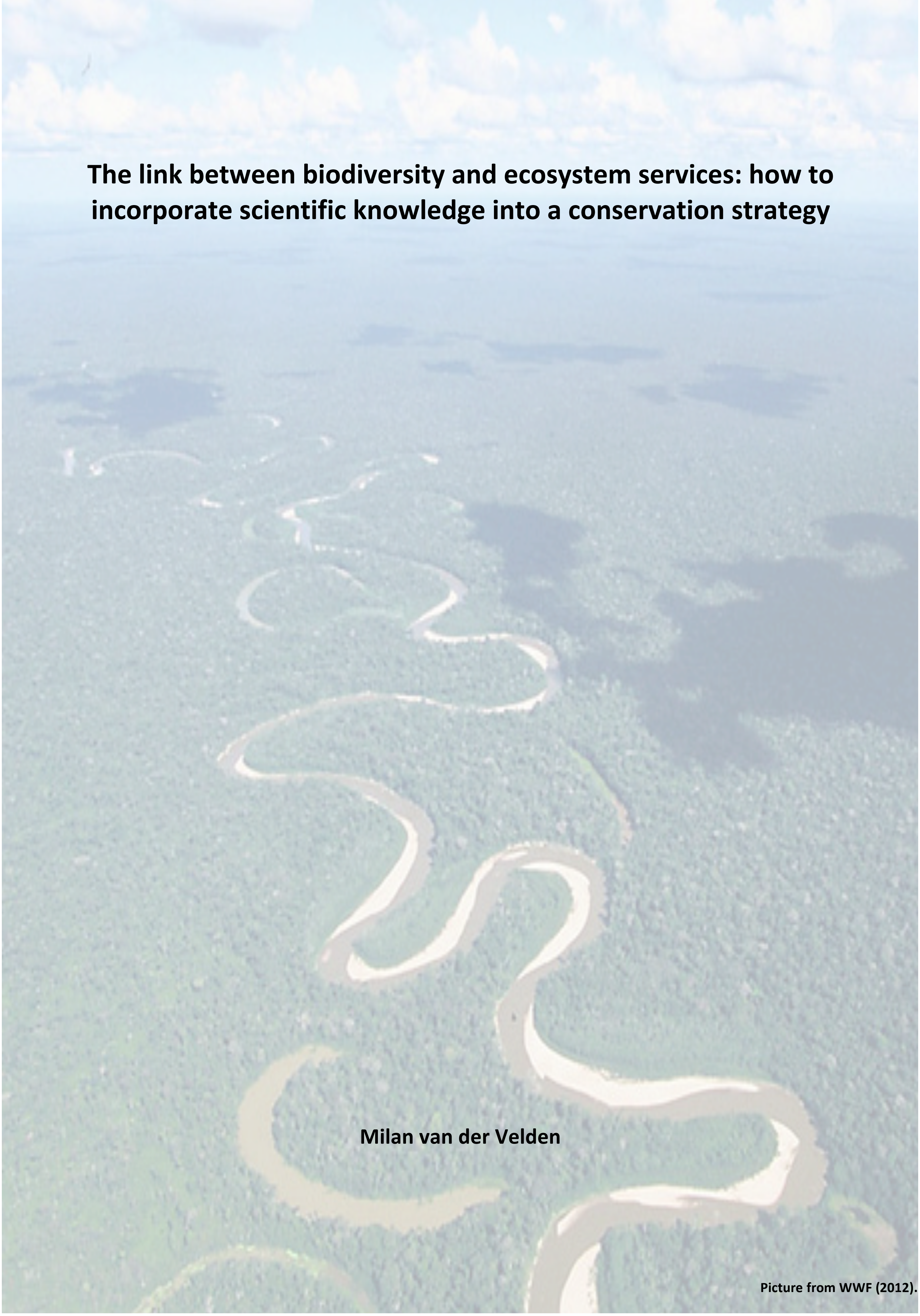

The link between biodiversity and ecosystem services: how to incorporate scientific knowledge into a conservation strategy

Milan van der Velden

Picture from WWF (2012).

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Table of contents

Abstract

The natural capital stocks and the associated ecosystem services are essential to the functioning of the earth's life-support system and invaluable for humankind as they contribute to human wellbeing and welfare (Constanza *et al*., 1997). However, humanity has been depleting these services during the past decades mainly due to deforestation and forest degradation. The loss of species associated with deforestation and forest degradation results in a decrease in valuable ecosystem services and a decrease in our wellbeing (Millennium Ecosystem Assessment, 2005).

Biodiversity can play multiple roles in ecosystem processes and services. Biodiversity can act as a regulator of key ecosystem processes, as a final ecosystem service, or as a good in itself. These roles support the regulation, habitat, production and information functions of ecosystems (De Groot *et al*, 2000). In turn, these functions underlie the proper functioning of ecosystems and the ability to provide services to humankind (Alcamo *et al*., 2003; Haines-Young & Potschin, 2010). Biological diversity is integrated into ecosystems in many ways. For example, species richness, species composition, functional group richness, genetic diversity, and species evenness all haven an effect on the functioning of ecosystems (Isbell, 2012). However, functional diversity seems to be the major factor involved in maintaining ecological integrity, and, in turn in the provision of ecosystem services (Chapin *et al*., 2000; Hooper *et al*., 2005; Díaz *et al*, 2006b).

One of the world's most important providers of ecosystem services is the Amazon rainforest. It harbors a rich array of flora and fauna and offers a wealth of services and goods to society. The Amazon represents 40% of the earth's remaining tropical rainforests and is the world's largest terrestrial store of carbon and biodiversity. Unfortunately at least half a million square kilometers of Amazonian rainforest have lost during the past 20 years due to deforestation. This not only threatens the livelihoods and wellbeing of local communities, but also effects the provision of ecosystem services that are of vital importance to humankind's survival. A loss of 30 to 40% of Amazonian rainforest is expected to result in irreversible large-scale disruptions of the Amazon biome. This ecological tip over point needs to be avoided if we are to preserve the Amazon (Verweij *et al*., 2009).

Up to 2004 deforestation in the Amazon increased each year, but since the year 2005 data show a decrease of over 70% (Nepstad, 2007; INPE, 2011; Boucher *et al*., 2013). This decrease has been triggered by new incentives to protect and conserve the Amazon. Examples of these incentives are expansions of protected areas, certification for biofuel, beef and soy products, reductions of worldwide livestock production system's dependence on soy feedstock, elimination of subsidies that favour the expansion of soy, oil palm, sugarcane and cattle ranching in the Amazon and payments for ecosystem services (e.g. REDD+). All these incentives favour the sustainable use of the Amazon and the services it provides so that future generations can also enjoy and benefit from what the Amazon provides. With international cooperation, legislation and commitment humankind can continue the positive trend and further reduce deforestation and forest degradation and their consequences in favour of a sustainable use of the natural world including its services. However, to achieve this we need to expand our knowledge and further identify the link between biological diversity and ecosystem functioning and the provision of services (Mace *et al*., 2012).

Introduction

In general, ecosystems provide much more than just the pristine intrinsic values to a number of people. They provide us with several vital services such as natural products, food, water, pest and disease regulation, and soil conservation (Millennium Ecosystem Assessment, 2005). On a more regional or global scale they potentially also have major influences on climate and hydrology and can act as major carbon sinks (The REDD desk, 2015). Ecosystems are however also under enormous pressure; tropical deforestation for instance is proceeding at a rate unprecedented in history and results in a decline of both biodiversity and ecosystem services with significant consequences to humanity as a result (Luck *et al*., 2003; Naeem *et al*., 2009). Already at the first Earth Summit in 1992, the majority of the world's countries stated that human actions were destroying the earth's ecosystems, eliminating species, biological traits and genes at a high rate (Cardinale *et al*., 2012). The actual loss of species is not uncommon in earth's history; species originate and go extinct at a regular rate (Center for Biological Diversity, 2015). The entire turnover of habitats for the sake of one species (i.e. humans) however, is uncommon and is currently proceeding at alarming rates (Walker & Salt, 2006).

Findings of the Millennium Ecosystem Assessment (2005) already concluded that; "*biodiversity loss and deteriorating ecosystem services contribute –directly or indirectly- to worsening health, higher food insecurety, increasing vulnerability, lower material wealth, worsening social relations, and less freedom for choice and action*". Their conclusion states clearly that the loss of biodiversity has an impact on human wellbeing. Despite the fact that humanity's wellbeing is apparently influenced by ecosystem functioning, species richness, species composition, functional group richness and genetic diversity, during the past centuries we have increased species extinction rates by 1,000 to 10,000 times the normal rates that during earth's history (Chivian & Bernstein, 2008; Isbell, 2012). Current extinction rates for birds, mammals, amphibians and reptiles are for example, greater than or as great as the rates that would have been produced during any of the five previous mass extinction events (Hoffmann *et al*., 2010; Barnosky *et al*., 2011). As these rates proceed, 30 to 50 percent of all species might be heading towards extinction by mid-century because the drivers of biodiversity loss are either steady, show no evidence of declining in the future, or are even increasing in intensity (Thomas *et al*., 2004). The recent and historic loss of biodiversity is now raising concerns, as people have recognized that ecosystem services, biodiversity and our wellbeing are intimately linked. This link arises because the loss of biodiversity potentially results in a decrease or loss of ecosystem services, which in turn could results in a decrease in our wellbeing (Millennium Ecosystem Assessment, 2005). More insight in the link between biodiversity and ecosystem services has been obtained during the last decades, and people are also more and more seeing the importance and value of this link (WWF, 2007). Sekercioglu (2010) states that "*with accelerating losses of unique species, humanity, far from hedging its bets, is moving ever closer to the day when we will run out of options on an increasingly unstable planet*". Thus, if humanity wants to keep existing and expanding on a planet that essentially provides every basic need, we have to be able to not only preserve our ecosystems but also learn more about the link between biodiversity and ecosystem services.

According to Mace *et al*. (2012) biodiversity is central to the production of ecosystem services; among others biodiversity can be an ecosystem service in itself, a regulator of fundamental ecosystem processes or a good. For example, the genetic diversity of wild crop relatives can be important for the improvement of crop strains (biodiversity as a service), diverse biological communities have increased resilience to pests (biodiversity as a regulator), and biodiversity has recreational, religious and educational values (biodiversity as a good) (Mace *et al*., 2012). Biodiversity can have direct and indirect influences on ecosystem services. Humankind directly derives most of its food and fibers from plants and animals but biodiversity indirectly affects the regulating services (e.g. seed dispersal and pollination) through the way energy and materials are circulated in ecosystems. Thus, changes in the loss of biodiversity can directly affect an ecosystem's capacity to produce and supply essential services, and hence can influence the long-term ability of economic, ecological and social systems to adapt and respond to global pressures (Department of the Environment, Water, Heritage and the Arts, 2009). It is because of these direct and indirect links between diversity and ecosystem services that we need to further our understanding of the relationship between them. Without having an understanding of this link we cannot hope to be able to not only preserve these ecosystems in the light of current decline in diversity but also the services they provide. It is this link that will be the main focus of this thesis.

To describe this relationship, the terms biodiversity and ecosystem services will first be discussed, where after the link between these will be discussed. In the last chapter of this thesis a practical example will be given by describing a number of ecosystem services and their link with the biodiversity of the Amazon rainforest. Being the world's largest rainforest at 5,500,000 square kilometres, it spreads across nine different countries and represents 40% of the world's remaining tropical rainforests. It is estimated that the Amazon harbours 390 billion trees distributed over 16,000 species (Ter Steege *et al*., 2013). The Amazon is also home to 24,000 other plant species, 2.5 million insect species, 3,000 fish species, 1,300 bird species, over 400 mammal species, over 400 amphibian species and almost 400 reptile species (Silva *et al*., 2005). The Amazon hence also offers a great range of services that are useful and some even essential for humanity. A few of these ecosystem services are nutrient cycling, the production of oxygen, carbon sequestration, water and air purification and the production of food, materials and energy (Millennium Ecosystem Assessment, 2005), which will be discussed. Finally, possible conservation strategies will be discussed regarding the Amazonian rainforests.

Throughout this thesis, the main research question will be:

"**What is the link between biodiversity and ecosystem services, how are they dependent on each other and how can we link this into conservation strategies?**"

To be able to answer this question, the following sub-questions have been formulated, which also are the chapters of this thesis:

1. How do we define biodiversity and what is its value and importance to humanity?
2. What are ecosystem services and what is their value and?
3. What is the link between biodiversity and ecosystem services?
4. What are threats to biodiversity and ecosystem services and what are the consequences of their decrease?
5. What value (biodiversity and ecosystem services) does the Amazon?
6. What are the causes and possible consequences of biodiversity loss in the Amazon?
7. What measures are being taken to conserve the Amazonian rainforests?

Defining biodiversity

Biological diversity is defined by the Convention on Biological Diversity (2015) 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*". Gaston & Spicer (2004) give more general description by describing biodiversity as "*the variety of life in all its many manifestations, a broad unifying concept, encompassing all forms, levels and combinations of natural variation, at all levels of biological organization*".

Biodiversity is essentially cosmopolitan, from *E. coli* bacteria under the bottom of your shoes to eyeless shrimps living near hydrothermal vents (>400 °C) at 5000 meters depth in the Caribbean Sea (Maxwell & Gerba, 2008; Connelly *et al*., 2012). Some environments however, harbour more species (i.e. are more species rich) than others. The most species rich environments are, among others, coral reefs, tropical rainforests, deciduous forests, large tropical lakes, and the deep sea (Primack, 2010). Especially tropical rain forests and coral reefs are considered to be the most biologically diverse ecosystems on planet earth (Millennium Ecosystem Assessment, 2005), although little is known from a number of ecosystems such as the deep sea environments. For example, the world's tropical rainforests encompass only 7% of the earth's land area, however they harbour over half the world's species (Corlett & Primack, 2010). Nevertheless, these figures are based on the number of described species, which is currently around 1.5 million, with insects being one of the most described taxonomic groups. Approximately 3 to 5 million species however are estimated to still be undescribed (figure 1) and about 20,000 species new to science are described each year with most of these still being insects or other arthropods (Gaston & Spicer, 2004).

Extant taxa that are being described make up today's biodiversity, but biodiversity changes through time and the biological diversity we know today is neither what it was before nor what it will be in the future. Over the last 3.5 billion years, since the estimated beginning of sustained, self-producing life approximately four billion species have evolved on earth (Schopf, 2006). Of these four billion species, over 99% are extinct today (Novacek, 2001). Although these numbers seem large, even today, between 10-50% of the world's species are currently threatened with extinction, based on IUCN criteria (Millennium Ecosystem Assessment, 2005).

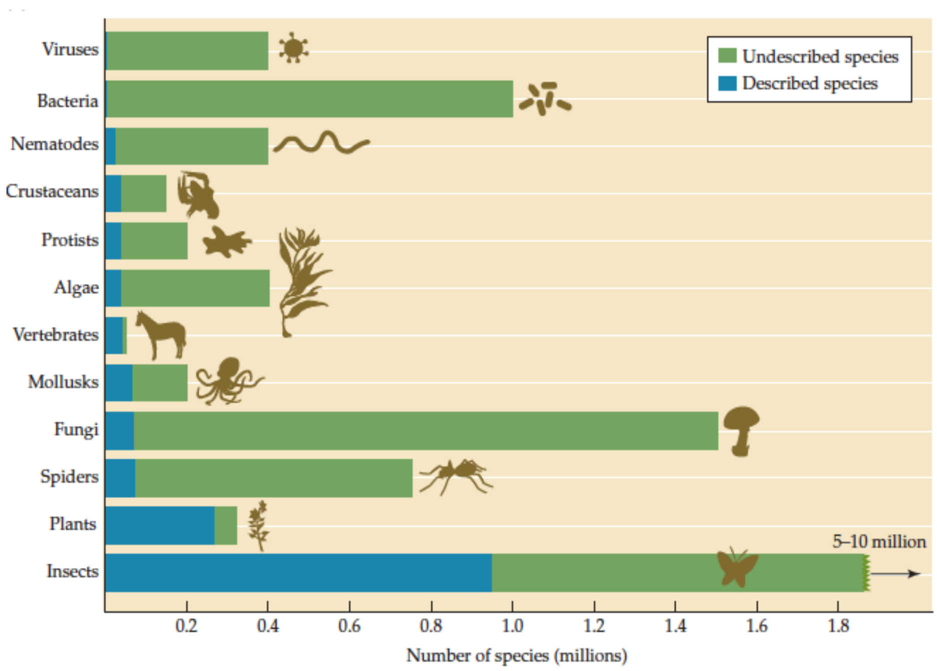

Figure 1: Numbers of described species and an estimate of the numbers of undescribed species per group (Primack, 2010).

In addition, due to most species on earth not yet being formally described, documented numbers are probably serious underestimates (Dirzo & Raven, 2003). During the past few decades species extinction rates have increased by 1,000 to 10,000 times the rates that were typical over earth's history (Chivian & Bernstein, 2008). This suggests that we are perhaps now headed towards a sixth mass extinction event, possibly caused by human activities through, among others, global climate change, habitat fragmentation, the introduction of non-native species, and the spreading of pathogens (Hoffmann *et al*., 2010). As the evolution of new species may take hundreds of thousands of years and recovery from mass extinction events possibly takes millions of years (Weir & Schluter, 2007; Alroy, 2008), this poses a serious threat to for instance ecosystem functioning. Still, the drivers of biodiversity loss and changes in ecosystem services are either steady, show no evidence of declining in the future, or are increasing in intensity (Millennium Ecosystem Assessment, 2005). Barnosky *et al*. (2011) even estimate that "*the earth could reach extreme diversity loss that characterized the five mass extinctions within just a few centuries if current threats to many species are not alleviated*". The loss of species diversity should raise concerns, not only for the loss per se but also for both the impact on ecosystem services and the functioning of ecosystems, a subject that will be further discussed in the following chapters.

Components of biodiversity

Several studies showed that ecosystems strongly depend on a number of components of biodiversity, which will be explained more thoroughly in the coming chapters. Among these components are species richness, species composition, and functional group richness and ecosystems can also depend on genetic diversity and species evenness (e.g. Isbell, 2012). Species richness is the number of different species in an ecological community, whereas species composition is the relative abundance of each species in an ecological community. Functional group richness is the number of groups of species with similar functional trait attributes, genetic diversity is the diversity within species and species evenness is the measure of the relative abundance of the different species making up the richness. Functional diversity, i.e. the kind, relative abundance, and range of the functional traits present in a community, seems to be the major factor involved in maintaining ecological integrity, and, in turn in the provision of ecosystem services (Chapin *et al*., 2000; Hooper *et al*., 2005; Díaz *et al*, 2006b). Major drivers of global change, including changes in land use, atmospheric composition, climate and biotic exchanges, affect and are affected by functional diversity (Luck *et al*., 2003). Several recent studies show the importance of functional diversity as the main ecosystem services providers (Luck *et al*., 2003; Andersson *et al*., 2007; Vandewalle *et al*., 2008). "*As functional diversity declines, the ecosystem becomes vulnerable, and progressively smaller external events can cause shifts. This might result in simplified ecosystems, which are vulnerable to disruptions in their capacity to generate service-providing functions*" (Martín-López *et al*., 2009).

In addition to the relationship between biodiversity and ecosystem services, diversity is also strongly linked with ecosystem stability (a natural system's capability to return to a steady state after a disturbance). The impacts of diversity loss on ecological processes for instance might be as large as the impacts of many other global causes of environmental change. Recent studies from Tilman *et al*. (2012) and Hooper *et al*. (2012) demonstrated that the effects of species loss on primary productivity are similar to the impacts of ozone, ultraviolet radiation, fire, climate warming, drought, herbivory, acidification, elevated CO_2 and nutrient pollution. For example, if a keystone species disappears from an ecosystem, the whole food web is likely to be disturbed, which could cause a collapse of the ecosystem (Loreau & De Mazancourt, 2013). These studies show that loss of biodiversity may have an impact on ecosystem functions as harmful as other stressors of global change (Cardinale *et al*., 2012). A decrease in biodiversity and ecosystem functioning therefore will very likely result in a decrease in the provision of ecosystem services. Ecosystems maintain in a natural stable state of functioning and when there is a disturbance or perturbation an ecosystem has the ability to recover itself. However, an unstable ecosystem that does not function properly, due to a loss of diversity for example, is not able to recover itself, let alone provide any services valuable to humankind (Constanza *et al*., 1997).

To summarize, biodiversity has changed through time and will continue to do so, the speed however, with which this change is now occurring is unprecedented in earth's history and is the consequence of human actions. The loss of biodiversity, ecosystem functions, and services has negative effects to our health, material wealth, food security, vulnerability, social relations, and freedom of choice and action (Millennium Ecosystem Assessment, 2005). The importance of biodiversity and the associated ecosystem functions and services are of vital importance to humanity's survival and should be our main focus for conservation. Throughout this thesis the term biodiversity will be considered as encompassing all forms of life on planet Earth. And if applicable, specific references will be made to the various categories of diversity as species diversity, genetic diversity, and functional diversity.

Ecosystem functions and services

Ecosystem services directly support over one billion people living in extreme poverty (World Bank, 2006). In addition, 80% of the world's population relies on medicinal products of natural origin (Ecological Society of America, 2006), and 15-30% of the United States' food production depends on crop pollination by bees (Kremen, 2005). Ecosystem functions provide services and goods that are valued by humankind, and in turn, these services and goods are essential to our survival (De Groot, 2002). De Groot (1992) describe ecosystem functions as "*the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly*" and ecosystem services are "*the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life*" according to Daily (1997). Many of these functions and services are not only beneficial, but also critical to our survival (air purification, climate regulation, crop pollination) while others might only enhance it (aesthetics). Kremen (2005) describe ecosystem services as "*the set of ecosystem functions that are useful to humans*". From this definition it becomes clear that without the proper functioning of ecosystems, we also are likely to have less or perhaps no ecosystem services. The human domination of the biosphere has led to significant changes in the structure, composition and functioning of ecosystems (Vitousek *et al*., 1997). These changes potentially have such large effects on ecosystem functioning that their capacity to function properly and provide services has already been diminished (Daily, 1997; Palmer *et al*., 2004). The Millennium Ecosystem Assessment (2005) documented that over 60% of ecosystem services are deteriorating or already overused. Although people have been long aware that natural ecosystems help support human societies, the explicit recognition of ecosystem services is relatively recent (Mooney & Ehrlich, 1997). In this chapter, the various potential services are categorized and explained in more detail.

Ecosystem functions can be divided into four general categories: regulation, habitat, production and information functions (Table 1) (De Groot *et al*, 2000), which will be further explained below. Regulation functions are those that relate to the capacity of ecosystems to regulate life support systems and ecological processes through bio-geochemical cycles and other biospheric processes, such as nutrient cycling and climate regulation. Besides maintaining ecosystem health, these functions support many services that benefit humans, such as clean water, soil and air, and biological control services. Habitat functions contribute to evolutionary processes and the conservation of genetic and biological diversity through the provision of reproduction habitat and refuge to flora and fauna. Production functions are the result of autotrophs converting water, energy, nutrients and carbon dioxide into many different carbohydrate structures, which are in turn used by secondary producers to create a larger variety of living biomass. This broad diversity provides many goods for humanity, such as food, energy resources, raw materials and genetic materials. Information functions are those that contribute to the maintenance of human health by providing opportunities for spiritual enrichment, reflection, recreation, aesthetic experience and cognitive development (De Groot *et al*., 2000).

These ecosystem functions underlie the proper functioning of ecosystems and the ability to provide services to humankind. Ecosystem services that are provided to us can be divided into four categories as well: provisioning, regulating, cultural and supporting services. Provisioning services provide us with actual products from ecosystems, such as fuel, food, fibres and fresh water. Regulating services are the benefits from the regulation of ecosystem processes, which have a more indirect benefit, such as climate regulation, water regulation, erosion control and the maintenance of air quality. Cultural services are the non-material benefits obtained from ecosystems through recreation, spiritual enrichment and aesthetic experiences. Supporting services do not directly benefit humanity, but are either indirect or occur over a long time and are part of the complex mechanisms and processes that generate other services. Examples of supporting services are nutrient cycling and soil formation (Alcamo *et al*., 2003; Haines-Young & Potschin, 2010).

Classification of ecosystem functions and services

Regulation functions

Natural ecosystems are crucial in the maintenance and regulation of life support systems and ecological processes. "*The maintenance of earth's biosphere as mankind's only life support system in an otherwise hostile cosmic environment depends on a very delicate equilibrium between many ecological processes*" (De Groot *et al*., 2002). A few examples of these processes are the storage and transfer of energy and minerals in food chains, mineralization of organic matter in sediments and soils, transformation of energy into biomass, biogeochemical cycles, and regulation of the physical climate system. Regulation functions are essential to human existence on earth, however, they are often only recognized after having already been severely disturbed or lost. In order for humankind to continue to benefit from these functions, we need to safeguard the continued integrity and existence of natural ecosystems and processes (Alcamo *et al*., 2003; Batker *et al*., 2005; Haines-Young & Potschin, 2010). The regulation functions as a main category can be split into different sub-functions:

<u>Climate and gas regulation</u>

The chemical composition of the earth's atmosphere is supported by bio-geochemical processes, which are influenced by the biotic and abiotic elements of ecosystems. Biotic and abiotic elements influence, for example, the maintenance of the ozone layer and the CO2/O2 balance. Gas regulation provides humanity with the general maintenance of a habitable planet, through e.g. the prevention of diseases and the maintenance of clean, breathable air. Gas regulation itself and an ecosystem's reflectance properties play an important role in climate regulation. Climate regulation then provides humankind with the maintenance of a favourable climate, which is important for our health, recreation and crop productivity for example (Costa and Foley, 2000).

<u>Water regulation and supply</u>

Water regulation is related to the regulation of hydrological flows at the earth's surface. Water regulation provides us with, for example, provision of a medium for transportation, buffering of extremes in discharge of rivers, maintenance of natural drainage and irrigation, and regulation of channel flow. Water supply refers to the retention, filtering and storage of water in lakes, streams and aquifers. Retention and storage depend on soil characteristics and topography of an ecosystem and filtering mostly depends on vegetation cover. Services we obtain from water supply relate to the use of water by agriculture, industry and households (De Groot *et al*., 2002; Haines-Young & Potschin, 2010).

<u>Disturbance prevention</u>

Disturbance prevention relates to an ecosystem's ability to revert the results of hazards and disruptive events. For example, coastlines are protected by from waves by coral reefs and effects from floods, droughts and storms are mitigated by vegetation through its surface resistance and storage capacity. The service that disturbance prevention provides relates to the provision of safety to human life and our constructions (De Groot *et al*., 2002; Alcamo *et al*., 2003).

<u>Soil formation and retention</u>

The formation of soil provides humanity with services related to the functioning and integrity of natural ecosystems and crop productivity. Soil retention mainly depends on vegetation cover and root system; leafs intercepts rainfall and roots stabilize the soil, which both prevent erosion and compaction of the soil. The services provided by soil retention play a major role in the prevention of damage due to erosion and in the maintenance of agricultural productivity (De Groot *et al*., 2002).

<u>Pollination and biological control</u>

Pollination is crucial to most commercial crops for reproduction. Pollination is provided by many wild species, including insects and birds. Cultivation of most crops would be impossible and many plant species would go extinct without this function. The service that this function provides can be derived from the dependence of cultivation on natural pollination (De Groot *et al*., 2000).

Habitat functions
The earth's ecosystems provide living space for all flora and fauna. Since it is this diversity of species, and their role in the ecosystems that provide most of the world's ecosystem functions (Batker *et al*., 2005), the maintenance of healthy habitats is necessary for the provision of all ecosystem services and goods. Habitat functions can be divided into two sub-functions; nursery and refugium functions. Many ecosystems worldwide provide nursery and breeding habitats to species that are important for humanity's subsistence and are of commercial value. Natural ecosystems are also indispensable to the maintenance of the earth's genetic and biological diversity through the provision of living space. These ecosystems can be considered as a genetic library and to maintain its viability, the maintenance of natural ecosystems is necessary (De Groot *et al*., 2002; Batker *et al*., 2005).

Production functions
Earth provides us with many resources, such as water, food, oxygen, medicinal and genetic resources, energy, and raw materials. Humankind has learned how to manipulate the productivity of ecosystems so they provide greater than natural quantities of resources (De Groot *et al*., 2002; Batker *et al*., 2005). These production functions can also be categorized into a number of different sub-functions:

<u>Food and raw materials</u>
Although today most foods are derived from crops and livestock, a considerable amount still comes from wild flora and fauna. Natural ecosystems provide an almost endless source of consumable plants and animals, ranging from fruits, vegetables, fungi, to game, fish and fowl. They also provide us with renewable resources such as wood, biochemicals, fibres, and organic matter. These materials are used for building, fuel, handicrafts, clothing etc. (Alcamo *et al*., 2003; Verweij *et al*., 2009; Haines-Young & Potschin, 2010).

<u>Genetic resources</u>
For example, humanity would not be able to maintain many commercial crops without the genetic variety of their wild relatives. In order to improve a crop's quality (e.g. size, taste, and resistance to diseases) or maintain its productivity regular inputs of genetic material from wild relatives is essential (De Groot *et al*., 2002).

<u>Medicinal resources</u>
Mother nature provides chemicals that can be used as pharmaceuticals and medicines. An example is epibatidine, a chemical from the skin of the Phantasmal poison frog (*Epipedobates tricolor*). A derivative from this chemical has the ability to kill pain 200 times more effective than morphine, without the negative side effects (Johnson, 1998). Also, animals serve as medicinal tools, student specimens or are used to test new drugs (De Groot *et al*, 2002; Foley *et al*., 2007).

Information functions
Natural ecosystems provide numerous opportunities for recreation, education, spirituality and mental development. Nature is a vital source of inspiration for art, science and culture, and provides many opportunities for research and education (Batker *et al*., 2005). As Forster (1973) already stated 40 years ago "*natural environments provide a highly inspirational and educative form of recreative experience, with opportunities for spiritual enrichment, cognitive development and reflection through exposure of life processes and natural systems*". Information functions can be divided into different sub-functions:

<u>Aesthetic information</u>
Most people enjoy and appreciate natural landscapes and areas. Aesthetic information also has considerable economic importance; through, for example, its influence on real estate prices and the exploitation of the world's natural beauty (De Groot *et al*., 2002).

<u>Recreation and tourism</u>
People enjoy nature through recreation, refreshment, rest and relaxation. The natural environment provides numerous activities, such as hiking, fishing, camping, biking, and swimming because of an almost limitless variety of landscapes and aesthetic qualities. The demand for natural areas for recreation will most likely continue to increase in the future due to the increasing number of people and wealth (De Groot *et al*., 2002).

Cultural, artistic, spiritual, historic, and educational information

The world's natural ecosystems and its elements provide us with an understanding of our place in the universe and a sense of continuity and religious values, such as worship of certain elements belong to this category of functions. Also provides the natural world us with almost unlimited opportunities for environmental education, excursions, and nature study. Natural areas also serve as the world's most important reference for monitoring environmental change. Nature is also important in culture and folklore and is used as a source of inspiration for films, books, art, music, fashion etc. (De Groot *et al*., 2002).

Table 1 below displays the described ecosystem functions, goods and services that can be ascribed to ecosystems and their associated processes and components. The first column lists the 23 functions, the second column indicates the underlying ecological processes and components, and the third column presents examples of the goods and services obtained from these functions.

Table 1: Ecosystem functions, their underlying processes and components and examples of the associated goods and services of natural and semi-natural ecosystems (De Groot *et al*., 2002). Adapted from Costanza *et al*. (1997), De Groot (1992), and De Groot *et al*. (2000).

	Functions	Ecosystem processes and components	Goods and services (examples)
	Regulation Functions	*Maintenance of essential ecological processes and life support systems*	
1	Gas regulation	Role of ecosystems in bio-geochemical cycles (e.g. CO_2/O_2 balance, ozone layer, etc.)	1.1 UVb-protection by O_3 (preventing disease). 1.2 Maintenance of (good) air quality. 1.3 Influence on climate (see also function 2.)
2	Climate regulation	Influence of land cover and biol. mediated processes (e.g. DMS-production) on climate	Maintenance of a favorable climate (temp., precipitation, etc) for, for example, human habitation, health, cultivation
3	Disturbance prevention	Influence of ecosystem structure on dampening env. disturbances	3.1 Storm protection (e.g. by coral reefs). 3.2 Flood prevention (e.g. by wetlands and forests)
4	Water regulation	Role of land cover in regulating runoff & river discharge	4.1 Drainage and natural irrigation. 4.2 Medium for transport
5	Water supply	Filtering, retention and storage of fresh water (e.g. in aquifers)	Provision of water for consumptive use (e.g.drinking, irrigation and industrial use)
6	Soil retention	Role of vegetation root matrix and soil biota in soil retention	6.1 Maintenance of arable land. 6.2 Prevention of damage from erosion/siltation
7	Soil formation	Weathering of rock, accumulation of organic matter	7.1 Maintenance of productivity on arable land. 7.2 Maintenance of natural productive soils
8	Nutrient regulation	Role of biota in storage and re-cycling of nutrients (eg. N,P&S)	Maintenance of healthy soils and productive ecosystems
9	Waste treatment	Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds	9.1 Pollution control/detoxification. 9.2 Filtering of dust particles. 9.3 Abatement of noise pollution
10	Pollination	Role of biota in movement of floral gametes	10.1 Pollination of wild plant species. 10.2 Pollination of crops
11	Biological control	Population control through trophic-dynamic relations	11.1 Control of pests and diseases. 11.2 Reduction of herbivory (crop damage)
	Habitat Functions	*Providing habitat (suitable living space) for wild plant and animal species*	Maintenance of biological & genetic diversity (and thus the basis for most other functions)
12	Refugium function	Suitable living space for wild plants and animals	Maintenance of commercially harvested species
13	Nursery function	Suitable reproduction habitat	13.1 Hunting, gathering of fish, game, fruits, etc. 13.2 Small-scale subsistence farming & aquaculture
	Production Functions	*Provision of natural resources*	
14	Food	Conversion of solar energy into edible plants and animals	14.1 Building & Manufacturing (e.g. lumber, skins). 14.2 Fuel and energy (e.g. fuel wood, organic matter). 14.3 Fodder and fertilizer (e.g. krill, leaves, litter).
15	Raw materials	Conversion of solar energy into biomass for human construction and other uses	15.1 Improve crop resistance to pathogens & pests. 15.2 Other applications (e.g. health care)
16	Genetic resources	Genetic material and evolution in wild plants and animals	16.1 Drugs and pharmaceuticals. 16.2 Chemical models & tools. 16.3 Test- and essay organisms
17	Medicinal resources	Variety in (bio)chemical substances in, and other medicinal uses of, natural biota	Resources for fashion, handicraft, jewelry, pets, worship, decoration & souvenirs (e.g. furs,
18	Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	feathers, ivory, orchids, butterflies, aquarium fish, shells, etc.)
	Information Functions	*Providing opportunities for cognitive development*	
19	Aesthetic information	Attractive landscape features	Enjoyment of scenery (scenic roads, housing, etc.)
20	Recreation	Variety in landscapes with (potential) recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
21	Cultural and artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbols, architect., advertising, etc.
22	Spiritual and historic information	Variety in natural features with spiritual and historic value	Use of nature for religious or historic purposes (i.e. heritage value of natural ecosystems and features)
23	Science and education	Variety in nature with scientific and educational value	Use of natural systems for school excursions, etc. Use of nature for scientific research

Valuing ecosystem functions and services

The concept of ecosystem valuation can very useful to understand and measure the importance of the functions and services provided by nature. Valuation of these functions and services is essential for guiding future human activities in a sustainable manner. The value of an ecosystem's functioning and services can be divided into three categories: economic, ecological and socio-cultural values, which are explained below.

Economic value

An ecosystem's economic value can be determined in four different ways: direct market value, indirect market value, group value, and contingent value. Direct market value is the exchange value that an ecosystem service has in trade, mainly production (e.g. food), regulation (e.g. water filtration), and information functions (e.g. recreation). Indirect market values are applicable when an ecosystem has no explicit market values. People's willingness to accept compensation and willingness to pay for the availability or loss of ecosystem services are examples of indirect valuation techniques. Contingent valuation involves surveying people about how much they are willing to pay for certain ecosystem services or how much compensation they would accept to give up certain services. Group valuation captures value types that are not included in contingent valuation methods, such as social justice, fairness and non-human values (De Groot *et al*., 2002; Spash, 2008; TEEB, 2010; Ecosystem Valuation, 2015). Unfortunately, the values of ecosystem services are not fully incorporated in commercial markets and it is difficult to express their value in monetary terms, hence they are often getting too little consideration in important policy decisions. Therefore Constanza *et al*. (1997) estimated the value of 17 ecosystem services on a biosphere-wide basis. Only renewable ecosystem services were included in the calculation, non-renewable minerals and fuel and the atmosphere were excluded. They estimated that ecosystems provide at least $33 trillion and possibly even $54 trillion worth of services per year. This annual value was approximately 1.8 times the global Gross National Product in 1997. Due to ecosystem services becoming more stressed and scarce, the value of these services is only expected to increase (Eftec, 2005; TEEB, 2010).

Ecological value

The ecological value of the services and functions an ecosystem provides can be defined as an ecosystem's capacity to actually provide these services and goods depending on the ecosystem processes and components providing them. The use of these services and goods should be restricted to sustainable levels to ensure the continued availability of ecosystem functions. If we use services and goods in an unsustainable manner, the pressure on ecosystems will further increase until the point of collapse. At this point, an ecosystem will not be able to provide its potential services. The limits of sustainable use are defined by ecological criteria (e.g. resistance, resilience, and integrity). Ecological measures of ecosystem's value are ecosystem parameters like diversity, rarity, and complexity, and the integrity of the regulation and habitat functions (De Groot *et al*., 2000; De Groot *et al*., 2002; TEEB, 2010).

Socio-cultural value

Many people regard biodiversity and natural ecosystems as a crucial source of non-material wellbeing through its influence on people's national, historical, religious, ethical, and spiritual values. Social reasons also play an important role in environmental functions, education, physical and mental health, freedom, and cultural diversity and identity (English Nature, 1994). Thus, natural systems are an essential source of non-material wellbeing and vital for a sustainable society (Norton, 1987; De Groot *et al*., 2002; TEEB, 2010).

The link between biodiversity, ecosystem functions and services

Human needs are being satisfied at the expense of our planet, our climate, species distributions and biogeochemical cycles, for example by altered land use and massive deforestation (Millennium Ecosystem Assessment, 2005). As a result, biodiversity in general is declining with alarming rates (Millenium Ecosystem Assessment, 2005), which raises concerns about the consequences of biodiversity loss for the provision of ecosystem services, ecosystem functioning, inevitably also human wellbeing (Hooper *et al*., 2005).

Biodiversity can play multiple roles in ecosystem processes and services. Biodiversity can for example act as a regulator of key ecosystem processes, as a final ecosystem service, or even as a good in itself. For example, a community's resilience to changes and pests increases with higher biodiversity (Cardinale *et al*., 2003), giving biodiversity the role of a regulator and hence controlling ecosystem processes that support ecosystem services. In relation to this, the composition of biological communities, a major component of biodiversity, also determines the dynamics of soil nutrient cycles by, for example decomposition and nutrient uptake (Bradford *et al*., 2002).

Higher biodiversity has already been shown to be associated with increased ecosystem functions and plays a key regulatory role in the delivery of ecosystem services (Balvanera *et al*., 2006; Hooper *et al*., 2005; Díaz *et al*., 2006a). In addition, biodiversity can be a final ecosystem service that contributes directly to several goods and their values. For example, the potential benefits and value of crops, biofuels, livestock and wild medicines increase directly with the number and diversity of species (Mace *et al*., 2012). Finally, biodiversity can be a good directly, being the object that people value for its pristine value or aesthetic appeal. For example, the appreciation of landscapes and wildlife and the spiritual, religious, recreational, cultural, and educational values people link to biodiversity. These examples demonstrate that biodiversity is a good with a distinct value in itself (Mace *et al*., 2012). In this chapter we study the link between diversity and the provision of ecosystem functions and services. How closely are they linked and what do we need to undertake to maintain ecosystem functioning and the services they provide?

The link between diversity and the functioning of ecosystems

The Millennium Ecosystem Assessment (2005) identifies biodiversity and the many associated ecosystem services as a major factor determining human wellbeing. Their findings support that "*biodiversity loss and the resulting deterioration of ecosystem services contribute -directly or indirectly- to worsening health, higher food insecurity, increasing vulnerability, lower material wealth, worsening social relations, and less freedom of choice and action*". This indicates the link between biodiversity and ecosystem functioning and the necessity of their services to humanity and should be an important motive for conservation. Table 2 displays several studies that investigated the hypothesis whether there is a positive relationship between biodiversity and ecosystem functions. This table shows that biodiversity indeed has a positive effect on ecosystem function in most of these studies. Naeem *et al*. (1999), among others, identified several impacts on ecosystem functioning as a result from biodiversity loss; plant production may decline with a decline in regional biodiversity, ecosystem resistance to environmental perturbations may decline as biodiversity decreases, and ecosystem processes may become more variable with decreasing biodiversity. Without ecosystems functioning properly, the risk of losing certain services also increases. Studies have shown that the functioning of ecosystems and hence also the ability to provide services is not only influenced by biological diversity per se, but is mostly affected by functional diversity. As described in the previous chapters, functional diversity is "*the value and range of those species and organismal traits that influence ecosystem functioning*" (Hooper *et al*., 2005). Functional diversity is therefore important because it is the diversity's component that influences ecosystem stability, dynamics, nutrient balance, productivity, and other aspects of ecosystem functioning (Tilman, 2001). In this light, conservation and restoration efforts should perhaps focus mainly on functional diversity, rather than just maximizing species numbers (Hooper *et al*., 2005; Kremen, 2005).

Biodiversity and ecosystem services

There are several well-documented examples that demonstrate the role of functional diversity in the provision of ecosystem services. Balvanera *et al*. (2006) conducted a meta-analysis of over 400 studies on the effect of biodiversity on primary production. Hoehn *et al*. (2008) showed that the diversity of pollinator species, and not the abundance of pollinator species determined seed set. And Bullock *et al*. (2007) demonstrated that mixed meadows of grasses are more productive under less pressure than meadows with low diversity. These studies show that there is clear evidence that biodiversity has positive effects on the provision of ecosystem services.
Research shows our knowledge of the complex link between biodiversity, ecosystem functions, and services. Biodiversity plays an important role in nutrient cycling, provision of clean air and water, crop pollination, provision of food, water cycling, climate regulation, disease regulation, carbon sequestration etc. and also has an economic value (e.g. Costa and Foley, 1997; Williams and Melack, 1997; Verweij *et al*., 2009). It is also known that functional diversity plays a key role in this story. Several researches indicate that the loss of functional diversity has a negative effect on the functioning of ecosystems and the provision of services (e.g. Kremen, 2005; Verweij *et al*., 2009). Although basic theory and knowledge of the link between biodiversity and ecosystem functions and services is available, but this not sufficient to address the current challenges in conservation and sustainable use. The links between biodiversity and ecosystem functions/services need to be further identified and analysed to optimize both the sustainable delivery of ecosystem services and the conservation of species, habitats and landscapes (Mace *et al*., 2012).

Table 2: Studies that investigated the hypothesis of a positive relationship between biodiversity and ecosystem function. The studies are classified based on whether they used observations or experiments to investigate this relationship (Schwartz *et al*., 2000).

Authors	Ecosystem function	Relationship supports the hypothesis[a]
Observational studies		
Measures of ecosystem function		
Bulla 1996	Productivity	NO (0)
Cuevas et al. 1991	Root biomass	YES (+)
Cuevas et al. 1991	Above ground productivity	NO (–)
Finlay et al. 1997	Nutrient cycling	unclear
Kutiel and Danin 1987	Field water capacity	YES (+)
Kutiel and Danin 1987	Biomass	YES (+)
Marques et al. 1997	Exergy	YES (+)
Wardle et al. 1997	Biomass	YES (–)
Wardle et al. 1997	Nitrogen retention (loss)	YES (+)
Wardle et al. 1997	Respiration	YES (–)
Experimental studies		
Measures of ecosystem function		
van der Heijden et al. 1998	Plant shoot biomass	Yes(+)
van der Heijden et al. 1998	Plant root biomass	Yes (+)
Hooper and Vitousek 1997	Above ground biomass	YES (+)
Hooper and Vitousek 1997	Nitrogen use	YES (–)
McGrady-Steed et al. 1997	Decomposition rates	YES (+)
McGrady-Steed et al. 1997	Invasion susceptibility	YES (+)
McGrady-Steed et al. 1997	CO_2 flux	YES (+)
Naeem et al. 1994	Nitrogen, potassium and phosphorus retention	NO (0)
Naeem et al. 1994	Percent cover	YES (+)
Naeem et al. 1994	Transmittance (as a measure of productivity)	YES (–)
Naeem et al. 1994	CO_2 flux	YES (+)
Naeem et al. 1995	Nitrogen retention	NO (0)
Naeem et al. 1995	Potassium retention	YES (+)
Naeem et al. 1995	Biomass	YES (+)
Naeem et al. 1995	Percent cover	YES (+)
Symstad et al. 1998	Biomass	YES (+)
Symstad et al. 1998	Nitrogen retention	YES (+)
Tilman et al. 1996	Extractable nitrogen	YES (–)
Tilman et al. 1996	Total cover	YES (+)
Tilman et al. 1997a	Biomass	YES (+)

The Amazon Rainforest: a practical example of the relationship between biodiversity and ecosystem functions and services

The Amazon rainforest accounts for 40% of the world's remaining rainforest and has been a permanent feature of South America for at least 55 million years (Maslin *et al*., 2005), covers about 5.5 million km^2 and spreads across nine countries (Soares-Filho *et al*., 2006). It hosts approximately a quarter of the world's terrestrial species and accounts for about 15% of global photosynthesis (Dirzo & Raven, 2003). In addition, the Amazon river, 3300 km's long, contains approximately 15% of all the earth's fresh water that is transported by rivers passes through the Amazon river (Neill *et al*., 2006).

It is assumed that the Amazon rainforests are the most biodiverse rainforests in existence in terms of species diversity and currently contains the earth's largest collection of living animal and plant species (figure 2). In one hectare of Amazon forest typically 200-300 tree species can be found, which is more than in entire Europe. It is estimated that at least 40,000 plant species, 2.5 million insects, 3,000 fish, 1294 birds, 427 mammals, 427 amphibians and 378 reptile species inhabit the Amazon biome (Silva *et al*., 2005). Ten percent of the world's known species live in the Amazon rainforest (Walker, 1992). Especially the western Amazon has a species richness unparalleled by any other place on this planet. Furthermore, the Amazon also contains many large areas of endemism (Silva *et al*., 2005).

However, the Amazon rainforest had been under great pressure during the last few decades and diversity and ecosystem services are diminishing. Deforestation and forest degradation are two of the main drivers of the deterioration of the Amazon. Despite the obvious negative effects of deforestation, it also has several positive outcomes on a local/regional scale: it provides jobs and income to developing countries and provides essential resources (e.g. timber, food, raw materials). Land use practices however also cause some ecosystem goods to be depleted faster, which often leads to short term key social and economic benefits. The long-term effects in general are devastating because land use degrades other ecosystem services, especially those responsible for long term functioning of ecosystems. Critical ecosystem services that may be reduced due to the loss of rainforest are the regulation of carbon stocks and climate, availability of pollinating insects, supply of non-timber products and the regulation and purification of the air freshwater flows. The reduction of these services has a direct or indirect on humankind's wellbeing as valuable resources are lost (Foley *et al*., 2007).

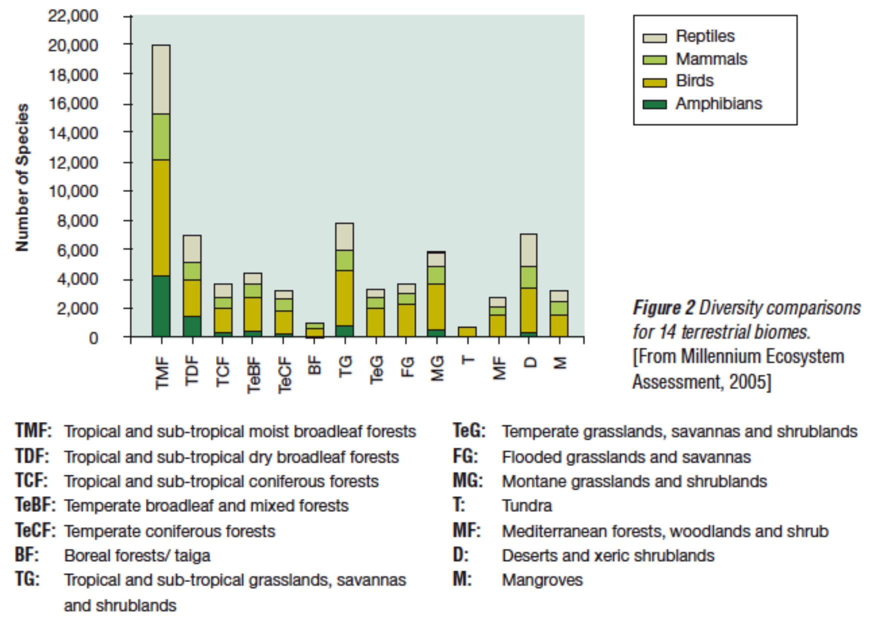

Figure 2: Diversity comparisons for 14 terrestrial biomes (Millennium Ecosystem Assessment (2005).

Ecosystem services of the Amazon

As one of the richest terrestrial ecosystems of our planet, the Amazonian forests provide us with many ecosystem services (Malhi *et al*., 2008). These services represent an economic value of $1,591 to 11.141 per hectare per year (table 3), accumulating to a value of $877 billion to $6,1 trillion dollar per year (Verweij *et al*., 2009). These services are divided into four categories; supporting, regulating, provisioning and cultural services. A number of these services are listed and explained below.

<u>Supporting services</u>

Biodiversity conservation

Ecosystems with great biodiversity are more likely to be stable and efficient and thus able to provide more services than ecosystems with less biodiversity (Hooper *et al*., 2005; Worm *et al*., 2006). Biodiversity is so important in the functioning of rainforests and the provision of ecosystem services that the conservation of biodiversity in itself can be regarded as an ecosystem service. The earth's tropical rainforests constitute a major source of biodiversity; even though rainforests make up only 7% of the world's terrestrial area, they harbour more than half of the world's species (Whitmore, 1998). Deforestation has direct and local impacts on biodiversity. The amount of species of flora and fauna obviously decrease in deforested areas. The impact of deforestation is greatest in areas of high endemism levels and areas with little remaining forest. Species with small population sizes and small distribution ranges are highly vulnerable to habitat loss and run the greatest risk of extinction (Fearnside, 2005).

Water cycling

Water has the ability to dissolve solid and gaseous substances, such as oxygen, carbon dioxide, dissolved organic carbon and nitrogen. The Amazon's solvent properties are vital to the ecosystems' functioning due to the enormous amount of water in the river system. Furthermore, the Amazon's hydrological cycle forms a key component of the global climate. Large-scale deforestation of the Amazon would lead to a decrease in evapotranspiration that leads to a significant decline in rainfall. This would in turn lead to irreversible changes in the Amazon basin, including damage to indigenous communities, agriculture and water quality (Verweij *et al*., 2009).

Table 3: Ecosystem services provided by the Amazon rainforest and their related economic values (Verweij *et al*., 2009).

Ecosystem services	Economic value
Production of non-timber forest products	50-100 US$ per ha per yr
Production of timber, net present value of Reduced Impact Logging (not necessarily sustainable production)	419-615 US$ per ha
Erosion prevention	238 US$ per ha per yr
Fire protection	6 US$ per ha per yr
Pollination of coffee plantations from forest (Ecuador)	49 US$ per ha per yr
Disease protection	unknown
Carbon storage: 1) damage avoided due to CO_2 emissions avoided 2) value of total carbon stored in intact forest	70-100 US$ per ha per yr 750–10,000 US$ per ha
Maintenance of biodiversity	unknown
Cultural and spiritual aspects of the forest	unknown
Existence value	10-26 US$ per ha per yr
Recreational and ecotourism use	3-7 US$ per ha per yr

Regulating services

Climate regulation

The Amazon river system's sheer size means that moisture and energy cycles in the Amazon have an essential role in climate regulation at different scales. Because vegetation cover partially determines CO_2 storage, water cycle and albedo (the reflected fraction of incoming radiation), the flora has a great influence on the climate. Silva Dias *et al*. (2002) estimated that over 70% of the Amazonian forest cover might be necessary to preserve the forest-dependent rainfall regime. As deforestation increases, the resulting atmospheric heating and reductions in evapotranspiration may reduce moisture recycling and convection in the Amazonian atmosphere and possibly even has an effect on the global climate (e.g. Costa and Foley, 2000).

Hydrological services

As being the largest river system on earth, the Amazon provides food sources, habitat for flora and fauna, navigable waters and hydroelectricity (Lundberg *et al*., 2000). The Amazon rainforest has a strong influence on this hydrological system by regulating the timing and volume of nutrient and water flows. The rainforest contributes also to erosion control by the regulation of runoff, sediment control and the regulation of flooding. The vegetation mitigates runoff by increasing the permeability of the topsoil and by slowing the raindrops velocity. Sediment from rivers is caught by vegetation because it slows the speed of the water and flooding of the Amazon river increases the nutrients in the soils (Bonnel & Bruijnzeel, 2005). Deforestation and forest degradation have the potential to change surface runoff, evapotranspiration, groundwater recharge and canopy interception and hence degrade the regulation of hydrological flows (Costa and Foley, 1997; Williams and Melack, 1997).

Nutrient retention

The Amazon's poor soil has a closed nutrient cycle. This means that nutrients from rainfall and litter decomposition are directly taken up by the flora and remain within the system. Not only do deforestation and forest degradation cause a direct loss of nutrients but also have a secondary effect; due to an insufficient amount of trees not all nutrients will be taken up and remain in the soil or surface waters (Verweij *et al*., 2009).

Carbon sequestration

The Amazon plays a great role in the earth's carbon balance because it stores large amounts of carbon in biomass, both in the soil and above ground. The vegetation in the Amazon alone contains 10-15% of the world's terrestrial carbon (Houghton *et al*., 2001). However, it is not yet sure if the Amazon is a carbon sink, a carbon source or is carbon neutral. Some scientists say the Amazon has a carbon uptake of 0.44-0.56 Pg per year (Phillips *et al*, 1998), while others say the Amazon acts as a carbon source (Wright, 2005). A third group argues that the Amazon is carbon neutral due to emissions from fire, decomposition and deforestation are balanced by the carbon uptake and regrowth (Schimel *et al*., 2001). Despite these uncertainties more recent studies show that old-growth tropical forest ecosystems are currently acting as a strong carbon sink (e.g. Stephens *et al*., 2007). However, further forest degradation and deforestation may initiate a switch from carbon sink to carbon source (Verweij *et al*., 2009). Between 20 and 30% of the total greenhouse gas emissions worldwide is caused by deforestation. It is suggested that tropical deforestation accounted for at least a quarter of the world's carbon emissions in the 1980s and 1990s (Houghton, 2003). The land use types that result from deforestation contain less carbon per hectare than tropical rainforests. So this means that not only deforestation in itself results in emissions of greenhouse gasses but also the subsequent land use types have a negative effect on the storage of carbon.

Disease regulation

The Amazon houses some of the world's most hazardous infectious diseases, including dengue and malaria. Approximately 40% of the world's population lives in areas where malaria is endemic and each year malaria causes 1.2 million deaths. Rainforests regulate the population of disease organisms, their hosts and the intermediary disease vectors and hence moderate the risk of infectious diseases. The loss of rainforest may cause an increase in the abundance of for example mosquitoes through changes in local habitat conditions, resulting in an increase in malaria infections (World Health Organization, 2005; Foley *et al*., 2007).

Provisioning services

Timber

The Amazon forest's timber is an important provisioning service to indigenous communities, local economies and international businesses. In Brazil approximately 6.2 million trees were harvested in 2004. This shows a decrease since 1998, probably due to increased control on illegal logging and improved efficiency in wood processing (Verweij *et al*., 2009).

Non-timber forest products

Another of the Amazon's provisioning services is the supply of non-timber forest products. These products (e.g. rubber, fruits, seeds, palm heart) provide the indigenous people with both a cash income as well as a means of living. Local and indigenous communities suffer most from deforestation and forest degradation because they lose valuable sources of timber and non-timber products (Verweij *et al*., 2009).

Cultural services

Non-use values

Non-use values include existence values and bequest values and are most valuable for local, indigenous peoples. Existence values derive from the knowledge that a service or good exists and bequest values relate to ensuring that services or goods will be preserved for future generations. Half a century ago the Brazilian Amazon supported over 200 native groups with a total population of over 6 million people. Deforestation has lead to the loss of cultural identity and death of indigenous peoples. By 1990 only half of these groups persisted with a total population of 100,000 people. Main causes of the deaths of these peoples were common diseases like measles and common colds. They became infected with these diseases due to contact with colonists and loggers (Pearce & Meyers, 1990).

Recreation and ecotourism

The tourism industry is one of the largest employers and industries in the world. It employs 260 million people and accounts for almost 11% of the world's gross domestic product. The Amazon attracts hundreds of thousands of visitors each year. Community based ecotourism is now a popular tool for the conservation of biodiversity through the revenues it generates. Deforestation and forest degradation may have a positive short term effect due to tourist wanting to see the Amazon before it is destroyed. However, the final effect of deforestation is the loss of the Amazon forest up to the point that there is nothing more to see and people are not willing to pay for a visit anymore (Kiss, 2004).

The Amazon's changing diversity

In 2001, approximately 13 % (837,000 km^2) of the Amazon rainforest had been lost, mostly due to clearance for pastures and soybean agriculture (Soares-Filho *et al*., 2006). The recent and predicted future rate of deforestation of the Amazon is at least 0.38% of forest each year (Achard *et al*., 2002). However, besides deforestation rainforest is lost due to illegal mining, selective logging, excessive hunting, surface fires and edge effects (Laurance & Peres, 2005). Due to human activity the Amazon rainforest seems to be entering a period with unprecedented deterioration and disruption. Data from White *et al*. (1999) and Cox *et al*. (2000) suggest that a significant part of the Amazon rainforest may have changed into savannah by the end of the twenty-first century. The main drivers of Amazonian climate change are increasing temperatures and decreasing precipitation, which is directly linked to deforestation and forest degradation. Temperatures in the Amazon are projected to rise between 3.3°C and 8°C this century and since the mid 1970s there has been a drying trend in the Amazon (Christensen *et al*., 2007). Deforestation and forest degradation have direct and indirect effects on biodiversity. The loss of forest results in a loss of biodiversity, which then results in a decrease in ecosystem services. Global warming will increase due to carbon being released in the air, a reduction of evapotranspiration will cause climate drying and weakened water cycling, the natural regulation of disease organisms will be disturbed, flooding will increase due to disturbance of the hydrological cycle etc. Still, Verweij *et al*. (2009) predict an increasing rate of deforestation and forest degradation in the Amazon rainforests over the coming decades associated with a decrease in biodiversity and ecosystem services. The same authors name several causes for the increase in deforestation and forest degradation:

- "*The expansion of infrastructure, including river transportation and roads, will open up large parts of the Amazon where agriculture is currently not profitable.*
- *Rising world population and rising commodity prices will promote agricultural expansion and non-sustainable timber production at an accelerated pace.*

- *Increasing demand for biofuels, added to the demand for timber and traditional agricultural commodities, promotes the agro-industrial production of oil palm and sugarcane, thus driving deforestation both directly and indirectly.*
- *Global climate change is expected to result in forest degradation over a large scale, which is accompanied by an increasing fire frequency.*
- *Widespread expansion of soy cultivation and pastures will significantly reduce rainfall, which exerts an adverse impact on the rainfall regime, promoting further degradation of the remaining forest.*
- *Massive emissions from deforestation and forest degradation in Amazonia will further fuel the problem of global climate change, partly because the region is expected to turn from a net sink into a net source of carbon emissions in the near future*".

Conservation strategies in the Amazon

It is only 40 years ago when conservation in the Brazilian Amazon started to receive serious attention (Mittermeier *et al*., 2005). Since then great steps were made to protect and conserve the Amazon for future generations. For example, in 1970 there was only one national park in Brazil covering 20,000 km^2 and in 2010 the area of protected Amazonian rainforest in Brazil was 500,000 km^2 (Verweij *et al*., 2009). Today, almost 40% of the Brazilian Amazon is protected, with 6% being strictly protected (Schulman *et al*., 2007). However, future progress requires significant measures that continue the current trend and address the important direct and indirect drivers of ecosystem function and service degradation and biodiversity loss.

Planning to keep the Amazon from ecological and climatic declines has several challenges: insufficient financial resources, the drive of globalizing market forces, ineffective enforcement of rule of law, provision of open access to information, and limited technical and governance capacity. New financial incentives are necessary to compensate the economic pressure for deforestation. The Kyoto Protocol created international markets in carbon (e.g. such as the European Union's Emissions Trading System) that make these financial incentives possible. Tropical forest carbon credits are particularly valuable within climate mitigation strategies due to the additional climatic services they bring such as evapotranspiration and precipitation, as well as extra ecosystem services such as pollination, watershed protection and biodiversity conservation. These incentives will support improved governance and the expansion of the capacity in forest monitoring. However, most important is that these incentives bring benefits to the groups and individuals making decisions about land use in the Amazon on a daily basis (smallholders, large landholders and indigenous people) (Bala *et al*., 2007; Malhi *et al*., 2008).

Protecting areas and species, conserving genetic diversity and restoring ecosystems are a few measures with a primary goal of conservation. Protected areas are extremely important, especially in areas where changes in key drivers have significant impacts on biodiversity loss. Protected areas are most valuable if protection focuses on the entire ecosystem with regard to external threats as climate change, pollution and invasive species. However, Verweij *et al*. (2009) state that "*the current system of protected areas is not sufficient for conservation of all components of biodiversity. Protected areas need to be better located, designed, and managed to deal with problems like lack of representatives, impacts of human settlement within protected areas, illegal harvesting of plants and animals, unsustainable tourism, impacts of invasive species, and vulnerability to global change*". Besides protecting areas, there is also a need for restoring ecosystems due to their degradation and the growing demand for their services. This however, is far more expensive than protecting the original ecosystem and not all of the lost biodiversity and services can be restored.

A few measures with a primary goal of sustainable use of biodiversity and ecosystem services are payments for biodiversity and services and incorporating forestry, fisheries and agriculture in conservation. Forestry, fisheries and agriculture can intensify their production instead of expanding their total area, this allows more area for conservation. A few examples of payments for biodiversity and reduction of deforestation are carbon markets, ecotourism and REDD+. REDD+ is an incentive that plans to reduce emissions from deforestation and forest degradation, conserve forest carbon stocks and promote the sustainable management of forest. Through the REDD+ framework developing countries are rewarded financially for a reduction in emissions and a decrease in deforestation (The REDD desk, 2015). But maybe public awareness and education are the most important and effective measures to protect and conserve the world's ecosystems and biodiversity. A large portion of the world's population is not aware of the services the natural world provides them and how valuable they are. Improved communication and education are essential to achieve sustainable management of natural resources and to conserve the world for future generations (Verweij *et al*., 2009).

Soares-Filho *et al*. (2006) state that limitation of the expansion of agriculture, and improved governance and protected area management are efficient ways to reduce deforestation. This includes improving the regulatory structure for environmental impact, measures against land speculation, improving land use planning and implementing already existing ecological-economical zoning, and exerting control on already existing regulation. The next decade represents a unique opportunity, maybe even the last, to maintain the biodiversity, ecosystem services, and resilience of the Amazon in the face of threats of significant drying and deforestation (Malhi *et al*., 2008). Several incentives that are created to reduce humanity's footprint on Mother Nature and promote conservation and sustainable use of ecosystems are stated below.

Protected Area Management

Deforestation is halted successfully in national parks and indigenous territories. Nepstad *et al*. (2006) used maps and satellite images from 1997-2000 to conclude that deforestation outside national parks and indigenous territories was 1.7 to 20 times greater than inside these reserves. Indigenous territories provide an essential barrier to deforestation of the Amazon, because they cover a much larger area than national parks in the entire Amazon. Almost all indigenous communities inhibit deforestation up to 400 years after contact with the national society. Verweij *et al*. (2009) recommend the creation of new protected areas and strengthening of existing protected areas to inhibit deforestation.

Payments for ecosystem services

Mechanisms of payments for ecosystem services are in important opportunity to counteract forest loss and degradation. REDD, commenced in 2007, is an example of such a payment mechanism whereby companies and governments can financially compensate developing countries for reducing emissions related to the loss and degradation of forests. The demand for REDD-related carbon credits could be very high if industrial nations cannot comply with their emission reduction targets, with lowering prices and stimulation of the conservation of rainforests as a result. "*REDD-related financing has the potential to become the largest financial flow into tropical forest conservation*" (Nepstad, 2007). Carbon finance at US $5 per tonne or less could shift the equilibrium from non-sustainable towards sustainable forest management over 96% of the Brazilian Amazon. In 2010 REDD became REDD+ to not only reduce emission from forest loss and degradation, but also conserve and enhance forest carbon stocks and promote sustainable forest management. Following the initiation of the REDD+ program the Prime Minister of Norway announced to offer US$ 2.5 billion to finance the REDD+ program during the next five years. A large part of this amount, US$ 1 billion, was destined for Brazil's Amazon Fund. In order to receive these funds, Brazil had to show clear documentation of successful reductions of deforestation. That incentives like these can be successful is supported by the decreasing deforestation trend since 2005 (see figure 3) (Nepstad, 2007; Boucher *et al*., 2013; The REDD desk, 2015).

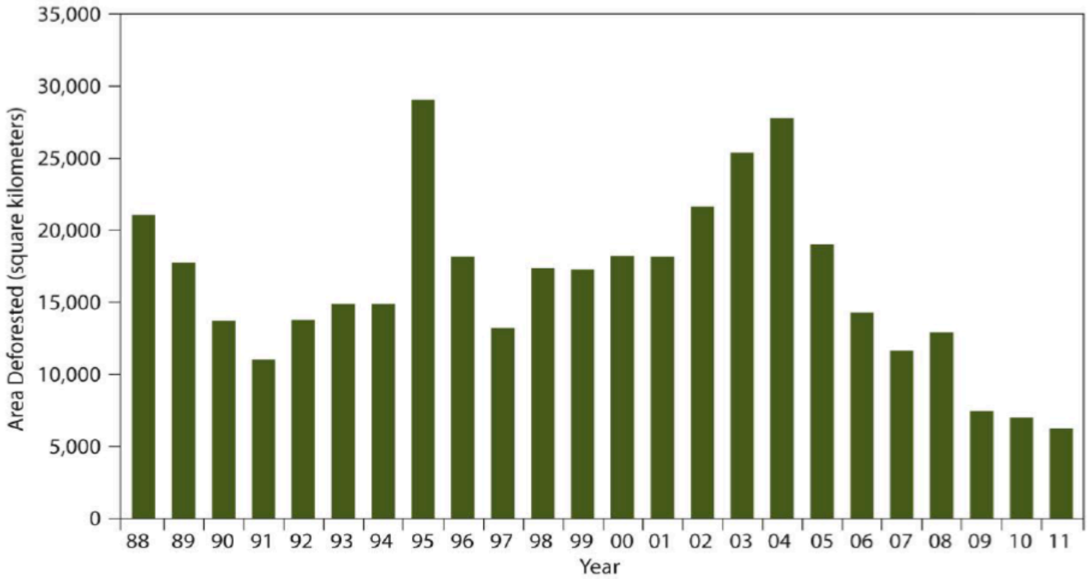

Figure 3: Deforestation in the Brazilian Amazon. A declining trend in deforestation since the years 2004/2005 is visible (INPE, 2011).

REDD+ is not the only way payments for biodiversity and ecosystem service conservation can be made. However, markets to capture the values of ecosystem services are often non-existent or only incipient, despite the high economic value of the manifold of ecosystem services provided by the Amazon. Especially payments for biodiversity, hydrological services and pollination will greatly contribute to the preservation of the Amazon. International instruments that aim at payments for the global service of biodiversity conservation should be developed. Also, markets for hydrological services should be developed. A favourable rainfall regime, for example, would benefit the agricultural industry, making them more likely to be willing to pay for this service (Verweij *et al*., 2009).

Sustainable production and consumption

The majority of timber, beef and soy producers today are unsustainable. For example, from 1996 to 2005 7.18 million hectares of Amazon rainforest was converted as a direct or indirect effect of the expansion of the soy industry. The existing agricultural lands can be used more efficiently. The agricultural production on already existing agricultural lands could be tripled without felling a single tree. Researches from the USDA (United States Department of Agriculture) and IBGE (Instituto Brasileiro de Geografia e Estatistica) estimate that Brazil's total cultivated area could increase with 145-170 million hectares without further deforestation. This can only be achieved if a number of financial, legal and technical constraints can be disposed. This involves the enforcement of environmental laws, a shift of the taxes to encourage the choice for processed products over raw material, and law enforcement actively prohibiting illegal acquisition of land (Shean, 2003).

Other possible incentives to reduce humanity's footprint on the Amazon are timber-like certifications for beef, soy and biofuel products, reductions of meat consumption worldwide, reductions of worldwide livestock productions system's dependence on soy feedstock and elimination of subsidies that favour the expansion of soy, oil palm, sugarcane and cattle ranching in the Amazon (Verweij *et al*., 2009).

To summarize, humankind has made great efforts during the past few decades to recognize the importance of nature to our survival and towards the protection of biodiversity and the associated functioning of ecosystems (Malhi *et al*., 2008). However, more knowledge and research is needed to define and protect the key factors of biodiversity. Humankind has been focussing protection and conservation towards the broad scale of biodiversity, while recent research indicates that certain groups of species play a key role in the functioning of ecosystems (functional diversity) and are possibly more important than biodiversity in general (Kremen, 2005; Verweij *et al*., 2009). This means that future research, conservation strategies, and laws and legislation should focus on the functional groups within ecosystems. With international cooperation and dedication the current positive trends can be continued and the Amazon will be conserved for future generations. With this prospect the future of the Amazon appears to be bright again.

Conclusion

People are starting to see the importance and value of biodiversity and ecosystem services provided by ecosystems. Some of these services are essential for our wellbeing, for example, air purification and the production of oxygen, fresh water and food (Millennium Ecosystem Assessment, 2005). Until recently the importance of biodiversity and ecosystem services was greatly underestimated. More biodiversity and ecosystem services were lost each year, mainly due to the direct or indirect effects of deforestation and forest degradation (Millennium Ecosystem Assessment, 2005).

One of the world's most important providers of ecosystem services is the Amazon rainforest, due to its sheer size and relative intactness. The Amazon represents 40% of the world's remaining tropical rainforests and is home to at least 10% of the world's known species (Walker, 1992; Ter Steege *et al*., 2013). A shift from years of intensive deforestation and forest degradation to sustainable use of the Amazon can be observed since a couple of years. Although scientists argue whether deforestation and forest degradation in the Amazon are increasing (Verweij *et al*., 2009) or decreasing (Nepstad, 2007; Boucher *et al*., 2013), the facts show a decline in deforestation of 70% in the Amazon since 2005 (INPE, 2011).

The ecosystem services provided by, among others, the Amazon are of essential importance to humankind's survival. For example, ecosystem services directly support over one billion people living in poverty (World Bank, 2006). The provision of ecosystem services depends on the functioning of ecosystems and this in turn depends on functional diversity in particular (Andersson *et al*., 2007; Vandewalle *et al*., 2008; Haines & Potschin, 2010). Functional diversity influences ecosystem productivity, dynamics, stability, nutrient balance etc. and is therefore of great importance (Tilman, 2001). The positive relationship between biodiversity and ecosystem function has been confirmed by Schwartz *et al*. (2000), they found several studies that indicated a positive relationship between biodiversity and ecosystem functions.

Payments/markets for ecosystem services (e.g. REDD+), involving indigenous communities in conservation strategies, certifications for beef, soy and biofuel products and an increase in protected areas are all great examples of incentives that favour conservation and have a decrease in deforestation and its negative effects as a result (Verweij *et al*., 2009). However, future conservation tactics should mainly focus on functional diversity, as this fulfils a major role in the functioning of ecosystems and the provision of ecosystem services.

Humanity alone has been responsible for the biodiversity crisis of the last decades and is now making the right steps towards conservation. This decade represents a unique opportunity, maybe even the last, to maintain the biodiversity, ecosystem services, and resilience of the Amazon in the face of threats of significant drying and deforestation (Malhi *et al*., 2008). With international cooperation and commitment humankind can continue the positive trend in conservation and further reduce deforestation and forest degradation in favour of a sustainable use of the natural world including its services.

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