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Chapter 1

Introductory Chapter: Land Use Change Ecosystem Services and Tropical Forests

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1. Introduction

Large regions of different ecosystems around the world (forests, grasslands, wetlands, farmlands, water bodies) are being managed for different uses, usually implicating the substitution of one ecosystem type for another. This process, known as land use change, is driven by the need to provide food, fiber, water, and shelter to more than seven billion people. Land use change has therefore moved from being a local environmental issue to becoming one of the most important causes of global change [1]. However, such changes in how humans use the land have caused global croplands, pastures, plantations, and urban areas to expand their surfaces in recent decades. In other words, humans are using an increasing share of the planet surface and its resources, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity. As a consequence, ecosystems' structures and functions are being increasingly altered, potentially undermining the capacity of ecosystems to sustain food production, maintain freshwater, regulate climate and air quality, ameliorate infectious diseases, and provide a large list of ecosystem services, usually as ignored as important they are [1].

We therefore face the challenge on how to maintain ecosystem services provided by tropical forests, while at the same time tropical regions experience important land use changes. The challenge is made even more complex by the difficulty of providing rules of thumb that can be easily applied across many different types of tropical forests. Differences between regions in forestry and agricultural management, good consumption, trade, culture and of course in ecological structure and function make generalization almost impossible.

Globally, forest cover has been reduced by 7–11 million km^2 over the last 300 years, mainly to make room for agriculture and timber extraction [2, 3]. On the other hand, the increase in technification and market development has led to the expansion of intensively planted forests, first in North America and Europe, but increasingly in South America, Africa, and the Asia-Pacific region, covering now 1.9 million km^2 worldwide [4]. Although impressive, only the 3%

of the world forest land is covered with productive forest plantations. However, this area expanded by 2 million ha annually in the 1990s and by 2.8 million ha in the 2000s [5].

All forest regions (tropical, subtropical, temperate, sub-boreal, and boreal) are being affected by land use change processes. In particular, tropical forests have suffered from the biggest changes (both positive and negative) of all the forest types although the loss rate is still 3.6 times bigger than the rate of surface gain [6]. These authors estimated that losses in tropical forests area accounted for 32% of total forest loss in the world, with half of those losses being concentrated in South American tropical forests. However, there are big differences among tropical countries in rates of loss and gain of forest area. For example, Brazil has recently shown a decline in annual forest area loss, moving from a high of over 40,000 km^2 $year^{-1}$ in 2004 to a low of under 20,000 km^2 $year^{-1}$ in 2011. On the other side, for the same period Indonesia has gone from losing 10,000 km^2 $year^{-1}$ in 2003 to over 20,000 km^2 $year^{-1}$ in 2012. In addition, subtropical forests are experiencing important land use change, with many planted forests being usually treated as crops, causing that old-growth natural forests to be relatively rare in these biomes [7]. As a result, although the absolute losses in surface are not as big as in the tropics, subtropical forests have experienced the largest relative changes in forest cover losses and the smallest relative gains [6].

Tropical forests have been extensively disturbed by human beings since long time, and the intensity and extent of disturbance will continue into the future [8]. Land use change in the tropics is caused mainly for agricultural use [9]. Land use change will affect ecosystem services, and climate change makes this a more complicated but emergent problem for human beings [10]. Many land use practices still widely extended in tropical forests (e.g., fuel-wood collection, forest grazing, and road expansion) can degrade forest ecosystem conditions—in terms of productivity, biomass, stand structure, and species composition—even without changing forest area. Changing the way the land is used also paves the way for the introduction of invasive species, including pests and pathogens that can degrade the original forests. Another major change is the alteration of fire regimes, by modifying fuel loads, removing coarse woody debris, increasing the number and frequency of ignition sources, and even modifying the local meteorological conditions [11]. On the other hand, human activity can also improve forest conditions, either by direct forest management or by unintended effects of other processes, such as increased nitrogen deposition, atmospheric concentrations of CO_2, and peatland drainage. Such processes have caused the increase in standing biomass of European forests by 40% between 1950 and 1990, while their area remained largely unchanged, accelerating forest growth in the twentieth century [12]. These forests have become a substantial sink of atmospheric carbon [13], although other ecosystem services including those provided by peatlands and biodiversity are likely diminished.

2. Land use change and biodiversity

All kinds of ecosystem services rely on the interplay of the organisms and the abiotic environmental factors of the ecosystems. Therefore, biodiversity of an ecosystem is the key property behind ecosystem services. Globally, the biodiversity is decreasing mainly due to the anthropogenic interferences [14]. Land use change has its first and direct impact on the land surface with the modification or removal of current organisms and thus will change the biodiversity to some extent. In the recent analysis of the intactness of biodiversity, as defined as the proportion of natural biodiversity remaining in local ecosystems, Newbold et al. [15] indicated that the 58% of the planet´s terrestrial ecological boundaries have been crossed. The main cause of this problem is the extensive land use changes that have disconnected natural ecosystems and rounded them up with human-made landscapes.

Land use change from forests worldwide has made ecosystem fragmentation a serious problem. Currently, 70% of the forest cover on Earth is within 1 km from the edge of the forests [16], indicating the loss of connectivity and the vulnerability to further disturbances. In a detailed modeling [17], the spatial patterns of fragmentation in Brazil were shown to have a strong effect on the final extent of influences on ecosystem services like biodiversity. For example, the farmland expansion on the forest edge would have much less impact on biodiversity and carbon storage compared to the farmland increase in the center of a forest. In the case of bird species richness, the fragmentation regime of forests plays a key role. Bregman et al. [18] analyzed the sensitivity to fragmentation of different bird species worldwide and found that the insectivores and large frugivorous are more negatively affected in larger forest fragmentations. This pattern is especially significant in the tropical area.

Barnes et al. [19] demonstrated a 45% reduction in soil invertebrate biodiversity after the conversion of tropical rainforests to oil palm plantations. They further calculated the change in ecosystem energy flux due to this land use change and found a surprisingly lower energy flux in oil palm plantations (51%) relative to what happens in the rainforest. Changes in biodiversity at the functional group level were also evident in a case study in Malaysian Borneo [20]. When comparing the community composition of dung beetles along a land use change gradient from primary forest to logged forest and oil palm plantation, the composition did change substantially. However, significant reduction in functional diversity only happened in the oil palm plantation.

Land use change modifies not just the biodiversity of higher plants and animals, but also that of microorganisms. Paula et al. [21] demonstrated that the change from Amazonian rainforests to pastures would decrease the microbial functional gene richness and diversity. The recovery from the disturbed lands to secondary forests may make the functional gene richness and diversity again similar to that in the primary forests, although not totally alike.

There are many different types of classifying ecosystem services, but a basic classification divides them into three main categories [22]. First, provisioning services are those related to goods generated by the forests that can be directly consumed: timber, food, water, fuel, medicinal plants, etc. Second, regulatory services are those that regulate the conditions in which humans inhabit the land and in which our economic activities take place: climate regulation, flood control, etc. Third, cultural services such as spiritual connection, recreation opportunities, cultural legacy, and sense of belonging are connected to ecosystems.

3. Provisioning services

Tropical forests maintain a high variety of plants, animals and microbes, and therefore many different species suitable for human consumption. In addition, to be a genetic reservoir for potential food sources [23], tropical forests can provide enough food to maintain the human population of traditional habitants [24], reaching values up to US $18.5 per hectare and year [25]. Fuelwood is also the main energy source for heating and cooking of millions of people in tropical countries. For example, in Mexico alone, 7 million of rural people depend on tropical forests [26]. Timber, usually of high quality and value, is among the most valued goods provided by tropical forests, sometimes being also the cause of the deforestation (often illegal) and land use change [27]. Similarly, traditional medicine from tropical communities is also providing new compounds for medicines, but at the same time can also cause local extinctions if their harvest is not controlled [25].

Among other goods, water is usually given from granted, but freshwater is a very valuable ecosystem service that comes mainly from higher elevation ecosystems. Ponette-González et al. [28] performed a meta-analysis of the effects of land use change on hydrological cycles of tropical high-elevation ecosystems. The types of land use change included the conversions from forest to grassland, agroforest to nonforest, nonforest to tree plantation, and recent glacier retreat. The deforestation did not lead to an expected substantial increase in downstream runoff in Latin America and the Caribbean and in Hawaii. On the other hand, Muñoz-Villers and McDonnell [29] compared the streamflow of three watersheds that have old-growth cloud forest, 20-year-old regenerated cloud forest, and heavily grazed pasture, respectively, in Mexico. The land use type of pasture produced 10% higher streamflow compared to the two forested catchments. Their results imply that a short period of 20 years of recovery from pasture to forest may be enough for the restoration of hydrological conditions.

4. Regulation services

Through plant-soil-atmosphere interactions, tropical forests have a major role in regulating atmospheric gases and therefore climate. Carbon emissions due to deforestation in the tropics were 810 Tg C year^{-1} between 2000 and 2005 [30], in which Brazil and Indonesia were the first two contributing countries with an emission rate of 340 and 105 Tg C year^{-1}, respectively. Soil carbon loss due to land use change in the tropical area was estimated to be 79 Pg CO_2 during the past 150 years (1860–2101, averaged from three different models) [31].

Peat swamp forests in Southeast Asia are an important carbon stock due to their predominant wet soil condition. However, the need for more farmland has largely changed the peatlands into different agricultural uses such as rice fields and oil palm plantations. Hergoualc'h and Verchot [32] demonstrated a very clear change in greenhouse gases (CO_2 + CH_4 + N_2O) budgets when original peatlands were converted to six different land use types including degraded forest, croplands and shrublands, rice fields, oil palm plantation, *Acacia crassicarpa* plantation, and Sago palm plantation. On average, the undisturbed peatlands are the strongest CH_4 source, which, however, could be offset by the CO_2 sink strength and thus remain the only net greenhouse gas sink of the magnitude of −1.3 ± 5.9 Mg CO_2-Eq ha^{-1} year^{-1}. The conversion of peatland into *Acacia crassicarpa* plantation turns the sink into the largest source of 72.0 ± 12.8 Mg CO_2-Eq ha^{-1} year^{-1}.

Coastal mangroves in many tropical countries have been destroyed and the land been used for aquafarming or other purposes like harbor construction. Kauffman et al. [33] showed an extremely high carbon emission accompanying the conversion of mangroves to shrimp ponds in the Dominican Republic. The carbon stocks of mangroves ranged from 706 to 1131 Mg C ha^{-1}, while that in the abandoned shrimp ponds were only 95 Mg C ha^{-1}. The estimated carbon emission of 2244–3799 Mg CO_2-Eq ha^{-1} was among the largest carbon emission due to land use change [33].

Land use change in tropical forests can also have indirect effects of the capacity of the ecosystems to regulate processes in water ecosystems. For example, land use change in a tropical watershed could change the decomposition rate of organic matter in tropical rivers [34].

Tropical forests also mitigate extreme weather. Structural complexity [35], together with other factors such as microtopography and soil features, modulates the impacts of extreme events [36]. In a model simulation of the precipitation regime under combined factors of land use change (transformation of rain forests to pasture) and different levels of soil water availability in the Amazonian rain forests, Bagley et al. [37] showed a clear reduction in precipitation and increase in drought degree under deforestation scenarios.

Tropical forests can also regulate air quality. Changes in air quality and atmospheric chemistry often arise when land use type has changed because the land-atmosphere fluxes of material and energy are to a certain extent vegetation-specific processes (e.g., see [38]). For example, isoprene is a biogenic volatile organic compound that emits naturally from forest vegetation. By deforestation, the emission of isoprene will decrease and the subsequent photochemical process of ozone formation will also decrease, leading to a decreased ozone deposition in the Amazonian rainforests [39]. On the other hand, the agricultural use of the deforested area has been shown to emit more NO_x to the atmosphere, mostly due to the higher N-fertilizer application.

In some tropical region, slash-and-burn is still a predominant method to create farmland [40]. The emissions from fires and smokes often cause regional problems of air quality. Marlier et al. [41] pointed out an important finding that ca. 80% of 2005–2009 fire emissions from Sumatra were related to degradation or land use maintenance. The fire emissions from land use conversion thus may have longer-term effect on the air quality.

5. Trade-off between different ecosystem services

Land use change may result in the increase in some ecosystem services but at the same time the reduction in other services. Such trade-offs always occur when management practices are oriented towards the production or use of a given ecosystem service, without taking into account the consequences for other services [23]. For example, the more forest that is transformed, services provided by plant-dominated ecosystems such as farmlands or pasture lands increase, with the production of agricultural and pastoral goods being increased, whereas the services provided by the tree-dominated forests decline. For example, Leh et al. [42] used InVEST model (Integrated Valuation of Ecosystem Services and Tradeoffs) to quantify the spatial pattern of ecosystem services including biodiversity, surface water yield, carbon storage, sediment retention, nitrogen retention, and phosphorous retention in the tropical African countries Ghana and Cote d'Ivoire. The land use scenarios from 2000 to 2005 and 2009 were used to analyze the change in those ecosystem services. By employing this tool, it is possible to quantitatively understand the change in ecosystem services at different spatial scales and thus makes the planning of land use strategy possible. The results of Leh et al.'s work emphasize the great challenges that we face to maintain ecosystem services provided by tropical forests, while land use change processes are becoming increasingly more important.

Another example of these complex trade-offs is the effect of land use change on freshwater availability when transforming tropical forests into other type of ecosystem. In theory, grasses and shrubs use less water than trees, having therefore lower evapotranspiration rates (Oliveira et al. this volume). This could lead to higher runoff and increased provision of water downstream [23]. However, clearing tropical forests also reduces infiltration rates, increasing erosion, soil evaporation, and runoff, which in turn can lead to reduction in water quality and decrease in water recharge rates (see above). The importance of trade-offs also appears when considering that ecosystem services also depend on the users: different stake holders value different services in different ways, and therefore, it is difficult to objectively determine whether a land use change is diminishing or increasing the provisioning of ecosystem services. It would depend on who is asked [23].

6. Final considerations

Tropical forests offer services of provision, regulation, and culture that are fundamental for the well-being of the societies that inhabit them, and for extension of all the Earth's inhabitants. The large extension and important biodiversity of these forests contribute to offer critical services for our society, which are being constantly modified by the management decisions that are part of the dynamics of human society. Food demand is one of the sectors that are related to flood control and climate regulation that tropical forests provide to a large section and the whole humanity, respectively. Management interventions such as forest restoration or payments for ecosystem services can help to recover or maintain ecosystem services that tropical forests offer.

Considering all the things, maintaining ecosystem services provided by tropical forests in the face of increasing land use change is a truly challenging task. Such task must start by understanding the components that make each tropical forest unique and how those components are linked and interact to create the ecological processes that maintain (and are maintained by) tropical forests. Then, understanding how human activities (economic, cultural, etc.) are dependent on such processes is the necessary step to analyze, and take decisions about, the consequences of land use change on the ecosystem services provided by tropical forests. It is time to address this challenge.

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