The Policy Process for Land Use/Cover Change and Forest Degradation in the Semi-Arid Latin American/Caribbean Region:

Perspectives and Opportunities

White Paper

A literature review prepared for the Inter-American Development Bank

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Acronyms

CRN	Collaborative Research Network
IAI	Inter-American Institute for Global Change Research
ICID	International Conference on Climate, Sustainability and Development in Semi-Arid Regions
IDB	Inter-American Development Bank
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and Caribbean
LUCC	land use and land-use cover change (land use/cover change)
NDVI	Normalized Difference Vegetation Index
TDF	tropical dry forest
UNFCCC	United Nations Framework Convention on Climate Change

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Executive Summary

During the last decade, environmental problems in tropical arid and semi-arid regions of the Americas have received very little attention from both the academic and scientific community. This lack of focus also extends to the response of these geographic parts to climate change. The policy focus in LAC is primarily on the complex ecosystems present in rainforests, casting a shadow over the extremely fragile and important ecosystems that characterize the drier regions. This trend creates a deficit in our understanding of how these ecosystems respond to climate change, which is reflected in the lack of mitigation and adaptation policies that are tailored for these specific regions.

This document provides a summary of the current state of the knowledge on land use and land-use cover change (LUCC) and land degradation in the arid and semi-arid regions of the Americas. It also presents the results of a recent IDB-commissioned scientific study to understand the spatial extent of the response to climate change in these the areas. The study suggests that there are both negative and positive responses, indicating that implementation of sound adaptation strategies in the region is complex. Therefore, there is no universal solution.. This document proposes that effort towards the development of adaptation policies should take advantage of international collaborative research networks driven by the Inter-American Institute for Global Change Research. These collaborative networks have more than 15 years of collective knowledge on both the response of tropical environments to climate change, and on the translation of scientific knowledge into policies.

1 Introduction

Our understanding of processes and cause-effect responses of semi-arid environments in Latin America resulting from anthropogenic and climate-change driven changes is limited and confined to a small number of scientific studies. There is an imbalance in the forestry sector with regard to information on tropical rainforests and other ecosystems, in particular the semi-dry environments where there is very little available online and in print. A study by Sanchez-Azofeifa et al. (2005) found that for every 300 hundred publications on tropical rainforests there is only one scientific publication on tropical dry forests (TDFs). The 2007 Intergovernmental Panel on Climate Change (IPCC) report confirms this astonishing ratio, and indicates that there are few, in fact only five, five publications that discuss the potential cause-relationship to climate change in Latin America. Of the five, none discusses the issue as it pertains to semi-arid or TDFs. The lack of available information hinders policy making to improve conservation and management of these ecosystems.

The TDF is the most common type of tropical forest, and accounts for 42 percent of the entire tropical forest area. In Latin America, it is an area that is both shrinking, estimated to be at only 44 percent of its original extent, and highly fragmented (Portillo and Sanchez-Azofeifa, 2010). With the high and increasing population densities in the region, together with relatively long histories of intensive land use practices, the TDF areas are one of the most exploited and endangered ecosystems in LAC (Kauffman et al., 1993, Murphy and Lugo, 1986). In addition, and depending of the geographic region, either deforestation (Mexico, Brazil and Argentina) or secondary growth (Costa Rica) is the most dominant land-use vector currently present (Calvo et al., 2010). Because of the current environmental constraints in these ecosystems, land degradation processes, biodiversity losses, and the ecosystems responses to climate change, these environmental conflicts could be significantly higher than those in other less rain-constrained environments in the Americas. Unfortunately, the extent to which these conflicts are occurring compared to other ecosystems and within the TDFs is unknown.

From the perspective of responses to climate change, at a more continental level, several studies show that global climate warming patterns may have resulted in long-term documented shifts in phenological events, such as changes in onset of the growing and dry season, in most ecosystems, including the TDFs (McCarthy, 2001, Parmesan and Yohe, 2003, White et al., 2005). Because growing and dry season changes are directly linked to the overall productivity of the area, there is a concern that the TDF systems may be subjected to even stronger agricultural intensification, and consequent land cover changes caused by increasing socioeconomic pressures in these areas. Apart from direct ecological consequences following deforestation and agricultural intensification, further warming trends in the local climate may occur as a result of increases on albedo, as it is believed that extensive land cover change can affect regional climate through a series of mechanisms reducing evaporative cooling and overcoming potential cooling albedo effects following land cover change (Englehart and Douglas, 2005). These mechanisms may cause extensive, localized droughts as recently observed in Mexican TDF areas (Cotler and Ortega-Larrocea, 2006, Stahle et. al., 2009).

In this context this study aims to provide a comprehensive overview of environmental degradation trends in TDF environments with emphasis on LUCC forces, biodiversity responses using invasive species, hunting, and selective logging as proxies for environmental degradation. In addition, it explores how TDFs could be responding to climate change forces at the continental level. This review is based on the limited, available information that exists in scientific literature. The report provides a series of recommendations to develop, in collaboration with the Collaborative Research Network program (coordinated by the Inter-American Institute for Global Change Research), a comprehensive network of information on the human and biophysical dimensions of TDFs in the Americas.

2 Literature Review on Forest Degradation in Semi-Arid Regions of Latin American and the Caribbean (LAC)

This section provides a review of literature on forest degradation in the semi-arid regions of LAC in the context of available information.

2.1 Comparison of insular and continental forces

Although on the surface, the forces driving LUCC in semi-arid environments appear to be similar to other sites in the tropics.[1] Sanchez & Portillo (In press) analyzed drivers of change reported for 35 Neotropical dry forest ecoregions in WWF's Global 200. At the continental and insular level, 50 percent of all sites studied showed the expansion of the agricultural frontier,

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[1] The WWF's (World Wildlife Fund) Global 200 is a listing of at-risk ecosystems.

cattle ranching and selective logging are the three main dominant forces. When island and continental sites are decoupled, sharp differences emerge in the forces of change in both regions.

- For *insular regions*, the main driving forces (defined as the forces that are identified on more than 50 percent of all sites) are: invasion of exotic species, urban sprawl, selective logging, agriculture, tourism development, and road construction.
- In the *continental sites* the main driving forces are: agriculture expansion, cattle ranching and grazing, selective logging, urban sprawl, and hunting.
- When *continental and insular regions* are compared against each other, only two drivers of change emerge: selective logging and urban sprawl are common to each region.

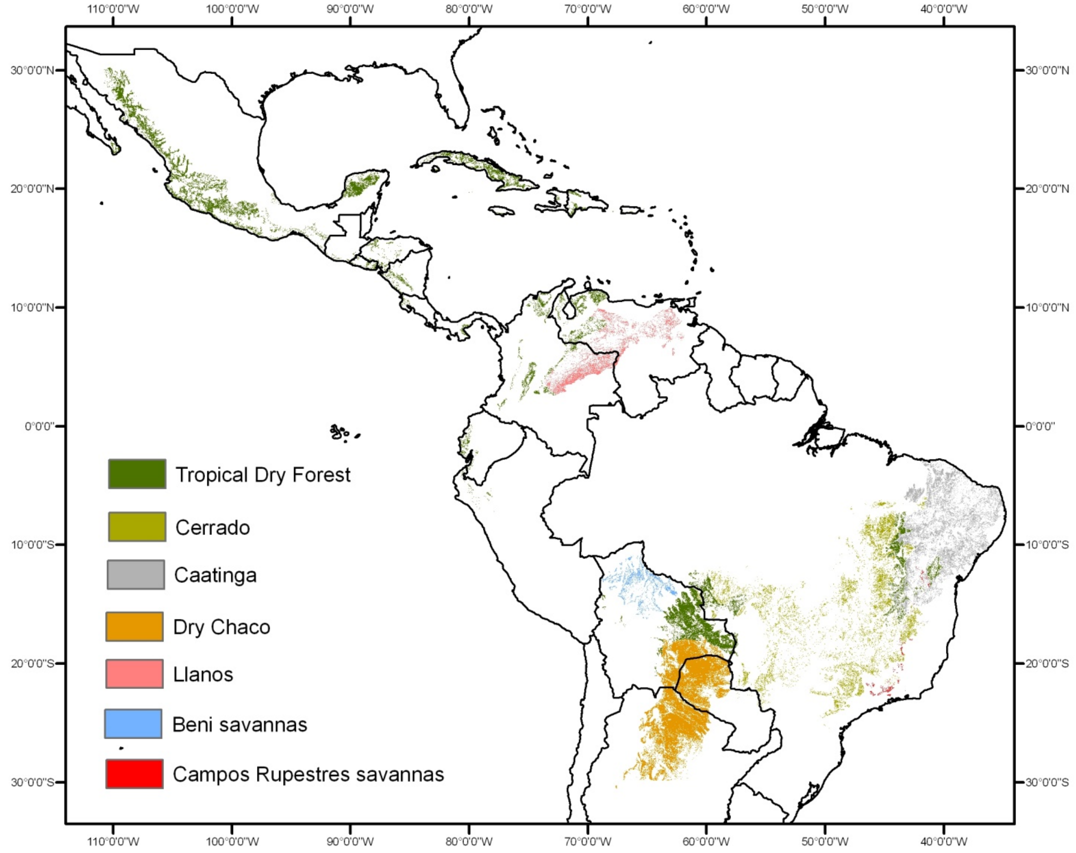
Though an indirect driver of change, alien species invasion is an important agent that affects natural restoration processes and increases the impact of fires in deciduous ecosystems and thus has an important impact on the dynamics of land cover. Hunting as well, disrupts plant-animal interactions that affect the seed dispersal and seedling predation that drive forest dynamics (Nunez-Iturri et al., 2008; Wright et al., 2007).

2.2 Effect of land use/cover change in LAC region

2.2.1 Level of forest fragmentation by region and country

A recently published assessment of TDF land cover maps of (Portillo & Sanchez, 2010) at the continental level analyzed the distribution of dry forest fragments across the Americas (see Figure 1). It categorized forest fragments into three sizes: small fragments (≤ 2.5 km^2), intermediate size fragments (≥ 2.5 km^2 and ≤ 10 km^2) and large forest fragments (≥ 10 km^2). Larger fragments capture the majority of species and processes vital for maintaining ecosystems functions, while critical size fragments (intermediate and smaller fragments) have higher species extinction rates and probability of being converted to other land covers (see Figure 2, Laurance et al., 2002; Rodriguez et al., 2007).

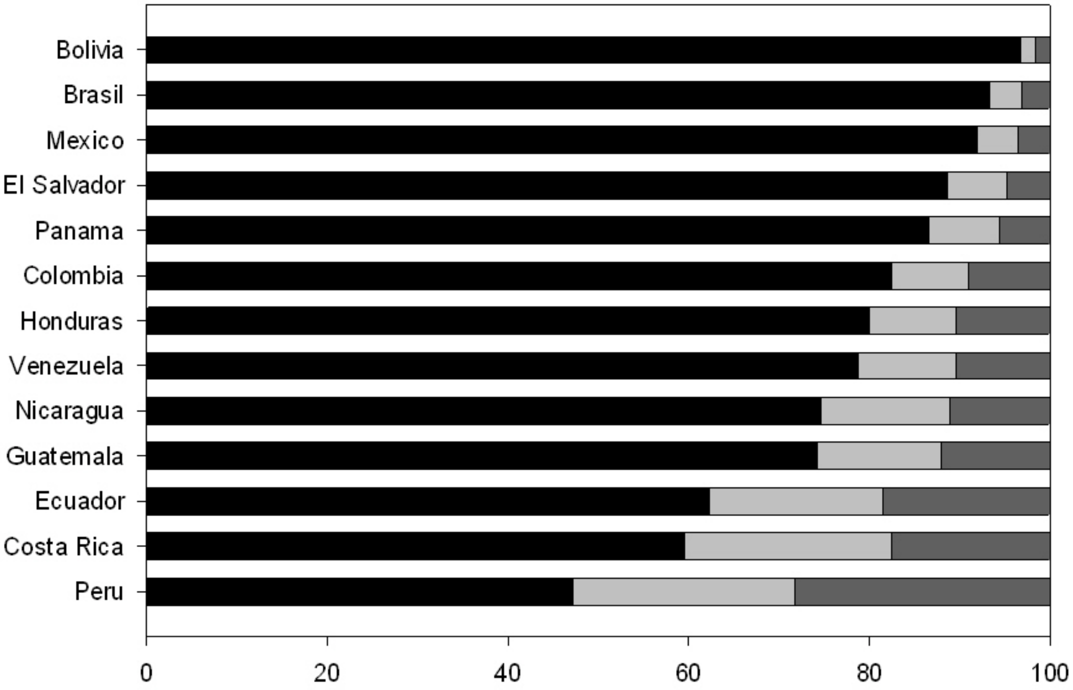
Figure 1 Extent of arid and semi-arid ecosystems in the Americas



Source: After Portillo and Sanchez-Azofeifa, 2010

Results show that Bolivia contains the highest proportion of dry forests in large fragments across the continent, followed by Brazil and Mexico. It is important to note that in almost all countries, the proportion of dry forests in larger fragments is ≥ 60 percent. This pattern might be due to the way deforestation advances, fragmenting lowland forests and leaving areas of more difficult access and gallery forests intact. Although this pattern of deforestation reduces a large part of dry forest biodiversity, it also provides opportunities for the design of nature reserves and corridors of remaining forests. The highest proportion of critical size fragments is found in countries like Nicaragua, Guatemala, Ecuador, Costa Rica and Peru, which are low in dry forest extent compared to other countries. The risk of human disturbance in TDFs found in these countries is high because of the combined effects of reduced general extent and increased fragmentation. Furthermore, most countries among the Caribbean Islands have a very high proportion of dry forests in larger fragments (~ ≥80 percent), except for Jamaica, which has a contrasting higher proportion of critical size fragments.

Figure 2 Percentage of tropical dry forest under three levels of fragmentation within the tropical and subtropical dry broadleaf forest biome for North, Central and South American countries



2.2.2 Fire as a driver of change and approximate deforestation rates

Scientific assessments regarding deforestation rates in TDFs are available at the national or site level, but global assessments are inexistent. In Mexico, Masera et al. (1997) discuss deforestation rates at the national level. The study shows a 2 percent annual TDF loss rate since the 1980's. This rate is not consistent for all areas in the region. For example, TDF deforestation rates in Chamela, Jalisco, an area on the pacific coast of Mexico, reach 3.8 percent per year. In Venezuela, the deforestation rates differ slightly by area. Fajardo et al. (2005) reports that deforestation rates in northwestern Venezuela are 2.6 percent, while the rate is somewhat smaller in northeastern Venezuela at 2 percent per year. In both areas, the main drivers of deforestation cattle grazing and agriculture. In Bolivia, Mertens et al. (2004) reports annual deforestation rates ranging from 3 to 4.1 percent in the colonization frontiers of the Department of Santa Cruz. In Tierras Bajas, also in Santa Cruz, Steninger et al. (2001) reported an annual deforestation rate in of 4.56 percent per year between 1990-1998.

The results above show that annual loss of TDF ranges from 2 to 4.56 percent in different parts of Latin America, with higher rates reported for the Bolivian dry forests. These rates coupled with the development of TDF environments, the historical contraction of its extent, and the under-representation of TDF by protected areas (Sanchez-Azofeifa et al. 2005; Masera et al. 1997), show without doubt that in absolute terms, the threat of deforestation threats is higher for deciduous vegetation than for humid forests in the Americas.

Fire occurrence is a main threat to dry forests and other semi-arid ecosystems in the Neotropics with the majority of the population there living within semi-arid regions and in a matrix of high intensity agriculture (Fajardo et al., 2005). The impact and use of fires differs across the region. Portillo-Quintero (2010) analyzed the relationship between fire occurrence, as detected by satellite imagery, and deforestation in a few dry forest sites in the Latin America. The study shows that the importance of fire varies—low, moderate, high or non-existent—depending on the frequency and intensity of the fire, and the nature of the fire (e.g. forest clearing practices) at each site. In other words, it is dependent on the type of land uses promoted at each site.

This dependency is shown through several examples. Strong correlations were found between fire occurrence and deforestation in one of the sites studied by Portillo-Quintero (2010) located in Santa Cruz, Bolivia where large-scale deforestation practices (to promote development) in the region use fire. Whereas the Mata Seca site in Brazil and the Chamela site in Mexico showed moderate correlations between fire and common land-use practices. In Chamela small-scale agriculture and logging activities are predominant, which are less dependent on fire. In Mata Seca a mixture of large-scale, small-scale and understory forest-clearing practices are the main activities promoted by local authorities, which also have a moderate fire risk. The Machango site showed correlation between deforestation and fire as non-existent. The satellite-detected fires were dispersed and occurred in low numbers. This is due to the nature of economic activities in Machango, including small-scale subsistence agriculture predominates, .

2.2.3 Forest response to fragmentation and deforestation

One of the most widespread anthropogenic changes to ecosystem integrity is the fragmentation and degradation of continuous vegetation through deforestation (Aizen & Feisinger, 1994). In addition, one of the major changes to tropical forests brought about by habitat fragmentation is an increase in the proportion of edge exposed to other habitats or "Edge Effects" (Kapos et al., 1997, Laurance & Curran, 2008). Abrupt exposure to different environmental conditions indirectly alters the microclimate, increasing tree mortality rates and decreasing plant species recruitment (Asquith & Mejia-Chang, 2005, Laurance et al., 1998). Direct changes to tropical forests include changes in air temperature, soil moisture, relative humidity and the amount of light penetrating the forest understory (Kapos et al., 1997; Pohlman et al., 2006).

Studies regarding edge effects in TDFs are few (Toledo-Aceves & Garcia-Olivo, 2008; Zelikova & Breed 2008). Tropical rainforests are generally sites for this type of study, and information about the resilience and regeneration capacity of TDF to these disturbances is unknown. Portillo-Quintero (2010) reports results from eight edge-to-interior transects surveyed in two TDF fragments located in Venezuela and Brazil. The specific objective of this study was to evaluate the magnitude and distance of edge influence on the amount of visible light penetrating the canopy and the magnitude and distance of edge influence on understory microclimate conditions.

Results indicate that increasing canopy gap fractions (driven by tree falls) across transects clearly indicate a physical and structural impact of edge exposure that extends up to 300 meters from the forest edge into the forest interior on both TDF fragments studied. Results also showed that light penetration to the understory increases at the edge of the forest and around created treefall gaps. This increment in light availability in the understory might be favoring an observed (but not documented) increase in abundance of understory vegetation at the edge and around treefall gaps. Temperature and relative humidity were also affected by edge conditions. Although edges studied by Portillo-Quintero (2010) were created >25 years ago, penetration of primary processes (tree damage) following edge creation is still high in magnitude and distance. Tree biomass, seasonality, plant growth rate and reproduction dynamics might play an important role in determining forest restoration (Quesada et al., 2009) and edge evolution in TDF fragments. Further research on the response of biological dynamics to edge effects is needed in order to better understand the resilience and regeneration capacity of TDFs to deforestation and fragmentation.

3 Other Forces Contributing to Forest Degradation

This section outlines forces other than fire that contribute to forest degradation. These forces include invasive species, hunting, selective timber logging and fuelwood harvesting.

3.1. Invasive species

Biological invasions represent one of the major causes of the planet´s biodiversity loss. Biological invasions by non-native invasive species are a primary cause of changes to biodiversity, working synergistically with other components of global change, such as pollution, climate change and habitat destruction. The presence of non-native invasive species in this ecosystem could modify the processes that lead to biodiversity and ecosystem services. Non-native invasive terrestrial plants are able to outperform native plants in low-resource environments. These species are responsible for an enormous economic damage to cities and ecosystems that can amount to billions of dollars. For this reason, millions are spent each year to control the spread into forest, agriculture, and now into cities and pristine ecosystems. As an example, Pimentel et al. (2005) estimated an expenditure of 120 billion dollars annually in the United States for the maintenance and control of invasive species. In Brazil these losses represent 50 billion dollars spent yearly to deal with prevention and mitigation for agriculture and human health (Pimentel et al., 2001).

Invasive species influence nutrient cycling and other many ecosystem functions. A good example is the introduction of the African grasses *Urochloa brizantha*, *Urochloa decumbens* and *Melinis minutiflora* in the Brazilian semi-arid cerrado (savanna). These species are now well adapted and widespread in pasture land and disturbed areas. They are also dispersing into natural reserves. These African species are robust and alter the fire regime where they take hold. This opens up the land for the species to expand (i.e. new habitats) and for other invasive species to germinate, which creates a positive feed back mechanism for new invasions. The net result is the loss of biodiversity and ecosystem services in these areas.

Otherwise, major and unique ecosystems are found in the semi-arid regions of Brazil. In such regions, vegetations vary from savanic (cerrado), to rocky outcrops, to seasonally dry forests, and even to gallery forests that border canyons, washes and rivers. These semi-arid vegetations support fragile ecosystems, and many of these present low levels of resilience to. The general public does not yet fully appreciate the value of these vegetations. These environments are harsh and are only successfully colonized by species that can live in a poor soil and high water stress environment. Despite the difficult conditions, a tremendous list of unique species and ecosystem products and services, which are unfortunately rarely considered in our valuation of ecosystems, come from these regions. Several of these different ecosystems are under threat due to their fragility, low or anecdotal reliance, and ever-growing human-imposed impacts.

Invasive species colonize disturbed sites. Once colonized, they stay for decades at low-population levels waiting for a disturbance to spread into adjacent, pristine habitats. The Mediterranean type ecosystem of Brazil, called rupestrian field, is a good example of how this works. Viana et al. (2005) and Moreira et al. (2009) illustrate the threats that roads impose to microendemic species. They found low genetic variability in species near the road. Barbosa et al. (2010) showed that in the rupestrian fields of *Serra do Cipó*, a unique ecosystem in southeastern Brazil with one of the highest level of species diversity and endemism in the tropics, high content of calcium at the roadside resulted from the paving process. This process uses limestone gravel in one of its several paving phases.

In the newly created habitats, there is less aluminum toxicity and more nutrient-rich soil. This type of environment is favorable to non-native, invasive species that are capable of colonizing and growing under these conditions. These species live in the habitats for undetermined periods of time before they invade the adjacent pristine habitats. Ecologists envisage that in the near future, society will start paying for the loss of the ecological services once provided by the native species. The widespread phenomenon poses considerable threats, and highlights the connection between the spread of invasive species and global climate warming. Therefore, there is a need for capacity building efforts to raise awareness on this issue amongst decision makers.

Scientists have a significant role to play in this awareness raising campaign; they hold data that will inform policy decisions that encourage monitoring of biological invasions. Intensive monitoring and control should prevent further establishment of weeds. It should also prevent further spreading, “colonizing,” of existing weeds to native vegetations. Further invasion would modify the landscape, cause serious damages to ecological services, and result in possible extinction of endemic species, provoking a strong feedback mechanism.

3.2. Hunting

Human harvesting of animals (i.e. hunting and capturing for the illegal pet trade) has profound effects on tropical forest structure and composition. This practice creates an imbalance in the natural ecosystems by eliminating animals that would normally participate in key ecological interactions that promote forest regeneration (Wright et al., 2007; Dirzo, 2001). As much as 98 percent of the Neotropical canopy and sub-canopy trees and up to 80 percent in Paleotropical forests are vertebrate dispersed (Howe & Smallwood, 1982). Medium- and large-sized mammals play a major role in seed dispersal in these areas, and are particularly important in tropical forest dynamics (Corlett, 1998; Jordano, 2001). This category of mammal is also the most sought after vertebrates for game (Palacios y Peres, 2007). Primates are perhaps the most important tropical seed disperser, because they disperse up to 40 percent of frugivore biomass seeds (Chapman, 1995), and they are key dispersers for many trees (Link and Di Fiore, 2006). For example, the spider monkey *Ateles geofforyi* may consume as much as 131 species at any one site, with frugivory representing as much as 94 percent of their total diet (Gonzalez-Zamora et al., 2009). Furthermore, spider monkeys are important dispersers because they consume many large-seeded species that are not dispersed by other animals (Stevenson and Aldana, 2008).

Worldwide, mammals are the most hunted vertebrate (Robinson & Bennett, 2000), and mammal hunting is on the rise. Numerous studies document the unsustainable nature of human mammal harvesting practices in tropical ecosystems (Corlett et al., 2007; Peres & Palacios, 2007; Taber et al., 1997). An astonishing number of mammal families, 18 out of the 26 mammal families, are vulnerable to human exploitation (hunting or trade; Stoner et al., 2007). These families also play important ecological roles in seed dispersal throughout tropical ecosystems. The extirpation or reduction in frugivores caused by hunting affects forest regeneration by changing patterns in predispersal seed predation, primary and secondary seed dispersal, postdispersal seed predation, and grazing (Wright et al., 2007). Furthermore, several studies suggest that the effects of mammal defaunation vary depending on plant species and stage of seed dispersal cycle. For example, in the seasonal forest of central Panama hunting effects two species in different ways during primary and secondary seed removal cycles. Hunting affects *Cordia bicolor* during the primary seed removal stage, lowering seed removal by 43 percent lower in hunted sites. During this stage, *Onecarpus mapora*, another species found in the season forests, is remains unaffected. For secondary removal, however, *O. mapora* seed removal is 59 percent lower in hunted sites, while *C. bicolor* remains unaffected. Finally, predispersal seed predation by mammals is significantly lower in hunted sites for *O. mapora*, but unaffected for *C. bicolor* (Beckman & Muller-Landau, 2007).

Several studies in tropical seasonal forests suggest that negative impacts may occur on forest regeneration due to hunting. For example, hunting reduces seed dispersal and population growth of the mammal-dispersed tree *Choerospondias axillaris* in seasonal forests of northern Thailand (Brodie et al., 2009). Flying foxes are hunted in tropical seasonal forests in Fiji (Luskin, 2010), and intensive hunting of these species occurs throughout Asia, the Pacific Islands and some western Indian Ocean Islands. Studies suggest that low flying fox reproductive rates, will inevitably give rise to sharp declines of many species if hunting restrictions are not broadly implemented (Mickleburgh et al., 2009). The possible implications of the elimination of these frugivores for seed dispersal and forest regeneration have not yet been explored.

Although hunting has been well documented in TDFs (Reyna-Hurtado et al., 2010, Timm et al., 2009; Stoner & Timm 2004; Taber et al., 1997), evaluation of the impact this may have on different stages of seed dispersal, plant recruitment, regeneration, forest composition and structure is needed. Data in other regions suggest that significant detrimental effects will likely occur. We suggest that this is an avenue that requires further research. Scientists should also pursue the parallel development of research evaluating the effects of defaunation and the development of controlled harvesting programs. The development of sustainable hunting programs in tropical regions depends on the ecosystem type and the amount of anthropogenic activities; both of these components must be taken into consideration when developing protected areas, wildlife harvesting areas, and harvest limits (Robinson & Bennett, 2004).

3.3 Selective timber logging and fuelwood harvesting

Degradation generally refers to the gradual reduction of biomass within the forest without resulting in land use conversion. Within this gradual process, forests can remain degraded for a long time before being converted to other uses. As previously described, TDFs are vulnerable ecosystems threatened by population pressure, urbanization, agriculture expansion and other land use change process (Lawrence et al., 2007). The major sources of forest degradation include fires and invasive species. Other sources of human-induced forest degradation exist and are outlined below.

- **Selective timber logging**: Selective timber logging leads to degradation through the direct removal of trees; collateral damage to live trees by logging equipment and skid trails; and increase in the effects of drought, windthrow, and fire in forest fragments.

Forests in TDF ecoregions in insular and continental sites are most vulnerable to selective logging exploitation. Logging is likely to expand in these areas due to growing timber demand and increased forest access, (Chomitz et al., 2006). Numerous studies have demonstrated that with appropriate harvest planning of log extraction paths, coupled with worker training in directional felling, 50 percent or more of this collateral damage could be avoided (ITTO, 2002). Implementing these basic reduced-impact logging techniques could substantially reduce negative impact on forest degradation.

- **Fuelwood harvesting**: Significant forest degradation can result from fuelwood harvesting either (i) by individuals, where population pressure is strong, sustainable practices are not used, and alternative fuels are not available, or (ii) due to commercial felling of large trees for direct sale to urban areas or for the production of charcoal. Extracting fuelwood from dry forests often causes more degradation than commercial timber logging (Skutch and Trines, 2008). Several strategies exist that are geared to alleviate the degrading pressures of fuelwood harvesting, which is a major driver of degradation in several developing countries. The negative impacts of fuelwood collection can be mitigated through a variety of land management measures, including agroforestry, afforestation/reforestation, as well as promotion of improved cooking stoves in the communities.

Often the driving forces for forest degradation in TDFs are different than those in the humid tropical forests. These range from conspicuous land-cover changes, such as deforestation, forest fragmentation and slash-and-burn agriculture, to less apparent changes in canopy structure driven by selective logging and surface wildfires, to perturbations that are almost undetectable using remote-sensing techniques (Peres et al., 2006). Unlike monitoring deforestation drivers, monitoring forest degradation drivers is not systematically usually done. Further discussion should be encouraged to take account of differing country circumstances.

4 Climate change impacts in semi-arid regions of LAC

A comprehensive literature review using the Web of Science database was conducted using the following tags: climate change and dry forests, climate change and semi arid environments, climate change and dry forests and Latin America, and climate change and semi-arid environments and Latin America. The results of the search indicated a significant mixture of papers with little or no relevance to the topic of this position paper. The paper review (746 papers in total) concluded that only two papers had a significant linkage to the topic covered in this document. The first paper by Zak et al. (2008) deals with climate change and land cover in central Argentina. The second paper by Santibanez & Santibanez (2007) deals with land use degradation trends in Latin America and the Caribbean and its linkages to climate change. This lack of basic reference information does not come as a surprise. Research at the continental level in the Americas is highly driven by studies in North America (IPCC, 2007) resulting in an imbalance in studies cover LAC. A review by the IPCC (2007) found that only eight studies on Latin America with linkages to climate change compared to over 1000 studies on North America on the same issue.

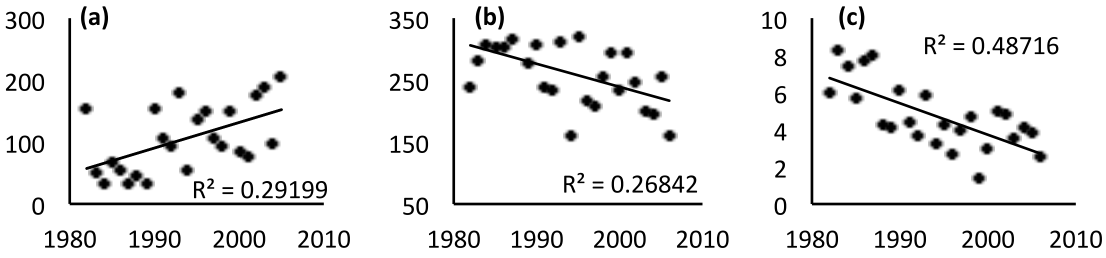
How tropical arid and semi-arid areas will respond to climate change is driven by the phonological response of those ecosystems to climate change. Therefore, our projections for how the area will respond are also based on the response linkages between the two. Several studies report that long-term documented shifts in phenological events, such as changes in onset of the growing and dry season in most ecosystems, including the TDFs, may be contributing to the global warming patterns (McCarthy, 2001; Parmesan and Yohe; 2003; White et al., 2005). Because growing and dry season changes are directly linked to overall productivity of the area, there is a concern that the TDF systems may be subjected to even stronger agricultural intensification and consequent land-cover changes caused by increasing socioeconomic pressures in these areas. Apart from direct ecological consequences following deforestation and agricultural intensification, further warming trends in local climate may occur, as it is believed that extensive land-cover change can affect regional climate through a series of mechanisms reducing evaporative cooling and overcoming potential cooling albedo effects following land-cover change (Englehart and Douglas, 2005). This mechanism may cause localized, extensive draughts as recently observed in Mexican TDF areas (Cotler and Ortega-Larrocea, 2006; Stahle et al., 2009).

Because most of the studies on phenological climate change focus on tropical rainforest, it is difficult to make associations between observations on rainforest ecosystems and tropical semi-arid and arid environments. This is due to the sharp differences in structure and composition of the different ecosystems as well as water availability. Further, the availability of information on regional temperature, relative humidity, and precipitation (key factors linked to phenological response) is limited for most of dry forest regions in the Americas. Table 2 from Sanchez-Azofeifa et al. (In review) demonstrates that IPCC (2007) projections for selected dry forest and semi-arid ecosystems in the America's have limited or no data that all. The former makes it almost impossible to validate climate change models for these regions.

One way to better understand responses of tropical arid and semi-arid environments is through the use of remote sensing technologies. Remote sensing is successfully employed in phenological studies with the use of vegetation indices such as the Normalized Difference Vegetation Index (NDVI). The value of this index is based on the combination of structural information provided by the Leaf Area Index and the properties and behavior of chlorophyll contained in green plants, which is highly reflective in the near infrared part of the spectrum and a little reflective in the visible part (Granados-Ramírez et al., 2008). Therefore, NDVI can serve as an estimator of vegetation "greenness," which can be analyzed in temporal context in order to describe characteristics of each season within an area. Consequently, if adequate historical data is available, NDVI properties and its changes can be used to search for and study phenological trends within a certain spatial and temporal area. Long-term time series of vegetation indices data can even provide means to detect changes in climatic zones behavior, indicating possible variations in large-scale circulation patterns.

A case study conducted by Sanchez-Azofeifa et al. (In review; see Figure 3) demonstrates the effects of climate change over the last 20 years of warming in the Pacific coast of Mexico. The study region has demonstrated significant increases in temperature (since 1978) and hardly any change on precipitation, which is consistent with observations from Magana et al. (1990). This is reflected on an increase in the length of the dry season, a reduction in the length of the growing season and therefore a decrease in the productivity of those TDFs. The consequences of such changes have not been studied until today both from a socio-economic and a natural science perspective.

Figure 3 Response of the tropical dry forests located at the Pacific Coast of Mexico (Chamela-Cuixmala Biosphere Reserve) for the length the dry season (a), growing season (b) and proxy productivity (c) derived from the analysis of satellite NDVI information generated from the Advance Very High Resolution Radiometer (AVHRR) between 1988 and 2006



Source: After Sanchez-Azofeifa et al. in review

5 Windows of opportunity and potential collaborative efforts LAC

Our interests on tropical rainforests have heavily controlled the way that we understand the impacts of climate change in tropical environments. The fundamental assumption is that the tropics do not exist outside of the tropical ecosystems; this has driven the amount of scientific literature available since 1945. Sanchez-Azofeifa et al. (2005) demonstrated that the ratio of scientific peer-reviewed papers between rainforests and dry ecosystems for the America is in the order of 300:1.

Efforts to better understand the human and biophysical impacts of land use domination of tropical arid and semi-arid environments have also lack at the continental level given the high priority of funding agencies given to rainforest environments vs. dry environments. In the last 20-years, only consistent efforts have been carry out by the Inter-American Institute for Global Change Research (IAI, http://www.iai.int) to build some level of understanding via its Collaborative Research Network (CRN) initiative.

Opportunities for TDFs research and semi-arid environments are also limited and no projects designed to build scientific knowledge from international organizations, such as the World Bank or the Inter-American Development Bank, were identified during this study. The former provides significant limitations in terms of sound decision-making given that little or nothing is actually known in terms of how these ecosystems are responding to both global environmental change (driven mostly by land use change and forest fragmentation), and climate change). Significant and coordinated efforts between countries, funding agencies and continental research organization such as the IAI are necessary.

The lack of existing opportunities open new doors to develop a comprehensive continental program to provide sound scientific knowledge to policy making, like the work started by the IAI via its CRN-2 program and its Tropi-Dry network (see: http://tropi-dry.eas.ualberta.ca). Specifically, three areas of research and translation into policy making can be identified:

a) Human responses to climate change in arid and semi-arid region;
b) Ecosystem response to both fragmentation and climate change in arid and semi-arid regions, including phenology and carbon sequestration; and
c) Infrastructure to support modeling of climate change effects and responses in arid and semi-arid regions.

These three areas of research and their transformation into policy making documents at the country and local level can generate a first inventory of the status and response of the tropical regions studies in this document. The current systematic lack of information across these three pillars significantly contributes to knowledge gaps that eventually are translated into policymaking that lacks a significant scientific background.

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Appendix

Table 1 Current tropical dry forest extent (Km^2) derived from MODIS 500-m data and area under protected areas at three levels: a) North, Central and South American countries; b) Countries of the Caribbean islands, c) Summary of results per subregion

Country	**TDF Potential Extent (based on Olson et al. 2001)**	**TDF Current Extent (this analysis)**	**TDF Converted (%)**	**TDF Protected (KM2)**	**Percentage under Protection**
Mexico	625,038	181,461	71	336	0.2
Bolivia	216,031	118,940	45	10,609	8.9
Brasil	168,164	81,046	52	5,015	6.2
Venezuela	113,143	29,396	74	302	1.0
Colombia	92,664	30,713	67	1,555	5.1
Peru	48,914	2,337	95	188	8.1
Nicaragua	32,277	7,414	77		
Honduras	26,582	6,280	76		
Ecuador	25,275	6,443	75	147	2.3
El Salvador	11,291	3,344	70	9	0.3
Guatemala	10,431	1,463	86		
Costa Rica	7,559	1,795	76	279	15.6
Panama	6,160	2,128	65		
Total	**1,383,529**	**472,759**	**66**	**18,620**	**3.9**
Subregion	**TDF Potential Extent**	**TDF Current Extent (KM2)**	**TDF Converted (%)**	**TDF Protected (KM2)**	**Percentage under Protection**
N&C America	719,338	203,884	72	624	0.3
South America	664,191	268,875	60	17,816	6.6
C. Islands	137,130	46,839	66	4,797	10.2
Total	**1,520,659**	**519,597**	**66**	**23,417**	**4.5**

Source: After Portillo and Sanchez-Azofeifa, 2010.

Table 2 Differences between NOAA, NASA and IPCC trends for arid and semi-arid regions of the Americas

Location	NASA Precip	NOAA Temp	IPCC Precip	IPCC Temp
West coast Mexico North	No trend	+*	No data	+
Chamella	No trend	+*	No data	No change
West coast Mexico centre	+	+*	No data	No change
West coast Mexico (South)	+*	+*	No data	No change
Yucatan	No trend	+*	No data	+
Santa Rosa	No trend	+*	No data	No data
Piñero	No trend	No trend	+	-
Caatinga North and Centre	No trend	+*	-	No data
Caatinga South	No trend	No trend	-	+
Mata Seca	No trend	No trend	-	+
Santa Cruz	-*	No trend	-	+
Chiquitano	No trend	No trend	-	+
Kaa-Iia	-*	No trend	-	+
Dry Chaco North, Centre, South	-	No trend	-	+
Dry Chaco Southern fragments	No trend	No trend	No change	+

Source: After Sanchez-Azofeifa et al. in review.