Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Tropical dry forests, water, biodiversity and the challenges of climate change in Nicaragua

Florestas tropicais secas, biodiversidade, água e os desafios das mudanças climáticas na Nicarágua

Iris Saldivar[a] and Katherine Vammen[b]*

[a]Red de Herbarios de Mesoamerica y el Caribe, Managua, Nicaragua
[b]Inter-American Network of Academies of Sciences – IANAS, Water Program, Managua, Nicaragua

Abstract

The Tropical Dry Forests of Nicaragua located mainly in the Pacific and Central-North zones play an essential role in maintaining resources such as water and the special biodiversity of this vulnerable ecosystem now under pressure from land-use changes and climate change These resources are essential to the well-being of the population as the main aquifers of the country are located in this area along with ecosystem services of this now heavily fragmented forest ecosystem. The ongoing influence of climate change along with land-use changes have caused the growth of arid zones in all of Central America. These on-going land use changes are lowering the resilience to the present and future climate change. Individual efforts to sustainable management of the forests are mentioned but it is nonetheless urgent to introduce wider and more intensive sustainable forestry and watershed management under a well-planned strategy based on findings of scientific research. The importance of the interrelationship between water and forests in the management of sustainable forest ecosystems will be stressed.

Keywords: tropical dry forests, water resources, land-use change, biodiversity.

Resumo

As florestas tropicais secas da Nicarágua, localizadas principalmente nas áreas do Pacífico e Centro-Norte, desempenham um papel essencial na manutenção dos recursos naturais como a água e a biodiversidade, agora pressionados pelas mudanças no uso da terra e pelas mudanças climáticas. Esses recursos são essenciais para o bem-estar da população, pois os principais aquíferos do país estão localizados nesta área, juntamente com os serviços ecossistêmicos deste ecossistema florestal agora fortemente fragmentado. A influência contínua das mudanças climáticas, juntamente com as mudanças no uso da terra, causou o crescimento de zonas áridas em toda a América Central. Essas mudanças contínuas no uso da terra estão diminuindo a resiliência às mudanças climáticas presentes e futuras.. São mencionados esforços individuais para uma gestão florestal sustentável, mas, no entanto, há uma necessidade urgente de introduzir uma gestão florestal e de bacias hidrográficas mais ampla e intensiva no âmbito de uma estratégia bem planejada baseada nos resultados da investigação científica. Será sublinhada a importância da inter-relação entre a água e as florestas na gestão de ecossisstemas florestais sustentáveis.

Palavras-chave: florestas tropicais secas, recursos hídricos, mudança no uso da terra, biodiversidade.

1. Introduction

The last decades of scientific studies show that the tropical dry forest (TDF) is the most threatened ecosystem on a global scale (Dryflor et al., 2016), and one of the most endemic ecosystems; globally the occurrence of the primary dry forest is estimated at 2% (Stand and Azofeida, 2019). Only 0.1% of the original "intact" forest was attributed to the shores of the Central American coasts (Gillespie et al., 2000). At present, this ecosystem is usually found as a fragmented secondary forest (Tarrasón et al., 2009) that continues to suffer from a constant change in land use (Chooksy, 2022).

In the last two decades, tropical dry forest ecosystems are under a process of extreme fragmentation. Several of its areas border with other ecosystems, such as (wetlands, mangroves, and cloud forests) that are also under the pressure of deforestation (Maes et al., In press). This ecosystem is strongly interrelated to water resources, surface and groundwater, in the designated area. Due to tree cover loss, the tropical dry forest also suffers from

*e-mail: kvammen23@gmail.com
Received: November 11, 2023 – Accepted: January 16, 2024

other threats, such as increased temperature and changing in the rainfall seasons (González Hernández et al., 2015; Weisse and Goldman, 2020).

1.1. Tropical dry forests in Nicaragua

The TDF in Nicaragua has a strip located in the Central American Dry Corridor, which is now subjected to aridification processes (Hidalgo, 2021) and possibly expanding. At the beginning of the 2000s, according to the forest census, the dry forest was estimated at 3,751.666 million hectares, distributed between Nicaragua's Pacific and north-central Zone (MAGFOR, 2000). In 2011, a new study showed that the dry forest strongholds throughout the territory was estimated at 406 813.89 ha (Alianza para la Conservación del Bosque Seco, 2011), a figure that represents a 90% reduction of forest in this ecosystem (Saldivar, 2021).

In Nicaragua, 3.9 million people live in the dry forest, where the most significant national commercial and industrial activity occurs (MARENA, 2017) however, this ecosystem has not been prioritized for protection, nor does a restoration plan for strategic areas exist at this time (Saldivar, 2021). This situation increases the vulnerability of species that are under pressure due to habitat loss, where species accepted on the IUCN red list for Nicaragua stand out, such as the Spider monkey *(Ateles geoffroyi,* Kellogg and Goldman, 1944) and the Yellow-naped parrot (*Amazona auropalliata,* Lesson, 1842) (Jovenes Ambientalistas de Nicaragua, 2018), not to mention that the revision of the flora species has not been updated on the CITES list since 2010 (CITES, 2010). There have been no recent monitoring studies on the status of threatened species, a panorama exacerbated by the alarming increase in heat points in the country and forest loss with official rates of 70,000 ha per year (MARENA, 2017). Dry forest fragmentation undermines the possibility of guaranteeing the ecosystem services that the TDFs provide to the well-being of citizens in the form of clean air, access to water, temperature regulation, and pollinators.

This manuscript aims to make visible the invaluable ecosystem services that this forest type contributes to biodiversity, food security, natural resources such as water and public health which indicates the strong need to create more outstanding efforts in further studies, the introduction of conservation measures, and strong restoration efforts as a resilience strategy to the threat posed by climate change.

2. Character of Tropical Dry Forests in Nicaragua and Biodiversity

Tropical dry forests are difficult to delimit, but the concepts are usually accepted in the altitudinal influence on vegetation formations (150-800 m.s.l.), the rainfall regime that occurs with precipitation between 500-2000 mm per year, and average temperatures of 20-29 °C according to the geographical region. In Nicaragua, the botanist Salas proposed the study of Nicaraguan forests framed mainly in four ecological regions; where the dry forest mainly covers Ecological Region I (Pacific Sector) and Ecological Region II (North-Central Sector of Nicaragua) and both zones were calculated with an ecological extension of 49,167 Km^2 in the late 90's (Salas, 1993; MARENA, 2017).

Figure 1 shows the distribution according to the delimitation of the ecoregions of Salas and the rainfall range.

The dry forest consists of a broadleaf forest (sparce or dense) with deciduous species as a support mechanism for periods of low rainfall. In the dry forest, the family Fabaceae Lindl usually predominates in order of representativeness (Gillespie et al., 2000; Bustillo, 2017) Fabaceae Lindl. – Caesalpiniaceae R.Br. and Flacourtiaceae Rich ex.D.C. (Castro-Marin, 2005), Meliaceae Juss., Bombacaceae Kunth., Moraceae Gaudich., Lauraceae Juss., Myrtaceae Juss., Rubiaceae Juss. and Sapindaceae Juss. (Zambrana, 2010; Saldívar, In press).

The Dry Corridor of Central America in Nicaragua is a geographical space that covers some territories of the dry forest but is not synonymous with the entire dry forest area. The municipalities most affected by severe drought conditions are 27 and are located in the department of Nueva Segovia, Madriz, Estelí, Matagalpa, Managua, and León. The territory of the dry corridor contains different ecosystems, such as dry forests, seasonal evergreen forests (submontane, montane), pine forests, mixed and gallery forests (FAO, 2012).

Deforestation is one of the biggest threats to the forest resource at a national and international level; it is estimated that Nicaragua has deforestation rates of 70,000 ha per year (MARENA, 2017). This number could even be an extremely prudent record, given that forest fires, the expansion of the agricultural frontier, and drought has increased between 2011 and 2021 in Nicaraguan territory (Centro Humboldt, 2018; El Economista, 2023).

An exact census of the state of the tropical dry forest ecosystem has yet to be carried out in Nicaragua. However, studies show a marked fragmentation process where sparse forests predominate and dense forest strongholds are small and dispersed (Alianza Para La Conservación Del Bosque Seco, 2011; Saldivar, 2021). The map of distribution and forest cover (see Figure 1) shows that this situation has persisted over time (Maes, et al., pending publication). It is an impossible task to define a number for the amount of current tropical dry forest since there is no existing design of methodologies that facilitate its spatiotemporal monitoring, and reports have varied in nomenclature over the decades.

Although Nicaragua has no census, non-native species can be observed with the naked eye dominating the dry forest landscape as ornamentals, live fences and even at the forest's edge. Some characteristic exotic species are Malinche (*Delonix regia* (Bojer ex. Hook) Raf.), Neem (*Azadirachta indica* A. Juss.), Almendra (*Terminalia catappa* L.), Tamarindo (*Tamarindus indica* L.), and Eucalipto (Eucalyptus sp. L'Hérs.), among others.

These apparently "non-important" changes in the landscape create essential disruptions in the availability of food for wildlife (Ness and Morin, 2008). Not to mention that the fragmentation and loss of the forest have put some species of dry forest fauna, such as the Spider Monkey and the Yellow-naped parrot under critical threat (Jovenes Ambientalistas de Nicaragua, 2018).

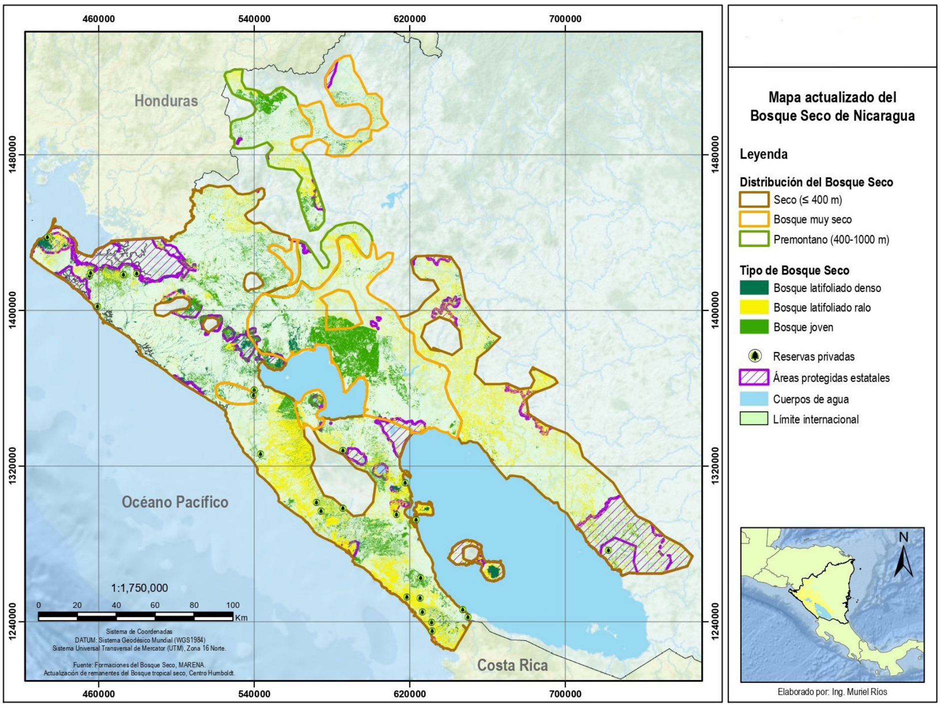

Figure 1. Distribution of Tropical Dry Forest (TDF) and categories of TDF coverage and protected areas in Nicaragua. (Elaborated by: Ing. Muriel Rios; Dry Forest Project Team; Teledetection (Jürguen Guevara), Sentinel II A).

In the case of flora, an ecological interpretation of the status of endangered species has yet to be carried out recently; however, changes in land use tend to show significant forest loss, and the remnants of the field are usually observed in a sparse forest state. An investigation of species richness indices in different forest remnants found that species richness indices were higher in areas where the tree cover belonged to a mature forest. Gallery forest and hillslope forests had higher species richness indices than remnants of vestigial and sparse forests (Tarrasón et al., 2009), indicating the importance of promoting forest connectivity and biological corridors. The native flora of dry forests represents an essential element in the ecosystem, not only providing food for wildlife (Rumiz, 2009) but also directly related to the productivity of food, energy (firewood) for local communities (IPBES, 2019).

3. Water and Forests: Importance of Tropical Dry Forests for Water Resources in Nicaragua

More than 75% of inland waters are accessible through forest watersheds (Newton, 2021); this shows the importance of the interrelationship between water and forests in the management of sustainable forest ecosystems. Water is also the most important factor which promotes growth and distribution of trees in the forest. But on the other hand, forests have the capacity to modulate the hydrological cycle. Deforestation can lead to changes in regional climate conditions reducing regional precipitation due to diminishing evapotranspiration. Also forests which have higher tree biodiversity can take better advantage of water (Gónzalez de Andrés et al., 2017) and are more resistant to variability in climate (Caldwell et al., 1998). It is especially important to emphasize that natural forests contribute greatly to the resilience of sources of water supply for human consumption and other uses to better encounter global climate change.

Tropical dry forests are seen as more vulnerable to the pressures of changing land use and climate change due to reduced content of humidity in the hydrological cycle. Presently many regions with tropical dry forest ecosystems under water stress have been observed indicating that the advance of climate change has greater consequences for the adequate functioning of these natural ecosystems as well as maintaining social-economic conditions dominating these areas. It has been predicted that 30% of tropical dry forests are under high risk of reduction with even higher risks in Central and South America of up to 38% of their area (Miles et al., 2006). Therefore, effects of global climate change on tropical dry forests could impact both quantity and quality of surface and groundwaters but also the availability of water in the soil to promote growth, biodiversity and expansion of tropical dry forests. The loss of tropical dry forests and its continuing fragmentation could result in a permanent shift to a state of reduced overall vegetation cover reaching a limiting level where atmospheric deposition doesn't permit the regrowth of a dense forest canopy (Runyan et al., 2012; Runyan and D'Odorico, 2016).

The functioning and density of forests are controlled by the hydrological cycle and maintain the cycle of nutrients and carbon; they promote the infiltration that facilitates recharge to the aquifers, regulate the flow of rivers and streams, stabilize the soils in protecting them from hydric and wind erosion (Bernex, 2021). As mentioned earlier, the tropical dry forests of Nicaragua are highly fragmented due to strong changes in land-use and increasing vulnerability to climate change. Deforestation and extreme fragmentation lead to the loss of the multifunction of forests and the diverse benefits to the population such as providing water resources to the inhabitants in these regions and ecosystem services with decreasing biodiversity of the forest habitats.

As observed above (see Figure 1), the coverage of tropical dry forests (TDF) in Nicaragua is dominated by sparse broadleaf forests in 51.6%, followed by secondary young forests in 26% and lastly, dense broadleaf forests in only 8.4%. The area of the TDF is located predominately in the largest watershed of Nicaragua called Río San Juan (952) in 45% and the Pacific Watershed (9533) in 39% of its total area. Other smaller portions can be found in the Río Coco Watershed (9516) in 8.6% and in the Río Grande de Matagalpa Watershed (9518) in 7.4% (Vammen et al., pending publication).

The largest remnants (93%) of the area of the TDF in Nicaragua is located in the zone of average annual precipitation of 1001-1900mm (INETER, 2010) which is favorable considering the normal range for TDF is between 250 and 2000mm (Murphy and Lugo, 1986). As tropical dry forests are characterized by changes in seasonality with a distinct dry season (in the case of Nicaragua from December to April) followed by a rainy season (May to November), an analysis of two periods of monthly annual precipitation 1) 1971-2010 and 2) 2011-2015 in 4 meteorological stations of the specific area of TDF does not show a significative tendency in changes of total annual rainfall per season (Vammen et al., pending publication). But there have been precipitation deficits in some periods in the last decade in the region of Central America within the rainy season that have been historically more humid. Precipitation regime patterns have been noted with increasing intensity, changes in duration and in seasonality in the last decade.

3.1. Groundwater and Aquifers in Nicaragua

In the hydrological cycle, precipitation is distributed in different partitions that provide water input for surface water, groundwater, runoff and to evapotranspiration from the vegetation which then is directed to atmospheric humidity.

In the specific area of the tropical dry forests, 12 aquifers can be found of hydrogeological importance due to their extension. They are presently being used for human consumption, irrigation and in industries. There are 15 minor areas known as intra-mountainous aquifers that serve as water supply for small populations (see Figure 2) (Vammen et al., pending publication).

The main aquifers with the largest area in the tropical dry forests coverage area are Occidente, Nandaime-Rivas, Villanueva and Tipitapa- Malacatoya (as shown in Table 1).

The largest area of dense broadleaf forest corresponds to 2 of the principal aquifers, Occidente and Malpaisillo with only 98.4 km^2 and 62.3 km^2 respectively. All other aquifers are predominately secondary young forests and sparse broadleaf forests. Unfortunately, this indicates limited coverage of forests in the areas of the major aquifers of Nicaragua.

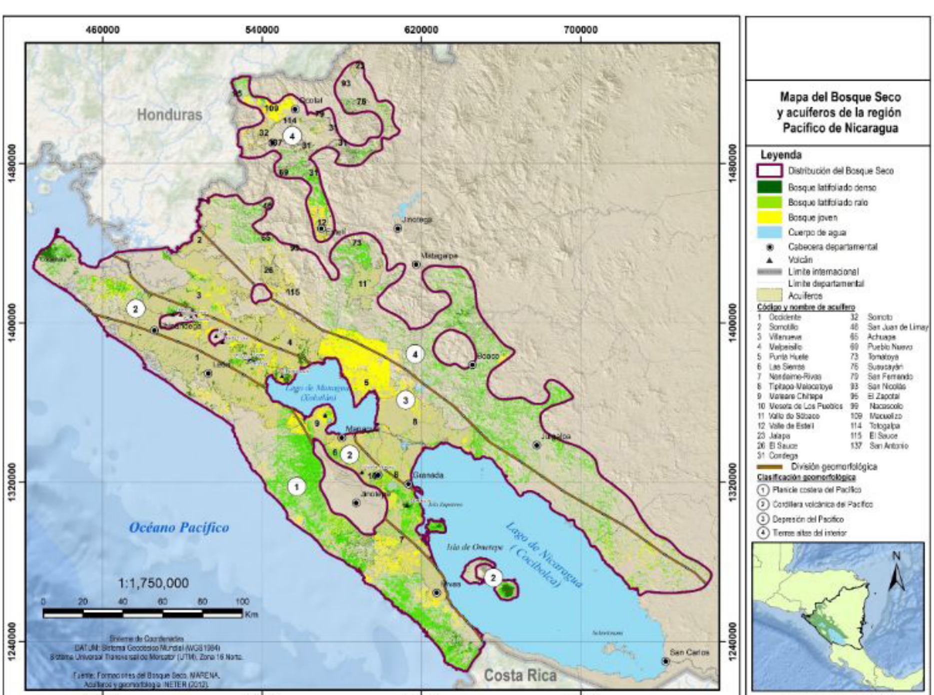

Figure 2. Map of Tropical Dry Forest indicating Location of Aquifers. (Elaborated by Ing. Muriel Ríos, Source: INETER, 2017).

Table 1. Total area of aquifer, area of aquifer in TDF and % Coverage of aquifer area in TDF . Source: Vammen et al. (pending publication).

	Total Area of Aquifer	Area of Aquifer in Tropical Dry Forests Remnants	% Aquifer Area in Tropical Dry Forest Remnants
Occidente	2117 km^2	299.2 km^2	14.00%
Nandaime-Rivas	1101 km^2	254.6 km^2	23.12%
Villanueva	1352 km^2	252.5 km^2	18.67%
Tipitapa-Malacatoya	1406 km^2	245.3 km^2	17.44%

According to the Nicaraguan Institute of Territorial Studies (INETER, 2010), 80% of the Nicaraguan population was supplied by groundwater used for irrigation, industry and drinking water in 2010. The Occident aquifer in the municipalities of León and Chinandega has the greatest water potential in volume; this area also has very fertile soils, and the water of the aquifer is used for irrigation of sugarcane, peanuts, and other perennial crops in the dry season (Vammen and Peña, 2022). The agricultural water withdrawal to total water withdrawal in Nicaragua is very high with 76.72% (FAO, 2022). Some indications of loss of water quality in groundwater has been observed due to intense application of persistent pesticides in the past and present (Delgado, 2003; Montenegro and Jiménez, 2009). Presently artisanal mining is also spreading in the area affecting surface waters as the "rastras" and other forms of processing are usually located on the shore of rivers (La Prensa, 2017). The location and capacity of the main aquifers mentioned correspond to areas where the highest activity of production of the main agricultural products of Nicaragua are found; loss in volume and quality of water would bring economic impacts affecting not only national exports but also employment opportunities and as a consequence local economies.

4. Climate Change in the Dry Corridor of Central America and Tropical Dry Forests in Nicaragua

4.1. Dry Corridor of Central America

Central America has a very pronounced Dry Corridor mainly in its Pacific region extending from Northwest (Guanacaste) in Costa Rica through the Pacific area of Nicaragua and in El Salvador, Honduras, and Guatemala. The area of the Dry Corridor in Nicaragua covers 21% of national territory (Graterol Matute et al., 2019) meaning ~66% of the national population (Source: from municipal populations (INIDE, 2020). But the extension is growing and varies for normal conditions (30.3% area of Central America), extreme dry (36.2%) and extreme wet years (21.3%) (Quesada-Hernández et al., 2019). Figure 3 shows this variation in 3 maps of the area according to the precipitation characteristics under different climate conditions. Specifically for Nicaragua, the changes mean a change in area from 45 495 km^2 in a year of dry conditions and 27 495 km^2 in wet conditions (As shown in Table 2).

Studies at the Central American scale show the advance of arid conditions in Central America, which will influence the dry forest in the dry corridor (Quesada-Hernández et al., 2019), where phenomena such as "El Niño" can further increase aridity. As a consequence, other threats appear,

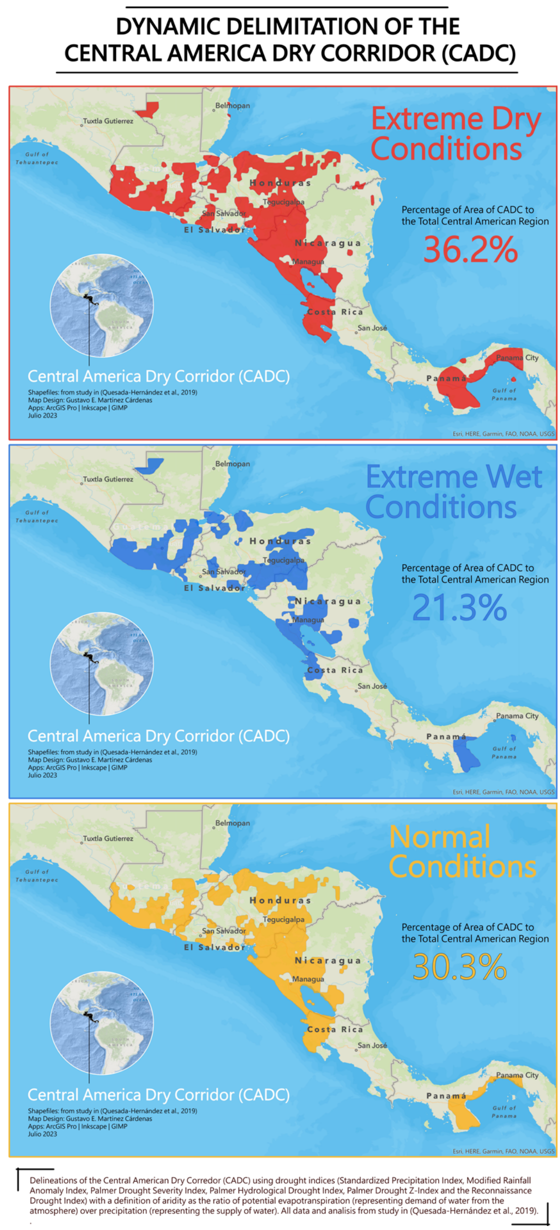

Figure 3. Delineation of Central American Dry Corridor under three different climate conditions. (Elaboration: Gustavo Martínez; Source: Quesada-Hernández et al., 2019).

Table 2. Three different climate conditions, total area of Central American Dry Corridor (CADC) and its area in Nicaragua. Source: Quesada-Hernández et al. (2019).

Dry Conditions	
Total Area of CADC 187 229km²	Area in Nicaragua 45 495 km²
Wet Conditions	
Total Area of CADC 110 502 km²	Area in Nicaragua 27 495 km²
Normal Conditions	
Total Area of CADC 156 870 km²	Area in Nicaragua 44 189 km²

such as exacerbating food insecurity in vulnerable areas, where 6 million Central Americans may be affected (El Economista, 2023) and a corresponding reduction and impact on water resources.

Increased aridity in forest areas, particularly in dry forests, also creates a significant susceptibility to increased wildfires due to potential evaporation increases (Bren, 2023). The ecological impact of these long-term changes at the forest level has yet to be studied. However, they could pose significant dangers to resilience, as the soil seed bank facilitating natural regeneration could be threatened. A recent study conducted in dry pine forests in the United States found that as aridity in dry forests increases, this reduces seed dormancy by up to 50%, which impacts seed bank productivity and the forest's ability to self-restoration in the long term (Petrie et al., 2017); with this, we can measure the threats that climate change represents for the dry forest ecosystem not yet quantified.

At the ecological scale, this can influence how species establish themselves in the ecosystem, where generalist species have better adaptation and therefore tend to expand their distribution, which generates greater resource competition for specialist species (Ness and Morin, 2008; Souza e Silva et al., 2019). Forests at the spatial scale are dynamic systems (Stand and Sanchez-Azofeifa, 2019), and the climatic and anthropogenic influence is raising new questions about their ecological significance.

The strip of tropical dry forests in the CADC is extremely fragmented and under risk of disappearance due to changes in land use, conversion to agriculture lands and cattle breeding pastures. Some droughts in particular are related to the anomalous distribution of precipitation during the rainy season specifically longer dry periods known as "canícula or veranillo." These longer dry periods during the rainy season are influenced by the higher ocean surface temperatures in the Pacific and reduced temperatures in Atlantic resulting in drier soils and more frequent dry periods. It has been predicted that this will cause an increase in aridity in a hotter climate in the future and prediction models of the Dry Corridor have shown significant tendencies in warmer temperature and less significative changes in total volume of precipitation. (Hidalgo et al., 2019). Temperature is increasing in all seasons and its further growth has been predicted for the future bringing increases in evapotranspiration and therefore higher demand for water from the atmosphere, drier soils, and higher aridity; consequently, affecting agriculture, ecosystems, and an increase in potential for forest fires (Hidalgo, 2021; Bren, 2023). Increasing arid conditions have a negative effect on the content of organic carbon and nitrogen in soils and therefore have less coverage of vegetation. This could also bring a decrease in groundwater storage and therefore more pressure on water resources for all uses. A reduction of soil fertility and less available water would bring social, economic, and ecological effects and the potential for restoration and adaptation to further climate change developments.

5. Changes in Land-Use and Habitat Loss in Tropical Dry Forest Areas of Nicaragua

Changes in human activities, such as modification of land use and the lack of practices of management of watersheds are the principle causes of the extreme fragmentation and decrease in area and type of coverage of the TDFs in Nicaragua.

Globally, tropical dry forests are known to be more conducive to pressures of land use changes that bring strong fragmentation and deforestation; they are more vulnerable also in particular as they are more attractive for human habitation and easier to clear for agriculture and pasture lands. Also, areas of dryland forests have higher belowground root biomass accounting for higher total organic matter in the soils (Murphy and Lugo, 1986; Trumper et al., 2008). These land-use changes that have led to fragmentation of the forests in Nicaragua have been induced with the objective of extending areas for agriculture and cattle grazing activities. A further factor is the deforestation due to use of firewood for domestic cooking use and conversion to carbon especially in rural areas where there are higher poverty rates. In a report from the Ministry of Environment and Natural Resources (MARENA, 2017), 87% of households consume firewood for cooking in the Pacific Ecological Zone I and 94% in the Central-North zone.

These changes increase tendencies to more intensive erosion processes in the former forest areas leading to impacts in waterbodies mainly surface waters and coastal areas. But this also presents risks for groundwater as massive deforestation affects infiltration processes that feed aquifers.

Globally the ecosystems of tropical dry forests are more exposed to the loss of biodiversity; of the 25 global hotspots exposed to loss of habitats and characterized for high level of endemism, 11 are located in tropical dry forests (Myers, et al., 2000). The remnants of forest are usually not connected or have no transition zones which means a loss of habitats causing reduction of biodiversity. This results in increases in the availability and number of invasive species in the landscape, where native flora is continuously replaced to meet the demand for fodder, bioinsecticides, food production, and even ornamentals. Invasive species are an ecological, economic, and even public health hazard, not to mention that they represent a driver of climate change (IPBES, 2019; Young et al., 2022).

Pollinators represent a group of species fundamental to the health of dry forests; these organisms of different species are part of the food chain of many carnivores, and they are also involved in seed dispersal and pollination of plants (Quesada et al., 2009). Habitat loss in the dry forest is causing a significant loss of stingless bee populations due to the anthropogenic impact of deforestation for agricultural purposes and the use of insecticides in this ecosystem. (May-Itzá et al., 2022). The Nicaraguan dry forest is not exempt from this threat, so its study and conservation should be a national priority.

The area of remnants of tropical dry forests in Nicaragua has been analyzed according to land-use in 2015 resulting in the following map (see Figure 4) where 9,279.77 km^2 are used as pasture lands and 3,968.93 km^2 as annual or permanent agricultural crops.

The largest watershed area represented in TDF area, Río San Juan (952) predominantly shows land-use as pastures, annual agricultural crops and bushy scrubland and the second largest watershed, Pacific (9533) as predominantly permanent crop cultivation, sparse broadleaf forests and pasture lands.

The changes in vegetation coverage due to the constant modification of land-use affect the forest hydrology which brings consequences such as the reduction of the resilience to climate change and could bring alterations of the local and regional climate. There is a clear overexploitation of the territory in favor of agricultural and pasture use that have caused the severe fragmentation and reduction of the tropical dry forests; therefore, there is a complete absence of control and regulation directed to the protection of groundwater, inland surface waters, coastal marine areas and hotspots of biodiversity. A reduction of soil fertility and availability of water would bring social, economic, and ecological affects and further reduce the potential for restoration and adaptation to coming climate change developments. The heavy withdrawal of water for agriculture use complicates more the unsustainable management of these resources. This reduction of vegetation and fragmentation has led to severe losses of habitat of the special biodiversity of tropical dry forests. This leaves the area of the tropical dry forests completely open to the impacts of climate change which could mean increasing aridity and the mentioned consequences for water resources and biodiversity. Land use exerts severe pressure on the soil, an element of biodiversity that we do not often mention but whose alterations and erosion of its richness and productivity directly affect the food security of several organisms, including humans (Mujtar et al., 2019).

6. Sustainable Forest Ecosystem Management-Is There a Path Forward for the Tropical Dry Forests of Nicaragua?

Globally forests contain 50% of carbon reserves and 75% of inland waters come from forest watersheds (Newton, 2021).

Due to the special vulnerability of tropical dry forests combined with the oncoming consequences of climate change and the present conditions in Nicaragua of extreme fragmentation and reduction of vegetation coverage, it is urgent to design a program to meet the challenges of climate change and stop the extreme land-use changes with measures and components of a program of regulation

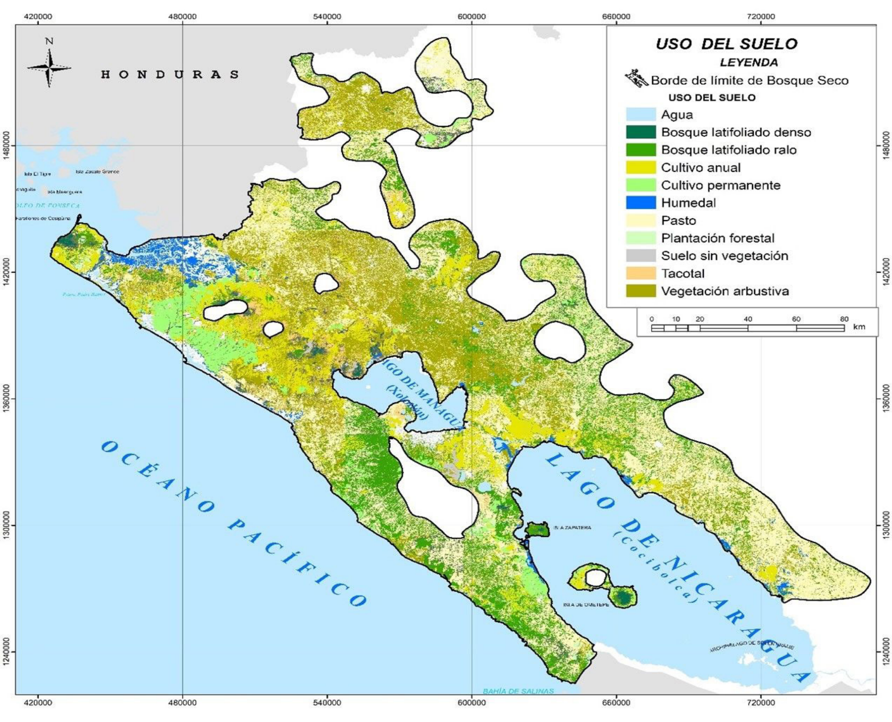

Figure 4. Land-use (2015) in the area of Tropical Dry Forests of Nicaragua. (Elaboration: Ing. Muriel Ríos; Source: INETER, 2015).

and control of the specific causes of deterioration of the forests and other corresponding resources such as water, biodiversity and soil. One component should include the integral management of the 4 watersheds that make up the area of the remnants of tropical dry forests.

Due to their high vulnerability to climate change and pressures from land use changes, it is even more important to have a better understanding of the complexity of dryland forest ecosystems. Research is needed emphasizing forest hydrology and other necessary interdisciplinary studies of resources such as water, soil and conditions for restoring biodiversity especially with native species of vegetation that can survive a certain degree of aridity and other climate change impacts. This knowledge should be promoted to obtain input for the better design of protection measures and to restore connecting areas of the tropical dry forest remnants. These investigations should take into consideration areas where there are special needs of protection and conservation of groundwater aquifers, surface waters and coastal areas under threat from climate change and further overexploitation processes. It is also important to identify areas with hotspots in biodiversity of national and international interests.

Payment for ecosystem services is an incentive that has given good results in conservation support policies (Becerra et al., 2021). This type of incentive has been suspended in Nicaragua (Saldivar, 2021), but it could be part of an essential strategy to promote efficient and environmentally friendly land use.

Certain measures to overcome drought periods should be introduced such as water harvesting, and natural restoration combined with reforestation efforts. The use of certain organisms such as arbuscular mycorrhizae (Auge, 2004) and ectomycorrhizas (Lehto and Zwiazek, 2011), to improve water absorption and nutrient uptake and therefore restoring soils of the territory, could be applied.

There have been individual protection and restoration initiatives from private-sector companies including those using groundwater and surface waters to irrigate their agricultural products, non-governmental organizations, and other environmental institutions:

A study conducted in the Asese Peninsula in Granada, Nicaragua, found that the vegetation composition in dry forest species was persistent in an analyzed period of 1200 years. The research found a great resilience capacity of dry forest vegetation species to adapt to the changes to which this ecosystem is subjected, such as anthropogenic disturbances, variations in the rainfall regime, and forest fires mainly (Harvey et al., 2019).

Based on this resilience capacity, strategic forest restoration and forest management play an essential role in the conservation of this ecosystem. In Nicaragua, some experiences have demonstrated this, such as the work carried out by different researchers and collaborators with the NGO, Paso Pacifico, where significant efforts and studies have been undertaken to improve the conditions of the dry forests. They work with a method where restoration occurs in a "strategic" way to accelerate the assembling tree and shrub species that help maintain wildlife habitat.

In 2007, they restored some 400 ha of dry forest and forest in transition in the department of Rivas. They planted 70 species of trees in 4x4 squares and assisted natural regeneration by clearing competing vegetation from young trees. As a result of this work, they observed in seven years that the average carbon increased almost three times, from 21.5±5.0 to 57.9±9.6 SE tons/ha, coinciding with values of much older forests (20 years). Also, significant increases were observed in species richness from 36 to 96 species. With this, the return to the area of sensitive species, such as the Spider Monkey, was observed in the trees of the restored site (Guillen et al., 2015).

Forest conservation is not a task exclusively for NGOs; considerable research shows that sustainable agriculture management through silvopastoral systems can also be a conservation tool. Through corporate social responsibility activities, private enterprises can also be actors of change, such as Private Wildlife Reserves, which are also ecotourism enterprises; private companies can provide support in assisted reforestation, environmental education, and water availability in the communities.

One example of private management and restoration of a segment of tropical dry forests (434 hectares) is *Reserva Natura* (Saenz, In press) which originated as a program of water compensation in private land from a company dedicated to sugar cane production. The forest reserve has had a continuation now for 16 years and has included interdisciplinary studies and application of a practical management strategy involving 40 different specialists in different sectors of environmental conservation.

Their mission was defined as "The conservation and development of forests to increase the infiltration of water to maintain a water reservoir in the site of the *Reserva Natura*. Transform the site into a reference area for national educational efforts for the management and conservation to demonstrate the assets and environmental services of tropical dry forests. The management demonstrates that conservation of forests brings economic, social and ecological sustainability; from this base of scientific-technical information generated by professionals in forestry, agriculture, economy, biology, ecology, hydrology and more, it is possible to design viable public policies." (see Figure 5) (Saenz, in press).

7. Conclusions

In Nicaragua, 3.9 million people live in the dry forest, where the most important commercial and industrial activity occurs at the national level (MARENA, 2017). In Nicaragua, sparse broadleaf forests dominate the dry forest cover at 51.6%. In particular, it is predominantly located in the largest watershed of Nicaragua, called San Juan River (952) and 45% of this ecosystem is located in the Pacific Basin (9533). The largest area of remaining dense broadleaf forest is located over 2 of the principal aquifers: Occidente and Malpaisillo. (Vammen et al., pending publication).

Due to the particular vulnerability of tropical dry forests combined with the oncoming consequences of climate change and the current conditions in Nicaragua of extreme fragmentation and reduction of vegetation cover, it is urgent to design a program to face the challenges of climate change and to guarantee the sustainability of the forest

Figure 5. a) Reservoirs of water conservation in *Reserva Natura* b) Reforestation initiatives with community and institutional participation in Reserva Natura. Source: (Saenz, in press).

and the availability of water. Scientific research should emphasize forest hydrology, specific nutrient cycling in dry forest and interdisciplinary studies to ensure biodiversity and social sustainability. The TDF have a high resilience capacity (Harvey et al., 2019), and because of this, strategic forest restoration and management play an essential role in the conservation of this ecosystem so important to the maintenance of natural resources of Nicaragua.

Nicaragua is a country rich in natural resources which bring a substantial potential to meet the challenge of climate change; therefore, the protection and conservation of its natural resources such as forests, water and biodiversity are key for an improved sustainable development in the future.

Considering the area of dryland forests is similar to that of tropical moist forests (Bastin et al., 2017), a better understanding, management and maintenance of tropical dry forests is gaining more importance and have a broader applicability globally as they are more vulnerable to climate change and more exposed to land use changes. Their strong interrelationship to water resources reinforces the need for special management steps for their restoration and protection.

References

ALIANZA PARA LA CONSERVACIÓN DEL BOSQUE SECO, 2011 [viewed 14 November 2023]. Programa nacional para la conservación,restauración y manejo del ecosistema de bosque seco en Nicaragua. Manágua: Alianza del Bosque Seco. 74 p. Available from: https://pasopacifico.org/wp-content/uploads/2019/09/programa-bosque-seco-nicaragua-fundenic-2011.pdf.

AUGÉ, R.M., 2004. Arbuscular mycorrhizae and soil/plant water relations. *Canadian Journal of Soil Science*, vol. 84, no. 4, pp. 373-381. http://doi.org/10.4141/S04-002.

BASTIN, J.F., BERRAHMOUNI, N., GRAINGER, A., MANIATIS, D., MOLLICONE, D., MOORE, R., PATRIARCA, C., PICARD, N., SPARROW, B., ABRAHAM, E.M., ALOUI, K., ATESOGLU, A., ATTORE, F., BASSÜLLÜ, Ç., BEY, A., GARZUGLIA, M., GARCÍA-MONTERO, L.G., GROOT, N., GUERIN, G., LAESTADIUS, L., LOWE, A.J., MAMANE, B., MARCHI, G., PATTERSON, P., REZENDE, M., RICCI, S., SALCEDO, I., DIAZ, A.S.-P., STOLLE, F., SURAPPAEVA, V. and CASTRO, R., 2017. The extent of forest in dryland biomes. *Science*, vol. 356, no. 6338, pp. 635-638. http://doi.org/10.1126/science.aam6527 PMid:28495750.

BECERRA, V., BEIZAGA, W. and VARGAS, R., 2021. Analysis of willingness to pay for ecosystem services: a review article. *Semestre Económico*, vol. 10, no. 1, pp. 93-104. http://doi.org/10.26867/se.2021.v10i1.115.

BERNEX, N., 2021. La Crisis Ecológica y los Ecosistemas Boscoso-Tropicales. In: G.L. DE MORI, M. BECKA and J.P. ANTONY, (eds.) *Amazonia: Don y Tarea*. Madrid: Concilium, pp. 505-517

BREN, L., 2023. *Forest hydrology and catchment management*. Cham: Springer, pp. 329-357. http://doi.org/10.1007/978-3-031-12840-0_13.

BUSTILLO, I., 2017. *Composición, Estructura y Dinámica de las Especies Arbóreas del Bosque de Galería de la Reserva Hídrica Forestal, Río Malacatoya, 2015-2016.* Managua: Universidad Nacional Agraria.

CALDWELL, M.M., DAWSON, T.E. and RICHARDS, J.H., 1998. Hydraulic lift: consequences of water efflux from the roots of plants. *Oecologia*, vol. 113, no. 2, pp. 151-161. http://doi.org/10.1007/s004420050363 PMid:28308192.

CASTRO-MARÍN, G., 2005 [viewed 14 November 2023]. *Stand dynamics and regeneration of tropical dry forest in Nicaragua*. Umeå: Swedish University of Agricultural Sciences. Available from: http://www.bio-nica.info/Biblioteca/Castro2005RegenerationDryForest.pdf.

CENTRO HUMBOLDT. FUNDACIÓN DEL RÍO, HEINRICH BÖLL STIFTUNG, 2018 [viewed 14 November 2023]. *Evaluación ecológica de los daños provocados por el huracán Otto y el incendio en la reserva de biosfera del Sur Este*. Managua: Centro Humboldt. Available from: https://sv.boell.org/sites/default/files/2021-03/Estudio-Evaluacion-Ecologica-INDIO-MAIZ-vf.pdf.

CHOOKSY, P., 2022 [viewed 14 November 2023]. Examining patterns and impacts of forest resource extraction and forest degradation in tropical dry forest. In: M. KHOWROW-POUR, ed. *Research anthology on ecosystem conservation and preserving biodiversity*. Pensilvania: IG Global. Available from: https://www.igi-global.com/chapter/examining-patterns-and-impacts-of-forest-resource-extraction-and-forest-degradation-in-tropical-dry-forests/303199.

CONVENCIÓN SOBRE EL COMERCIO INTERNACIONAL DE ESPECIES AMENAZADOS DE FAUNA Y FLORA SILVESTRES – CITES, 2010 [viewed 14 November 2023]. *Listados actualizados de las especies de fauna y flora.* CITES. Available from: http://www.caftadrenvironment.org/spanish/outreach/publications/CITES%20Updated%20Fauna%20and%20Flora%20Species%20(Spanish).pdf.

DELGADO, V., 2003 [viewed 14 November 2023]. *Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua.* Calgary: University of Calgary, 196 p. Master thesis. Available from: http://repositorio.unan.edu.ni/2649.

DRYFLOR, K.B., DELGADO-SALINAS, A., DEXTER, K.G. and PENNINGTON, R.T., 2016. Plant diversity patterns in neotropical dry forests and their conservation implications. *Science*, vol.

353, no. 6306, pp.1383-1387. https://science.sciencemag.org/content/353/6306/1383.

EL ECONOMISTA, 21 July 2023 [viewed 14 November 2023]. *Sequía en Corredor Seco coloca en inseguridad alimentaria a 6 millones de centroamericanos*. El Economista. Available from: https://www.eleconomista.net/centroamerica/Sequia-en-Corredor-Seco-coloca-en-inseguridad-alimentaria-a-6-millones-de-centroamericanos-20230621-0021.html.

FOOD AND AGRICULTURE ORGANIZATION – FAO, 2012 [viewed 14 November 2023]. *Caracterización del Corredor Seco Centroamericano*. Rome: FAO. Available from: https://bibliotecasemiaridos.ufv.br/bitstream/123456789/367/1/Texto%20completo.pdf.

FOOD AND AGRICULTURE ORGANIZATION – FAO. AQUASTAT, 2022 [viewed 14 November 2023]. *Database Query Results, Central America*. FAO/AQUASTAT. Available from: https://www.fao.org/aquastat/statistics/query/index.

GILLESPIE, T.W., GRIJALVA, A. and FARRIS, C.N., 2000. Diversity, composition, and structure of tropical dry forests in Central America. *Plant Ecology*, vol. 147, no. 1, pp. 37-47. http://doi.org/10.1023/A:1009848525399.

GONZÁLEZ DE ANDRÉS, E., SEELY, B., BLANCO, J.A., IMBERT, J.B., LO, Y.H. and CASTILLO, F.J., 2017. Increased complementarity in water-limited environments in Scots pine and European beech mixtures under climate change. *Ecohydrology*, vol. 10, no. 2, pp. e1810. http://doi.org/10.1002/eco.1810.

GONZÁLEZ HERNÁNDEZ, A., PÉREZ MIRANDA, R., MORENO SÁNCHEZ, F., RAMÍREZ OJEDA, G., ROSALES MATA, S. and CANO PINEDA, A., 2015. Variabilidad de la temperatura local en bosques de coníferas por efectos de la deforestación. *Revista Mexicana de Ciencias Forestales*, vol. 6, no. 31, pp. 22-39. http://doi.org/10.29298/rmcf.v6i31.193.

GRATEROL MATUTE, E.J., PULVER, E., JARAMILLO CARDONA, S., URIOSTE DAZA, S.A., LABARTA, R.A. and ARANA SALAZAR, J.A., REYES, B., OBANDO, M. and MORENO, C., 2019 [viewed 14 November 2023]. *Estrategia de diversificación y aumento de la productividad a en el corredor seco de Nicaragua con base en la gestión integral del recurso hídricos*. Banco Interamericano de Desarrollo-BID. Available from: https://publications.iadb.org/es/estrategia-de-diversificacion-y-aumento-de-la-productividad-agropecuaria-en-el-corredor-seco-de.

GUILLÉN, W.K., OTTERSTROM, S. and PERLA, C., 2015 [viewed 14 November 2023]. *Diversified native species Restoration for Recovery of Multiple Ecosystem Services in a Highly Disturbed Trupical Dry Forest Landscape of Southwestern Nicaragua*. Washington, D.C.: American Geophysical Union. Available from: https://ui.adsabs.harvard.edu/abs/2015AGUFM.B23F0660W/abstract.

HARVEY, J.W., STANSELL, N., NOGUÉ, S. and WILLIS, K.J., 2019. The apparent resilience of dry tropical forests of the nicaraguan region of the central american dry corridor to variations in climate over the last C.1200 years. *Quaternary*, vol. 2, no. 3, pp. 25. http://doi.org/10.3390/quat2030025.

HIDALGO, H.G., 2021. Climate variability and change in Central America: what does it mean for water managers? *Front. Water*, vol. 2, pp. 632739. http://doi.org/10.3389/frwa.2020.632739.

HIDALGO, H.G., ALFARO, E.J., AMADOR, J.A. and BASTIDAS, A., 2019. Precursors of quasi-decadal dry-spells in the Central America Dry Corridor. *Climate Dynamics*, vol. 53, no. 3-4, pp. 1307-1322. http://doi.org/10.1007/s00382-019-04638-y.

INSTITUTO NACIONAL DE INFORMACIÓN DE DESARROLLO – INIDE, 2020. *Anuario Estadístico 2020*. Managua: INIDE.

INSTITUTO NICARAGÜENSE DE ESTUDIOS TERRITORIALES – INETER, 2010 [viewed 4 February 2022]. *Mapa de Precipitación Media anual en milímetros (Periodo 1971-2010)*. Managua: INETER. Available from: https://www.ineter.gob.ni/documentos/atlas-climatico-precip-web.pdf.

INSTITUTO NICARAGÜENSE DE ESTUDIOS TERRITORIALES – INETER, 2017. *Red de monitoreo de acuíferos de Nicaragua*. Managua: INETER.

INSTITUTO NICARAGÜENSE DE ESTUDIOS TERRITORIALES – INETER. INSTITUTO NACIONAL DE TECNOLOGÍA AGROPECUARIA – INTA, INSTITUTO NACIONAL FORESTAL – INAFOR, MINISTERIO AGROPECUARIO Y FORESTAL DE NICARAGUA – MAGFOR, UNIVERSIDAD NACIONAL AGRARIA – UNA, 2015 [viewed 4 February 2022]. *Mapa de cobertura de uso de suelos y uso potencial*. Managua: INETER. Available from: https://www.ineter.gob.ni/geoportales/atlasnacionalsuelo/index.html.

INTERGOVERNMENTAL SCIENCE-POLICY PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES – IPBES, 2019. [viewed 4 February 2022]. *Summary for policymakers of the IPBES global assessment report on biodiversity and ecosystems services*. IPBES. Available from: https://ipbes.net/global-assessment.

JÓVENES AMBIENTALISTAS DE NICARAGUA, 2018. *Lista Roja, Todo sobre el estado de la fauna silvestre vertebrada de Nicaragua*. Gland: IUCN Library System. Available from: https://portals.iucn.org/library/node/48418.

LA PRENSA, 23 April 2017. *La Fiebre del Oro en Villanueva, Nicaragua*. La Prensa. Available from: https://www.laprensani.com/2017/04/23/suplemento/la-prensa-domingo/2217943-la-fiebre-del-oro-en-villanueva-nicaragua.

LEHTO, T. and ZWIAZEK, J., 2011. Ectomycorrhizas and water relations of trees: a review. *Mycorrhiza*, vol. 21, no. 2, pp. 71-90. http://doi.org/10.1007/s00572-010-0348-9 PMid:21140277.

MAES, J., SALDÍVAR, I, RIOS, M. and GUEVARA, J. [In Press]. Delimitando y caracterizando el bosque seco tropical nicaraguense. In: I. SALDÍVAR, ed. *Historia Natural del Bosque Tropical Seco de Nicaragua*. Managua: Revista Nicaragüense de Biodiversidad.

MAY-ITZÁ, W.J., MARTÍNEZ-FORTÚN, S., ZARAGOZA-TRELLO, C. and RUIZ, C., 2022. Stingless bees in tropical dry forests: global context and challenges of an integrated conservation management. *Journal of Apicultural Research*, vol. 61, no. 5, pp. 642-653. http://doi.org/10.1080/00218839.2022.2095709.

MILES, L., NEWTON, A.C., DEFRIES, R.S., RAVILIOUS, C., MAY, I., BLYTH, S., KAPOS, V. and GORDON, J.E., 2006. A global overview of the conservation status of tropical dry forests. *Journal of Biogeography*, vol. 33, no. 3, pp. 491-505. http://doi.org/10.1111/j.1365-2699.2005.01424.x.

MINISTERIO AGROPECUARIO Y FORESTAL – MAGFOR, 2000 [viewed February 2022]. *Valoración Forestal Nicaragua 2000*. Managua: MAGFOR. Available from: https://www.yumpu.com/es/document/view/38160632/valoracion-forestal-nicaragua-2000-magfor.

MINISTERIO DEL AMBIENTE Y LOS RECURSOS NATURALES – MARENA, 2017 [viewed February 2022]. *Estudios de las causas de deforestación y degradación forestal. La problemática de las existencias de carbono forestal, en el marco de la ENDEREDD+*. Managua: MAGFOR. Available from: http://www.marena.gob.ni/Enderedd/otros/indicadores- deresultados.

MONTENEGRO, G.S. and JIMÉNEZ, G.M., 2009. Residuos de plaguicidas en agua de pozos en Chinandega, Nicaragua. *Universidad y Ciencia*, vol. 4, no. 7.

MUJTAR, V.E., MUÑOZ, N., MC CORMICK, B., PULLEMAN, M. and TITONELL, P., 2019. Role and management of soil biodiversity for food security and nutrition; where do we stand? *Global Food Security*, vol. 20, pp. 132-144. https://doi.org/10.1016/j.gfs.2019.01.007.

MURPHY, P. and LUGO, A., 1986. Nutrient dynamics of a Puerto Rican subtropical dry forest. *Journal of Tropical Ecology*, vol. 2, no. 1, pp. 55-72. https://doi.org/doi:10.1017/S0266467400000602.

MYERS, N., MITTERMEIER, R., MITTERMEIER, C., DA FONSECA, G.A.B. and KENT, J., 2000. Biodiversity hotspots for conservation priorities. *Nature*, vol. 403, no. 6772, pp. 853-858. http://doi.org/10.1038/35002501 PMid:10706275.

NESS, J.H. and MORIN, D.F., 2008. Forest edges and landscape history shape interactions between plants,seed-dispersing ants and seed predators. *Biological Conservation*, vol. 141, no. 3, pp. 838-847. http://doi.org/10.1016/j.biocon.2007.12.029.

NEWTON, A.C., 2021. *Ecosystem Collapse and Recovery, Ecology, Biodiversity and Conservation.* Cambridge: Cambridge University Press. http://doi.org/10.1017/9781108561105.

PETRIE, M.D., BRADFORD, J.B., HUBBARD, R.M., LAUENROTH, W.K., ANDREWS, C.M. and SCHLAEPFER, D.R., 2017. Climate change may restrict dryland forest regeneration in the 21st century. *Ecology*, vol. 98, no. 6, pp. 1548-1559. http://doi.org/10.1002/ecy.1791 PMid:28266031.

QUESADA, M., SANCHEZ-AZOFEIFA, G.A., ALVAREZ-AÑORVE, M., STONER, K.E., AVILA-CABADILLA, L., CALVO-ALVARADO, J., CASTILLO, A., ESPÍRITO-SANTO, M.M., FAGUNDES, M., FERNANDES, G.W., GAMON, J., LOPEZARAIZA-MIKEL, M., LAWRENCE, D., MORELLATO, L.P.C., POWERS, J.S., NEVES, F.S., ROSAS-GUERRERO, V., SAYAGO, R. and SANCHEZ-MONTOYA, G., 2009. Succession and management of tropical dry forests in the Americas: review and new perspectives. *Forest Ecology and Management*, vol. 257, no. 6, pp. 1014-1024. http://doi.org/10.1016/j.foreco.2009.06.023.

QUESADA-HERNÁNDEZ, L.E., CALVO-SOLANO, O.D., HIDALGO, H.G., PÉREZ-BRICEÑO, P.M. and ALFARO, E.J., 2019. Dynamical delimitation of the Central America Dry Corridor (CADC) using drought indices and aridity values. *Progress in Physical Geography: Earth and Environment*, vol. 43, no. 5, pp. 627-642. http://doi.org/10.1177/0309133319860224.

RUMIZ, D., 2009 [viewed February 2022]. Manejo de fauna y conservación a nivel de paisaje en los bosques secos de Santa Cruz. In: *Memorias Simposio XXX Aniversario Instituto de Ecología. Conference: Simposio XXX Aniversario Instituto de Ecología.* 2009, La Paz. La Paz: Universidad Mayor de San Andrés, pp. 293-302. Available from: https://www.researchgate.net/publication/265162892_Manejo_de_fauna_y_conservacion_a_nivel_depaisaje_en_los_bosques_secos_de_Santa_Cruz.

RUNYAN, C. and D'ODORICO, P., 2016. *Global Deforestation*. Cambridge: Cambridge University Press. http://doi.org/10.1017/CBO9781316471548.

RUNYAN, C.W., D'ODORICO, P. and LAWRENCE, D., 2012. Effect of repeated deforestation on vegetation dynamics for phosphorus-limited tropical forests. *Journal of Geophysical Research. Biogeosciences*, vol. 117, no. G1, pp. G01008. http://doi.org/10.1029/2011JG001841.

SAENZ, R., [In Press]. Experiencias en Restauración de Bosque Seco, pending publication. In: I. SALDÍVAR, ed. *Historia Natural del Bosque Tropical Seco de Nicaragua*. Managua: Revista Nicaragüense de Biodiversidad.

SALAS, J.B., 1993 [viewed February 2022]. Árboles de Nicaragua. Managua: Instituto Nicaragüense de Recursos Naturales y del Ambiente – IRENA. Available from: https://bibliotecadigital.infor.cl/handle/20.500.12220/562.

SALDÍVAR, I. [In Press]. Vegetación Bosque Tropical Seco. In: I. SALDÍVAR, ed. *Historia Natural del Bosque Tropical Seco de Nicaragua*. Managua: Revista Nicaragüense de Biodiversidad.

SALDÍVAR, I., 2021. Gestión de la Conservación de los bosques nicaragüenses, un reto multisectorial. In*: La Investigación científica para la incidencia social y ambie*ntal. Ensayos Universitarios sobre problemas nacionales. Cádiz: UCA Publicaciones, pp. 157-166.

SILVA, L.S., CRUZ-NETO, O., PERES, C.A., TABARELLI, M. and LOPES, A.V., 2019. Climate change will reduce suitable Caatinga dry forest habitat for endemic plants with disproportionate impacts on specialized reproductive strategies. *PLoS One*, vol. 14, no. 5, pp. e0217028. http://doi.org/10.1371/journal.pone.0217028 PMid:31141533.

STAND, K. and SANCHEZ-AZOFEIDA, A., 2019. Tropical Dry Forest Diversity, Climatic Response, and Resilience in a Changing Climate. *Forests*, vol. 10, no. 5, pp. 443. http://doi.org/10.3390/f10050443.

TARRASÓN, D., URRUTIA, J.T., RAVERA, F., HERRERA, E., ANDRÉS, P. and ESPELTA, J.M., 2009. Conservation status of tropical dry forest remnants in Nicaragua: do ecological indicators and social perception tally? *Biodiversity and Conservation*, vol. 19, no. 3, pp. 813-827. http://doi.org/10.1007/s10531-009-9736-x.

TRUMPER, K., RAVILIOUS, C. and DICKSON, B., 2008 [viewed February 2022]. Carbon in Drylands: Desertification, Climate Change and Carbon Finance. UNEP-UNDP-UNCCD Technical Note for Discussions. In: *CRIC 7*, 2008, Istanbul. Istanbul: CRIC. Available from: https://wedocs.unep.org/20.500.11822/8692.

VAMMEN, K. and PEÑA, E., 2022. Water and climate: global environmental sustainability and the current state in a developing country, Nicaragua. *Front. Water*, vol. 4, pp. 975102. http://doi.org/10.3389/frwa.2022.975102.

VAMMEN, K., PEÑA, E. and RÍOS, M. [In Press]. Bosque Seco y Agua. In: I. SALDÍVAR, ed. *Historia Natural del Bosque Tropical Seco de Nicaragua*. Managua: Revista Nicaragüense de Biodiversidad.

WEISSE, M. and GOLDMAN, L., 2020 [viewed 11 November 2023]. *La Destrucción de los Bosques Primarios Aumentó un 12% de 2019 a 2020. Global Forest Watch.* Available from: https://www.globalforestwatch.org/blog/es/data-and- research/datos-globales-de-perdida-de-cobertura-arborea-2020/.

YOUNG, L.S., KIMBALL, S. and NOVAK, B., 2022 [viewed 11 November 2023] *Invasion of Plant Communities*. USDA-ARS/UNL. Available from: https://digitalcommons.unl.edu/usdaarsfacpub/2529.

ZAMBRANA, M., 2010. *Caracterización de la Flora y Estructura de un Bosque Transicional Húmedo a Seco Miramar, Puntarenas, Costa Rica.* Cartago: Instituto Tecnológico de Costa Rica.