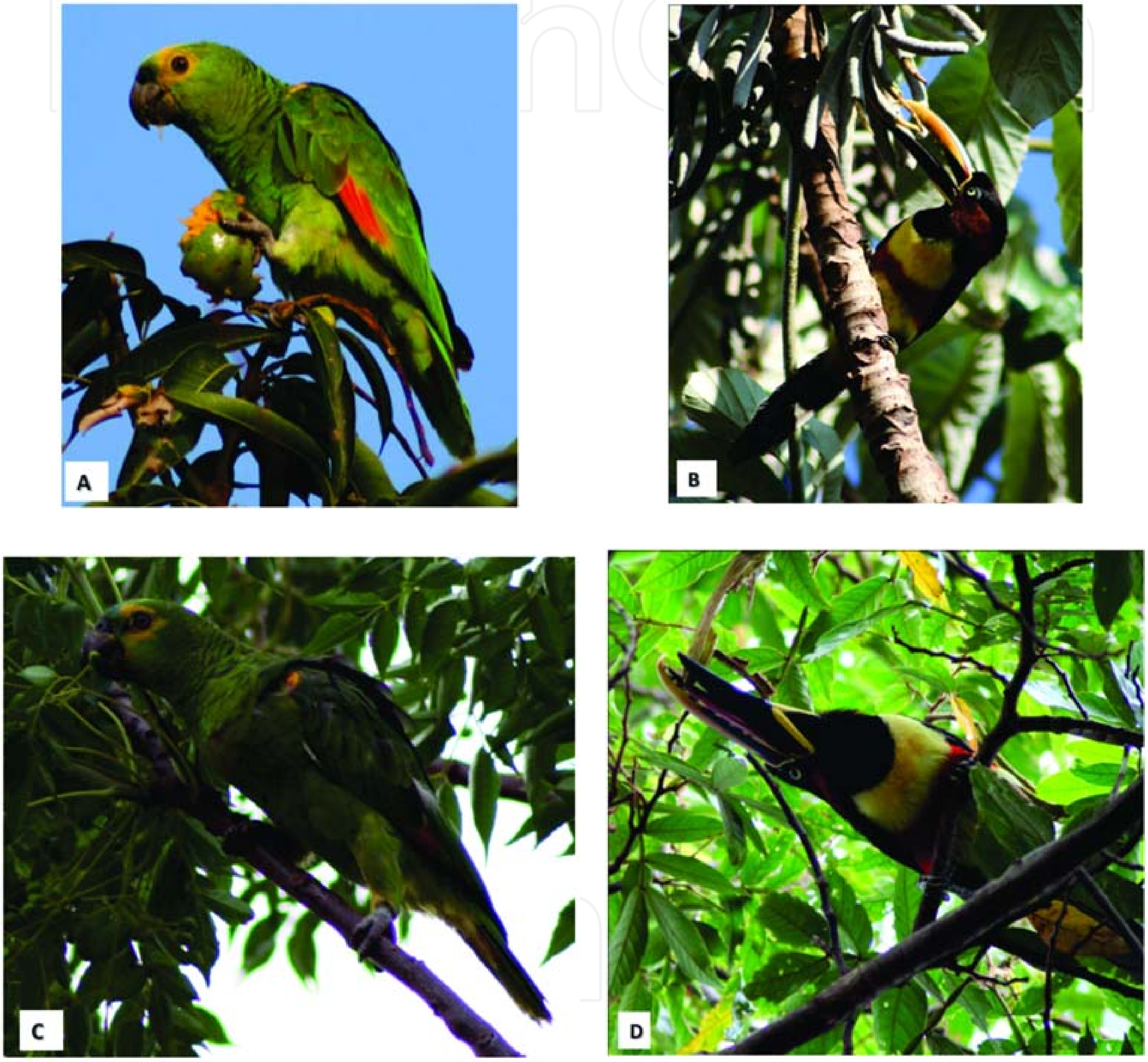

Figure 7. Blue-fronted Amazon *(Amazona aestiva)* feeding on a mango tree (*Mangifera indica,* Fig. 3.A) and *Melia azedarach* (Fig 3.C). Chestnut-eared Acari (*Pteroglossus castanotis)* feeding on *Cecropia pachystachya* (Fig 3.b) and *Inga vera* (Fig 3.D). Photos by F.F.Goulart

Living organisms usually contain a relatively constant proportion of chemical elements, especially carbon, nitrogen, and phosphorus. In natural ecosystems, the regulation of biogeochemical cycles work at different space and time scales, allowing the adjustment of the nutrient flows from microbial activity to plant demand, reducing nutrient losses within ecosystems. The synchrony between nutrient release, plant use demand, and microorganisms is determined by complex chemical, biological, and physical interactions. These nutrient maintenance processes are rarely achieved in agroecosystems, in which nutrients are lost to the atmosphere and to aquatic ecosystems [105]. In spite of this, agricultural practices vary widely on their efficiency of conserving/losing nutrients. Agricultural intensification, by creating open systems, in which nutrients are lost, are highly dependent on constant inputs (mainly fertilization) in order to sustain production.

5.1. Carbon, nitrogen and phosphorous cycles

Ecosystem nutrient input to produce goods and services to humanity have amplified N and P global cycles by 100% and 400% after the industrial revolution, respectively [106]. Agriculture is responsible for approximately 15% of anthropogenic CO_2 emissions, 58% methane (CH_4) emissions, and 47% of N_2O emissions [107]. The global N cycle was changed by human activities, so that more N is fixed annually by human activities than by all natural means combined [108]. Furthermore, high N concentration in the biosphere interacts with the carbon and sulfur amplified cycles, affecting the global climate [109].

Ecosystem nitrogen increase has been recognized as an important cause for changes in plant species' composition, and for biodiversity loss in a wide range of ecosystems in the globe. According to Bobbink et al [110], an increase in N availability influences species composition and diversity due to changes in competitive interactions among plants, either through the direct effects of nitrogenous gases and aerosols toxicity, or by ammonium nitrate toxicity, which is the predominant N soil form. Increase in soil acidity, cation leaching, and Al concentration promotes ecosystem stress and susceptibility to disturbance, with direct effects on species diversity. Furthermore, changes in competitive interactions due to changes on N amount may be influenced by other edaphic conditions, such as P limitation.

The phosphorus cycle is also greatly affected by agriculture. Globally, 17 tetragrams of phosphorous are applied in the soil every year as fertilizers, and this element is the main driver of water eutrophication worldwide [111]. Menge and Field [111] have argued that an increase in N atmospheric deposition, coupled with increased CO_2 atmospheric concentration stimulates net primary productivity, increasing P demand or limitation. N limitation reduction can cause an increase in P limitation in many ecosystems where N is limiting. The increase in P limitation can modify plant communities by increasing organic P demand, increasing phosphatase enzyme levels in plants and microorganisms. This represents a phosphorus stress that induces limitation changes (from N to P), favouring species that may use P in its organic form [112].

However, effects due to changes in a particular nutrient concentration may be manifested not only in quantitative changes, but also in qualitative changes in the nature of nutrient limitation. According to Elser et al [114], and Davidson and Howarth [115], limitation by N and P are equivalent in terrestrial ecosystems, and the supply and demand of these nutrients are significantly correlated. Thus, the addition of a specific nutrient causes a modest limitation by another, which reduces both nutrients' limitation, causing synergistic positive effects in net primary production in several terrestrial ecosystems. The authors suggest that there is a stoichiometric relationship between N and P supply for autotrophic primary production due to the balance between cellular demand for protein synthesis, or by ATP and nucleotide synthesis. Jacobson et al [116] observed that simultaneous N and P addition affected density, dominance, richness, and diversity patterns in a central Brazilian Cerrado area, with increased rates of plant decomposition. Increased N levels resulted in a greater N loss, and a combined increase (N plus P) resulted in litter N immobilization.

Soil NO emissions were also higher when only N levels were increased, indicating that when increased P availability is not proportional to N increased availability, N losses are intensified. Nutrient cycling in the Brazilian Cerrado is very conservative [117], and increasing human disturbance may cause changes in chemical composition of the organisms' tissues, and also change nutrient cycling in an ecosystem adapted to low nutrient availability. Nutrient dynamic changes may lead to an environmental improvement for some species, increasing their competitiveness in relation to others, which may cause changes in species composition in response to long-term fertilization [118]. A large effect on the diversity of the soil microorganism should also be expected, principally on species rich ecosystems such as in some the Cerrado ecosystems [e.g., 119].

Despite these facts, agroforestry systems are sinks for many green house gases, such as carbon dioxide and atmospheric nitrogen. By using N-fixing leguminous species, agroforestry systems absorb nitrogen from the atmosphere, conserving this nutrient in the soil [119]. A study in USA concluded that agroforestry systems accumulated 530 kg of nitrogen per hectare. Agroforests are also sinks of carbon because of the wood density on these systems. On a global scale, agroforestry systems could potentially be established on 585 to 1275 million hectares of suitable land and these systems could store from 12 to 228 tons of CO_2 per hectare under current climate and soil conditions [120].

5.2. Water

Agroecosystems represent the planet's largest fresh water consumers, with 250 million hectares of irrigated agroecosystems accounting for 69% of the water withdrawing, and 84% of consumptive uses [6]. Forty percent of the world's food production derives from irrigated systems [2]. Water requirements from agriculture are high. For example, it takes 500 litters, 900 litters, and 2000 litters of transpired water to produce 1 kilogram of potatoes, wheat, maize, and rice, respectively [122]. Besides consuming large quantities of fresh-water, agricultural intensification can deeply affect the quality of water resources. Eutrophication of water bodies is mostly related to fertilizer use by intensive agricultural practices [123].

Agricultural development has historically been the main driver of inland water quality loss worldwide. It has been estimated that by 1985 56-65% of the suitable inland water had been used by intensive agriculture in Europe and North America, 27% in Asia, 6% in South America [124]. The nitrate concentration in the biggest rivers in the US increased from three to ten times since the beginning of the century. High quantities of this nutrient is responsible for the baby blue disease (Methemoglobinemia) [125].

Additionally, large quantities of money are spent on irrigation projects. In the 1970s, US investments had reached their peak of 1 billion dollars per year. In Brazil, there is great controversy involved in the project by the present government to transpose the São Francisco River. The ongoing project consists in deviating part of the river course into 600 kilometres of channels, and is costing 3.7 billion dollars to the Brazilian society. The main objective of the transposition is to increase water supply for shrimp farms, and agroindustry in the northeast region, so that only 4% of the water would be directed to the population. The ecological impacts of such enterprise will be enormous. The Rio São Francisco harbours 137 species, many of which are endemic or threatened with extinction [126]. The withdrawing of the river water will lower water levels, possibly causing profound impacts on fish assemblages.

One way of reducing the need for intensive irrigation systems is conserving the water in the agricultural systems, which is basically related to the presence of organic matter. Agricultural management that increases organic matter in the soil, such as no-till and specially agroforestry systems, increase water conservation in the soil. Many agroforestry management use trees (e.g. banana trees) that enhance soil moisture.

5.3. Ecosystems services

Several groups at the base of the food chain, from microorganisms to soil micro- and meso-fauna, present ecological roles that affect nutrient fixation, cycling, and mobilization in the soil. Arthropods are by far the most studied group regarding their ecological roles in agroecosystems. They have been shown to have crucial roles in pollination [127], and predation of or competition with pest species [128]. De Marco and Coelho [129] noted that the raw production of coffee systems near forest fragments increased 14%, due to an increase in pollination activity in the agroecosystem. Figure 4 shows the diversity of flower visiting insects in coffee plants in home-gardens of the Pontal of the Paranapanema, southwest of Brazil. Ecosystem services provided by arthropods are also negatively affected by the use of biocides [130]. The loss of base species, as well as the structural simplification inside farms, leads in turn to a decrease in richness and abundance of several vertebrate groups [131]. These processes that follow agricultural intensification cause agroecosystems to lose basic regulation processes, including soil fertility and pest control. The latter is the most well-known consequence of biodiversity reduction [131], with a great number of studies demonstrating the effects of native arthropod predation on pest species abundance and richness [e.g. 61,72,132,133].Vertebrate species, such as bats and birds, also present important ecological roles related to pollination, pest predation, and seed dispersal [61,72]. All these groups can be affected by agricultural intensification, which in turn could affect production in a feed-back fashion.

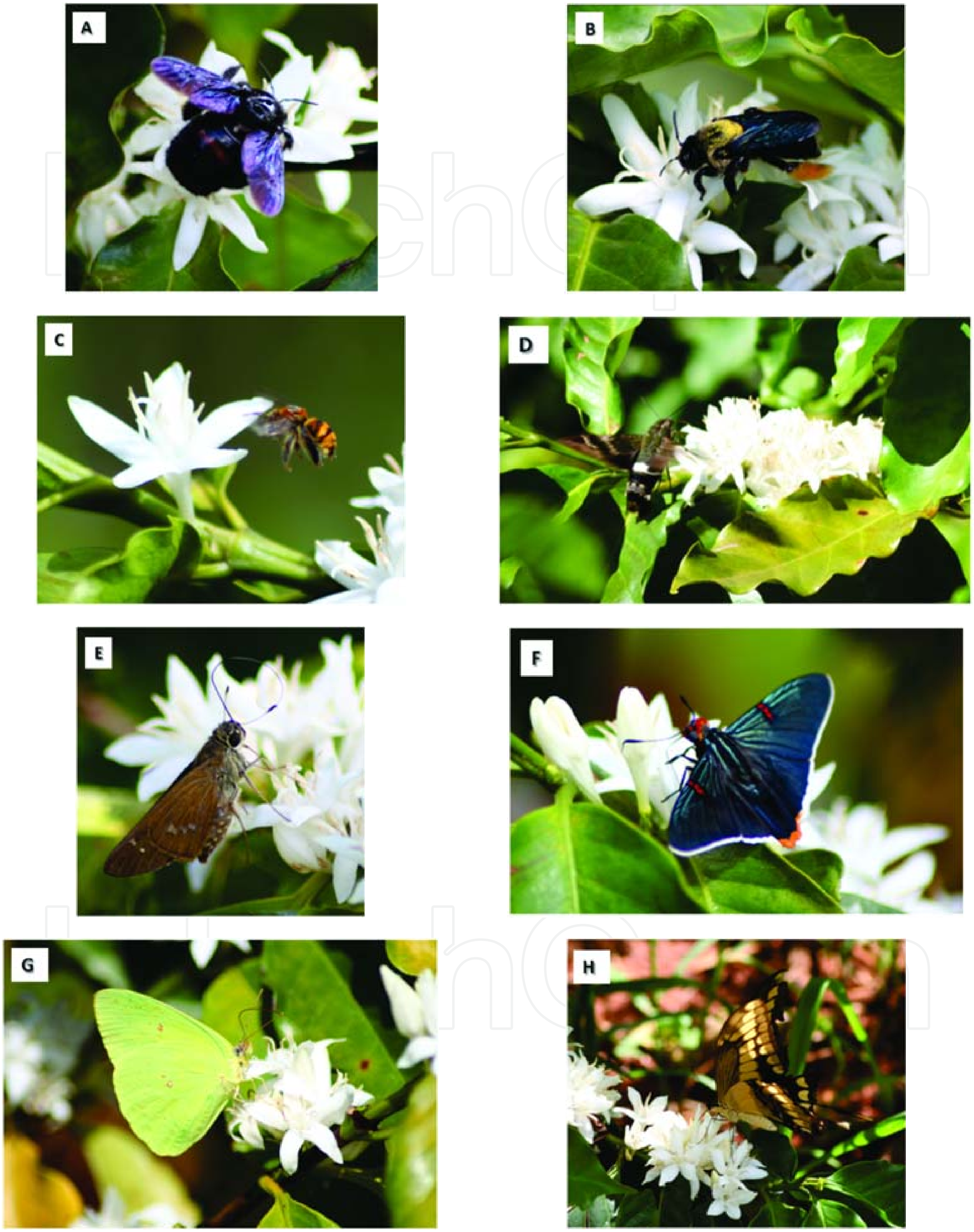

Figure 8. High diversity of flower visiting insects, such as bees (*Xylocopa sp*, (fig 4.A), *Epicharis flava* (fig 4.B), *Exomalopsis fulvofasciata* (fig 4.C), moths (Fig 4.D, 4.F), and butterflies (Fig 4.G, 4.E, 4.H) in coffee plants of home-gardens of Pontal do Paranapanema, southwest of Brazil (Photos: F.F.Goulart.)

It is possible measure the effect of the functional groups, such as predators and pollinator by assessing production or variables that are correlated to it (such as biomas, insect damage, herbivore abundance, etc..) with predator presence or abundance. With this respect, experiments that exclude pollination or predation action have been useful to estimate the value of these services.

A table showing selected studies on the influence of functional groups regarding predation of potential agronomic pests and pollination of cocoa and coffee systems are shown in the appendix A.

The mechanisms that lead to biodiversity simplification through agricultural intensification vary. Soil microorganisms and micro-fauna have been shown to decrease in richness and abundance with intensive soil tillage [135,136] due to the closing of soil cracks and pores, with the consequent drying of the soil surface [137].

The result of these losses is the dependence on external inputs, which increases the costs involved in food, fiber and fuel production, as well as a decrease in soil and water quality, quality of the food produced and of rural life [134]. As an example, Boyles et al. [138] have estimated that agricultural losses caused by the decline of bat populations in North America are worth more than 3.7 billion dollars/year. For the entire biosphere, estimates of the value of natural ecosystem services vary between 16 and 54 trillion dollars/year, with an average of 33 trillion dollars/year [127]. However, as Martis [139] has pointed out, although it is possible to evaluate objectively the ecological value of certain species within a complex net of relationships and connections, we currently do not appreciate the importance of certain species, until after their disappearance.

The ecological roles of a wide variety of taxa and functional groups are object of considerable research, but we still do not fully understand the roles and the links between them [140]. Anyway, since those ecological processes on which productive systems depend on are largely biological, feed-back loops caused by the modification of natural systems are bound to occur, affecting agricultural yield and stability. Therefore, there is a growing body of knowledge that demonstrates the beneficial economic effects of managing biodiversity so as to maintain ecosystems services functional [134, 141]. For instance, no-till practices generate more biologically complex soils, so that they could potentially enhance these groups' diversity [141]. Also, tropical crop productivity can be enhanced by the promotion of a more heterogeneous environment inside farms and at the landscape level, so that the occurrence of native pollinator species, pest species' natural predators [62], and competitors is promoted. Generally, diversified cropping systems harbour more arthropod populations, because these species respond to: 1) habitat heterogeneity; 2) higher predation, which facilitates species coexistence though density control mechanisms; 3) and higher stability and resource-partitioning, since production stability and predictability promotes temporal and spatial partitioning of the environment, permitting coexistence of species [131]. In a landscape perspective, management options which promotes biodiversity conservation by enhancing native or planned heterogeneity inside farms or in their surroundings, have been suggested [131,143].

Structurally complex landscapes, which involve mosaic formations and corridors, facilitate native species' dispersal between farms and natural strips of vegetation [144]. There is a strong relationship between pollination activity and distance from farms to the closer forests areas (Fig. 9). Therefore, forests are sources of pollinators, and agricultural landscapes that preserve landscape heterogeneity and the forest protection can increase agricultural yield.

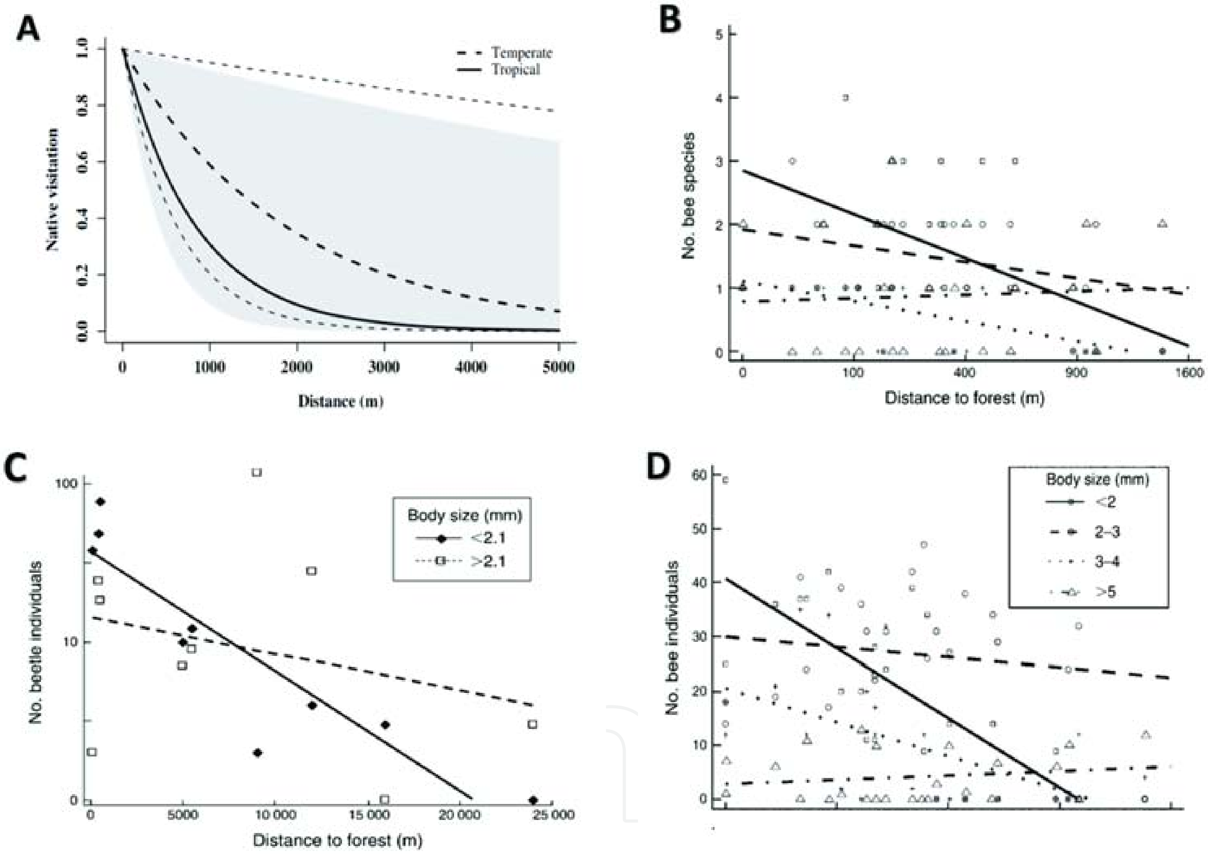

Figure 9. Decay curves for native visitation rates in cultivated systems of tropical and temperate region (A), so that solid line and shading are for tropical region, while dashed lines and lighter dashed lines concerns temperade region. (A). Source: Ricketts et., 2008. Distance from the nearest forest and the abundance of beetles (C), abundance of bees (B) and bees richness (D) of different body sizes in coffee farms of Indonesia. Source: [145]

6. Prospects for the future of farming and biodiversity

Farming practices are one of the greatest emitters of green house gases, such as carbon dioxide, methane, and atmospheric nitrogen, contributing greatly to climate change. Therefore agriculture is in part responsible for future climate changes. Climate change is affecting and will affect even more people's lives, biodiversity, and ecosystems. Climate change is already one of the major drivers of biodiversity loss worldwide [10]. Climate relates with many population processes, such as disease dynamics. In the highlands of Costa Rica, the outbreak of the disease caused by the fungus *Batrachochytrium dendrobatidis*, associated with global warming caused the extinction of many frog species, such as of the golden toad (*Bufo periglenes*) [146].

Predictions of the impact of future climate change on species, ecosystems and agriculture are alarming, if not catastrophic. Climate change is expected to be the major drivers of ecological shifts in a near future [147]. Simulations of International Panel of Climate Change (IPCC) suggest that the mean earth temperature will rise up to 5.8 C^{o}, and the weather will become significantly drier [148].

This will involve several changes, and one of the most notable will be the shift in the range of species distributions. Using bioclimatic models, scientists have predicted the future distribution of several species. A review of 2,954 mammals, birds, and amphibians in the Western Hemisphere suggested that 10% of the extant fauna will be lost due to climatic change. Greater changes are predicted for the Tundra, Central America, and the Andes species, which will undergo over 90% of species turnover, assuming no dispersal [149]. For instance, one of the world's most species rich ecosystems, the high altitude rupestrian fields of Brazil, might have only 15-20% of species left by the year 2080 under the best IPCC scenario [150]. Because such models do not consider process such as biotic interactions the real scenario can be worse. In a study conducted at a smaller scale, Marini and colleagues [151] modelled the present and the future distribution of *Amazona pretreii,* a threatened parrot of the Atlantic Forest of Brazil. They conclude that the year-round distribution of this species will decrease 47% until 2060. A similar analysis was conducted with 120 bat species on the Brazilian Cerrado (woodland savanna) [152]. The study was aimed to evaluate possible responses by this group for climate change, considering the IPCC scenario for 2050. The results indicated that bat species would find, in average, similar climate conditions in the future 480 km away from current regions. For the majority of the 120 species modeled, suitable regions will be located to the South (80% of the species) and to the West (56% of the species). For two bat species there will be no suitable conditions on the Brazilian Cerrado on the future, and they will be locally extinct. For 96 species the models indicate a significant contraction on their distribution (41% of actual distribution in average) only due to climate change (not accounting habitat lost by deforestation). The region were the distribution shift is expected by bat species in the future is already extremely fragmented. According to the Ministry of Environment [153], the states of Parana and São Paulo, the region where the models indicated that most of bat species would find better climate conditions in the future, are two of the worst region in terms of natural vegetation coverage. The Cerrado areas were reduced to less than 10% of its original area. Due to its flight ability, perhaps bat species can cross large deforested area easily, but we can not say the same about the species that they depend on, such as plant species, insects, and small vertebrates. Species will have to disperse large distance to reach areas in which climate is the same as today. This suggests that future landscape connectivity will play a major role in the effectiveness of the species in reaching new areas. In this context, agroforestry systems will have a key importance in the maintenance of matrix permeability [154,93].

Climate change will affect not only species and natural ecosystems but also the agriculture. The Brazilian Center for Agriculture Research - EMBRAPA has already projected momentous changes for the regions where cultures such as soybean, sugarcane, cotton, coffee, cassava and corn are currently implemented. According to EMBRAPA and UNICAMP [155] all cultures cited above, except sugarcane and cassava, will have their areas decreasing due to climate change and global warming. Projections based on IPCC A2 scenario for 2050 verify that appropriate areas for soybean plantation will be mainly on the center and Southeastern regions of Brazil. The Southeastern region of Brazil is quite the projected area that will be sufficient to, for instance, birds and bat species of the Brazilian Cerrado. Thus, spatial competition for food production and species protection is a serious issue nowadays and for the future.

Regarding human aspects, the exponential growth of human population, and the increased *per capita* consumption reflected in the development of a highly expansive and intensive agriculture. It has been estimated that the human population will increase by 50% until 2050, with a higher expected proportion of individual meat consumption in the daily diet (feeding at higher levels of the trophic pyramid) [26]. Sustaining food production in the same magnitude of human growth is a challenge for all areas of human knowledge.

Already 1.2 billion people live in areas in which water is physically scarce, and this number should double by 2030 [6]. Projections of the proportion of total global food supply obtained from rain fed areas (non-irrigated) should decline from 65% currently to 48% in 2030 [156]. The total irrigated area is expected to grow from 254 million ha in 1995 to between to 280 and 350 million ha in 2025. Fertilizer use is expected to increase 188 million tons by 2030 [157], and the world's meat consumption is expected to grow by 70% in the 2000-2030 period, and 120% in the 2000-2050 period [6]. Concerning food production, future predictions are also alarming. Global cereal production is predicted to decline by more than 5%, but this value may reach more than 10%. The risk of hunger may rise up to almost 60% in the developing world [158]. In some countries, such as India, production of crops may decrease by 70% [159]. When food security, availability, stability, utilization, and access are considered, between 5 to 170 million additional people will be at risk of hunger by 2080 [160]. However, childhood malnutrition is projected to decline from 149 million children in 2000 to 130 million children by 2025, and 99 million children by 2050 [6]. In the Amazon, soybean yields will suffer a reduction of 44% by 2050 [161]. It is estimated that the average rate of atmospheric N deposition in 34 world biodiversity hotspots by 2050 will be twice the rate in all terrestrial ecosystems during the mid-nineties [162]. This will greatly affect plant assemblages through altered competition patterns.

According to the International Assessment of Agricultural Knowledge, Science and Technology for Development [6], an international report involving 800 well known scientists, the best way to nurse today's and future hunger problem is by fostering small scale agriculture based on agroecological principles. The problem of climate change is due to high quantities of green house gases that affect the earth surface temperature, and agroforestry systems are sinks of some of these gases, such as nitrogen and carbon [119]. Therefore, a possible alleviation for climate change is to 're-green' [163] the planet, using agroforestry systems over large areas. Agroforestry systems thus represent a keynote in this re-greening strategy. Because it enables the association between agriculture production and biodiversity and ecosystem conservation.

7. Conclusion

Overall, this chapter presents an overview on the agricultural systems and the effect of different types of management on biodiversity and ecosystems. We analyse data for shade-cocoa, shade-coffee and agroforestry home gardens in Brazilian atlantic forest region. In most situations, win-win relationship between conservation and production is possible, as farms with intermediate levels of yield are associated with high biodiversity. Also, the idea that there is a need to intensify agricultural systems to increase food production to feed the hungry does not apply to many tropical agriculture landscapes. Instead, changing food habits and promoting a more even food distribution using small scale eco-agriculture will guarantee a more resilient, social, and biodiversity friendly practices.

The future of farming and biodiversity depends on the type of agricultural management that will be applied in landscapes. If the agricultural intensification continues to expand, it is very likely that yields will increase, but with high variance and low resilience to environmental uncertainties, which are predicted to increase due to climatic changes and loss of ecosystem services. On the other hand, stakeholders may opt for more biodiversity friendly agricultural practices, which sometimes (but not always) are less productive than intensive systems, but have more productive stability and are more resilient. Additionally, these non-intensive systems can mitigate climate change by being sinks of green house gases.

Food security in the tropics depends on the recognition of the importance of the poor small holder agricultural systems, because they are the majority of the hungry people in the world. The '*business as usual*' strategy should increase economic inequality, increasing poverty and starvation, as well as causing deep ecological impacts. On the other hand, small-holder mixed-farming systems increase food security during times of ecological and economical instability. As we see it, heterogeneous agroforestry is the best option for biological conservation and social justice. It is expected that in the near future, millions of hectares of land will be occupied by agroforestry systems.

Appendix

Ecosystem service (taxa)	Plant species	Proportional yield loss or indirect effect caused by the reduction or absence of the functional group	Forest distance and functional group richness/abundance	Main findings	Country	Exclusion experiment	Ref.
Pollination (bees)	Coffee	0,15 (sites near forests)	Highly correlated	Pollination accounted for US$ 1860.55 ha per year.	Brazil	Yes	129
Pollination (bees)	Coffee	0,05 to 0,56 (mean = 0,17)	Not correlated	*Appis melifera* (honeybee) accounted for high proportion of the visits (95% of the visits)	Panama	Yes	164
Pollination (bees)	Coffee	0,27	Highly correlated.	Solitary bees generally show low abundance, but high pollination effectiveness. Diversity, rather than abundance explained variation in fruit set. Rare solitary bees are more important than abundant social bees.	Indonesia	Yes*	165, 166
Pollination (bees)	Coffee	0,8	Not addressed	*Appis melifera* showed high visitation rate.	Ecuador	No	169
Pollination (bees and ants)	Coffee	0,1 (low shade) to 0,41 (high shade)	Not addressed	Flying pollinators alone did not affect fruit set or fruit weight. In spite of it, the exclusion of ants and flying pollinators decrease fruit weight in shade plantations.	Mexico	Yes	168
Pollination (midges)	Cocoa	0,77	Not correlated	Ceratopogonidae midges have high effectiveness.	Ghana	No	169
Predation (birds)	Coffee	0,01 to 0,14	Landscape heterogeneity had significant effect	The migrant *Dendroica caerulescens* (Black throated Blue Warbler) showed high predation effectiveness.	Jamaica	Yes	72
Predation (birds)		Indirect effect: reduction in 64% to 80% of large arthropods caused by birds	Not addressed		Guatemala	Yes	62
Predation (birds, lizards, arthropods predator and parasitoids)	Coffee	Indirect effect: reduction in the abundance of the pests (*Leucoptera coffeella* and *Petrusa epilepis)*	Not addressed	Birds and lizards had additive effects. Both groups fed on arthropods and parasitoids (intra-guild predation).	Porto Rico	Yes	170
Predation (birds)	Coffee	Indirect effect: Lepidoptera pest removal was smaller in the controls	Not addressed	The bird (*Basileuterus rufifrons)* showed high predation effectiveness.	Mexico	Yes	171
Predation (ants)	Coffee	Indirect effect: higher predation rates of coffee berry border	Not addressed	Higher removal rates were found in shade systems in the wet season.	Colombia	No	172
Predation (birds)	Cocoa	Indirect effect: Birds reduce leaf damage from 9.7% to 7.6%	Not addressed	*Dendroica pensylvanica* showed high predation effectiveness.	Panama	Yes	173
Predation (bats)	Coffee	Indirect effect: Bats and birds reduce arthropod abundance	Not addressed	Arthropods in the control were 46% higher than in the treatment in which both bats and birds were excluded.	Mexico	Yes	174
Predation *Basileuterus rufifrons*	Coffee	Indirect effect: birds can reduce arthropod abundance in 58%	Not addressed	When migrants are present, birds forage more frequently in the understory, where there is lower competition with migrants.	Mexico	Yes	175
Predation: (*Azteca spp*. ants)	Coffee	Indirect effect: *Pieris rapae* (a coffee pest) suffered higher removal	Not addressed	Contradictory results show that the ants can have potential as pests through their positive effect on scale, but also as biological control agents	Mexico	No	176
Predation: (*Wasmannia spp*. ants)	Cocoa	no significant effect:	Not addressed	This species have low effectiveness of predating on potential pests.	Brazil	No	177
Parasitoid	Cocoa	Indirect effects: parasitoids species correlated tree species	Not addressed	Higher diversity of shade trees maintains high parasitoid levels.	Brazil	No	178

Appendix A: Selected studies concerning ecosystem services in coffee and cocoa plantations in the tropics highlighting the main findings.

Author details

F.F. Goulart*, B.Q.C. Zimbres and R.B. Machado
Laboratório de Planejamento para a Conservação da Biodiversidade,
Departamento de Zoologia, Universidade de Brasília, Campus Darcy Ribeiro, Brasília, DF, Brazil

T.K.B. Jacobson
Campus Planaltina, Universidade de Brasília/
Centro de Estudos UnB Cerrado, Universidade de Brasília, Brasília, DF, Brazil

L.M.S. Aguiar
Laboratório de Biologia e Conservação de Mamíferos,
Departamento de Zoologia, Universidade de Brasília, Campus Darcy Ribeiro, Brasília, DF, Brazil

G.W. Fernandes
Laboratório de Ecologia Evolutiva e Biodiversidade/DBG,
ICB/Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil

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* Corresponding Author

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