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Review Article

The impacts of oil palm agriculture on Colombia's biodiversity: what we know and still need to know

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Abstract

The inexorable expansion of oil palm plantations has been a major driver of biodiversity loss in the tropics. This is particularly evident in Malaysia and Indonesia, where the majority of the world's oil palm is cultivated. In Latin America oil palm acreage has also been steadily increasing, especially in countries such as Colombia, the largest producer by far. However, information on the biological implications of rapid land conversion to oil palm in the region remains scarce. Here, we review the state of knowledge about the impacts of oil palm on biodiversity in Colombia. We also discuss the conservation strategies that have been implemented in the country, and propose research that we need to develop best management practices. The vast majority of research has focused on biotechnology, soils, biological pest control, carbon stock and reduction of greenhouse gases emission, but research on biodiversity is very scarce, or is not published yet. However, important investment and research on this topic are being developed. The most threatened ecosystems are the savannas in the Orinoquia region, where most of the expansion is predicted. The demands for green markets and certification are slowly encouraging oil palm corporations to mitigate their 'biological footprint'. However, applied research on the possible impacts of oil palm on biodiversity are urgently needed to support conservation efforts in the oil-palm-dominated landscapes of Colombia, along with commitments by the government and companies to adopt the resulting recommendations.

Key words: palm oil, deforestation, Llanos, RSPO, biofuels, African palm

Resumen

La incontrolable expansión del cultivo de palma de aceite en el trópico ha sido una de las principales causas de la pérdida de biodiversidad. Esta situación ha sido particularmente evidente en Malasia e Indonesia, donde se cultiva la mayoría de palma en el mundo. En Latinoamérica el área cultivada con palma de aceite también ha mantenido un crecimiento constante, especialmente en países como Colombia, el mayor productor. Sin embargo, la información sobre las implicaciones biológicas de esta rápida conversión de tierra a palma de aceite es muy escasa. Aquí, revisamos el estado de conocimiento relacionado con el impacto del cultivo de palma de aceite sobre la biodiversidad en Colombia. También discutimos las estrategias de conservación que se han implementado en el país y proponemos el tipo de investigaciones que se deben llevar a cabo para mejorar las prácticas de manejo. La gran mayoría de publicaciones están relacionadas con biotecnología, suelos, control biológico de plagas y reducción de gases de efecto invernadero, pero investigaciones en biodiversidad son muy escasas o no han sido publicadas. Sin embargo, actualmente se desarrollan inversiones importantes e investigaciones en este tema. El ecosistema más amenazado es el de sabana en la región de la Orinoquia, donde se predice la mayor expansión. La demanda de mercados verdes y los esquemas de certificación ha alentado poco a poco a los productores a mitigar su "huella biológica". Sin embargo, se requiere con urgencia de investigación aplicada relacionada con los posibles impactos de la expansión del cultivo sobre la biodiversidad, con el ánimo de apoyar los esfuerzos de conservación en este tipo de agropaisajes en Colombia. Así como del compromiso gubernamental y empresarial para adoptar las recomendaciones resultantes.

Palabras clave: aceite de palma, deforestación, Llanos, RSPO, biocombustibles, palma africana

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Introduction

Oil palm (*Elaeis guineensis*) is the world's fastest expanding agricultural crop in production, with an annual rate of increase of approximately 9% [1]. More than 13 million ha of land are under oil palm cultivation in the tropics [2]. This expansion, however, has been a major driver of biodiversity loss, particularly in Malaysia and Indonesia, where the majority of the world's oil palm is cultivated. In both countries, at least 55% of oil palm expansion has occurred at the expense of natural forests [3], making this crop one of the biggest threats to tropical biodiversity conservation.

The negative impacts of oil palm on tropical biodiversity have been well-documented for Southeast Asia (*e.g.,* [1,3-11]). In Malaysia, mammals are particularly sensitive to the conversion of natural forests to oil palm. One study [8] showed that only 10% of medium and large-sized mammalian species used plantations to cross between primary forest patches, and these were generally species of least conservation concern. Similar results have been observed in other taxa. For example, in Malaysia, forest conversion to oil palm has reduced species richness of forest birds in some areas by as much as 80% [12].

Comparatively, there is a paucity of information on the biological implications of oil palm expansion in Latin America. In a single decade, land planted with oil palm in Colombia more than doubled, from 181,724 ha in 2002 to 452,435 ha in 2012 [13]. By the end of 2013, around 476,781 ha of land (just under the size of Trinidad and Tobago) have been cultivated for oil palm, ranking the country as the 5th highest producer in the world and the largest producer in America [13,14]. More worryingly, projections suggest there will be at least a two-fold increase from current levels by 2020, when just under a million hectares of land are expected to be allocated to palm oil production [15].

Due to its rapid increase and projected expansion, there is growing concern over how oil palm agriculture could affect Colombia's biodiversity, given the negative impacts already documented in Southeast Asia. However, scientific research on the impacts of oil palm on biodiversity remains scarce in Colombia. Studies on how the expansion of oil palm plantations has affected the diversity and relative abundance of different taxonomic groups are urgently needed. Such information will not only be useful for modeling species extinction risk under different land-use change scenarios, but will help forecast whether the country can maintain its current trajectory of oil palm expansion without compromising national standards of biodiversity conservation.

We synthesized oil palm-related information, particularly from Colombia, in order to: 1) determine the extent of oil palm research on biodiversity and conservation; 2) summarize the impacts of oil palm on land use and biodiversity; 3) provide an outlook for oil palm expansion; 4) describe relevant biodiversity conservation strategies that are being followed to mitigate impacts from oil palm; and 4) propose future research for development of best management practices by government and businesses to alleviate the impacts of oil palm on Colombia's biodiversity.

Background

Oil palm production in Colombia began around the 1960s. Currently, 106 towns in 16 Departments (States) are dedicated to this agribusiness, with four main production zones in the country: 1) the Western Zone, at the southwestern part Colombia on the Pacific coast; 2) the Northern Zone, in the northeastern part of the country near the Atlantic coast; 3) the Central Zone, an inter-Andean valley of the Magdalena River system; and 4) the Eastern Zone, at the foothills of the eastern chain of the Andes [16] (Fig. 1). The Eastern Zone has the greatest planted area, but the oldest plantations are in the Northern and Central Zones. The Western zone is the least developed of the zones [16].

In 2001, the Colombian government identified oil palm as one of the country's most important economic sectors, which has stimulated its expansion as a major component of the country's biofuel program [17]. As part of this program, the government provided a range of economic incentives to promote palm oil production, including price supports, subsidies, tax exemptions, preferential taxes, research funding in biotechnology and production [18; see also 19-21 for details]. The use of palm oil has been endorsed by government policies, such as the legislature requiring the mixing of biofuels with fossil fuels (*i.e.,* a mixture of 10% of biodiesel with 90% of diesel since 1 January 2010) [17, 20].

While oil palm agriculture has undoubtedly provided benefits to Colombia's economy, it has also been associated with problems such as social displacement, violence, illegal land appropriation, and paramilitary development, especially in the Western Zone (Chocó) and Northern Zone (Caribe) (e.g [21-31]). Compared to these negative socioeconomic issues, however, the negative impacts of oil palm expansion on local biodiversity are poorly documented.

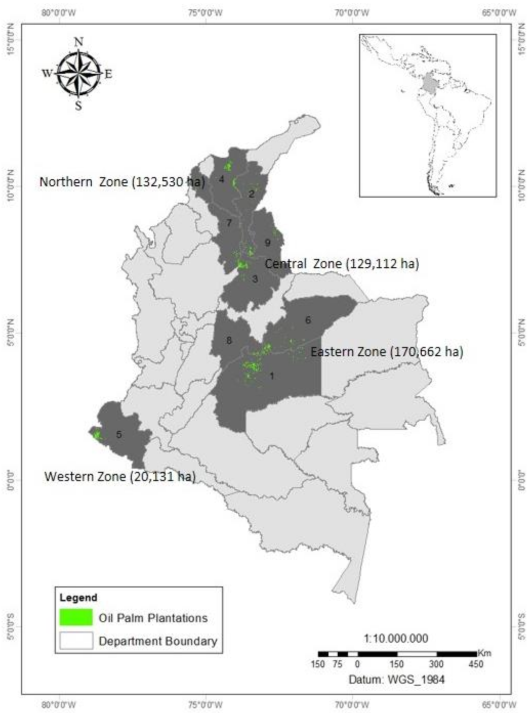

Fig. 1. Location of oil palm plantations in Colombia. In parenthesis total cultivated area (ha) per zone by 2012. Numbers represent the ranking of the biggest producers Departments: Meta (1), Cesar (2), Santander (3), Magdalena (4), Nariño (5), Casanare (6), Bolivar (7), Cundinamarca (8), and Norte de Santander (9). Source: Statistical Yearbook 2013 (Fedepalma 2013, available at www.fedepalma.org) and GEF/BID PPB Project.

Oil palm research involving biodiversity and conservation

Global context

Within the global oil palm research community, studies on the impacts of oil palm on biodiversity have been relatively scarce. Between 1970 and 2006, fewer than 1% (23) of all peer-reviewed publications related to oil palm addressed its possible impacts on biodiversity [32]. To obtain a more up-to-date overview of oil-palm research globally, including those related to biodiversity and conservation, we first conducted a general search in the Web of Science database using the keywords “oil palm” and selected peer-reviewed publications between the period 2006 and 2015. To make our search more comprehensive, we also examined other search engines such as the Sustainable Palm oil Platform (SPP, http://www.sustainablepalmoil.org), and searched for oil-palm related documents from Colombia in different databases (*e.g.,* from The Documentation Center of The National Federation of Oil Palm Growers: Fedepalma-http://cidpalmero.fedepalma.org/), university catalogues, and Google Scholar.

A total of 7,975 publications were obtained for the period 2006-2015 using the keyword “oil palm.” As these publications were distributed among more than 60 subject categories, we only examined papers from the following nine categories relevant to environmental research: remote sensing, zoology, biology, biodiversity and conservation, planning development, forestry, environmental studies, environmental sciences, and ecology. A total of 988 publications were obtained for these categories (12.4% of all records). However, after checking every single publication, we discarded 493 papers because they were either unrelated to oil palm, or unrelated to any of the selected categories. For example, we omitted publications involving research on other palm or plant species (*e.g.,* Jatropha), socioeconomic issues, general concepts of sustainability with vague links to biofuels, and chemistry of oils, among others. We were left with 502 oil palm publications belonging to relevant categories and environmental research. Among these relevant publications, 141 were related to biodiversity and conservation globally (Table 1).

The vast majority of studies (230 papers, 45.8%) were conducted in Southeast Asia, especially in the fields of environment and biotechnology. Only 59 (12%) and 82 (16.5%) publications were related to biodiversity and conservation, respectively. Invertebrates have been the most studied taxonomic group (24 papers), followed by mammals (18 papers), and birds (13 papers). Mammals interest focused on rodents (3), bats (3), carnivores (3), primates of the Neotropics (1), great apes (5 related to orangutan and 1 to great apes in Africa), and general communities (2). Notably, there was a scarcity of oil palm research related to the environment in Latin America; only 34 studies (6.8%) were conducted in this region and only 14 publications involved biodiversity and conservation issues (Table 1).

Colombian context

When we used keywords “oil palm” *and* “Colombia” to search the Web of Science database, 75 publications related to the categories described above appeared for the period 1970-2014. The majority (54 papers) were related to biotechnology, soil studies (including one paper on soil macro-invertebrate communities and soil-based ecosystem services [33]), and behavior or biology of insects (especially beetles and biological control). Seven publications were related to environmental issues such as carbon and greenhouse gases, and eight papers focused on the socioeconomic aspects and history of oil palm development in Colombia. Only three papers were related to landscape planning or land-use change [34-36], and, notably, just three were related to biodiversity: one included birds, dung beetles, ants and herpetofauna [37], another snakes [38], and one was related to ants [39].

The only reference to Colombia in the Sustainable Palm Oil Platform was a short mention in the booklet “High Conservation Value Forests: The concept in theory and practice” [40]. Such paucity of oil palm research on biodiversity and conservation in Colombia impairs efforts to mitigate the potential impacts of this crop on native species. Although research conducted in oil palm landscapes appears to have increased in the last five years, most findings have not yet been published, or have been published in local literature. Below, we summarize some findings from oil palm-related biodiversity research in Colombia.

Table 1. Countries and general type of publications reported in Web of Science database from 2006-2015, using the keyword "oil palm". The categories used were remote sensing, zoology, biology, biodiversity and conservation, planning development, forestry, environmental studies, environmental sciences, and ecology.

Country	Mammals	Birds	Amphibians	Snakes	Arthropods	Conservation /Planning	Environmental	Biotechnology	Total	%
Malaysia	8	10(a)	2		20	19 (b)	37	32	128	25,50
Indonesia	7	1				20	34 (c)	6	68	13,55
Malasia and Indonesia						8	12	6	26	5,18
Thailand							5	2	7	1,39
Cambodia							1		1	0,20
Papua New Guine						2	1	2	5	1,00
India					1			1	2	0,40
Ghana							2		2	0,40
Cameroon							2		2	0,40
Benin					1				1	0,20
Nigeria			1	1		1	1		4	0,80
Tanzania							1		1	0,20
Colombia		1(d)				2	4	2	9	1,79
Brazil					2	3	4	8	17	3,39
Peru						3			3	0,60
Costa Rica	1					1			2	0,40
Mexico						1	2		3	0,60
Woldwide/ tropics	2	1				22	55 (e)	141	221	44,02
TOTAL	18	13	3	1	24	82	161	200	**502**	
%	3,59	2,59	0,60	0,20	4,78	16,33	32,07	39,84		

Conservation/Planning includes studies on the effect of fragmentation on animal communities, vegetation, logging, landscape and HCV; many of these documents are reviews. The category Environmental also includes studies concerned with ecosystem services, REED and Carbon Stock, policies and economic analysis for conservation. Biotechnology includes topics related with phytopathology and biochemistry. a: two studies deal with birds and butterflies [70,71], other with birds, beetles and ants [72] and other with arthropods, lizards, terrestrial mammals, birds and bats [10]. b: one related to hunting in oil palm zones [73]. c: one study includes also Singapur and Malaysia [74] and two of them also explore consequences on mammals [75,76]. d: includes dung beetles, ants and herpetofauna. e: generally reviews or laboratory research. A second filter using "Colombia" in the key words added one paper on snakes [38], one on ants [39] and one on conservation [36] for Colombia

Impacts of oil palm in Colombia

Land conversion

The construction of oil palm plantations often involves the clearing of primary forest, particularly in the Western Zone or Choco state [22, 24, 26, 41]. However, reliable data on how oil palm has expanded at the expense of natural ecosystems have been unavailable until 2012-2013 [34-36]. This lack of data can be attribute in part to the fact that oil palm development does not require an environmental license (except for the water concession and other issues related to industrial processes of mills), which has led to unregulated expansion [22]. In areas such as Guapi, Catatumbo, and Amazonia, for example, no environmental impact studies were carried out prior to oil palm development [29].

The first attempt to assess the possible impacts of oil palm expansion on land use and biodiversity was made by the Institute Alexander von Humboldt [22], which analyzed the economic incentives to promote oil palm in Colombia using a model simulating its effects on the biodiversity in two oil palm zones (Northern and Western). They constructed an index of biodiversity change using the diversity of mammals in different ecosystems as a proxy for the possible effect of land-use change if expansion took place. Their results showed that expanding the crop into the proposed areas (*i.e.,* primary forest, secondary forest, pastures, and other crops) would reduce the biodiversity of these two zones by 21.8%. Further analysis at the municipality level suggests that if the expansion took place only in current pasture lands and replaced other crops in Tumaco city, the effect on biodiversity would be positive, and would increase biodiversity by 80% [22].

Depending on the region, the degree of disturbance to natural ecosystems caused by oil palm plantations appears to vary. In fact, the impacts of oil palm are not very clear for certain zones and time periods, particularly between the 1960s and 1970s. For example, anecdotal information on the development by the first companies indicated that in San Alberto town (Northern Zone), almost 2,000 ha of oil palm between 1961 and 1964 replaced "…amazing primary forest." [42]. Conversely, Rodriguez-Becerra and van Hoof [44] argued that only 17.5% of oil palm plantation expansion in Colombia has occurred in natural ecosystems (*e.g.,* forest, savannas, or wetlands), while 82.5% has occurred in lands that were previously used for cattle ranching or crops. Similarly, Gomez et al. [43] stated that even though a high proportion of the area was originally forested, 87% of the areas planted for oil palm were previously used for annual crops and extensive cattle grazing with some degree of degradation.

Most worryingly, illegal clearance for oil palm and associated social problems have been recorded in the Western Zone, which includes the region of Chocó, one of the most important biodiversity hotspots in the world [45]. However, there are no exact calculations of the proportion of natural forest converted to oil palm in this zone since the beginning of oil palm cultivation. Some people argue that forest loss was not a consequence of oil palm production, while others blame oil palm for causing a substantial loss of biodiversity. Corponariño (the environmental authority in this area), for example, argues that oil palm has caused the loss of 30% of the native natural vegetation in the area of "Alto Mira" in Tumaco city [46].

The Ministry of Environment indicates that in the Orinoquia region (eastern Colombia), approximately 25% (3,626 ha) of the lands planted with oil palm between 2001 and 2005 occurred at the expense of gallery or riparian forest, wetlands, foothills, or natural savannas, while the other 75% were mainly transitional crops and pastures [47] (Table 2). However, the expansion of biofuels in Santander and the Magdalena Medio region between 2000 and 2005 may have had a low impact on natural ecosystems [47].

Modern techniques have improved the accuracy of estimating the amount of land converted to oil palm in Colombia. Romero-Ruiz et al. [36] made a detailed description of land-use changes between 1987 and 2007 in the Orinoquia region. They identified oil palm cultivation as one of the main drivers for the alteration of savannas, reporting an increase of the land cultivated by oil palm from 31 km^2 in 1987 to 163 km^2 in 2007, with a greater rate of increase between 2000 and 2007 (Table 3). Castiblanco et al. [34] using spatial regression analysis and econometric models, suggested that present (and possibly future) oil palm expansion will concentrate on areas dominated by pastures, and to a lesser extent, areas that are a mixture of agricultural land and natural forests. The authors examined historical trends of oil palm expansion between 2002 and 2008, and found that the majority (80%) of newly created oil palm plantations (155,100 ha) during this period replaced non-natural ecosystems (Table 2).

Table 2. Main estimates of land conversion to oil palm in Colombia and in the eastern region of Colombia.

	Author	Period Analyzed	Land Cover	% Transformed To Oil Palm
Colombia	Castiblanco et al. (2013)	2002-2008	Pastures	51
			crop lands	29.1
			natural ecosystems (forest+savannas)	16
	Rodriguez-Becerra & van Hoff (2003)	not explicitly stated, but is interpreted from the beginning of cultivation in Colombia to 2003	natural ecosystem (Forest+savannas +wetlands)	17.5
			crop lands and cattle pastures	82.5
Orinoco region	Romero-Ruiz et al. (2012)	1987-2000	Forest	0.03
			crops and exotic pastures	0.16
			High savannas	0.06
			Flooded savannas	0.04
		2000-2007	Forest	0.12
			crops and exotic pastures	0.36
			High savannas	0.03
			Flooded savannas	0.04
	MAVDT (2008)	2001-2005	Gallery forest, wetlands, foothills and savanna	25
			transitional crops and pastures	75

Transition from pastures to oil palm was more dominant in the Eastern and Central Zones, while the transitions from heterogeneous agricultural areas were highest in the Northern zone [34]. In the Western zone, there were no changes in the area of palm oil plantations during the period investigated. In the Eastern and Central zones, oil palm plantations showed the largest expansion, with 68,600 and 68,500 ha, respectively. In the Eastern Zone, 58% occurred at the expense of pastures, 11% of savannas, and 12% of irrigated rice crops. In the Central Zone, 51% originated from areas that were in pastures in 2002, and approximately 20% and 11% of the transformation occurred in heterogeneous agricultural areas and natural forests, respectively. In addition, 4% of the change took place in secondary vegetation. In the Northern Zone, 18,000 ha of new plantations were created between 2002 and 2008, mostly from pastures (26%), followed by heterogeneous agricultural areas (24%) [34].

Biodiversity

Few published studies have compared species diversity in different ecosystems within oil palm-dominated landscapes [37, 38, 39, 48]. Although some biodiversity surveys have been conducted in larger plantations, most of their results have not been published and need better methodology. Olarte and Carillo [49] conducted a survey in a plantation of Puerto Wilches (northern zone), and Rodríguez [50] undertook a rapid ecological assessment in Mapiripan (State of Meta). In this town, Olarte-González and Escovar-Fadul [51] reported the presence of a mountain lion (*Puma concolor*) inside the lots of a young oil palm plantation. Although such information provides an idea of possible species occurring around these plantations, more systematic sampling efforts are clearly needed.

Interestingly, recent and ongoing oil–palm-related biodiversity research is largely conducted by postgraduates. Two studies using jaguars (*Panthera onca*) as a focal species have been conducted in the Northern Zone (*i.e.,* J. Figel and V. Boron, pers. comm.). One study on mammalian diversity is being conducted in a plantation at the foothills of the Llanos Region (Z. Alvarez pers. comm.), and another is currently quantifying bird diversity (D. Tamaris pers. comm.). T. Angarita (pers. comm.) is currently studying the demography and the impacts of daily crop labor on snake populations in the Meta State, while the organization Yoluka (www.yoluka.org.co) has been studying the use of bats and snakes as biological controls. The authors of this review are also studying the diversity and habitat use of mid- and large-sized mammals in different plantations in the Eastern Zone.

Overall, the impacts of oil palm on species diversity appears to be variable, and we have yet to find any research documenting the extinction of animal species within them. Gilroy et al. [37] compared the diversity of ants, dung beetles, birds, and herpetofauna in oil palm plantations versus cattle pastures in the foothills of the Eastern Zone. They showed that in all four taxonomic groups, oil palm plantations have similar to or higher species richness than improved pasture. For dung beetles, species richness in oil palm was equal to that of forest, whereas the other three taxa had highest species richness in forests.

Boron [52] (see also [53]) compared the diversity of carnivores and their prey in a 640 ha oil palm plantation and the surrounding natural forest in the Northern Zone, concluding that oil palm plantations have a negative impact on the presence of these mammals. However, they also stated that the number of species was similar between the major types of ecosystems, but their composition and relative abundances varied. Large felids (pumas - *Puma concolor* and jaguar - *Panthera onca*) preferred secondary forests and the edge of oil palm plantations, whereas medium felids were recorded in higher frequencies in the plantations. Important prey for big felids, such as capybaras (*Hydrochoerus hydrochaeris*), spotted pacas (*Cuniculus paca*), and collared peccaries (*Pecari tajacu*), were also recorded only in forests.

Pardo and Payán [48] studied the diversity and capture frequencies (a proxy for relative abundance) of medium- and large-sized mammals in three of the main ecosystems (*i.e.* gallery or riparian forest, oil palm plantation, and savanna) in a plantation of about 3,000 ha in the eastern Llanos (Casanare department, Eastern Zone). They found 16 medium- and large-sized mammals (including two mouse species), whose capture frequencies varied according to the type of land use. All 16 species were present in the riparian forest, eight of which were also associated with the oil palm plantation and six with savannas. Mammals found in the plantations were mainly mesopredators and generalist species, whose frequencies were higher in the plantation than in natural ecosystems. For example, jaguarondi (*Puma yagouaroundi*), fox (*Cerdocyon thous*), and white-tailed deer (*Odocoileus cariacou*) were more frequently detected inside plantations than in the surrounding natural ecosystems [48].

We found only one publication on herpetofauna and ants inside oil palm plantations in Colombia. Lynch [38] related his explorations in different plantations across the country during 2006-2013, estimating a total of 35 snake species in this monoculture. He also suggested that the rate of encounter for some species was greater in oil palm than in natural or transformed ecosystems, and discussed the potential role of plantations in the conservation of snakes. Sanabria et al. [39] studied the diversity of ants among different agricultural land uses in the Orinoco Basin (including oil palm), to identify species that could be used as indicators of soil ecosystem services. They found that improved pastures showed the highest species richness and semi-natural savanna the greatest abundance of ants.

Pardo et al. [54] also studied the diversity of birds and herpetofauna in the same ecosystems, recording 38 species of birds (detected only by camera trapping), 12 species of amphibians and 18 of reptiles in the study area. The number of amphibians was very similar between the natural ecosystems and oil palm plantation, with seven and six species detected in these respective habitats. However, reptilian composition varied between both ecosystems, with eight species found in oil palm versus 13 species in natural ecosystems.

Outlook for oil palm expansion in Colombia

Estimates of the amount and types of land suitable for oil palm production have been variable and most have a degree of uncertainty, especially regarding their compliance with conservation goals. Cenipalma-Corpoica [55] suggested that Colombia has around 3.5 million ha suitable for oil palm cultivation without any restrictions, and another 6.1 million ha would have moderate restrictions. These areas are mainly located in the Eastern Zone, where around 1.9 million ha could be planted [18]. These calculations were made at a scale of 1:500,000 imagery, based only on soil quality and the climatic characteristics of the zones. The only restriction or criterion addressing biodiversity was the exclusion of the natural forest of Amazon and the Pacific. Even though this is an important restriction, it is still somewhat limited because it does not consider other ecosystems and important areas in the country, such as wetlands, savannas, and gallery (riparian) forests.

The maps of Cenipalma-Corpoica [55] were updated in 2009 with the inclusion of environmental, ecological, and socioeconomic factors to determine the suitability of soil for oil palm [56]. The scale of this map was 1:500,000 and its purpose was to identify zones that are suitable for oil palm cultivation, but several existing areas where productive plantations are already located were deemed non-suitable according to the map [34].

Another study by Biofuels Consulting (2007), which was reviewed, analyzed and cited by the Ministry of Environment MAVDT [47], estimates around 15 million ha to be suitable for the eventual production of raw materials for biofuels in Colombia, including palm oil, sugar cane, and other biofuel materials. However, an analysis comparing these suggested areas with the Continental, Coastal and Marine Ecosystems Map of Colombia [57] indicates that around 38% of these areas overlapped with natural ecosystems [47]. Biofuel Consulting's report, using other indicators, estimated that Colombia has close to 1.1 million ha appropriate for oil palm cultivation without restriction, particularly in the Northern and Eastern regions. Most worryingly, the analysis of MAVDT [47] found that 15% of this area (164,331 ha) would overlap with natural ecosystems, with another expansion zone predicted in the south of the Eastern Zone, around the colonization front of the Northern Amazon region [34].

Economic interest in the Orinoquia region, or Llanos, is increasing. The United States Department of Agriculture (USDA), for example, suggests that the "Altillanura" or highlands of the eastern region of Colombia have about 4.5 million ha that are suitable for agriculture, without the need for deforestation [58]. The USDA has called this region the "new agricultural frontier of Colombia" and describes the important and recent interest of agro-industrial organizations in planting soybean, corn, and oil palm. Its low elevation, relatively flat terrain, and a mixture of pastures and savannah ecosystems make the region attractive for important investments in agribusiness. It is estimated that 70% of the Llanos region has been identified for conversion to plantations, or for petroleum and mining purposes [36]. This is worrying as the Llanos region is rich in savannas and wetlands, shrubs, gallery forest, isolated groups of palms or native vegetation (*e.g.,* "morichales", "matas de monte"), and other types of natural ecosystems that make it one of the most important regions for biodiversity in Colombia and South America (Fig. 2) [59]. Thus, research is urgently needed to better understand the threats in order to design best management practices for this unique region.

Developing oil palm plantations on degraded land is one way to mitigate biodiversity loss. Garcia-Ulloa et al.[35] used spatially explicit modeling at the national level to compare the possible impacts of oil palm expansion under different scenarios. They suggested that Colombia would require 730,000 ha of land to meet the target of 3.5 million metric tons (Mt) of crude palm oil by 2020. The conversion of this area would imply the loss of approximately 4.4 Mt C of biomass carbon (production-oriented scenario). However, a carbon conservation scenario would substantially reduce biomass carbon losses from the production-oriented scenario (87% decrease to 0.55 Mt), but it would also require twice as much land as the production-oriented scenario to reach the same production level. Garcia-Ulloa et al.[35] suggest a hybrid scenario as the most environmental friendly approach, minimizing the impact of oil palm by using current cattle lands dominated by pastures, which have poor biodiversity values, low sustainability for long-term food production, and low biomass content. Geraldes et al. [60] reached similar conclusions when analyzing 65 scenarios involving a combination of alternative land use and fertilizer application.

Alternative land-use scenarios can help preserve ecosystems most at risk. The ecosystems most threatened with the expansion of oil palm and other biofuel crops are mainly located in the Eastern Zone and include the following Departments (States): wetlands and grasslands of Meta and Vichada, and the natural forests and gallery forests of Casanare, Meta, Santander and Vichada, including flooding savannas. There are also some concerns about the shrubs of La Guajira (Northern Zone) and especially about the dry forest of the Northern Zone, given its imperiled state of conservation [47]. Besides the afore-mentioned threats to forested habitats and disturbance to natural ecosystems, Pérez-Rincón [61] also pointed out important repercussions of increased water demand and possible alterations of hydrobiological regimes.

Castiblanco et al. [34] suggest an expansion to approximately 647,687 ha by 2020 in Colombia, based on an econometric time intervention model that included the effect of subsidy policies that took effect in the country after 2002. Modeling a projection based on additional production requirements of the increasing biodiesel mixture targets established by the government increases that predicted area to approximately 930,000 ha. However, the Colombian National Federation of Oil Palm Growers (Fedepalma) expects to reach at least 1,600,000 ha by 2032 [62].

Fig. 2. Aerial view of oil palm expansion in the Llanos region of Colombia, Casanare State (left) and Meta State (right). Photo credit Lain Pardo.

Conservation strategies to mitigate impacts from oil palm

Our literature search indicated that research in Colombia has mostly focused on environmental and biotechnological issues. The guidelines for environmental impact assessments (EIAs) have centered on production and carbon emissions reduction, and the effects on biodiversity and ecosystems have therefore become secondary. Recently, there has been greater interest in including these aspects in EIAs, an issueraised by different institutions such as research agencies (including NGOs), public entities, and oil palm growers.

Certification schemes along with national environmental regulations and international agreements have increased awareness of biodiversity conservation issues. However, companies have a variable attitude toward environmental management, with some more committed than others [44, 63]. Nevertheless, the environmental performance of the oil palm industry in Colombia has improved substantively during the last few decades, along with international and national tendencies [see 44, 63, and 64 for details]. In 2002, for example, Fedepalma in conjunction with Ministry of Environment and the National Farmers Association (SAC), created the “Environmental Guide for the oil palm sector” [65]. This document briefly discusses the importance of protecting and conserving different types of forest and wetlands to maintain their fauna and flora species and allow connectivity between ecosystems. Colombia is now working to update this guide [16], making ecosystems and biodiversity issues more relevant, particularly through the identification of High Conservation Value Areas (HCV) and conservation planning.

Rodríguez and van Hoff [44, 63] investigated the environmental perspectives of the oil palm sector. They suggested important advances in soil management, highlighting the progress in biological control and organic fertilization (particularly in the Northern Zone). There have also been important advances in the reduction of water pollution, and some important investments have been made in water management in the Northern zone. Currently, more than 98% of the oil palm mills have water treatment systems before discharging effluents, compared to only 6% in 1992. Plantations now remove more than 95% of the organic load of the waste flow and, thus, companies in the sector generally adhere to current regulations [44]. Most of these processes have been conducted under the coordination of Fedepalma and Cenipalma (Colombian Oil Palm Research Center). However, strong interest in biodiversity-related research was only observed recently.

In 2008, the Alexander Von Humboldt Institute conducted a strategic environmental assessment of the policies, plans, and programs of biofuels in Colombia, with emphasis on biodiversity [47]. It was a good start, as they assessed the situation and provided a number of criteria for land use planning in biofuels. However, the studies did not develop very far and were never integrated as part of a monitoring plan.

The increasing role of the RSPO (Roundtable on Sustainable Palm Oil; www.rspo.org), albeit with some criticism (*e.g.,* [66, 31]) has apparently served to regulate the oil palm activity in recent years. In October 2008, Colombia hosted the First Latin American Meeting of the RSPO, in Cartagena one year after public commitment Conpes 3477 [19] or "Policy for the Competitive Development of the Colombian oil palm sector." This policy focused mainly on production, and there were almost no guidelines for any biodiversity considerations, except a vague mention of the importance of considering "social and environmental responsibility" in the oil palm business. However, a subsequent policy in 2008 [20] resulted in the government paying more attention to environmental aspects, especially those related to carbon emissions reduction. This policy recommended updating the environmental guidelines for the sector, and encouraged the sector to work toward certification schemes, in order to be more competitive in the international market. An analysis of the process of the national interpretation of RSPO is presented in Seeboldt and Salinas [67] and Marin-Burgos et al. [31].

Fedepalma, the Ministry of Environment and Regional Autonomous Corporations [1] subscribed to an agreement on Cleaner Production, but this was mostly concerned with carbon related issues. The only apparent policy designed to regulate agroindustry has been developed by the Regional Autonomous Corporation of Casanare (Corporinoquia) [68]. This public organization developed specific regulations on the use of water and of some ecosystems, which must be followed in some parts of the Orinoquia region before an environmental license will be issued.

Important work on biodiversity conservationwas conducted by WWF-Colombia, which has worked on the identification of High-Conservation Value (HCV) ecosystems in the Orinoco and Chocó ecoregions for the past 3 years [40]. Currently, the most ambitious and important investment in biodiversity issues in Colombia (and Latin America) has been through The Global Environment Facility of the United Nations (GEF). This initiative, called "Biodiversity Conservation in the areas of oil palm plantations" (GEF/BID PPB) is being developed jointly by Fedepalma, Cenipalma, IAvH, and WWF-Colombia. The project, which will be developed over five years, dedicates US$18.3 million to strengthen biodiversity in agro-ecosystems through the characterization and maintenance of protected areas, biological corridors, and environmental services [62]. This is a very important effort that will undoubtedly increase knowledge of this agro-ecosystem in Colombia and provide important input into appropriate managing decisions for this sector.

Future research directions

As discussed in this review, the vast majority of research associated with oil palm plantations in Colombia has focused on biotechnology, soils, biological pest control, carbon stock research, and reduction of greenhouse gases. Landscape approaches such as land-use change modeling and the identification of HCV areas have been recently reported, but knowledge about the biodiversity within

[1] The Governmental Environmental Authority that works at regional levels in different parts of the Colombia.

oil palm landscapes remains very scarce, and in consequence there is still great uncertainty about its impacts. The few investigations of wildlife have mostly focused on vertebrates, especially mammals and birds. Most research has been performed by independent academics, but not as part of a governmental program or the biofuel incentives program. The GEF/BID PPB -project (described above) is the first national program for conservation planning in these landscapes that hopefully will generate important information about the specific needs of the country for environmental sustainability.

We urge greater investment in the following research themes:

- Diversity and population studies of all animal groups inside plantations and surrounding natural ecosystems (including fish and invertebrates); habitat use and dispersal of focal species.
- Define thresholds or maximum plantation areas that could maintain natural movements and dispersal of species throughout production landscapes, allow permeability, and provide landscape features that enhance the conservation value of these private lands.
- Additional priorities include complementary landscape studies at local scales, including work on structural and functional connectivity research, ecosystem services, and multi-temporal assessment of land use changes. In this regard it is important to monitor the advance of plantations in both forested and non-forested ecosystems using modern techniques of spatial analysis in a multicriteria scheme to update the map of suitable zones for the expansion of oil palm, including not only soil or climatic characteristics, but also ecosystems and biodiversity aspects.
- As most of the expansion seem to take place in the Llanos region, it is important to properly delimit areas of natural savannas, seminatural savannas, low intensity pasture, and improved pasture to properly assess areas suitable for oil palm cultivation.
- Finally, it is necessary to understand how hydrobiological cycles and carrying capacity of water sources (*e.g.,* rivers, “caños”) in savannas are altered following the expansion of oil palm in the Orinoquia region.

Although several natural ecosystems have been transformed into oil palm plantations (especially in the Western Zone), this expansion has not been as aggressive as in countries such as Indonesia or Malaysia. Unlike these countries, Colombia has a large amount of land that was already transformed to pastures or other types of agriculture before oil palm was planted, which has minimized the impact of expansion on forested ecosystems. This is clearly positive in reducing the negative impacts of growing oil palm production, and also provides an opportunity to improve competitiveness in a world that demands more environmentally-friendly products. However, there is an important concern regarding the future of the Orinoquia or Llanos Orientales region in Colombia. Most of the agro-industrial development apart from oil palm (*e.g.,* soybean, rice, forestry plantations) has targeted this region. Given the pressure for mineral or fossil fuel extraction and the explosion of agro-business, the future of this complex and biodiversity-rich ecosystem is uncertain.

Conservation planning, where economic and environmental interests meet, is urgently needed. It is necessary to carefully analyze how this expansion is going to take place. Environmental and conservation assessments tend to focus on forested ecosystems, ignoring the importance of “non-forested” ecosystems such as savannas. Although production in the Eastern zone does not generate considerable carbon debt [69], there are other issues and important concerns related to the Llanos´ ecosystems. We therefore encourage analyzing how conservation strategies are being applied in non-forested ecosystems such as savannas and associated ecosystems (*e.g.,* wetlands) because habitat loss does not mean forest loss only. Emphasis should be placed on the Eastern and Northern zones of Colombia.

The availability of pastures and lands with other type of uses in Colombia also offers an opportunity to minimize the impacts of future oil palm expansion, but we need evidence about the possible impacts, or the potential benefits, of oil palm on biodiversity. We recognize the importance of the oil palm sector for the economic development of the country and for the creation of jobs for different people, but finding a balance between the economic revenues and the social and environmental (including biodiversity) aspects is critical. Heterogeneous landscapes or agro-ecosystems tend to be given low importance for conservation of nature, but biodiversity within complex land uses needs to be addressed. It should be an obligation for the companies to identify their territory in ecological terms and to protect the Natural Capital of Colombia.

To conclude, Colombia has the potential to be a leader in sustainable oil palm development. Certification schemes like RSPO and the growing demands of green markets have encouraged oil palm growers to improve their practices, and hopefully they will maintain this interest in the long run. National regulations and international commitments (*e.g.,* Ramsar, Convention on Biological Diversity) can also help to monitor the expansion of oil palm. However, official commitments and monitoring programs to evaluate the implementation, results, and recommendation of current efforts are also essential.

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