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A Conservation Model: Costa Rican conservation strategies effectively preserve their threatened primates

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A Conservation Model:

Costa Rican conservation strategies effectively preserve their threatened primates

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ABSTRACT

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A Conservation Model:

Costa Rican conservation strategies effectively preserve their threatened primates.

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Reader's Name: Mike Ghedotti Ph.D.

The wildlife of Costa Rica has experienced various anthropogenic threats over the last century including climate change and agricultural expansion. The mantled howler monkey (*Alloutta palliata*), Central American spider monkey (*Ateles geoffroyi*), white-faced capuchin (*Cebus imitator*), and the Central American squirrel monkey (*Saimiri oerstedii*) are Costa Rica's native primates that face several anthropogenic threats such as deforestation for agriculture and climate change. In response to increased threats to its four native species of non-human primates, Costa Rica has implemented effective governmental conservation tactics such as the Payments for Environmental Services program, ecotourism within protected areas, and various laws implemented to protect and preserve these primates and ensure a balanced rainforest ecosystem. Through the analysis of these conservation efforts made by the Costa Rican government and local organizations, this thesis aims to challenge primate conservation tactics in other countries hosting nonhuman primates to reform current regulations and implement new standards to protect their native primate species whose current populations have been recognized as having conservations statuses that range from "vulnerable" to "critically endangered" through the example of Costa Rican tactics and implementations.

Introduction

Costa Rica is one of the most biodiverse places on earth, approximately containing nearly 6% of the world's biodiversity and accounting for nearly half a million species (Johnston, 2022). Among these species, Costa Rica is home to four native primates known as the Central American squirrel monkey (*Saimiri oerstedii*), the white-faced capuchin (*Cebus capucinus imitator),* the mantled howler monkey (*Alouatta palliata),* and the Central American spider monkey (*Ateles geoffroyi)*, facing various anthropogenic stressors such as deforestation and climate change. Due to impending environmental threats that Costa Rica has experienced over the course of more than a hundred years, the collaboration of the Costa Rican government and various organizations have implemented many laws and regulations in order to prevent and combat the destruction of natural habitats and the organisms that they contain. One of the first major steps towards the country's conservation tactics was the creation of the first national park within Costa Rica, Poas Volcano National Park, in 1970. Due to the beauty and uniqueness of Costa Rica's landscape, this national park allowed visitors to see and support its protection through donations that enabled the creation of more national parks throughout the country (University of Michigan). Now Costa Rica contains 29 national parks that cover over more than 25% of the land mass of the country itself, making it the country with largest percentage of protected areas (Global Alliance of National Parks).

Another notable conservation policy, first started in 1966 within Costa Rica, is the Payments for Environmental Services (PES) Program. Through this program, landowners are paid for the ecosystem services that their land provides, as well as for dedicating their environmental practices to sustainability and conservation (United Nations Climate Change). Ecosystem services such as the protection of wildlife biodiversity and sustainable land practices are just some tactics that landowners have the opportunity to be paid for (Rodricks, 2010). By committing to several different sustainable forest management contracts, often for periods of 15 years, landowners can receive up to $537 per hectare for their service to the protection of Costa Rica's natural environments (Malavasi & Kellenberg, 2002). The need for these services became vital when Costa Rica began losing significant percentages of their tropical rainforests each year due to deforestation (Pearce, 2023). These tactics and services, along with various other efforts, have played major roles in protecting and restoring the landscapes and biodiversity of primates within Costa Rica after its rapid destruction began with agriculture. The collaboration between governmental regulation and the Costa Rican population has been a vital contributor to the success of restoration which makes Costa Rica a valuable template for other regions containing similar primates and ecosystems.

The planned creation of The Electric Passenger Train of the Greater Metropolitan Area of Costa Rica reveals Costa Rica's major step forward in lessening carbon emissions that contribute to climate change (UNEP). This project will not only decrease the country's overall emissions but will also create many employment opportunities for the nation's citizens (Central American Bank). Costa Rica's Nationally Determined Contribution plan in alignment with the Paris Agreement of 2015 to keep emissions low enough to follow the 1.5-Celsius temperature trajectory has led to the creation of many laws and regulations that limit and restrict certain practices that significantly contribute to the climate change crisis. By creating guidelines and timelines pertaining to national emissions goals, it has given the nation accountability in their own role towards lessening the overall global emissions (Contribucion Nationalmente, 2020).

Through efficient efforts Costa Rica has succeeded in lessening the rates of deforestation within the country as well as reversing deforestation itself by reforesting areas to expand overall forest cover that result in increased canopy heights and increase forest areas (Kerr et al., 2003; Johnson et al., 2023). The regeneration of tropical rainforests throughout the country has allowed wildlife populations that were once significantly affected by the consequences of deforestation to rebound (Fedigan & Jack, 2001). Combatting stressors that influence the effects of climate change will secure the survival of many species that are sensitive to the changes caused by climate changes' effects on their own ecosystems. Costa Rica's use of ecotourism is a valuable tool in promoting their conservation efforts. By creating new employment opportunities, making monetary profit that allows for the continuation of conservation efforts, and the protection of ecosystems, ecotourism ensures the success and survival of many platforms that are necessary to promoting conservation. Although ecotourism could result in negative consequences if done incorrectly, Costa Rica has been able to find a balance that promotes conservation in the least invasive form to their wildlife. Because of this, Costa Rica serves as an efficient model for other nations hosting native primates in need of enhanced conservation efforts in order to ensure the survivability of their species. Through the collective contributions of ecotourism, the PES program, Costa Rica's NDC, and other environmental services previously mentioned, they have outlined an adequate template for the conservation of other regions.

Chapter 1: Costa Rican habitat structures, economy, and wildlife

Costa Rica is nearly 21,000 square miles which is only slightly smaller than the U.S. state of West Virginia (Figure 1.1). As of 2020, its current human population size was just under five million people, which is relatively low compared to other nearby regions (Bateman, 2020). The main economic industries for export from Costa Rica include medical instruments, electronics, fruit and nuts, and machinery. Exports of agricultural products in Costa Rica reached nearly $1.14 billion dollars, where bananas and plantains, coffee, processed and unprocessed fruits and vegetables were the main products, making it a substantial contributor to the world production of essential agriculture that is vital to its own economy (The Observatory of Economic Complexity). The volume of export of both bananas and coffee between 1890-1977 exponentially rose allowing Costa Rica to produce nearly one fifth of the fruit entering world trade (Hall, 1985).

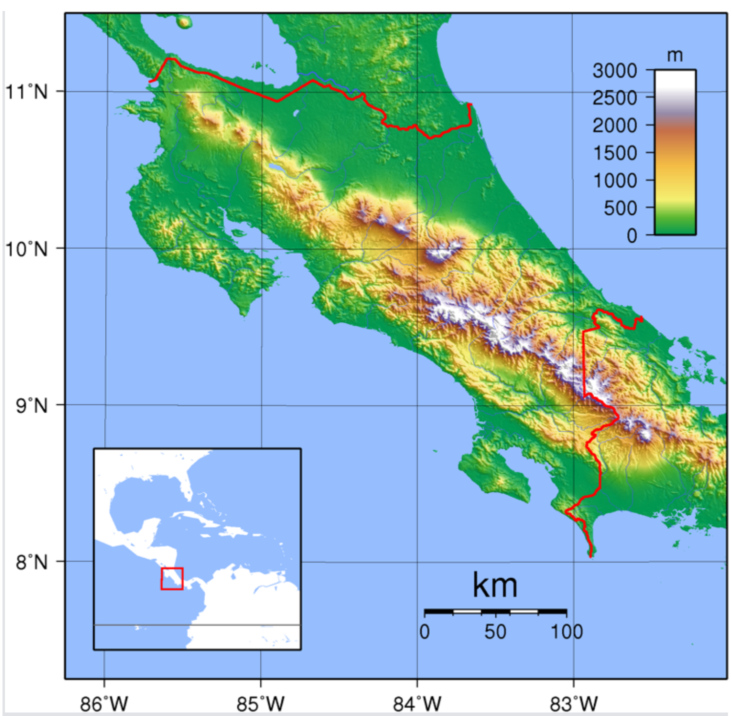

Figure 1.1 Topographic Map of Costa Rica. (Wikimedia Foundation)

Although classified as a third world country, Costa Rica is one of the least impoverished nations within this category (Evans, 2010). In addition, Costa Rica has the highest per capita income, literacy rates, and formal education of all third world countries (Evans, 2010). Much of Costa Rica's opportunity wealth is linked to the distribution of their federal funds via the abolishment of their military in 1948. Because of this act by then-president José Figueres, Costa Rica was able to put their funds into assets they deemed vital to the integrity of their country and the health of its people such as clean water and health resources (Biesanz et al., 1999). One of the major uses of these funds is wildlife and environmental conservation (Evans, 2010). Costa Rica contains numerous national parks, refuges, and reserves that dedicate much of their service to wildlife and environmental conservation in this immensely biodiverse region. Costa Rica contains some of the highest biodiversity in the world with species diversity surpassing both the United States and Canada combined. This is mostly due to its wide variety of mountain ranges (Central, Guanacaste, Talamanca Cordilleras) and what scientists call "the biological bridge and filter" (Evans, 2010), connecting a bridged space for species between North and South America.

Costa Rica contains five life zones. The tropical zones (tropical dry forest, tropical moist forest, and tropical wet forest) make up 57.1% of the total area of Costa Rica, the premontane zones (premontane moist forest, premontane wet forest, and premontane rain forest) make up 28.1%, the lower montane zone (lower montane moist forest, lower montane wet forest, and lower montane rain forest) makes up 9.1%, the montane zone (montane wet forest and montane rain forest) makes up 5.5%, and the subalpine zone (subalpine rain paramo) makes up 0.2% (Hall, 1985). Ninety percent of the country lies within humid regions, where precipitation surpasses the rate of evapotranspiration (Hall, 1985; Figure 1.1). The mean minimum annual temperature of Costa Rica is 24 degrees Celsius. With tropical zones occupying most of the country, the majority of vegetation ranges from semideciduous to dense forest (Hall, 1985).

Costa Rica's small land area consists of only 0.03% of the earth's surface, however it holds nearly 6% of the world's biodiversity making it a location of international priority (Embajada de Costa Rica). It would make sense that Costa Rica, meaning "rich coast," would have the richest flora and fauna within Central America. Having the largest area of protected land, Costa Rica contains nearly 9,000 species of plants including 800 species of ferns. As for fauna, Costa Rica contains around 200 species of mammals including four species of non-human primates, 850 species of birds including the great green macaw, around 220 species of reptiles including the eyelash viper, 200 species of amphibians including the red-eyed tree frog, and over 300,000 species of insects including the bullet ant (Costa Rica Guides, 2011). The biodiversity of Costa Rica provides a uniqueness to the world that cannot be replaced, meaning that its protection is ultimately necessary in order to provide safety and protection to all life within the country.

Costa Rica is home to four non-human primate species including the Central American squirrel monkey (*Saimiri oerstedii*), the white-faced capuchin (*Cebus capucinus imitator),* the mantled howler monkey (*Alouatta palliata),* and the Central American spider monkey (*Ateles geoffroyi).* The IUCN RedList, which assigns a conservation threat rating to all animal and plant species around the world, recognizes the white-faced capuchin and the mantled howler monkey as "vulnerable," and the Central American spider monkey and the Central American squirrel monkey as "endangered" (Solano-Rojas, 2021; de la Torre, 2021, Cortes-Ortíz et al., 2021; Cortes-Ortíz et al., 2021).

Costa Rica's four primate species are most commonly found within the tropical rainforests with the spider monkey preferring older neotropical forests containing larger trees to swing from (Chapman et al., 1989). The white-faced capuchin prefers younger, successional forests within the neotropical regions and cross through grasslands during the changing seasons (Chapman et al., 1989). Mantled howler monkeys inhabit various regions that most often contain riparian and rainforests (Chapman et al., 1989), and squirrel monkeys prefer secondary rainforest during the highest resource abundance and primary and late successional forest during low resource abundances (Boinski, 1987). Within these areas, each species resides within groups of 10-30 individuals, on average containing more females than males (Chapman et al., 1989).

The mantled howler monkeys reside in social groups consisting of 13-24 adult males and females where male howlers utter deep howls often in defense and to advertise their location to other howler groups (Milton, 1980). Howler monkeys have seasonally specific folivorous-frugivorous diets where the wet seasons provide them with mature leaves and fruits while the dry season yields newly budded leaves and flowers which requires them to spend much of their activity budget resting to digest the toxins and fibrous compounds within the leaves (Crockett & Eisenberg, 1986). Mantled howler monkey groups are spatially cohesive and separate groups often come into contact with one another and can even overlap despite them being generally territorial (Bolt et al., 2019). Male mantled howler monkeys are often significantly bigger than the females and "alpha" males within troops have higher chances of mating with females who are at the peak stage of their estrus (Jones, 1985). Contrary to many other primate species, both sexes disperse from their natal groups (Azkarate et al., 2015). At Hacienda La Pacifica, Costa Rica, 79% of males and nearly 96% of females leave their natal groups, each sex spending at least a year living alone before joining another group. This dispersing behavior decreases competition for resources between related individuals, and decreases chances of inbreeding (Glander, 1992).

The squirrel monkey has a diet mainly consisting of insects, though their diets become flexible when resource abundance alters during seasonal changes. During the wet season, squirrel monkeys consume more fruit as it becomes more available throughout their habitat (Stone, 2007). Their most preferred insects are orthopterans, such as grasshoppers, and lepidopterans, such as butterflies and moths (Lima & Ferrari, 2003). Squirrel monkeys display apparent kinship behaviors where individuals who are related are more spatially cohesive with one another than those who are not. Females also display more foraging and feeding behavior, seeking out their food more actively, and rest less than males (Montague et al., 2014). Troops of squirrel monkeys can vary in size depending on the size of the forest in which they reside. Their troops can have anywhere from 120-300 individuals in unaltered habitats (Baldwin & Baldwin, 1971). The troop often travels as single unit and social hierarchies do not play a dominant factor in their social systems, though dominant males rise to a higher rank during mating season while adult females make up the core of the social organizations (Baldwin, 1971). Male squirrel monkeys are also philopatric, often remaining in their birth group, allowing them to create strong bonds with other natal males (Boinski, 2005). The mating season for the squirrel monkeys within troops last around 6-8 weeks (Wilson, 1977). The squirrel monkey is the most elusive out of the four primates located in Costa Rica and research demonstrates that they can persist in highly disturbed habitats (Ceballos et al., 2019). Despite this, some studies have revealed that there are less than 4,000 individuals left in the region, with their populations continually decreasing (Boinski & Siwt, 1997).

The spider monkey has a diverse frugivorous diet where ripe fruits often consist of more than half of their total diet, ultimately influencing their habitat use and the range they spread across within their communities as seasonal variations alter fruit abundance (Di Fiore et al., 2008; Wallace, 2006). During the dry season, spider monkeys spend less time feeding than in the wet season (Chaves et al., 2011). Spider monkeys display fission-fusion dynamics within their groups. Splitting into sub-groups throughout the day allows them to decrease within-group competition for resources, especially when resources become scarcer throughout the year (Aguilar-Melo et al., 2018). The larger the area of land that the spider monkeys have to inhabit, the larger their sub-groups can be due to a vaster quantity of nutritional resources (Symington, 1988). The majority of their feeding occurs early in the morning and then picks up slightly during the evening hours (Wallace, 2001).

White-faced capuchins are considered the most intelligent New World monkey because they exhibit sophisticated social behaviors that include hand sniffing, sucking of body parts, and engage in various types of games with their peers (Perry et al., 2003). Young capuchins are exceedingly curious, given their intelligence, and exhibit many unique behaviors out of this curiosity. They often invent new foraging behaviors, are very observant, and are extremely playful with others within their group, allowing their new experiences to mold necessary behaviors for survival such as innovation, trial-and-error learning, and social learning (Perry, 2020). The white-faced capuchins, weighing anywhere from 4 to 6 pounds, most often feed on fruits and small insects, but large invertebrates and even some vertebrates make up a small portion of their diets when the opportunity presents itself (ACMCR, 2017). Female capuchins spend more time foraging than males, focusing on small invertebrates, such as caterpillars (ACMCR, 2017; Bergstrom et al., 2018; Mossdossy et al., 2015). Males, on the other hand. eat larger invertebrates and even some vertebrates when available (Bergstrom et al., 2018). Capuchins travel in groups consisting of males and females, where the group size ranges anywhere from 18 to 20 monkeys (ACMCR, 2017). Males comigrate with related male group members, allowing them to form long-term bonds with their kin. The groups contain hierarchies consisting of alpha males, who can lead for as long as 18 years, and sire most of the offspring within the group as long as there is no genetic relationship between the alpha and the female he breeds with (Perry, 2012).

Understanding the feeding behaviors, group dynamics, and social behaviors of these primate species residing in Costa Rica's tropical rainforest is vital to understanding the importance of the environments that they inhabit. As deforestation and climate change continue to pressure the natural systems of Costa Rica, the Costa Rican government and organizations have been vital contributors to the conservation of these species and their unique habitats. The extinction of any one of these primates, after all, could contribute to ecological chaos within these sensitive tropical food chains.

Chapter 2: Deforestation in Costa Rica and strategies used for conservation

According to National Geographic, “deforestation is the intentional clearing of forested land.” Although deforestation is happening at rapid rates around the world, tropical rainforests are being deforested at the most rapid rate. Much of this deforestation is occurring for road construction and urbanization, which is causing rainforests to become more vulnerable to the outside world (National Geographic). During the time between 1850 to 1980, the world’s forests were diminished by 15% in order to clear the land for other uses. During the early 2000’s, forested areas around the world were cleared at such a rapid rate that the loss would be equivalent to the size of Costa Rica within a single year (Chakravarty et al., 2012). While deforestation has struck the world, developed countries in the temperate zone are no longer experiencing deforestation at such rapid rates and actually display overall forest growth in some areas (Anonymous, 1990). For example, between the years of 1990 and 2015 the United States has reforested 26,364,000 hectares of land utilizing methods of natural regeneration, commercial plantations, and agroforestry (Pearce, 2021). Along with temperate regions, some tropical regions such as areas within Central America have also experienced a decrease in deforestation. From the years 1990 to 2000, North and Central America experienced 289 ha of net forest lost per year. This decreased to only 10 ha of net forest area lost per year between the years 2000 to 2010 (Table 1.1).

Table 1.1 Net global deforestation change each year from 1990-2010 (Chakravarty et al., 2012)

Region/subregion	1990-2000		2000-2010	
	1 000 ha/year	%	1 000 ha/year	%
Eastern and Southern Africa	-1841	-0.62	-1839	-0.66
Northern Africa	-590	-0.72	-41	-0.05
Western and Central Africa	-1637	-0.46	-1535	-0.46
Total Africa	**-4067**	**-0.56**	**-3414**	**-0.49**
East Asia	1762	0.81	2781	1.16
South and Southeast Asia	-2428	-0.77	-677	-0.23
Western and Central Asia	72	0.17	131	0.31
Total Asia	**-595**	**-0.10**	**2235**	**0.39**
Russian Federation (RF)	32	n.s.	-18	n.s.
Europe excluding RF	845	0.46	694	0.36
Total Europe	**877**	**0.09**	**676**	**0.07**
Caribbean	53	0.87	50	0.75
Central America	-374	-1.56	-248	-1.19
North America	32	n.s.	188	0.03
Total North and Central America	**-289**	**-0.04**	**-10**	**0.00**
Total Oceania	**-41**	**-0.02**	**-700**	**-0.36**
Total South America	**-4213**	**-0.45**	**-3997**	**-0.45**
World	**-8327**	**-0.20**	**-5211**	**-0.13**

Why are tropical rainforests the main target for deforestation around the world? The main contributors to this crisis consist of slash and burn farmers, urban developers, ranchers, loggers, and commercial farmers (Chakravarty et al., 2012). In fact, cattle ranching makes up a large contribution to global deforestation and is often inefficient with its land use since nearly 60% of land cleared for cattle pastures is used for grazing (UNEP). A central cause of deforestation occurs through slash and burn agriculture where a forested area is burned in order to create temporary fertile land for farming. However, once the fertility of the soil at the site is exhausted, the location of this farmed land is moved elsewhere and the process repeats itself (Chakravarty et al., 2012). Commercial agriculture contributes to the largest portion of deforestation, where 80% of the world's deforestation occurs from this process and animal agriculture accounts for 60% of the world's greenhouse gas emissions (Greenpeace, 2019). In order to produce large quantities of food such as fruits, nuts, livestock, etc., commercial farmers create large plantations by cutting down the forest for land to farm. Unlike small-scale farming, commercial farm productions are provided for sale by large global markets which requires large amounts of land (Open Geography Education). Chemicals used in commercial agriculture contaminates natural water supplies which can harm nearby ecosystems and impede the habitats of native organisms (UNEP). Within Costa Rica, coffee, banana, pineapple, and sugar plantations make up a large portion of the agricultural practices (Celis & Lizano, 1993). As the global population continues to rise, the pressure for agricultural expansion grows and expands into forested areas that were once unaffected in order to meet the demand for product distribution (Greenpeace USA, 2019).

Forested areas are also cleared for urban development in order to alter the land for commercial uses including industrial development and residential expansion. This correspondingly lowers species diversity in these areas and removes the benefits that the once forested land used to provide (Zipperer et al., 2012). The logging industry is an important economic commodity for many regions, creating jobs and revenue for the areas where logging occurs. Companies such as Georgia Pacific substantially influenced the logging industry by producing high-quality wood, targeting several tree species types, and projected export around the world. The consequence of these logging practices is extreme reductions in forest cover causing major environmental damage (Asner et al., 2009).

A result of this type of expansion is habitat fragmentation. As humans clear-cut trees via large scale operations within the rainforest, it creates disconnected fragments within the forest. These fragments appear as “mini” versions of the once large and continuous forest. Habitat fragmentation occurs when a large, continuous piece of forested area is separated into small, discontinuous fragments disrupting the habitats within it (Franklin et al., 2002). In this way, what was once large stretches of forest turn into small patches, creating difficult bridges, or none at all, between habitats for organisms residing in fragmented areas. Although fragmentation can occur naturally via fires and wind, anthropogenic stressors play a large role in the issue which is most often caused by humans clearing the land (Franklin et al., 2002). Habitat fragmentation often results in two main issues. First, wildlife populations can become isolated and accordingly reduced in size which increases the risk of inbreeding and extinction due to the effects that genetic drift holds on small populations. Fragmentation limits the ability for organisms to disperse from the fragments, often resulting in inbreeding and the loss of genetic variation (Templeton et al, 1990). The other issue is that fragmentation alters the habitat's landscape, varying resource availability which may force populations to modify their behavior in response to this change (Lienert, 2004; Bolt et al., 2019).

Tropical rainforests act as sponges. Deforestation causes increased nutrients into aquatic ecosystems since vegetation can no longer uptake these nutrients. Ultimately, this causes a rapid increase in nitrification and the leaching of nitrate into aquatic areas (Feller, 2009). During extreme rainfall, such as during tropical storms, tree cover assists in slowing stream flows created during flooding events by taking up the moisture, which ultimately can't occur when deforestation decreases tree cover within these forests. This correspondingly causes areas surrounding the deforested area to flood due to such rapid water loss while also causing extreme erosion due to rapid stream speeds. Drought can then occur quickly after due to this same water loss. Instead of the forest soaking up the rainfall, it is ultimately lost when it is much needed during the dry season. Increased drought leads to a loss of humidity creating a feedback loop where decreased evapotranspiration created by humidity decreases future rainfall (Butler, 2019).

Deforestation results in habitat destruction for native species. Due to extensive deforestation, many species' survivability is threatened. Studies show that some species in Costa Rica such as the Central American squirrel monkey were left with only 31% of their original dense forest cover between 1940-1977. The extent of habitat destruction over the years has reduced forest sizes so much that some species are expected to become extinct within Costa Rica between 50 to 100 years. Some of the most endangered species within Costa Rica include the West Indian manatee (*Trichechus manatus),* the Giant anteater *(Mymecophaga tridactyla),* the Harpy eagle *(Harpia harpyja)*, the American crocodile (*Crocodylus acutus),* the jaguar *(Panthera onca),* and the White-lipped peccari (*Tayassu pecari)* (Vaughan, 2011).

Mantled howler monkeys within Hacienda La Pacifica, Costa Rica, displayed an increase in infant deaths after deforestation had occurred in their habitat. Reductions in food availability and damaged migration resulted in a decrease in their group sizes (Clarke et al., 2002). In areas of high disturbance and deforestation, white-faced capuchins prefer areas with the lowest disturbances, forcing them to migrate out of their typical habitat when agricultural practices infringe upon their own habitats. Spider monkeys also display lower population density in areas of high disturbance and human development, possibly due to the fact that their large body sizes cannot be sustained in areas of regenerating secondary forest (Van Hulle & Vaughan, 2009). Due to deforestation and habitat fragmentation caused by agriculture, in 1996, only 1,246 squirrel monkeys were found in nearly 26 different areas around the country (Boinski et al., 1998). A small forest fragment of 15 hectares in La Suerte Biological Field Station, last deforested in the 1970's, showed high densities of mantled howler monkeys and white-faced capuchins living within the fragment. This was caused by crowding, which could lead to a resource depletion that threatens the future survival of these primate populations within the fragment (Pruetz & Leasor, 2002). From 2017 to 2022, La Suerte had a population density of 109.5 howlers per square kilometer, nearly three times higher than other sites containing mantled howler monkeys (Bolt et al., 2022).

Costa Rica has experienced some of the highest rates of deforestation in the world. Of an area of nearly 51,000 square kilometers, 75% of this land contained forest cover in 1940. In the beginning of colonialism, Costa Rica was not necessarily considered a region of interest since it lacked the desired minerals and resources of many other locations that colonists discovered. Spaniards of colonial times were not heavily concentrated in this area which prevented early agricultural practices that other parts of Central America began to endure (Evans, 2010). Unfortunately, the 1800's introduced discoveries of the fertile soils that Costa Rica's volcanoes provided, ultimately leading to the expansions of crops around the nation, continually degrading forest cover and threatening vital ecosystems (Evans, 2010). The peak of this deforestation occurred between 1979 to 1986 (Kerr et al., 2003). Due to the rapid expansion of agriculture, logging, and urban development, the cover of forested areas decreased from 59.9% to 40.8% from 1960 to 1986 (Allen et al., 2017). At the peak of deforestation, Costa Rica was losing nearly 4% of its forested area a year. A major contributor to this deforestation was the cattle industry expanding into forested lands and selling more than half of their product to Burger Kings by the influence of United States loans to deforest the land. The degradation of this land led to many consequences such as droughts, floods, and landslides that motivated a need for reform within the country (Pearce, 2023). The result of these threats influenced the development of many policies, regulations, and incentive programs to deter further deforestation and restore the habitats of Costa Rica.

As the global human population rises, the use of natural resources becomes ever more prevalent as they have become depleted. Agricultural land and timber extractions continue to grow larger and invade the natural habitats of many species, including the primates of Costa Rica (Foley et al., 2005). Costa Rica has experienced forest degradation over time due to expansion of pineapple, coffee, and banana plantations, fragmenting associated forests (Garber et al., 2010). Deforestation was sparked by titling laws during the 1930’s and 1940’s that incentivized deforestation; a massive spike in population growth during the 1960’s; and a major increase in pastures and plantations (Rodricks, 2010). Rincon de la Vieja, a national park in northwestern Costa Rica, has around 8 fragments per 1000 ha, while Cabo Blanco, located on the southern tip of the Nicoya Peninsula, has around 2. Located in the Guanacaste Province, Diria has around 5 and Palo Verde, also located in the Nicoya Peninsula, has around 13 fragments per 1000 hectares Barrantes et al., 2016). In an agricultural cover assessment, of 300 agricultural training points surveyed, only 23% had more than 0% tree cover which included banana, oil palm, and sugar cane plantations (Cunningham & Cunningham, 2020).

The agriculture of coffee contributes to a portion of Costa Rican agriculture that occurs in approximately eight regions spread across the country. These regions include Valle Central, Tres Rios, Turrialba, Brunca, Guanacaste, Tarrazu, Orosi, and Valle Occidental. Although the number of coffee growers has decreased by 46% from 2010 to 2022, there are 93,697.3 hectares of land used for growing coffee (U.S. Department of Agriculture, 2022). Coffee agriculture requires the removal of shade trees and increased amounts of nitrogen-based fertilizer in order to facilitate growth which results in the leaching of nitrogen into groundwater and into the atmosphere, all having consequences for wildlife and habitat structures (Babbar & Zak, 1995). In addition, the expansion of large coffee farms fragments tropical forests, negatively affecting the native fauna that rely on connective forests for their survival (Monetero et al., 2021).

Costa Rica is one of the top producers of the world's pineapple and there are currently 65,000 hectares of land used for the production of pineapples within the country (Girres et al., 2023). Between the years 2000 to 2019, around 6,300 hectares of land were deforested in order to facilitate emerging pineapple crops, where most of the expansion occurred in Los Chiles and San Carlos, closely bordered to Nicaragua (Girres et al., 2023). The deforestation caused by pineapple plantations results in large areas of forest removed to create monocultures which is a type of farming that is dedicated to growing a single type of species. Although the process is efficient in producing large crop yields, the growth of the same species risks disease pressures that can wipe out entire crops and depletes the nutrients within the soils of the growing crops. While traditional farming relies on crop rotations to restore the health of soils to continue farming year by year, monocultures do not utilize this method. Because of this, once the nutrients are depleted, the monoculture is moved to another area, increasing the pressure of deforestation to continue growing the crop (Salaheen & Biswas, 2019).

Along with pineapple, Costa Rica is the second largest producer of bananas in the world (Hernández et al., 2000). Banana farming, similar to pineapples, is a major contributor to the deforestation of Costa Rica's tropical forests. In 1992, the Province of Limon removed around 4,677 hectares of forest to expand banana farming through Corbana, a national banana industry (Emaus, 1998). Del Monte, Chiquita, and Dole are now the dominant companies who produce bananas within Costa Rica (Banana Link, 2021). Today, 51,800 hectares of Costa Rican land is used for banana production which is presently impeding on the habitats of native species and negatively impacting biodiversity due to the fragmentation of forests from deforestation itself (Vargas, 2006).

Due to these disturbances Costa Rica has created nearly 34 national parks, reserves, and designated protected areas to conserve the wildlife and ecosystems within the region. These areas, spread across the country, are dedicated to the preservation and rehabilitation of wildlife and habitat structures (Figure 2.1). For example, core forest cover increased from 66.7% to 77.1% in protected areas while background areas only increased from 25.1% to 28.1% (Cunningham & Cunningham, 2020). Through governmental regulation, 28% of Costa Rica's land mass is designated as legally protected land (Evans, 2010). Type "1" locations include areas such as national parks, reserves, refuges, and historical sites that are under strict protection from human destruction (Evans, 2010). Type "2" locations have more relaxed restrictions of protected locations that "partially protect under certain conditions" when exposed to stressors such as tourism and logging activities. This includes circumstantial protection when wildlife and watersheds become at risk. Type "3" locations include indigenous and cultural reserves to not only protect cultural livelihoods but necessary resources as well (Table 2.1).

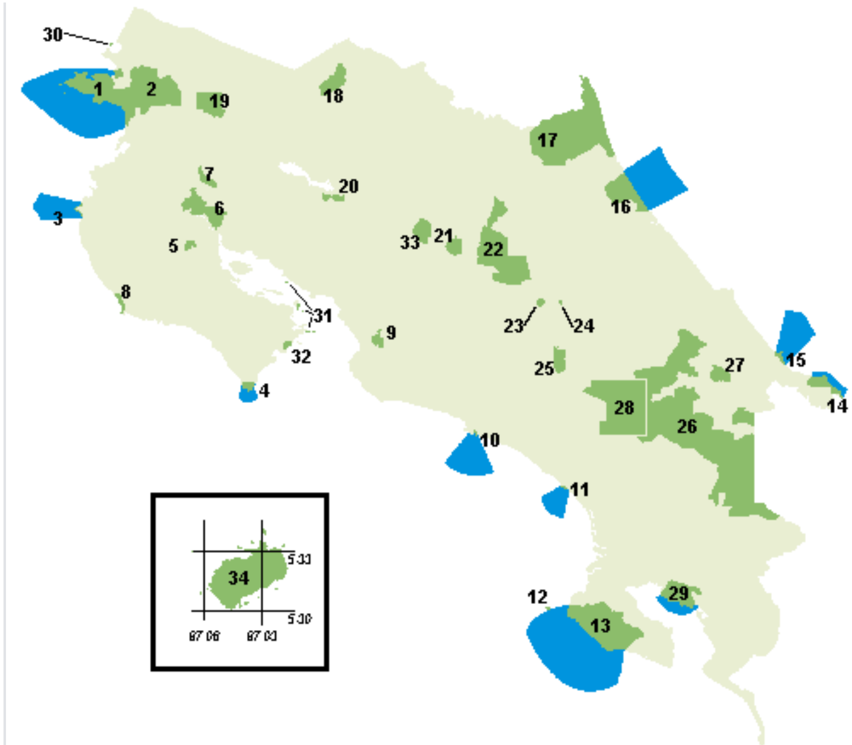

Figure 2.1. Costa Rican National Parks, Reserves and Protected Areas. (Costa Rica Bureau).

Table 2.1. Protected Areas in Costa Rica (Evans, 2010).

Table I. Protected Areas in Costa Rica

Designation	No. of Acres	% of Total
1. National Parks	1,336,196	37.7
2. National Monuments*	3,624	.1
3. Wildlife Refuges	397,820	11.2
4. Biological Reserves	94,954	2.7
5. Forest Reserves	651,920	18.4
6. *Zonas protectoras***	426,730	12.0
7. *Humedales****	96,485	2.8
8. Indigenous Reserves	536,316	15.1
Total	3,544,045	100.0

Costa Rica's wildlife and environmental structure is mainly controlled by Wildlife Management, a government funded body, under the Conservation of Wildlife Act No. 7317 implemented in 1998 (Sistema Nacional de Areas de Conservación). The purpose of this proclamation, along with Costa Rica's many other laws and regulations regarding wildlife, is to serve and protect the flora and fauna within the nation (Sistema Nacional de Areas de Conservación). In order to combat illegal pet trade, deforestation, poaching, and excessive use of pesticides, Wildlife Management has dedicated themselves to several objectives, including the effort to establish a program committed to the creation of Private Wildlife Refuges.

In response to increased anthropogenic threats throughout Costa Rica and the rapid decline in biodiversity over the past century, governmental regulations and conservation organizations have made increasing efforts to protect and restore primate populations and habitats. By the year 2000, deforestation rates within Costa Rica dropped, with policies and regulations having a large sway in the matter (Kerr et al., 2003). In a study conducted throughout Costa Rican rainforests, in all areas assessed, regions protected by Protected Areas (PAs) had lower deforestation rates than areas that were unprotected (Tafoya et al., 2020). The passing of the 1955 Environmental Law 7554 that "mandates a 'balanced and ecologically driven environment,'" the 1996 Forestry Law 7575 which "mandates 'rational use' of all natural resources and prohibits landcover change in forests," and the 1998 Biodiversity Law that "promotes the conservation and 'rational use' of biodiversity resources" all contribute to the immense rehabilitation of Costa Rica's reforestation efforts as well as the monumental decrease in deforestation rates around the country (Sanchez-Azofeifa et al., 2007).

In addition to these initiatives, Costa Rica has begun to increase environmental incentives for its human inhabitants. During the 1980's Costa Rica was experiencing the most deforestation in the world where the country's forest cover declined from 50% to nearly 26%. Costa Rica created the Payments for Environmental Services (PES) Program in 1996, which serves to promote rainforest conservation and limit the degradation of forests. Although Costa Rica was the first country in the world to implement this program, other regions around the world have since implemented PES including Vietnam, China, South Africa, Mexico, Ecuador, and the United States (Calvet-Mir et al., 2015). By abiding by sustainable practices and implementing conservation techniques, landowners within Costa Rica have the opportunity to be paid for the environmental services that their land provides (United Nations Climate Change).

The Costa Rican government pays landowners directly for the environmental services protected and produced by their lands based on their value. These services include protection of wildlife biodiversity, sustainable land practices, lessening greenhouse gases, water protection, environmental research, protection of wildlife and their ecosystems, and the preservation of the beauty of nature for ecotourism (Rodricks, 2010). By incentivizing landowners, the hope for this program is to significantly increase the protection of natural systems within Costa Rica and to preserve areas that are the most vulnerable to destruction. In interviews conducted across 60 private nature reserves associated with Costa Rica's governmental incentive program, landowners reported many benefits they could receive for participating in conservation efforts. For example, owners of land whose forests provided services like carbon sequestration and watershed protection have the opportunity to receive cash payments from the government (Langholz et al., 2000).

The PES program currently contains three types of contracts for landowners. The forest conservation contract pays $210 per hectare of land over a five-year period in order to support the conservation of primary and secondary forest. This contract, although ending every five years, can be renewed and holds 85% of the contracts within the PES program. The sustainable forest management contract pays $327 per hectare to landowners who commit to maintaining and creating sustainable practices in their forested land for at least 15 years. Finally, the reforestation contracts pay $537 to landowners who commit to at least 15 years of reforestation efforts on their land (Malavasi & Kellenberg, 2002).

Other than incentivization, PES also contains laws to ensure protection of natural systems within Costa Rica. The 1955 Environmental Law 7554, the 1996 Forestry Law 7575, and the 1998 Biodiversity Law make up the legalities of the program, but there has also been many other laws that have allowed Costa Rica to maximize environmental protection. The Forest Law No. 4475 of 1969 allowed reforestation projects to be tax deductible, beneficial conservation strategies to undergo tax exemptions, and prohibitions on timber exports and imports on forested products. Then, in 1997 the Forest Law No. 6184 placed a 2% minimum on agricultural loans that would be allocated to reforestation projects with increased interest rates on agricultural loans to be given to these same projects. Finally, the Forest Law No. 7032 of 1986 created certificates that incentivized landowners to partake in reforestation of their own properties. Such certificates gifted from forest restoration could be sold for profit or to pay taxes (Rodricks, 2010). All of these laws ultimately led to the creation of PES.

Apart from the PES program, the National System of Conservation (SINAC), which undertakes the protection and management of wildlife and environmental conservation, created The National Biological Corridors Program (PNCB) in 2006. Biological corridors are designated territory used as connective paths between protected forested areas in order to allow wildlife promised spaces to travel and expanded habitat area. The main objectives for the PNCB project include increasing the resilience of protected areas and the pathways that connect them, promoting activism against climate change including mitigation measures and necessary adaptations, promoting the integrity of biodiversity throughout the region, coordinating with urban development, and connecting the governing models within the plan in order to assist society through conservation and sustainability (SINAC).

Although still in development, Costa Rica currently contains 44 biological corridors throughout the country, serving to protect vulnerable species (Figure 2.2). The biological corridors within Costa Rica cover diverse landscapes throughout the country, providing adequate access to the pathways for the abundant species native to the region. In order to provide sufficient pathways, it is essential that corridors connect the fragments with natural cover. With this being said, nearly 80% of Costa Rica’s corridors meet this requirement (Morera-Beita et al., 2021). PES has been a vital contributor to the PCNB project as it has given 52% of its monetary resources, between 2011 to 2015, through the incentivization of forest restoration to designated corridors, allowing for significant increases in forest cover (Morera-Beita et al., 2015). The program is still in the works, meaning that the specific benefits on native species are still unknown, but as the program expands, the promise of biological corridors will most likely become more prominent.

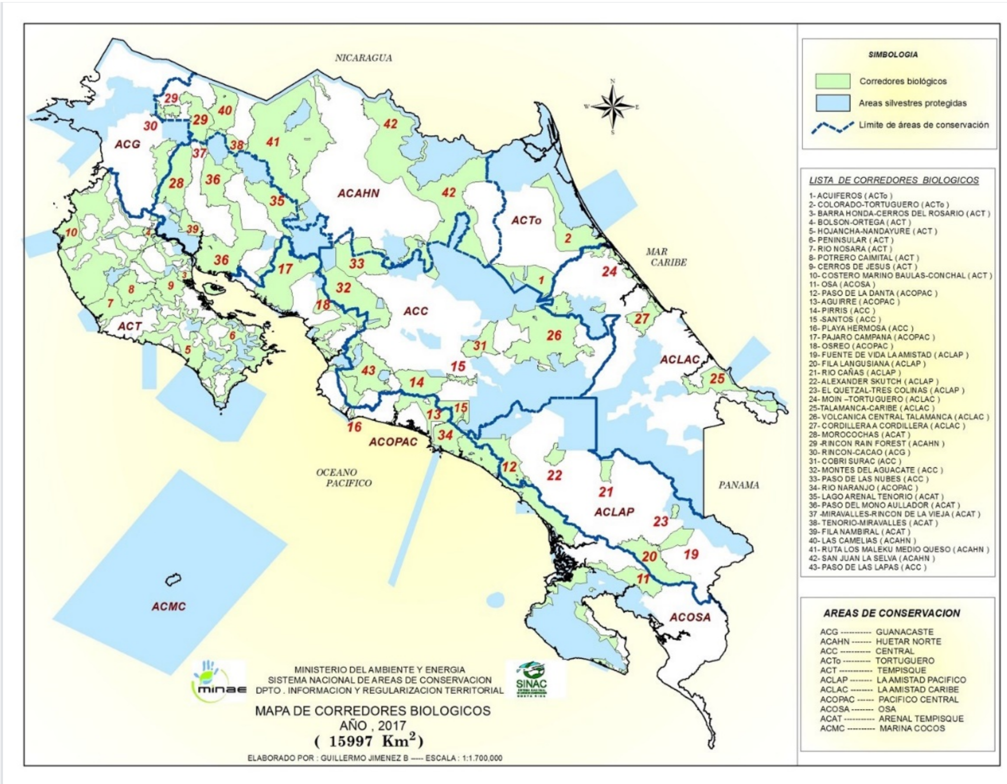

Figure 2.2 Biological Corridors of Costa Rica. (SINAC).

The various implementations and regulations within Costa Rica have allowed land to regenerate over time. A study in Santa Rosa National Park revealed that the regeneration of tropical rainforests within primate habitats allowed the howler monkey and white-faced capuchin populations to significantly increase in size as the forest regenerated (Fedigan & Jack, 2001). Another study found that protected areas of forest had the tallest canopy heights, best fulfilling the needs of spider monkeys and mantled howler monkeys. Mantled howler monkeys and spider monkeys were more abundant in forests that were larger and had higher canopies, resulting from protected areas and incentivized private forests. In addition, areas of privately owned forest with incentivization through PES looked more similar to protected areas where the area of the forest was larger and had taller canopies, unlike privately owned unincentivized forest (Johnson et al., 2023). When comparing areas that had a higher percentage of protected land and higher community participation via PES and ecotourism to areas of lower protection and less community participation, the areas with more protected land and participation such as Piro Biological Station and Manuel Antonio National Park had lower deforestation rates and higher primate group encounter rates than the lower protected areas with less community involvement such as La Selva Biological Station and Las Cruces Biological Station (Tafoya et al., 2020). This reveals that protected areas with community collaboration through PES and ecotourism aids in forest rehabilitation and facilitates the survival and prosperity of primate communities. All of the efforts made by Costa Rica, both via communities and governmental action, have given the primates of Costa Rica a chance to become more resilient and regenerate after the damage caused by excessive deforestation during the 1900's.

Although the there is much work still to do regarding habitat protection and forest regeneration, the PES program and SINAC's PCNB project are the vital contributors to progress being made to protect and safeguard the survival of native species. By finding ways to benefit society and nature, Costa Rica's coordination via the government and public has the best fighting chance at providing long-term action and protection for primates. Ultimately, the fight against deforestation safeguards the future of Costa Rican flora and fauna.

Chapter 3: Climate change in the tropical rainforests of Costa Rica

Among the many devastations that the primates of Costa Rica face, climate change poses one of the greatest risks to their survival. Climate change induces shifts in weather patterns and temperature ranges in tropical rainforests, commonly due to anthropogenic effects, altering vital carbon cycles (Kemp et al., 2022). Burning of fossil fuels, deforestation, and overconsumption of natural resources - all of which causes sea level rises, ocean acidification, and imbalances in natural processes due to anthropogenic activities – are occurring around the world (Ciais et al., 2020). Changes in seasonality, overall temperature increases, and detrimental impacts on vegetation and terrain may require changes in flora and fauna residing in tropical rainforests in order for them to persist in their own environment (Rising et al., 2022; Watson et al., 2018). Through the use of greenhouse gases which exacerbate climate change, the Earth is expected to warm up to nearly 5.8 degrees Celsius by the end of the 21st century and sea levels are to rise up to 0.88 millimeters (Ciais et al., 2020; Facchinelli et al., 2022, Suarez et al., 2002).

As climate change has accelerated, the average annual rainfall within tropical rainforests decreased by 1 percent each decade between the years 1960 to 1998, ultimately affecting many species within Costa Rican rainforests (Mahli & Wright, 2004). Climate change causes more frequent extreme weather events and changes in seasonality within natural ecosystems that can devastate vital agricultural locations that are essential for the economic and health sectors of human populations (McMichael et al., 2006). Globally, these extreme events include tsunamis, droughts, unnatural wildfires, glacial meltdowns, and increases in oceanic temperature and acidity (Kemp et al., 2022). Animals and humans alike rely on much of the same ecosystems to survive, so what is devastating to one species is also devastating to others.

Although the Earth's climate has changed over the past 800,000 years, our current climate is changing at a far greater scale and speed. As humans became more advanced in medicine and resource retrieval, the size of the human population rose exponentially, launching what we know climate change as today (Hardy, 2003). The industrial revolution began in Britain during the 1770's when high rates of deforestation caused shortages in lumber, ultimately necessary for fuel. In order to account for this loss, Britain turned to coal as their primary energy source, leading to large and wide-spread mining operations around the nation. This discovery influenced a rise in technology, tools, and machines that ultimately brought our world to where it is today (National Geographic).

Although the discovery of coal energy provided an alternative to the intensity of the lumber industry at the time, the scale of this new industry contributed to various issues in the future. The burning of fossil fuels for energy, such as coal and oil, releases carbon dioxide into the atmosphere creating higher concentrations. In 1900, research revealed atmospheric CO_2 concentrations to be around 300 parts per million (ppm), in 1958 it was 316 ppm, and then in 1985 it was 345 ppm (MacCracken, 1985). Based on recent monitoring, the global average CO_2 concentration was 417 ppm, creating a new record for the highest recorded concentration which are vastly too high in comparison to past measurements (Figure 3.1; Lindsey, 2023). According to the Global Carbon Budget, global carbon dioxide emission went from 11 billion tons during the 1960's to nearly 36.6 billion tons of carbon dioxide in 2022. Despite the fact that CO_2 occurs naturally throughout the world, carbon dioxide that enters the atmosphere absorbs infrared radiation and traps heat (Soeder & Soeder, 2021). It is necessary for the Earth to have carbon dioxide from freezing but rapidly released CO_2 derived from carbon previously stored within the ground causes this CO_2 layer to collect additional heat and radiate back to the Earth, causing global temperatures to rise (Lindsey, 2023). Between the years 1880 to 1900, global surface temperatures increased by 1 degree Celsius. Present studies completed by the Global Climate Report indicate that every month of the year 2022 ranked in the top ten warmest months ever recorded (Lindsey & Dahlman, 2023).

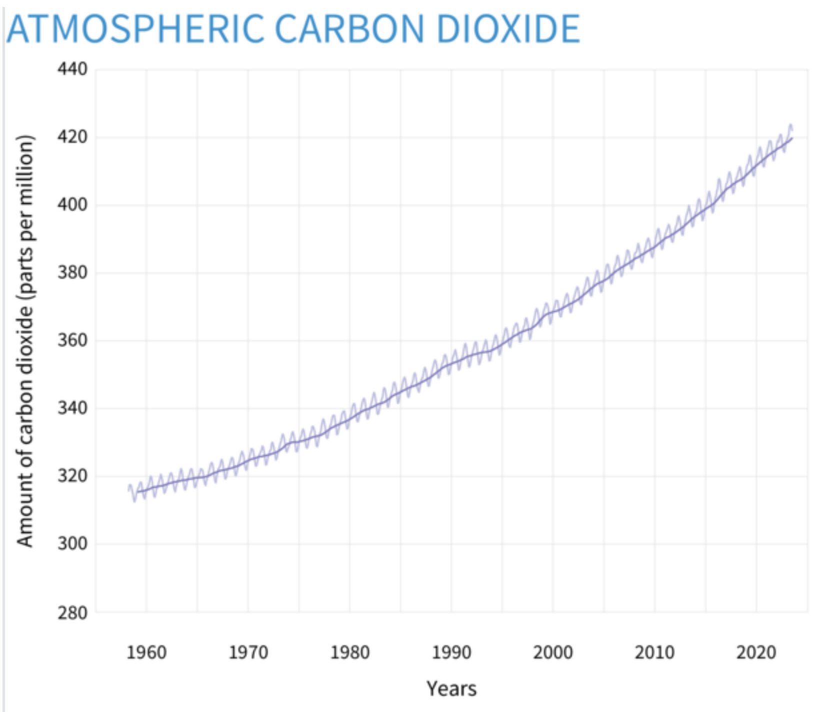

Figure 3.1. Atmospheric Carbon Dioxide Concentration from 1958-2023. (Lindsey, 2023).

There are three locations where carbon dioxide ends up: almost half is in the atmosphere, a fourth is absorbed by terrestrial components, and the last fourth is dissolved in the ocean (Gattuso & Hansson, 2011). Increased CO_2 emissions not only enter into the Earth's atmosphere but also dissolve into the world's oceans. Carbon dioxide enters the ocean via surface waters to create carbonic acid, which correspondingly decreases the pH of the ocean for what is known as ocean acidification (Jagers et al., 2019). The ocean acts as a natural carbon sink for anthropogenically produced carbon dioxide which is extremely important. The more CO_2

that is taken up by the ocean as a sink, the less CO_2 that is released into the atmosphere which would otherwise worsen climate change and its effects on the Earth's ecosystems (Guttoso & Hansson, 2011). Although this sink is important, it does not come without consequences to marine ecosystems that rely on stable pH balances. For example, it is expected that as carbon dioxide increases within oceans, phytoplankton will correspondingly increase primary production, causing increased biomass that then causes a decrease of dissolved oxygen within marine waters when it dies and decomposes (Riebesell & Tortell, 2011).

Scientists have concluded that by 2100, the climate change trajectory will increase global temperatures by 1.5 degrees Celsius compared to temperatures during the pre-industrial era (IPCC). Global warming caused by climate change is slowed by the absorption of this heat through the ocean; however, this causes ocean temperatures to warm in response (Xie, 2020). Between the mid-1950's and mid-1990s, the world's ocean layer from surface to 300 feet in depth increased a total of 0.31 degrees Celsius (Levitus et al., 2000). Global warming causes sea levels to rise through the melting of ice caps and thermal expansion of the water itself (Raper & Braithwaite, 2006). These rises threaten wetlands and lowlands through permanent flooding and coastal erosion, which can threaten the safety of terrestrial organisms (Titus, 1986). Such flooding could force coastal organisms inland by degrading their previous habitat, exposing them to unfamiliar stressors (Kennedy et al., 2002).

Global warming poses risks not only to oceans and their wildlife, but terrestrial ecosystems as well. As deforestation continues to occur within tropical rainforests, slash-and-burn clearing causes carbon dioxide to be released from the land that was cleared of soil and vegetation, consequently exacerbating the rate of climate change by increasing atmospheric CO_2 (Tinker et al., 1996). Vegetation also plays a vital role in carbon dioxide uptake through photosynthesis, which can also no longer occur due to deforestation (Bala et al., 2007). As tropical forests become degraded and turned into pastures, the temperature of these areas increases. Evapotranspiration, a process that occurs via vegetation, also decreases, limiting the moisture that can be recycled back to the atmosphere, decreasing precipitation over these corresponding areas. These cascading effects ultimately lead to increasing lengths of the dry season within tropical rainforests (Shukla & Sellers, 1990).

Organisms may have to alter their life histories in response to increasing lengths of dry seasons (Correa et al., 2021). The dry season experiences less rainfall and higher average temperatures than the wet season, but moisture is normally kept in the soil by deep-rooted flora (Nepstad et al., 1994). When these structures are removed, moisture can no longer be stored during the drought-like conditions of the dry seasons. As the length of dry seasons increase, food availability becomes scarcer and resources are less nutritional, which may cause species like the mantled howler monkey to alter their behavior in response to these ecosystemic pressures (Crockett & Eisenberg, 1986). Climate change models and projections have revealed that high elevation locations within Costa Rica are at great risk from climate change. As elevation increases, climate change will account for up to 30% less precipitation and significant temperature increases. In addition, the frequency of precipitation will also decrease, possibly leading to extreme instances of drought (Karmalkar et al., 2008). A study looking at climatic models in Costa Rican life zones revealed potential changes in ecoclimatic projections for two different climate change scenarios. The 2.5-degree Celsius increase scenario revealed a 38% change in ecoclimatic zones while the 3.6 degree Celsius scenario displayed a nearly 47% change in conditions, where the most prominent of these changes would occur in tropical dry forest, montane rain forest, and sub-alpine paramo. These changes reveal the potential loss of three unique life zones, which threatens the biodiversity of these specific areas (Halpin & Secrett, 1995).

Other regions around the world have already begun to display the effects that climate change poses to the environments of native primates, also occurring in tropical rainforests like those the primates of Costa Rica inhabit. As temperatures shift due to climate change, orangutans in Borneo's rainforests will likely be forced into higher altitudes, forcing them out of their natural ranges and threatening the structure of their life histories and population structures (Struebig et al., 2015). Reductions in rainfall can also lead to habitat fragmentation, constraining access to normal home ranges. For example, extreme precipitation shifts in Senegal has caused fragmentation within the habitat of red colobus monkeys, restricting their range and threatening their survival (Galat et al., 2009). Finally, climate change could lead to changes in community compositions. Shifts in environmental conditions from climate change have significantly altered the food availability and structure of the forests within Kibale National Park, Uganda, leading to changes in population densities of the primates who reside there (Chapman et al., 2013). Climate change induces phenological changes to rainforest ecosystems by causing irregular variations in fruiting and flowering times, hibernation, and migrations (IPCC, 2013). Flowering and fruiting events are often cued by extreme climatic conditions, such as extreme temperatures shift between the wet and dry season. As these conditions become more variable and the shifts become less prominent, primates will face resource availability issues within Costa Rica as seen in other areas around the world (Butt et al., 2015).

Another impact of climate change is that pathogens are able to grow and spread better under warmer and often wetter conditions (Harvell et al., 2002). Diseases spread through vectors, such as mosquitos, are better able to expand latitudinally as global temperatures conducted an experiment that revealed that of the 384 individual primates that were tested from Costa Rica, including all four native species, 8.9% of them carried a parasitic infection, such as malaria rise (Nunn et al., 2005, Chavez et al., 2022).This prevalence reveals the dangers that these primates face as climate change continues to warm these tropical regions within Costa Rica. Not only does extreme temperature and precipitation fluctuations spread pathogens, but it also alters behaviors of primates. In Santa Rosa National Park, white-faced capuchins rested significantly more and traveled less during times of extreme drought and increased temperatures. In addition, as surface waters began to dry up, capuchins would centralize their home ranges in areas located near a permanent water source. This ultimately reveals primate dependency and behavioral responses to stabilized resources and the threat climate change poses as these resources become variable and depleted (Campos & Fedigan, 2009).

With the impending threats to primate species located in Costa Rica and other areas around the world, many countries including Costa Rica have made significant efforts in mitigating climate change and the consequences it poses. Costa Rica has a proposed Nationally Determined Contribution plan (NDC) which has made environmental promises to several sectors of their country. First, Costa Rica plans a maximum net carbon emission of 9.11 million tons by 2030 (Contribucion Nationalmente, 2020). In 2019, Costa Rica then promised to commit to zero emissions by 2050 in order to prevent global temperatures from gaining more than 1.5 degrees Celsius (Government of Costa Rica). Carlos Alvarado Quasada, president of the United Nations Environment Programme, states that, “The decarbonization plan consists of maintaining an upward curve in terms of economic growth and at the same time generating a downward curve in the use of fossil fuels, in order to stop polluting” (UNEP). Between the years 2021 to 2030, they have also promised a maximum carbon emission of 106.53 million tons over all 9 years

(Contribucion Nationalmente, 2020). The Communication on Adaptation portion of their NDC also includes their commitment to implementing nature-based solutions into their social, economic, and environmental sectors through financing, public services, and infrastructure (Contribucion Nationalmente, 2020).

Some of the environmentally friendly initiatives that are planned include the creation of an electric train known as The Electric Passenger Train of the Greater Metropolitan Area of Costa Rica by providing transportation within the capital of San Jose. This is vital due to the transportation sector accounting for 40% of Costa Rica's emissions (UNEP). This project, funded partially by the Central American Bank for Economic Integration (CABEI), is projected to cost nearly $1.554 billion. CABEI will be financing $550 million towards the project while also receiving another $250 million through a loan to the Costa Rican government from the Green Climate Fund along with $21.3 million dollar donation towards the plan (Honduras, 2021). Not only will the implementation of this train provide transportation for 2.7 million residents and employ nearly 1,200 workers, but it will also reduce carbon emissions by 7.6 million tons (Honduras, 2021)). A part of Costa Rica's climate change action includes urbanization regulation plans. These plans include implementing important criteria, such as the creation of adaptation criteria and instruments, for territorial planning, development, coastal management, biological corridors, and wildlife sanctuaries by the year 2030. In an effort to continue a downward trend in fossil fuel production, the country has also committed to transferring to 100% renewable electricity by the year 2030, by updating their energy efficiency standards and technology (UNDP; NDC).

The Climate Action Tracker (CAT), an independent project tracking Costa Rica's government climate efforts, rates Costa Rica's policies and climate change prevention efforts as

"Almost Sufficient." This sufficiency is based on the country's 1.5-degree Celsius compatibility trajectory. The 1.5-degree Celsius compatibility trajectory reveals the quality of efforts to contain and decrease the increasing temperatures caused by climate change. The 1.5-degree Celsius compatibility trajectory was originally presented by the Paris Climate Agreement of 2015 which initially aimed to keep global temperatures from exceeding 2 degrees Celsius, but eventually transitioned this goal to 1.5 degrees Celsius. Having a score of "Almost Sufficient" reveals that Costa Rica is near the level that will keep their global contribution under the 1.5-degree Celsius trajectory (IPCC). The CAT also reveals, while possibility insufficient in data, that Costa Rica is the only country within Central America who has reached an "Almost Sufficient" score. In 2017, Honduras, Nicaragua, and Guatemala were included in the top ten countries most vulnerable to climate change (Council on Foreign Relations). In the Caribbean, climate reports predict that temperatures are to increase anywhere from 1.4 to 3.2 degrees Celsius by the end of the 21st century. From the years 1990 to 2002, three of Costa Rica's presidents encouraged oil exploration throughout the country. Harken Energy, a United States energy company, made initial agreements with previous leaders to conduct large scale oil drilling operations within the country. In 2002, President Abel Pacheco then announced a moratorium on oil exploration which created a long legal battle between Harken Energy and Costa Rica itself. Demanding reparations, Harken Energy attempted to sue Costa Rica for $57 billion but ultimately failed (Engler & Martinez, 2004). While the ban was originally supposed to end in 2014, it was thus extended, protecting the environment and continuing Costa Rica's history of zero drilling operations. The most notable contributions made by Costa Rica was the extension of their moratorium on oil exploration and exploitation to 2050 by reforming its Executive Decree No. 41578 in 2019

(Climate Action Tracker, 2023). This protects the progress to limit emissions and protect ecosystems from the effects of oil exploration.

Over recent years, Costa Rica has succeeded in making more than 98% of its energy renewable and restored forest cover to 53% of the total land mass, allowing for necessary carbon sinks to reduce the negative effects of continued carbon emissions (UNEP). The NDC has a goal of producing zero emissions that would be offset by collaborating in efforts to expand and maintain forested areas by 2050 (UNEP). By following the Paris Climate Agreement of 2015, the country has been able to contribute as little as 0.02% of the global emissions, despite having a population size of over 5 million people comprising 0.06% of the global population. The Initiative for Climate Action Transparency (ICAT), an international organization guided by multiple stakeholder partnerships providing nations with support and tools to build transparency for climate action, has been supporting Costa Rica's efforts and the operation of the National Climate Change Metrics System (SINAMECC; ICAT, 2021). SINAMECC is designed as a tool to ensure and improve evidence-based decisions in regard to climate action and the implementation of policies (ICAT). Within ICAT, there are three projects that include Project 3, which is the strengthening of SINAMECC as a tool to enhance its own replicability and sustainability under the guidelines of the Paris Agreement. Project 2 drives to further analyze the impacts of sustainable developmental practices and changes within the Decarbonization Plan. Project 1 extends on Project 3 by strengthening SINAMECC to better supply transparent tracking and report efforts in the mitigation tasks against climate change in Costa Rica (ICAT). Through collaboration among many organizations and facilities, Costa Rica has made strong headway in combating climate change which has drastically altered the planet preceding the pre-industrial era. Their efforts have been an awakening and motivating factor for other regions around the world to do their part in combatting climate change, especially countries leaving behind vastly larger carbon footprints than Costa Rica itself. When comparing the per capita CO_2 emissions of Latin American and Carribean countries, Costa Rica ranks fairly low for its population size. For example, Trinidad and Tobago produced 21.17 metric tonnes of CO_2 while only having a population size of 1.5 million people, while Costa Rica produced 1.68 metric tonnes and has a population size of over 5 million residents. Puerto Rico also has a population size of 3.264 residents while producing 3.47 metric tonnes of CO_2 in 2022, exceeding Costa Rica while having a smaller number of residents (Tiseo, 2023). According to Earth.org, Costa Rica is ranked as 31st in the world in the Global Sustainability Index which considers pollution, climate change, biodiversity, policy, oceans, and energy. Their updated NDC has been one of the largest contributors to the success of their environmental conservation (Mulhern, 2021). In comparison, Venezuela, home to the Venezuelan red howler monkey, ranks 131st in the world. Despite plans proposed for a 20% reduction in emissions by 2030, there has been little effort from the Venezuelan government to implement this goal via policies. This goal, despite moving in the right direction, will also not reach the necessary goals to mitigate the damage being caused at such a rapid rate (Mulhern, 2020). A study analyzing the effects of climate change on the agriculture of Guatemala and Honduras found that climate disasters such as hurricanes, temperature, and precipitation fluctuations threaten both countries' food security as they rely heavily on agricultural production. Both countries, between 1996 to 2015, were also among the top ten most affected by climate change (Waddick, 2017). In order to protect the environment and the residents of countries such as Guatemala and Honduras, it is vital that threated countries begin making the first steps towards combatting climate change, such as following the Paris Climate Agreement of 2015.

Understanding the ways that wildlife is directly and indirectly affected by climate change is important in understanding the necessary efforts that must be made in order to protect them. The primates of Costa Rica are vulnerable and rely on consistent seasonality for their own life histories and survival itself (Campos et al., 2017). As climate change alters seasonality within Costa Rican tropical rainforests primates may be in danger (Pounds et al., 1999). To prove the issue at hand, I cite below my own research study conducted at La Selva Research Station in Puerto Viejo, Costa Rica conducted in May of 2022. The following study investigates the ways that mantled howler monkeys within La Selva Research Station alter their activity and spatial cohesion patterns in response to seasonality, providing evidence of the necessity of stable seasonal conditions for their survival while climate change remains ever impending. My passion for this topic is not abstract; I saw firsthand the importance if resource and social stability in howler monkey groups located within the research station. The results indicate that howler monkeys alter their activity budgets based on seasonal changes and highlights that as climate change continues to increase the length of the dry seasons, their population structures may be placed under increasing stress.

Chapter 4: Mantled howler monkeys modify activity and spatial cohesion in response to seasonality

Introduction

Climate change encompasses shifts in weather patterns and temperatures across vast areas of the planet, commonly due to anthropogenic effects (Kemp et al., 2022). Some anthropogenic factors that induce climate change include burning of fossil fuels, deforestation, and overconsumption of natural resources, all of which cause sea level rises, ocean acidification, and imbalances in natural processes (Ciais et al., 2020). These threats include changes in seasonality, overall temperature increases, and detrimental impacts on vegetation and terrain, which can lead to behavioral changes in plants and wildlife in tropical rainforests (Rising et al., 2022; Watson et al., 2018). Anthropogenic practices such as logging and agriculture damage many wildlife populations throughout the world's rainforests by eliminating important food resources; climate change exacerbates these impacts through the increasing emission of greenhouse gases which pose further risks to rainforests (Ciais et al., 2020; Facchinelli et al., 2022). The occurrence of extreme weather events and alterations in seasonality can be found as a results of climate change which threatens agricultural locations of areas who heavily rely on production (McMichael et al., 2006). Some of these events can trigger tsunamis, droughts, unnatural wildfires, glacial meltdowns, and increases in oceanic temperature and acidity (Kemp et al., 2022). Animals and humans alike rely on much of the same ecosystems to survive, so what is devastating to one species is also devastating to others.

The average annual rainfall throughout tropical rainforests is steadily decreasing by 1% each year due to climate change (Mahli and Wright, 2004) and average temperature is expected to increase in tropical rainforests (Beaumont et al., 2011). Lack of precipitation and increasing temperatures results in drought conditions that hinder flora and fauna that serve as important resources for non-human primates (Mahli & Wright, 2004). Decreases in freshwater resources, caused not only by temperature increases and limited rainfall but also habitat depletion, risk energy loss for many native species (Barbaree et al., 2020). Drought triggers forest fires that severely affect the fauna of forests by further increasing the temperature, limiting resource availability for many species (Torkkola et al., 2022). Forest fires cause habitat fragmentation where portions of large forest expanses are fragmented into smaller pieces, isolating inhabitants within these locations (Fahrig, 2003). Rainforests have not initially been at risk for wildfires, but the longer dry seasons have posed a new risk of megafires, from which rainforests have difficulty recovering (Torkkola et al., 2022). Overall, the fragility and continued climate change within rainforests is revealing current and future challenges for many wildlife populations within these areas.

Seasonality contributes prominently to certain functions throughout tropical rainforests. Tropical rainforests have two seasons, wet and dry, where the dry season typically lasts around four months and the wet season for the remainder of the year (Restrepo-Coupe et al., 2013). Although the dry season receives less rainfall and experiences higher average temperatures, rainforests maintain their moisture through deep-rooted flora spread through the landscapes which help endure the lack of precipitation (Nepstad, 1994). The sprouting of new flora occurs during the dry season with increased sunlight and higher overall temperatures while the wet season aids growth of these plants (Huete et al., 2006). Stable transitions between the seasons greatly influence species diversity with vast numbers of species residing within rainforests (Correa et al., 2021).

As the dry season increases in intensity due to climate change, this affects many of the specialized cycles and mechanisms that species use to reproduce and disperse (Correa et al., 2021). For example, dung beetles become increasingly threatened as alterations in seasonality hinder their systematic burials and seed dispersals (Correa et al., 2021). Increased temperature fluctuations within corresponding seasons are causing late flowering times for some plant species, possibly due to temperature shock or insignificant cues in order to spark new growth (Von Holle et al., 2010). As more species and populations continue to be disrupted by changes in rainforest seasonality, chain reactions could occur that permanently alter the food chain, threatening many species. For example, litter-dwelling beetles and ants require consistent resource abundance throughout the year. Their population size peaks in the wet season due to greater litterfall that occurs with adequate temperatures and increased rainfall (Grimbacher et al., 2018). As seasonality influences reproduction, abundance, and growth of organisms, it begs the question of what effect these changes in seasonality have on vertebrates, such as primates (Grimbacher et al., 2018).

When examining how seasonality influences primates globally, sportive lemurs spend more of their time resting and feeding, and less time traveling during the dry season because of lower resource abundance in order to conserve their energy; this results in diets that consist mostly of leaves year-round, and the addition of fruit during the wet season (Mandl & Schwitzer, 2018). Slender lorises have birthing preferences where births and estrus peak during the months of April, May, and June, as well as October, November, and December (Radhakrishna and Singh, 2004). Lorises born in these months can then be weaned before two prominent rainy periods that result in high resource abundance (Radhakrishna and Singh, 2004). Samango monkeys increased resting times during the dry season due to the shorter days, where foraging for food poses higher risks during nightfall (Coleman et al., 2021). Although not all in the same way, seasonality affects the habits of many species of primates, including howler monkeys within Costa Rica.

Mantled howler monkeys (*Alouatta palliata*) are one of the largest Central American monkeys (Glander, 2006). They have seasonally specific folivorous-frugivorous diets (Crockett and Eisenberg, 1987). During the wet season they focus on mature leaves and fruits while the dry season provides them with newly budded leaves and flowers (Glander, 1978). Howler monkeys favor young leaves instead of mature ones and spend most of the day resting since their preferred leaves contain toxic compounds and fibers that require energy to digest (Crockett & Eisenberg, 1987). Howler monkeys live in social groups consisting of 13-24 individuals, including adult males and females (Ryan et al., 2008). Adult males utter deep howls, echoing extremely long distances, as a defensive mechanism or warning call to advertise their location and detect other groups of howlers (Milton, 1980). Mantled howler monkeys display spatial cohesiveness where different groups often come into close contact with one another and can overlap despite the species generally being territorial (Bolt et al., 2019).

Seasonal changes through mantled howler habitats induce behavioral changes, individually and throughout their groups. During the wet seasons, male howlers in Veracruz, Mexico spent more time within familial-related groups including related males due to decreased reproductive competition during this time (Dias & Luna, 2006). The cohesiveness also indicated territorial defense over the few females who are sexually receptive (Dias & Luna, 2006). Dry seasons revealed sub-groups with fewer males and less male cohesion due to increased sexually receptive females (Dias & Luna, 2006). For their eating habits, mantled howlers increase fruit consumption during the wet season when fruits and flowers are available, and decrease consumption during the dry season, displaying the importance of seasonality on their diets (Dunn, et al, 2010). In Los Tuxtlas, Mexico, mantled howlers spent more time feeding and traveling during the dry season and less time resting due to lower energy yields provided by leaf consumption (Dunn et al., 2010). Due to high levels of toxins in leaves and lower levels of nutrients, howlers move to find a wider range of food sources during the dry season to diversify their diets to avoid over-dosing on leaf toxins and to compensate for lower nutritional values of leaves (Glander, 1981; Dunn, et al., 2010). Understanding the effects of seasonality on the behavior and spatial cohesion of mantled howlers is important in understanding the sensitivity and reliance they have to the consistency of these seasons, especially when climate change is increasing the length of dry seasons.

We investigated mantled howler monkeys' behavioral response to seasonal changes at La Selva Research Station, a large, continuous forest in Northeastern Costa Rica. We predicted that howler monkeys would rest more, feed less, and locomote less during the wet season compared to the dry season, due to increased nutritional resources. We also predicted they would be more spatially cohesive during the wet season as greater food availability precludes the need to spread apart to obtain resources.

Methods

Study Site

We collected data in La Selva Research Station in northeastern Costa Rica. La Selva contains 1600 ha of tropical rainforest providing an ideal setting to analyze major components of mantled howler monkey behavior. The southern border of La Selva is adjacent to Braulio Carrillo National Park which consists of 44,000 ha of cloud and tropical rainforest (Bell & Donnelly, 2006). This area is protected from anthropogenic activity which provides an opportunity to examine natural systems and primates' responses to climate change. There are currently 25 groups of howler monkeys at La Selva, with a mean groups size of 14.3 monkeys, and howler population density of 23.4 individuals/km^2 (Schreier et al., in review).

The dry season throughout tropical rainforests often occurs between the months of January to April with the wet season occurring throughout the rest of the year (Clark, Clark, and Oberbauer, 2021). During the study period, the wet season within this region experienced an average rainfall of 11.04 mm per day and the dry season experienced an average of 2.58 mm per day.

Data Collection and Analysis

We collected data on the behavior and spatial cohesion of mantled howler monkeys at La Selva during the dry season (November 2018-February 2019: 225 hours of behavioral data) and the wet season (May-June 2022 and 2023: 376 hours).

We began data collection in the early morning by identifying mantled howler monkey groups and following them throughout the day until the study groups could no longer be located. We utilized instantaneous scan sampling in 2-minute intervals over 30-minute samples to record the activity of singular mantled howler monkeys (Altmann, 1974). We recorded the focal animal's activity (i.e., resting, feeding, travelling) at each 2-min scan (Paterson, 2001; Schreier et al., 2021). During each scan, we also recorded the number of howler monkeys within a 5-m radius of the focal monkey, and we estimated the distance (in meters) between the focal animal and its nearest neighbor utilizing distance classes of 0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 m or >10 m (Irwin, 2007; Schreier et al., 2021). We sampled adult males and adult females, rotating between them to collect equal amounts of data on each age-sex class (Schreier et al., 2021).

We compared monkey activity and spatial cohesion across the wet and dry seasons. To analyze data, we utilized Mann-Whitney U tests since the data were not normally distributed (via SPSS software ver.26) to compare the activity and spatial cohesion patterns of mantled howlers in La Selva across the wet and dry seasons. Statistical significance was set at $p<0.05$.

Results

Activity Budgets

The mantled howler monkey activity budgets significantly differed across the wet and dry season. As predicted, the monkeys rested significantly more in the wet season (75%) than the dry season (70%; $p<0.001$; Figure X). Also, as predicted the monkeys spent a significantly greater percentage of time feeding in the dry season (15%) than the wet season (8%; $p<0.001$). There was no significant difference between the mean percentage of time the monkeys spent locomoting between the wet (6%) and dry (6%) season.

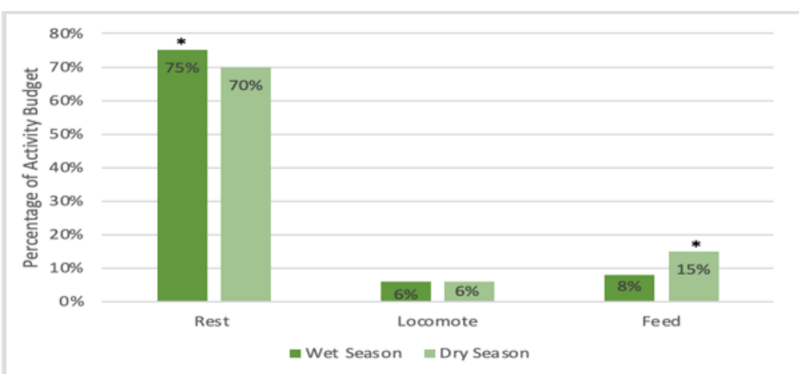

Figure 4.1. Comparisons of activity across wet and dry seasons. Asterisk indicates statistical significance.

Spatial Cohesion

Mantled howler monkey nearest neighbor distance was significantly different across seasons. As predicted, the mean nearest neighbor distance was significantly higher in the dry season (2.8m) than the wet (2.48m; $p<0.001$). There was no significant difference between the mean number of nearest neighbors between the wet (2.12) and dry (1.87) season.

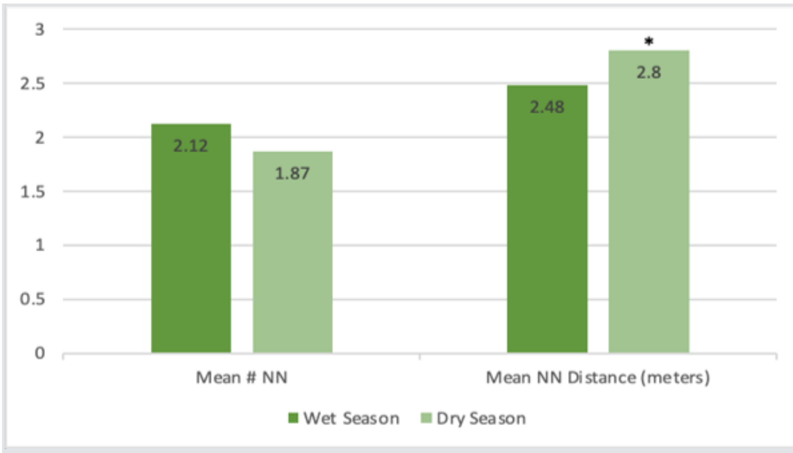

Figure 4.2. Average distance and number of nearest neighbors across seasons. Asterisk indicates statistical significance.

<u>Discussion</u>

Our hypothesis that mantled howler monkeys would modify their activity budgets and spatial cohesion patterns in response to seasonality was partially supported. As predicted, the howler monkeys rested significantly more and fed less during the wet season than the dry season. There was no difference in locomoting behavior between the wet and dry season. While the monkeys were farther from nearest neighbors in the dry season than the wet season, there was no significant difference in the number of monkeys within 5 meters.

Our activity results are consistent with some previous research. In Brazil, southern muriquis (*Brachyteles arachnoides*) spent significantly more time feeding during the dry austral winter and rested significantly more during the wet austral summer, as did howler monkeys in our study in Costa Rica. Like howler monkeys, muriquis have a folivorous-frugivorous diet that influenced their ability to adjust to climatic constraints. Spending more time feeding during the dry winter and more time resting during the wet summer allowed them to meet their energy requirements (Talebi & Lee, 2010). For howler monkeys, the lower nutritional value of leaves produced more abundantly in the dry season requires them to spend more time feeding in order to meet necessary energy requirements during the harsh dry season (Crocket & Eisenberg, 1986). Ring tailed lemurs (*Lemur catta)* in Madagascar also spent significantly more time feeding during the dry season than wet season, similar to the howler monkeys in our study. Researchers attribute this variance in activity budget to resource scarcity during the dry season and the need to feed more in order to meet the lemurs' necessary energy requirements (Gould & Gabriel, 2015).

However, other species' activity patterns with respect to seasonality were not consistent with our results. For example, vervet monkeys (*Chlorocebus pygerythrus*) in South Africa spent more time resting and less time feeding, foraging, locomoting, and completing other social behaviors during drought periods (which have similarities to the dry season), revealing the necessary plasticity of their behavior in order to adapt to changing climatic conditions (Young et al., 2019). The difference in activity patterns between the vervet monkeys and the howler monkeys in our study may result from the extremity of the drought that the vervet monkeys experienced. Their results showed higher levels of stress hormones when there was a lack of water in their home range and monkeys' higher mortality rates correlating with increased stress hormone concentrations during extreme environmental conditions (Young et al., 2019). This stress could certainly have differing influences on the behavioral requirements of vervet monkeys living in these extreme conditions as compared to the mantled howler monkeys. In extreme drought conditions, energy expenditure for foraging and locomoting could be too much of a risk for survival for the vervet monkey.

Spider monkeys (*Ateles geoffroyi vellerosus*) in Mexico also displayed contradictory activity to that of the mantled howler monkeys in our study. Spider monkeys rested more during the dry season and fed more during the wet season (Chaves et al., 2011). This difference in resting behavior between the two species may be due to temperature variation. While spider monkeys rested more during peak ambient temperatures in the dry season and fed less, there were no significant temperature differences between the wet and dry season at La Selva, precluding the influence of temperature on the howler monkeys' activity budgets (Chaves et al., 2011). Spider monkeys also maintain a more frugivorous diet than the mantled howler monkeys, suggesting that the high nutritional yields that spider monkeys obtain from fruit may temper the need to feed more during the dry season. In Brazil, the black-pencilled marmoset (*Callithrix penicillate*) locomoted significantly more during the wet season than the dry season due to greater food availability and wider distribution of nutritional resources (Vilela & De Faria, 2004). Although the howler monkeys in our study did not vary time in spent locomoting across seasons, this may be due to differences in habitat and seasonal abundance. Marmoset monkeys live in scrub savannah and semi decidual woodlands (Vilela & De Faria, 2004), while the howler monkeys inhabit a large continuous rainforest. The marmoset monkeys' food sources are thus likely spread farther apart than those of the howler monkeys, who do not need to travel long distances to find food in the dense rain forest, which may explain why the howler monkeys did not vary time spent locomoting across the wet and dry seasons. On the other hand, fruit distribution within a scrub savannah and semi decidual woodland area is scattered during the wet season requiring the marmoset monkeys to locomote more often and for farther distances (Vilela & De Faria, 2004). Although howler monkeys have diets that consist mostly of leaves, their gut is not specialized for a heavy leaf diet that they must endure during the dry season when less fruit is available (Milton, 1980). Their resting requirement to effectively digest these leaves subjects them to activity budgets centered around resting. This, in turn, may limit the howlers' ability to significantly alter their activity budgets and spend more time in activities including locomoting (Arroyo-Rodriguez & Diaz, 2010).

Our data reveal that there was no significant difference in the number of nearest neighbor numbers within five meters of sampled individuals. Although there was a statistically significant difference in the distance between monkeys across seasons, the distance across the two seasons only varied by a third of a meter which is likely not biologically meaningful (Zhan et al., 2017). The statistically significant difference is likely an artifact of the large sample size (Schreier et al., 2021).

While mantled howler monkeys displayed little variation in spatial cohesion pertaining to seasonality, other factors may be more likely to impact spatial cohesion patterns. For example, woolly monkeys (*Lagothrix lugens*) in Colombia varied their spatial cohesion based on age/sex class, reproductive status, and activity (Stevenson, 1998). For example, the monkeys were less spatially cohesive when feeding than resting. Monkeys who were genetically related were also more spatially cohesive as they spend more time grooming one another. Subadult females and subadult males were more spatially cohesive than any other age/sex class while females with infants were more spatially cohesive with other monkeys within the group. While mantled howler monkeys displayed little variation in spatial cohesion in relation to seasonality, other factors may reveal differences in spatial cohesion patterns like those observed in the woolly monkeys. For example, blue monkeys (*Cercopithicus mitis*) were more vigilant when they were less spatially cohesive (Treves, 1999).

Spider monkeys (*Ateles geoffroyi*) in Belize displayed larger sub-groups during the wet season than the dry season (Hartwell et al., 2018). The increase of nutritional resources during the wet season may allow for bigger group sizes when feeding competition is lower. Mantled howler monkeys did not demonstrate meaningful biological differences between the wet and dry season, suggesting that group sizing may be a larger factor affected by seasonal variation than spatial cohesion. Spider monkeys and mantled howlers also have different social systems. Spider monkey groups contain fission-fusion dynamics where they split into sub-groups in order to thrive in group-based living. Food availability, rainfall, and habitat type are all factors influencing fission-fusion dynamics in spider monkeys, lessening the effects of competition for resources (Aguilar-Melo et al., 2018). Large patch sizes, and thus larger fruit availability, allow for larger sub-groups while smaller sub-groups are necessary in smaller patch sizes in order to decrease competition for nutritional resources (Symington, 1988). However, howler monkeys live in social groups consisting of 13-24 individuals, where more females than males are present within the troop (Ryan et al., 2008). The lack of sub-grouping may require them to alter their behavior differently than spider monkeys.

Overall, our feeding and resting behavior results suggest that mantled howler monkeys significantly alter their activity budgets in response to seasonal factors. As climate change continues to increase the length of dry seasons by decreasing the average annual rainfall and increasing average temperatures in tropical rainforests, this places overwhelming pressure on mantled howler monkeys (Mahli & Wright, 2004; Beaumont et al., 2011). Decreases in precipitation not only limit the overall growth of flora within tropical rainforests but increased temperature fluctuations delay flowering times, increasing the likelihood that mantled howler monkeys and other wildlife will have to alter their activity budgets more drastically for survival

(Mahli & Wright, 2004; Von Holle et al., 2010). Rainforests are extremely sensitive to climatic changes because they do not normally experience extreme alterations in environmental cues from year to year; thus, species who inhabit them also experience the effects of this sensitivity (Shinya et al., 2022).

Many other species residing within rainforests also may not be able to persist in the face of climate change. For example, rainforest ringtail possums (*Pseudochirulus cinereus*) are predicted to decline by nearly 90% of their total populations by the year 2050 (de la Fuente & Williams, 2023). Climate change is causing rapid changes to habitats and the possum species may not be evolutionarily tolerant to these changes; other species like mantled howler monkeys in Costa Rica and other regions may suffer the same fate in response to further and more extreme seasonal changes (de la Fuente & Williams, 2023). Future behavioral observations of mantled howler monkey activity and spatial cohesion will provide more detailed insight into the response of these monkeys. It is crucial to examine how the howler monkeys respond to seasonal changes over many years to understand the impacts of climate change more fully. Our current study is therefore a first step in this direction. Observing long-term behavioral and demographic changes of these howler monkeys in response to seasonal variation at La Selva Research Station could provide conservation guidelines for howler monkeys and other species living in tropical rainforests and help inform well-constructed climate change protocols for these delicate habitats.

Chapter 5: The benefits of ecotourism in Costa Rican primate conservation

Other regions hosting nonhuman primates should reform and implement effective conservation standards to protect their native species, especially those whose current IUCN Red List status ranges from “vulnerable” to “critically endangered.” Other countries could utilize Costa Rican conservation tactics and policies for environmental protection as a model to improve their conservation record. An important consideration when determining the applicability of implementing Costa Rican conservation tactics in regions that may not be as affluent as Costa Rica is the allocation of funds to support these tactics. I believe that ecotourism may be the ultimate answer to this issue. By first focusing on ecotourism, other countries can have the opportunity to allocate those funds to implement policy reforms and regulations that are similarly utilized by Costa Rica. In addition, ecotourism would allow them to get a jump start on conservation efforts that are inherently offered through ecotourism. Ecotourism, if done properly, is an efficient way to not only educate people about the ecosystems they visit and the dangers tropical rainforests face but to increase income for these regions by creating new employment opportunities. Between making more jobs for the regions’ citizens and by raising money for conservation tactics and policies, ecotourism could allow other countries to take the first step in creating real change for the conservation of their native primates.

Ecotourism, as defined by The International Ecotourism Society, is the “responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education” (The International Ecotourism Society). In short, it is a form of nature-based tourism that has recently been assessed as a tool for sustainable development (Wood, 2002). Ecotourism is encompassed by travel from visitors across the world who visit natural areas that are preserved with the purpose of witnessing and learning about the environment (Wearing & Neil, 2009). Core principles of ecotourism include conservation, communities, and interpretation. For conservation, ecotourism should provide economic incentives that motivate the conservation of natural biodiversity. By including local communities, ecotourism should also increase connections and employment opportunities for local residents. Finally, those who partake in ecotourism should leave the experience with a better understanding of the natural world, conservation efforts, and awareness of environmental concerns while creating minimal impacts on the area itself (International Ecotourism Society).

Ecotourism may have surpassed oil as the world's largest industry: it supports almost 215 million jobs worldwide and accounts for almost 6% of the global gross national profit (Honey, 2003; Lepree, 2008). The expansion of ecotourism also accounts for over 20% of international travel (Dowling, 2000). Travel and tourism industries work closely together in order to accommodate the rising demand of ecotourism. In 2016, travel and tourism of the global sector employed 112 million people, approximately 3.6% of total global employment (The International Ecotourism Society). The mid-twentieth century catapulted what is today defined as ecotourism through an increase in tourism and environmental awareness that has sparked numerous efforts around the world (Dowling, 2013). The benefits of ecotourism are evident in many of its applications around the world as well. Overall, developing countries receive a revenue of nearly $29 billion a year from ecotourism, revealing the vitality of the industry (Kirkby et al., 2011).

Ecotourism occurs in various areas of the globe, and its benefits are clear in many different cases. The rise of ecotourism and its appeal to wildlife conservation, as well as its creation of a new employment sector, is evident through visitation demographics. Africa, in particular, has had much ecotourism success due to the diversity and uniqueness of their native wildlife (Lindsey et al., 2007). For example, South Africa had a 486% increase in visitors to nature-based destinations from 1990 to 1999 due to the rise of ecotourism efforts in the country. Indonesia, in the same way, had a 136% increase in visitors in these same years (Wood, 2002). Two percent of global travelers in 2005 were arriving in Africa to take part in ecotourism throughout the continent. One notable ecotourism group within Africa is the Pafuri Lodge of Wilderness Safaris which upholds effective work in wildlife conservation while collaborating with the local community, the Makuleke, who reside on the land and receive a portion of the income obtained by ecotourism and employment on the reserve (Spenceley, 2000). The employees of Phinda Private Game Reserve, located in in South Africa, are 80% from the local community and have done extensive work to increase the population of the black rhinoceros while also protecting the 12,699 hectares of reserve land (Spenceley, 2000).

This form of tourism necessitates increasing and maintaining forest cover in regions where the tourism is occurring (Kirkby et al., 2011). With this in mind, ecotourism correspondingly increases conservation efforts. A study completed in Kenya during the 1970's revealed that the economic benefit of ecotourism exceeds that of hunting activities, an activity that wasn't banned in this area until 1977 (Wood, 2002). The economic success of ecotourism can allow it to grow, providing safety for wildlife and secure employment for millions of people. Those who partake in ecological tourist activities can become active environmental enthusiasts, which would incentivize sustainable tourism in the future and promote conservation to others (Black & Crabtree, 2007). A study that interviewed domestic Chinese tourists revealed that they became more environmentally conscious after attending an ecotourism location (Cheng et al., 2014). Ecotourism can assist in eradicating poverty within areas that contain natural land that would be appealing to outside tourists (Surendran & Sekhar, 2011). It offers up new employment opportunities to local residents, positively affecting economic standards and expansion of production for the nation (Stronza, 2007). For example, Redank Island Marine Park in Malaysia provided 938 jobs to the local community. In 2001, this ecotourist destination received more than 73,000 visitors whose fees and donations contributed to the protection of marine life and their habitats (Yacob et al., 2007). Finally, ecotourism can assist in combatting climate change where ecotourist areas become important carbon sinks (Bishop, 2022). In Peru, land utilized for ecotourist purposes can sequester anywhere from 5.3 to 8.7 billion tons of carbon (Kirkby, 2010).

Despite the clear benefits that ecotourism provides around the world, there has been some controversy regarding its efficiency. First off, a downside to ecotourism is that it can cause degradation to the land, posing risks to the ecosystem and its inhabitants. In Himachal Pradesh, India, ecotourist hubs experienced more deforestation than in locations where ecotourism wasn’t as common. This occurs due to the fact that ecotourism requires some facilities such as hotels and restaurants to accommodate visitors which necessitates the clearing of trees to make room for the buildings. However, the opposite occurred in China in the Yunnan province. Areas that experienced more ecotourism in fact had less deforestation occur than areas that were not ecotourist hubs (Brandt et al., 2019). In Manuel Antonio National Park, Costa Rica, the high presence of tourists has had a negative effect on primate populations, where they have become accustomed to visitors and feed off their trash. The high traffic of visitors during the high season also is increasing trail erosion (Van Tassell & Daniel, 2006). All of this emphasizes that research is an important component of ecotourism and determining carrying capacity for specific areas is vital to the success of the ecotourism (Obua, 1997). These varying results reveal that every ecotourist location experiences different circumstances that require specific protocols in order to maintain the integrity of wildlife conservation around the world. If done correctly, as seen in China, ecotourism can maintain forests while also producing economic gain from ecotourism to promote more conservation.

Another issue that may arise from ecotourism is that the presence of people in protected areas and reserves can disrupt the behavior and health of wildlife. For example, the behavior of five species of water bird at Loxahatchee National Wildlife Reserve in Florida was altered in the presence of visitors. The amount of time that the birds spent feeding and foraging decreased in the presence of people. Time spent foraging also decreased as noise increased (Burger & Gochfeld, 1998). Although some consequences may seem large, proper research on the land used for ecotourism can help determine the carrying capacity of human presence in these areas in order to have the least impact on the wildlife (Obua,1997). Recognizing carrying capacity in the context of the ecosystem and its residents can be a beneficial tool in controlling the number of tourists who enter these locations, avoiding degradation all together and limiting their effect on natural systems. There is always a chance that the introduction of ecotourism could require indigenous people to relocate, as seen in Tanzania where the Maasai people lost control of their land for an ecotourist operation (Bishop, 2022). If done responsibly, however, both parties - ecotourism and indigenous people - can benefit from the sector. When education, both natural and cultural, is included as a pillar of ecotourism, it has the opportunity to broaden the perspectives of tourists and locals together. This education can then turn into appreciation and value for the land and one’s own home, enhancing conservation efforts as a whole (Abuamoud et al., 2015).

Costa Rica's tourism market began in the 1950's with domestic beaches (Jones & Spadafora, 2017). The creation of new railways and the expansion of the Pan-American highway in 1946 allowed for easier access to locations more desired by tourists. With the expansion of more roads that allowed access to remote areas of the country and the creation of an international airport in San Jose in 1957, it became easier and easier for tourists to explore the country's natural scenery (Jones & Spadafora, 2017). Costa Rica's National Park system was created in 1974, making 25% of its natural flora protected and public to tourists and locals alike, giving the largest access to Costa Rican ecosystems to date (Jampol, 2014). As ecotourism's popularity increased over the years, it is now one of Costa Rica's largest economic sector along with the industries involved with it, such as agritourism and the travel sector that assists in getting ecotourists to their desired destinations (Rojas, 2003; Library of Congress). By attracting nearly 4 million people, Costa Rica made $3.4 billion from ecotourism in 2019, accounting for 5% of the country's GDP (Thelwell, 2020).

Costa Rica contains many designated ecotourist locations around the country. One of these locations resides two hours outside of San Jose, Costa in Puerto Viejo de Sarapiqui, called La Selva Research Station. Created in 1968, it was the first of many private forest reserves created throughout the country. The station maintains nearly 1,600 hectares of natural and protected tropical rainforest that is utilized by researchers to study its natural systems, for academic learning opportunities, and ecotourism itself (Madrigal, 2023). Another notable location is Costa Rica's Monteverde Cloud Forest Biological Reserve, which was created in 1972 and contains 10,500 hectares of cloud forest. Cloud forests now only account for 1% of the remaining forests around the world, making this reserve vital to its inhabitants. Much like La Selva, this reserve also promotes research, incorporates the community, and provides insightful knowledge to 70,000 visitors per year regarding eco-literacy. Non-national adults can visit the reserve for $25 and resident adults for only $8, and the profits return to protect the reserve and provide income for its employees. Researchers at the reserve work attentively at determining the appropriate visitor carrying capacity that best caters to the wellbeing of the forest and its inhabitants (Monteverde Cloud Forest Biological Reserve, 2023).

Ecotourism is prosperous in Costa Rica, making it a model of success for many other countries. A part of this success correlates with the sustainable practices utilized within the services of ecotourism. For example, Selva Bananito Ecolodge in the Limon Province of Costa Rica utilizes recycled wood from waste to construct their lodges and heat their facilities with solar panels. In addition, they also limit their noise production and pollutions in order to minimize effects on the natural flora and fauna located there (Secrets Edition, 2022). In an article analyzing the benefits and drawbacks to ecotourism in Manuel Antonio, Monteverde, and Tortugero, Costa Rica, researchers found that there were no net negative consequences of ecotourism regarding the environmental, economic, and social impacts. Through their comparison between the benefits and drawbacks of ecotourism within each these sectors, the negative consequences did not outweigh the benefits. In fact, they found that the environmental benefits outweighed the drawbacks in Tortugero, giving it a sustainable rating (Koens et al., 2009).

The benefits of ecotourism in Costa Rica can thus be correlated to their native species of primates. When ecotourism is a critical contributor to the protection of habitats, the wildlife tends to flourish, specifically primates. A study looking at the conservation portfolios of four different regions in Costa Rica examined the correlation between participation in only ecotourism, excluding the PES program, and primate abundance. The more involvement in ecotourism by landowners increased the percentages of the encounter rates for the four native primates within the corresponding areas. For example, the Las Cruces area had 10% participation in ecotourism and had a group encounter rate of primates of 0.07 groups per kilometer. The La Selva area had a participation percentage of 29% and a group encounter rate of 0.35 groups per kilometer. Manuel Antonio had participation in ecotourism of 50% and had a group encounter rate of 0.7 groups per kilometer. Finally, the Piro area had the highest participation in ecotourism of 56% and a primate group encounter rate of 0.8 groups per kilometer. These results show that the application of ecotourism provides positive benefits to primates, allowing them to roam freely throughout their native habitat. In fact, the Piro area, the location with the highest percentage of ecotourism, also encountered the largest number of primates groups at 59 groups. On the other hand, Lac Cruces, the area with the lowest participation in ecotourism only had an encounter of 3 different groups (Tafoya et al., 2020). It seems to be that ecotourism supports the growth of primate populations when applied in the correct manner.

Costa Rica, as a hub for ecotourism, has had the privilege of being able to directly see the benefits that result from it. Creating various employment opportunities in running and managing ecotourism operations can assist local community members and generate income for local and indigenous groups, despite some saying that ecotourism does otherwise (Horton, 2009). For example, ecotourism within Tortugero National Park provides the rural communities located close to the park with part-time employment, allowing them to remain connected to their native land (Jacobson & Robles, 1992). Ecotourism is one of the most valuable tools utilized by the National Park System (NPS), substantially increasing its sustainability. Of the 230 protected areas under the NPS, around 110 of them contain “ecolodges” offering enjoyable activities for tourists such as learning about wildlife, conservation, and local cultural heritage, substantially increasing their popularity and allowing another source of income for the NPS (Honey, 2003; Lepree, 2008). A study analyzing the sustainability of ecotourism in Lapas Rios Ecolodge Nature Reserve in Costa Rica found that tour activities within the reserve had little to no negative effect on the native wildlife and instead shielded the area from mining and other anthropogenic threats. In fact, the reserve was able to increase the abundance of endangered rodents and ground birds through their conservation efforts (Lopez Gutierrez et al., 2020). The Punta Islita eco-lodge in the Nicoya Peninsula, Costa Rica not only had positive effects on the economic gain of local communities but on the reforestation rates of the surrounding area as well (Almeyda et al., 2010). Finally, a clear benefit of Costa Rican ecotourism has been its economic gain to the country. Ecotourism itself has a profound influence on the Gross National Profit of the country where from 1970 to 1995, the GNP increased from $1,000 million to $9,000 million, ultimately giving it an increase in international operations and production (Narayan, 1998). As of 2009, 17% of the country's GNP was influenced by tourism and this number continues to grow at least 5% each year (Rutter, 2009). It is clear that ecotourism is a useful tool for sustainable wildlife conservation in Costa Rica, despite some possible negative consequences.

In order to prevent the potential downsides of ecotourism, it is important that those who are partaking in the business focus on a few guidelines. These include limiting social and behavioral impacts on wildlife, focusing the intent of ecotourism on environmental and cultural education, and contributing to the conservation of nature in some way. Education in ecotourism is extremely important when it comes to outweighing the risks with the benefits. Some may argue that ecotourism supports urbanization and deforestation of natural forest because an increase of ecotourists could lead to the need for more roads and buildings, all to account for the increase in local and international visitors (Brandt & Buckley, 2018). Indeed, if done under the wrong circumstances, ecotourism can exacerbate the negative effects of anthropogenic activities, but there are ways to get around this while also promoting ecotourism. For example, in 2003 Lapos Rios Ecolodge received a Certificate for Sustainable Tourism and was awarded five-leaf status, a ranking of sustainability, from the Costa Rica Tourism Board regarding their hotel. Guests not only get to immerse themselves within the rainforest but also can embark in other activities such as native craftwork and kayaking (Lanier, 2014).

Some studies show that ecotourism affects primate behavior and feeding tendencies due to visitor interactions, possibly threatening both parties due to aggressive behavior exhibited by the primates (Webb & McCoy, 2014). However, a study conducted in Curu Wildlife Reserve in Costa Rica revealed that white-faced capuchin behavior did not significantly differ between areas with visitors and without. The mantled howler monkeys within the study did display an increased sensitivity to noise in areas with tourists, often howling in response to the noise (McKinney, 2014). This ultimately reveals the importance of research and applying important protocols for ecotourist activities. Clearly, every species is different and reacts to variables in different ways. The best practice is to sufficiently inform tourists about safety protocols and to respect wildlife by implementing the necessary components to limit the direct impact on wildlife itself. Additionally, ecotourism poses increased risk of disease transmission between humans and non-human primates (Tafoya et al., 2020). Applying necessary regulations and prohibitions to ecotourism excursions such as restricting littering, using face coverings when ill, remaining a certain distance from the animals, and providing educational seminars before tours, can significantly prevent the dangers posed by zoonotic disease transmission from both parties, humans and primates (Muehlenbein & Ancrenaz, 2009).

Along with Costa Rica's effective policies and action towards deforestation and climate change, ecotourism is the last key factor that makes this country especially effective at wildlife conservation, and ultimately, primate conservation. Through this conservation technique, Costa Rica has been able to find an efficient balance that not only assists native primates but also native human communities. Costa Rica will continue to provide a prime example of the benefits of ecotourism.

Chapter 6: Costa Rica as an effective model for primate conservation

Humans and our non-human primate relatives are connected in more ways than we think, and the fate of our planet is not just an issue for wildlife, it's an issue for humans as well. Ultimately, we should care about these situations that are affecting primates and their environment because, down the line, they will affect us too. When forests become depleted, the organisms residing within them do not simply remain stagnant. Instead, wildlife tends to migrate into the territory of humans. These migrations substantially increase the chances of spreading zoonotic diseases from human to animal, or animal to human (The Humane League). For example, one study revealed that greater increases in cumulative deforestation percentages were positively associated with the incidence of malaria within Brazil. For every 4.3% change in deforestation, there would be a 48% increase in the incidence of malaria (Olson et al., 2010). As deforestation continues to occur for many reasons, sometimes for cattle pastures, those who work in the industry are almost twice as likely to be infected by an infectious disease (Shah et al., 2019).

Deforestation also increases the risk of food insecurity to many people, especially indigenous peoples who heavily rely on the resources provided by the rainforest. Losing these resources can cause food insecurity for many human communities which can displace entire populations of people. After all, nearly 25% of the global population relies on forests for their livelihood (The Humane League). Also, industrial agriculture almost always results in soil infertility. Soil degradation from the planting of monocultures causes the soil to be unusable for future crop growth due to the nutrients being depleted (Uren, 1992). There are nearly 783 million people across the globe who are currently experiencing chronic hunger and the threat that deforestation poses, especially in the face of nutrient depletion and the spread of disease from monocultures, increases this number substantially (UN World Food Programme).

Furthermore, current environmental conditions worldwide are the cause of a third of the 25,000 child deaths every day from circumstances such as infectious diseases, food and water toxins, air contaminants, extreme weather, and population displacement (Myers, 2009; Sheffield & Landrigan, 2011). If climate change progresses, large portions of the human population will begin experiencing heat waves and increased risk of wildfires. In 1995, nearly 800 lives were lost in Chicago due to extreme temperatures caused by heat waves (Hayhoe et al., 2010). Natural disasters are becoming not so natural as well. With increases to sea water levels and decreases in reef roughness, tsunamis pose higher threats in areas located near reefed coasts, threatening the safety of millions of people (Shao et al., 2019). In the 1990s, natural disasters accounted for over 62,000 deaths, displaced 200 million people, and accumulated economic losses of more than $69 billion (Myers, 2009). The effort to end climate change cannot just occur in one region but must occur collectively across all regions.

Regardless of whether protecting the world's primates inherently protects us too, is it not our duty to protect these organisms because it is the right thing to do? It is my opinion that animals, specifically non-human primates, have moral status. This claim means that primates matter, not because of any relationships or interests they share with humans, but simply because they matter in their own right (DeGrazia, 2002). The dangers we pose to primates through deforestation and climate change aren't just wrong because they also hurt us, they are wrong because it hurts them. It is because primates have moral status that they also have moral rights through equal consideration. These moral rights inherently should allow them protection from suffering because they have interests that are as of much importance as humans (DeGrazia, 2002). In this way, the suffering of primates through these anthropogenic stressors is as morally important, and detrimental, as it would be for humans. Because of their moral status that gives them moral rights, they should be treated with enough consideration as would be permissible to humans. Ending climate change and deforestation would be important steps in eliminating their suffering and allowing them their right of moral status.

Peter Singer, Professor of Bioethics and philosopher, once said, “the speciesist allows the interests of his own species to override the greater interests of members of other species” (Singer, 2019). Speceisism refers to the idea that humans are preferred, or superior, than other species and thus other species are exploitable. The poor reason in regard to speciesism can be viewed through this analogy. Being born into one race or another is as completely random of a chance as being born into a certain species (Gruen, 2017). As humans, we have already established that racism is morally wrong, which can correspondingly be said for speciesism. The random chance of who we are should serve as reason enough to protect wildlife and not view them as inferior because they are not the human species. We do not get to decide who we are until after we are born unto the Earth, and the same goes for other animals. Our basic instincts drive us to survive and prosper, and the same goes for other species. Just like how we believe we deserve the right to live, and more precisely, live a fulfilled life, animals desire this as well. Is it permissible to deny them this right? I think not.

I argue that believing that our species is inherently superior because we may be more advanced or intelligent than another species doesn’t give us the right to exploit the lives of other species. As humans, we have constructed so many ideas that we believe only apply to ourselves, but the application of our constructs onto other organisms reveals that all species share something in common with one another: we are alive and strive to remain alive. One may argue that humans are an exceptional species because we have social systems, problem solve, and feel emotion, but as previously relayed, there are certainly many species who experience these same abilities. Like humans, primates are highly sentient beings, meaning that they have high levels of awareness and increasingly high cognitive abilities. Their high cognition gives them the ability to be self-aware and to reflect on their own feelings (Marino, 2010). Primates feel pain as we do, where this pain can result from the stressors of indirect human actions on primates such as starvation through resource deprivation (Manning & Vierck, 1973). Just as we wish to avoid pain and limit the pain we cause onto other humans; the same principle should be valued pertaining to primates. Pain is pain, no matter the being. If we wish to live in a peaceful and cohesive world, we should limit the infliction of pain in all aspects.

Through vast efforts, Costa Rica has been extremely effective at restoring and protecting its nation's wildlife, including the four species of primates that reside there. The increasing population sizes of mantled howler monkeys and white-faced capuchins in reforested areas are an important example of this (Fedigan & Jack, 2001). The Payment for Ecosystem Services, The National Biological Corridors Program, their Nationally Determined Contribution plan, their commitment to The Paris Agreement of 2015, and ecotourism, all contribute substantially to Costa Rica's success. these programs, regulations, and tactics allow the restoration and preservation of their unique wildlife so that they can persist on for years to come. By reforesting their deforested areas that were so vastly depleted at one point, they have been able to successfully restore ecosystems and protect the organisms within these systems. The effective work of ecotourism has promoted their success by allowing the monetary contributions of ecotourism to continue the efforts of conservation, educating ecotourists in environmental concerns, and providing employment opportunities to native residents. The incentivization program, Payments for Ecosystem Services, that Costa Rica's government provides not only assists in reforesting areas and protecting pre-existing forests but benefits the public by providing monetary compensation that can be used for the improvement of family structures and commitment to community projects (UNCC).

By implementing sustainable transportation via an electric train, creating and updating a National Decarbonization Plan, and committing to their National Decarbonization Plan, Costa Rica has made many necessary leaps in order to combat its own carbon emissions (*Contribution Nationalmente Determinada*). Costa Rica's proposed plans and actions involve many sectors and organizations who all have vocalized their commitment to the 1.5-degree Celsius trajectory for carbon emissions. By replanting forests and minimizing the release of carbon emissions, Costa Rica has tackled climate change in several different ways, all with the same goal of protecting the natural world and humans who also live within it. Their efforts provide a superb model for other areas around the world who also host non-human primates (IPCC, UNDC). The regeneration of forests has assisted in the population growth of various primates species and the use of PES has given primates the opportunity to remain in their preferred habitats (Fedigan & Jack, 2001; Tafoya et al., 2020). Costa Rica's commitment to their NDC will slow the pace of climate change, lessening the risk of seasonality changing and influencing the behavior of primates (UNEP). Finally, ecotourism also assisted in the increase of the abundance of primates and allowed for further regeneration of forests to provide suitable habitats for primates in the future (Tafoya et al., 2020; Kerr et al., 2003).

Guatemala**,** for example**,** containing similar primate species to Costa Rica, would drastically benefit from Costa Rica's conservation structure. Guatemala is home to four species of primates. These include the Mexican howling monkey (*Alouatta palliata mexicana),* the black howling monkey (*Alouatta pigra),* the Mexican spider monkey (*Ateles geoffroyi vellerosus),* and the Yucatan spider monkey (*Ateles geoffroyi yucatanensis).* According to the International Union for Conservation's Red List, all four of these species are threatened, ranging from "vulnerable" to "critically endangered" (Primates-SG, 2007). Extremely similar to Costa Rican howlers, the howler monkeys of Guatemala are located within lowland forests and swamps, also having folivorous-frugivorous diets where they consume nearly 130 different plant species located within their habitats (New England Primate Conservancy).

In Guatemala, the Mayan Lowlands have experienced extreme rates of deforestation from 2000 to 2008 (Manoharan, 2009). Due to this deforestation, these regions have now begun to experience unstable seasonal variations that threaten all wildlife living within and around these regions, including primates (Manoharan, 2009). These variations include decreased soil moisture and increased average temperatures during the dry season (Manoharan, 2009). The Guatemalan government, although making wildlife and pet trade illegal, experiences illegal catch of various species throughout the nation, exacerbating declining populations suffering from climate change and deforestation all together (Pasachnik & Ariano, 2010). In the 2011 Climate Change Vulnerability Index, Guatemala was considered the 19th most vulnerable country to the impacts caused by climate change (Maplecroft, 2010). Guatemala also ranks in the top five of countries who suffer the most from natural disasters, which will continue to be detrimental to the rural populations who rely on agriculture for income as long as these negative anthropogenic activities continue on (Climate Change Knowledge Portal).

Nicaragua similarly is home to the mantled howler monkey, two species of spider monkey, and the white-faced capuchin. This country has also experienced deforestation for agricultural purposes and has begun displaying warming land temperatures across the region via climate change (Gourdji et al., 2015). In a study investigating primate populations in fragmented forests in several areas of the country, researchers found that spider monkeys and white-faced capuchins were significantly diminished in the largest remaining fragmented forest of the region. In fact, both species were extinct inside and outside of some protected locations (Williams-Guillén et al., 2013). The struggling populations of native Nicaraguan primate species also necessitates the utilization of Costa Rica's conservation tactics. In order to heal primate populations and forests, action must be taken immediately. The combination of climate change and deforestation will only exacerbate the negative consequences that result from these stressors.

Countries like Guatemala and Nicaragua would substantially benefit from utilizing the conservation tactics and policies of Costa Rica. It's clear that the conservation efforts made by Costa Rica not only benefit nature, but humans as well, as can be seen through the PES program. The stark fact is that nearly 62% of the world's primates are threatened and around 14% of them are considered directly threatened by extinction (Deutsches Primatenzentrum). The safety of the world's primates is directly correlated to the safety of humans because of the stories that primates tell us. Primates provide useful insights into human evolution and play valuable roles in the religious beliefs of many people (Estrada et al., 2017). For example, in the religious traditions of Buddhism, Hinduism, and Shintoism, primates are believed to be highly spiritual beings that are to be respected (Gerstein, 2011). Like us, social constructs and behavioral adaptations influence the cultural processes of chimpanzee communities (Van Leeuwen et al., 2018). Without the efforts of other countries around the world making the same progress towards environmental sustainability and wildlife conservation as Costa Rica, primates will continue to be in danger and so will we.

The question remains of how other areas would go about increasing ecotourism in their country or region since they may not be as popular of an ecotourist destination as Costa Rica currently is. Would the additional funds brought in from ecotourism offset the potential environmental detriments that too much tourism can have on habitats? These other regions have to start somewhere in order to begin the necessary process of conservation. Starting out small at least puts them on the map as tourist destinations providing something unique that no one has seen before. From there, they can begin to build bigger and more efficient ecotourist locations for the areas where these primates reside and for the ones that need the most help and protection. Although these proposed regions for primate conservation may not be as biodiverse as Costa Rica, they all have unique features that can attract an audience which can then create a chain reaction to more ecotourism, more sites, more protection, more money, and thus more policies and tactics for their conservation. There are always downsides to natural locations that humans end up coming in close contact with, but with efficient regulations such as those used in Costa Rica, they can be maintained. By utilizing ecotourism, attaining similar conservation policies and regulations, and implementing vital conservation organizations, these nearby countries can also be contributors in saving their native primate species. In order to safeguard Central American primates, Costa Rica cannot be the only country treating conservation with the importance that it deserves.

After the implementation and success of ecotourism, protected areas can be expanded throughout the proposed country through the help of the country's government and the funds allocated through ecotourism itself. The expansion of protected areas and reserves will guide more ecotourist locations, creating more money that will not only increase conservation but also increase employment opportunities. From there it is up to the government itself to begin implementing laws and regulations that pertain to the wellbeing of native primates and other species of concern. The creation of an NDC in coordination with the Paris Agreement of 2015 as well as an incentivization program would launch primate conservation further, motivating landowners, the average citizen, and the country as whole to do their part in conservation efforts. Eventually enough money will be accumulated to implement the appropriate laws that fight against deforestation and climate change, finally giving primates a chance at recovering and thriving.

The loss of primates, no matter the species, would be detrimental to so many regions of the world. The ecosystems that exist on Earth contain life that can't be replaced and the roles that each organism fulfills are necessary for the cycle of many life forms to continue (Gascon et al., 2015). Primates bring a special value to the tropical forests of many regions by contributing to biodiversity through seed dispersal and even pollination which substantiates the importance of protecting them (Link & Di Fiore, 2006). Costa Rica is an excellent model of their protection through their various policies and tactics which, I believe, can be efficiently used by other regions of the world who need to utilize primate conservation tactics in order to protect their own primates.

References

Abuamoud, I., Alrousan, R. M., & Bader, M. A. (2015). Impacts of ecotourism in Jordan: wadi rum. *European Journal of Social Sciences*, *50*(1), 119-129.

White-faced Capuchin Monkeys. ACMCR. (2017, April 25). https://acmcr.org/content/white-faced-capuchin-monkeys/

Aguilar-Melo, A. R., Calmé, S., Smith-Aguilar, S. E., & Ramos-Fernandez, G. (2018). Fission-fusion dynamics as a temporally and spatially flexible behavioral strategy in spider monkeys. *Behavioral Ecology and Sociobiology*, *72*, 1-11.

Allen, K. E., & Padgett Vásquez, S. (2017). Forest cover, development, and Sustainability in Costa Rica: Can One policy fit all? *Land Use Policy*, *67*, 212–221. https://doi.org/10.1016/j.landusepol.2017.05.008

Almeyda, A. M., Broadbent, E. N., Wyman, M. S., & Durham, W. H. (2010). Ecotourism impacts in the Nicoya peninsula, Costa Rica. *International Journal of Tourism Research*, *12*(6), 803-819.

Altmann, J. (1974). Observational study of behavior: sampling methods. *Behaviour*, *49*(3-4), 227-266.

Anonymous, 1990. *The Forest Resources of the Temperate Zones*, *Vol. II*. FAO, Rome.

Arroyo-Rodríguez, V., & Dias, P. A. D. (2010). Effects of habitat fragmentation and disturbance on howler monkeys: a review. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, *72*(1), 1-16.

Asner, G. P., Keller, M., Lentini, M., Merry, F., & Souza Jr, C. (2009). Selective logging and its relation to deforestation. *Amazonia and Global Change*, *186*, 25-42.

Azkarate, J. C., Dunn, J. C., Balcells, C. D., & Baró, J. V. (2015). A ten-year demographic history of a population of howler monkeys (Alouatta palliata) living in a fragmented landscape in Mexico. *PeerJ*, 5, e3547. https://doi.org/10.7717/peerj.3547

Babbar, L. I., & Zak, D. R. (1995). Nitrogen loss from Coffee Agroecosystems in Costa Rica: Leaching and denitrification in the presence and absence of shade trees. *Journal of Environmental Quality*, *24*(2), 227–233. https://doi.org/10.2134/jeq1995.00472425002400020003x

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C., & Mirin, A. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences*, *104*(16), 6550-6555.

Baldwin, J. D., & Baldwin, J. I. (1971). Squirrel monkeys (Saimiri) in natural habitats in Panama, Colombia, Brazil, and Peru. *Primates*, *12*, 45-61.

Baldwin, J. D. (1971). The social organization of a semifree-ranging troop of squirrel monkeys (Saimiri sciureus). *Folia Primatologica*, *14*(1-2), 23-50.

Baldwin, J. D., & Baldwin, J. I. (1971). Squirrel monkeys (Saimiri) in natural habitats in Panama, Colombia, Brazil, and Peru. *Primates*, *12*, 45-61.

Costa Rica & SITRAP: Banana link partners. Banana Link. (2021, June 4). https://www.bananalink.org.uk/partners/costa-rica/

Barbaree, B. A., Reiter, M. E., Hickey, C. M., Strum, K. M., Isola, J. E., Jennings, S., ... & Shuford, W. D. (2020). Effects of drought on the abundance and distribution of non-breeding shorebirds in central California, USA. *Plos One*, *15*(10), e0240931.

Barrantes, G., Ocampo, D., Ramírez-Fernández, J. D., & Fuchs, E. J. (2016). Effect of fragmentation on the Costa Rican dry forest avifauna. *PeerJ*, *4*, e2422. https://doi.org/10.7717/peerj.2422

Bateman, J. (2020, October 19). *Costa Rica population*. CostaRica.Org. https://costarica.org/facts/population/

Beaumont, L. J., Pitman, A., Perkins, S., Zimmermann, N. E., Yoccoz, N. G., & Thuiller, W. (2011). Impacts of climate change on the world's most exceptional ecoregions. *Proceedings of the National Academy of Sciences*, *108*(6), 2306-2311.

Bell, K. E., & Donnelly, M. A. (2006). Influence of forest fragmentation on community structure of frogs and lizards in northeastern Costa Rica. *Conservation Biology*, *20*(6), 1750-1760.

Bergstrom, M. L., Melin, A. D., Myers, M. S., & Fedigan, L. M. (2018). Dietary profile, food composition, and nutritional intake of female white-faced capuchins. *Primate Life Histories, Sex Roles, and Adaptability*, 213–243. https://doi.org/10.1007/978-3-319-98285-4_11

Biesanz, M. H., Biesanz, R., & Biesanz, K. Z. (1999). *The ticos: Culture an Costa Rica*. Lynne Rienner Publishers.

Bishop, C. (2022, November 14). *Ecotourism benefits, activities, and tips*. WebMD. https://www.webmd.com/balance/what-to-know-about-ecotourism

Black, R., & Crabtree, A. (Eds.). (2007). *Quality assurance and certification in ecotourism*. CABI.

Boinski, S. (1987). Habitat use by squirrel monkeys (Saimiri oerstedi) in Costa Rica. *Folia Primatologica*, *49*(3-4), 151-167.

Boinski, S., & Siwt, L. (1997). Uncertain conservation status of squirrel monkeys in Costa Rica, Saimiri oerstedi oerstedi and Saimiri oerstedi citrinellus. *Folia Primatologica*, *68*(3-5), 181-193.

Boinski, S., Jack, K., Lamarsh, C., & Coltrane, J. A. (1998). Squirrel monkeys in costa rica: Drifting to extinction. *Oryx, 32*(1), 45-58. Retrieved from http://dml.regis.edu/login?url=https://www.proquest.com/scholarly-journals/squirrel-monkeys-costa-rica-drifting-extinction/docview/16298382/se-2

Boinski, S. (2005). Dispersal patterns among three species of squirrel monkeys (saimiri oerstedii, S. boliviensis and S. sciureus): III. cognition. *Behaviour, 142*(5), 679-699. Retrieved from http://dml.regis.edu/login?url=https://www.proquest.com/scholarly-journals/dispersal-patterns-among-three-species-squirrel/docview/17634162/se-2

Bolt, L. M., Schreier, A. L., Russell, D. G., Jacobson, Z. S., Merrigan-Johnson, C., Barton, M. C., & Coggeshall, E. M. (2019). Howling on the edge: Mantled howler monkey (Alouatta palliata) howling behaviour and anthropogenic edge effects in a fragmented tropical rainforest in Costa Rica. *Ethology*, *125*(9), 593-602.

Bolt, L. M., Russell, D. G., Coggeshall, E. M. C., Jacobson, Z. S., Merrigan-Johnson, C., & Schreier, A. L. (2019). Howling by the river: Howler monkey (alouatta palliata) communication in an anthropogenically-altered riparian forest in costa rica. *Behaviour, 157*(1), 77. doi:https://doi.org/10.1163/1568539X-00003582.

Bolt, L. M., Hadley, C. M., & Schreier, A. L. (2022). Crowded in a fragment: High population density of mantled howler monkeys (Alouatta palliata) in an anthropogenically-disturbed Costa Rican rainforest. *Primate Conservation*, *36*, 1-9.

Brandt, J. S., & Buckley, R. C. (2018). A global systematic review of empirical evidence of ecotourism impacts on forests in biodiversity hotspots. *Current Opinion in Environmental Sustainability*, *32*, 112-118.

Brandt, J. S., Radeloff, V., Allendorf, T., Butsic, V., & Roopsind, A. (2019). Effects of ecotourism on forest loss in the Himalayan biodiversity hotspot based on counterfactual analyses. *Conservation Biology*, *33*(6), 1318-1328.

Burger, J., & Gochfeld, M. (1998). Effects of ecotourists on bird behaviour at Loxahatchee National Wildlife Refuge, Florida. *Environmental Conservation*, *25*(1), 13-21.

Butler, A. R. (2019). Consequences of deforestation. *Mongabay: Menlo Park, CA, USA*.

Butt, N., Seabrook, L., Maron, M., Law, B. S., Dawson, T. P., Syktus, J., & McAlpine, C. A. (2015). Cascading effects of climate extremes on vertebrate fauna through changes to low-latitude tree flowering and fruiting phenology. *Global Change Biology*, *21*(9), 3267-3277.

Calvet-Mir, L., Corbera, E., Martin, A., Fisher, J., & Gross-Camp, N. (2015). Payments for ecosystem services in the tropics: a closer look at effectiveness and equity. *Current Opinion in Environmental Sustainability*, *14*, 150-162.

Campos, F. A., & Fedigan, L. M. (2009). Behavioral adaptations to heat stress and water scarcity in white-faced capuchins (Cebus capucinus) in Santa Rosa National Park, Costa

Rica. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *138*(1), 101-111.

Campos, F. A., Morris, W. F., Alberts, S. C., Altmann, J., Brockman, D. K., Cords, M., ... & Fedigan, L. M. (2017). Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species. *Global Change Biology*, *23*(11), 4907-4921.

Ceballos, G., Ehrlich, P. R., Pacheco, J., Valverde-Zúñiga, N., & Daily, G. C. (2019). Conservation in human-dominated landscapes: Lessons from the distribution of the Central American squirrel monkey. *Biological Conservation*, *237*, 41-49.

Celis, R., & Lizano, E. (1993). Development of Costa Rica: the key role of agriculture. *Unpublished manuscript*.

Electric train of Costa Rica. Central American Bank for Economic Integration. (2021, August 28). https://www.bcie.org/en/electric-train-of-costa-rica

Chakravarty, S., Ghosh, S. K., Suresh, C. P., Dey, A. N., & Shukla, G. (2012). Deforestation: causes, effects and control strategies. *Global Perspectives on Sustainable Forest Management*, *1*, 1-26.

Chapman, C. A., Chapman, L., & Glander, K. E. (1989). Primate populations in northwestern Costa Rica: potential for recovery. *Primate Conservation*, *10*, 37-44.

Chapman, C. A., Ghai, R., Jacob, A., Koojo, S. M., Reyna-Hurtado, R., Rothman, J. M., ... & Goldberg, T. L. (2013). Going, going, gone: a 15-year history of the decline of primates in forest fragments near Kibale National Park, Uganda. *Primates in Fragments: Complexity and Resilience*, 89-100.

Chaves, Ó. M., Stoner, K. E., & Arroyo-Rodríguez, V. (2011). Seasonal differences in activity patterns of Geoffroyi´ s spider monkeys (Ateles geoffroyi) living in continuous and fragmented forests in southern Mexico. *International Journal of Primatology*, *32*, 960-973.

Chaves, A., Dolz, G., Ibarra-Cerdeña, C. N., Núñez, G., Ortiz-Malavasi E, E., Bernal-Valle, S., & Gutiérrez-Espeleta, G. A. (2022). Presence and potential distribution of malaria-infected New World primates of Costa Rica. *Malaria Journal*, *21*(1), 17.

Cheng, M., Jin, X., & Wong, I. A. (2014). Ecotourism site in relation to tourist attitude and further behavioural changes. *Current Issues in Tourism*, *17*(4), 303-311.

Ciais, P., Wang, Y., Andrew, R., Bréon, F. M., Chevallier, F., Broquet, G., Nabuurs, G. J., Peters, G., McGrath, M., Meng, W., Zheng, B., & Tao, S. (2020). Biofuel burning and human respiration bias on satellite estimates of fossil fuel co2 emissions. *Environmental Research Letters*, *15*(7), 074036. https://doi.org/10.1088/1748-9326/ab7835

Clark, D. A., Clark, D. B., & Oberbauer, S. F. (2021). Annual Tropical-Rainforest Productivity Through Two Decades: Complex Responses to Climatic Factors, [CO2] and Storm Damage. *Journal of Geophysical Research: Biogeosciences*, *126*(12), e2021JG006557.

Clarke, M. R., Collins, D. A., & Zucker, E. L. (2002). Responses to deforestation in a group of mantled howlers (Alouatta palliata) in Costa Rica. *International Journal of Primatology*, *23*, 365-381.

Costa Rica. Climate Action Tracker. (2023, April 5). https://climateactiontracker.org/countries/costa-rica/#:~:text=In%202019%2C%20Costa%20Rica%20took,from%20reversal%20by%20future%20administrations.

World Bank Climate Change Knowledge Portal. Vulnerability | Climate Change Knowledge Portal. (n.d.). https://climateknowledgeportal.worldbank.org/country/guatemala/vulnerability

Coleman, B. T., Setchell, J. M., & Hill, R. A. (2021). Seasonal variation in the behavioural ecology of samango monkeys (Cercopithecus albogularis schwarzi) in a southern latitude montane environment. *Primates*, *62*(6), 1005-1018.

Contribution Nationalmente Determinada. Unfccc.int. (2020). https://unfccc.int/NDCREG

Correa, C. M., da Silva, P. G., Puker, A., Gil, R. L., & Ferreira, K. R. (2021). Rainfall seasonality drives the spatiotemporal patterns of dung beetles in Amazonian forests in the arc of deforestation. *Journal of Insect Conservation*, *25*, 453-463.

Cortes-Ortíz, L., Rosales-Meda, M., Williams-Guillén, K., Solano-Rojas, D., Méndez-Carvajal, P.G., de la Torre, S., Moscoso, P., Rodríguez, V., Palacios, E., Canales-Espinosa, D., Link, A., Guzman-Caro, D. & Cornejo, F.M. 2021. *Alouatta palliata* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2021: e.T39960A190425583. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T39960A190425583.en. Accessed on 22 September 2023.

Cortes-Ortíz, L., Solano-Rojas, D., Rosales-Meda, M., Williams-Guillén, K., Méndez-Carvajal, P.G., Marsh, L.K., Canales-Espinosa, D. & Mittermeier, R.A. 2021. *Ateles geoffroyi* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2021: e.T2279A191688782. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T2279A191688782.en. Accessed on 22 September 2023.

National Parks of Costa Rica, Reserves and Protected areas. Costa Rica Bureau. (n.d.). https://www.costaricabureau.com/nationalparks/

Flora and fauna of Costa Rica. Flora and Fauna of Costa Rica - Costa Rica Guides. (2011). https://www.costaricaguides.com/articles/flora_fauna.html#:~:text=Flora%20in%20Costa%20Rica,are%20spread%20throughout%20the%20country.

Council on Foreign Relations. (n.d.). *Climate change and regional instability in Central America*. Council on Foreign Relations. https://www.cfr.org/report/climate-change-and-regional-instability-central-america

Crockett, C. & Eisenberg, J. (1986). 6. Howlers: Variations in Group Size and Demography. In B. Smuts, D. Cheney, R. Seyfarth & R. Wrangham (Ed.), *Primate Societies* (pp. 54-68). Chicago: University of Chicago Press. https://doi.org/10.7208/9780226220468-008

Crockett, C. M., & Eisenberg, J. F. (1987). Howlers: variations in group size and demography. *Primate Societies*, 54-68.

Cunningham, D., & Cunningham, P. (2020). Evaluating forest cover and fragmentation in costa rica with a corrected global tree cover map. *Remote Sensing, 12*(19), 3226. doi:https://doi.org/10.3390/rs12193226

DeGrazia, D. (2002). *Animal rights a very short introduction*. Oxford University Press.

de la Fuente, A., & Williams, S. E. (2023). Climate change threatens the future of rain forest ringtail possums by 2050. *Diversity and Distributions, 29*(1), 173-183. doi:https://doi.org/10.1111/ddi.13652

de la Torre, S., Moscoso, P., Méndez-Carvajal, P.G., Rosales-Meda, M., Palacios, E., Link, A., Lynch Alfaro, J.W. & Mittermeier, R.A. 2021. *Cebus capucinus* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2021: e.T81257277A191708164. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T81257277A191708164.en. Accessed on 22 September 2023.

Dias, P. A. D., & Luna, E. R. (2006). Seasonal changes in male associative behavior and subgrouping of Alouatta palliata on an island. *International Journal of Primatology*, *27*, 1635-1651.

Di Fiore, A., Link, A., & Dew, J. L. (2008). Diets of wild spider monkeys. Spider monkeys: behavior, ecology and evolution of the genus Ateles. *Cambridge Studies in Biological and Evolutionary Anthropology*, *55*, 81137.

Dowling, R. K. (2000). Global ecotourism at the start of the new millennium. *World Leisure Journal*, *42*(2), 11-19.

Dowling, R. (2013). The history of ecotourism. *International handbook on ecotourism*, 15-30.

Dunn, J. C., Cristóbal-Azkarate, J., & Veà, J. J. (2010). Seasonal variations in the diet and feeding effort of two groups of howlers in different sized forest fragments. *International Journal of Primatology*, *31*, 887-903.

Emaus Forum. 1998. For ecology and human rights. Costa Rica: Foro Emaus.

Endangered Primates. Deutsches Primatenzentrum: Endangered Primates. (n.d.). https://www.dpz.eu/en/info-center/knowledge/primates/endangered-primates.html#:~:text=Two%2Dthirds%20of%20the%20approximately,be%20directly%20threatened%20with%20extinction.

Engler, M., & Martinez, N. (2004, May 27). *Harken v. Costa Rica: US companies employ blackmail in "free trade" with Central America*. Bilaterals.org. https://www.bilaterals.org/?harken-v-costa-rica-us-companies

Environment: Embajada de Costa Rica en dc. Environment | Embajada de Costa Rica en DC. (n.d.). http://www.costarica-embassy.org/index.php?q=node%2F12

Estrada, A., Garber, P. A., Rylands, A. B., Roos, C., Fernandez-Duque, E., Di Fiore, A., Nekaris, K. A., Nijman, V., Heymann, E. W., Lambert, J. E., Rovero, F., Barelli, C., Setchell, J. M., Gillespie, T. R., Mittermeier, R. A., Arregoitia, L. V., de Guinea, M., Gouveia, S., Dobrovolski, R., Shanee, S., … Li, B. (2017). Impending extinction crisis of the world's primates: Why primates matter. *Science Advances*, *3*(1), e1600946. https://doi.org/10.1126/sciadv.1600946

Evans, S. (2010). *The green republic: A conservation history of Costa Rica*. University of Texas Press.

Facchinelli, F., Pappalardo, S. E., Della Fera, G., Crescini, E., Codato, D., Diantini, A., ... & De Marchi, M. (2022). Extreme citizens science for climate justice: linking pixel to people for mapping gas flaring in Amazon rainforest. *Environmental Research Letters*, *17*(2), 024003.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *34*(1), 487-515.

Fedigan, L. M., & Jack, K. (2001). Neotropical primates in a regenerating Costa Rican dry forest: a comparison of howler and capuchin population patterns. *International Journal of Primatology*, *22*, 689-713.

Feller, M. C. (2009). Deforestation and nutrient loading to fresh waters. *Encyclopedia of Inland Waters*, 29–44. https://doi.org/10.1016/b978-012370626-3.00227-1

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., & al, e. (2005). Global consequences of land use. *Science, 309*(5734), 570-574. Retrieved from http://dml.regis.edu/login?url=https://www.proquest.com/scholarly-journals/global-consequences-land-use/docview/213600813/se-2

Franklin, A. B., Noon, B. R., & George, T. L. (2002). What is habitat fragmentation?. *Studies in Avian Biology*, *25*, 20-29.

Galat, G., Galat-Luong, A., & Nizinski, G. (2009). Increasing dryness and regression of the geographical range of temminck's red colobus procolobus badius temminckii: Implications for its conservation. *Mammalia, 73*(4), 365-368. doi:https://doi.org/10.1515/MAMM.2009.051

Garber, P. A., Molina, A., & Molina, R. L. (2010). Putting the community back in Community Ecology and education: The Role of Field Schools and private reserves in the ethical training of primatologists. *American Journal of Primatology*, *72*(9), 785–793. https://doi.org/10.1002/ajp.20837

Gascon, C., Brooks, T. M., Contreras-MacBeath, T., Heard, N., Konstant, W., Lamoreux, J., ... & Vié, J. C. (2015). The importance and benefits of species. *Current Biology*, *25*(10), R431-R438.

Gattuso, J. P., & Hansson, L. (Eds.). (2011). *Ocean acidification*. Oxford University Press, USA.

Gerstein, J. (2013, February 6). *Sacred Monkeys of the east: 4 sites in Asia to monkey see, monkey do, and Monkey Worship*. Atlas Obscura. https://www.atlasobscura.com/articles/sacred-monkeys-of-the-east

Girres, J. F., Prunier, D., Rodriguez, T., Pottier, A., Léonard, E., Audic, V., ... & Magnaudet, J. A. (2023). Analysis of the spatial extension of pineapple monocultures in northern Costa Rica using heterogeneous geographic data. *Advances in Cartography and GIScience of the ICA*, *4*, 9.

Glander, K. E. (1978). Howling monkey feeding behavior and plant secondary compounds: A study of strategies. *The Ecology of Arboreal Folivores*, 561-573.

Glander, K. E. (1981). Feeding patterns in mantled howling monkeys. *Foraging Behavior: Ecological, Ethological, and Psychological Approaches*, 231-259.

Glander, K. E. (1992). Dispersal patterns in Costa Rican mantled howling monkeys. *International Journal of Primatology*, *13*, 415-436.

Glander, K. E. (2006). Average body weight for mantled howling monkeys (Alouatta palliata): an assessment of average values and variability. In *New Perspectives in the Study of Mesoamerican Primates: Distribution, Ecology, Behavior, and Conservation* (pp. 247-263). Boston, MA: Springer US.

Costa Rica national parks: Global alliance of national parks. Costa Rica National Parks | Global Alliance of National Parks. (n.d.). https://national-parks.org/costa-rica#:~:text=Cost%20Rica%20is%20one%20of,any%20country%20in%20the%20world.

Costa Rica national parks: Global alliance of national parks. National Parks. (n.d.). https://national-parks.org/costa-rica

Gould, L., & Gabriel, D. N. (2015). Wet and dry season diets of the Endangered Lemur catta (ring-tailed lemur) in two mountainous rocky outcrop forest fragments in south-central M adagascar. *African Journal of Ecology*, *53*(3), 320-330.

Gourdji, S., Läderach, P., Valle, A. M., Martinez, C. Z., & Lobell, D. B. (2015). Historical climate trends, deforestation, and maize and bean yields in Nicaragua. *Agricultural and Forest Meteorology*, *200*, 270-281.

Government of Costa Rica. (2018). *National Decarbonization Plan*. Decarbonizing Costa Rica. https://unfccc.int/sites/default/files/resource/tp2023_04.pdf

Agribusiness & Deforestation. Greenpeace USA . (2019, October 3). https://www.greenpeace.org/usa/forests/issues/agribusiness/#:~:text=Some%2080%25%20of%20global%20deforestation,greenhouse%20gas%20(GHG)%20emissions.

Agribusiness & Deforestation. Greenpeace USA - We fight for a greener, more peaceful world. (2019, October 3). https://www.greenpeace.org/usa/forests/issues/agribusiness/#:~:text=Some%2080%25%20of%20global%20deforestation,greenhouse%20gas%20(GHG)%20emissions.

Grimbacher, P. S., Edwards, W., Liddell, M. J., Nelson, P. N., Nichols, C., Wardhaugh, C. W., & Stork, N. E. (2018). Temporal variation in abundance of leaf litter beetles and ants in an Australian lowland tropical rainforest is driven by climate and litter fall. *Biodiversity and Conservation*, *27*, 2625-2640.

Gruen, L. (2017, August 23). *The moral status of animals*. Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/moral-animal/

Hall, C. (1985). *Costa Rica: A geographical interpretation in historical perspective*. Westview Press.

Halpin, P. N., & Secrett, C. M. (1995). Potential impacts of climate change on forest protection in the humid tropics: A case study in Costa Rica. *Impacts of Climate Change on Ecosystems and Species: Terrestrial Ecosystems*, 2, 1-21.

Hardy, J. T. (2003). *Climate change: causes, effects, and solutions*. John Wiley & Sons.

Hartwell, K. S., Notman, H., & Pavelka, M. S. M. (2018). Seasonal and sex differences in the fission–fusion dynamics of spider monkeys (ateles geoffroyi yucatanensis) in belize. *Primates, 59*(6), 531-539. doi:https://doi.org/10.1007/s10329-018-0685-4

Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S., & Samuel, M. D. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science*, *296*(5576), 2158-2162.

Hayhoe, K., Sheridan, S., Kalkstein, L., & Greene, S. (2010). Climate change, heat waves, and mortality projections for Chicago. *Journal of Great Lakes Research*, *36*, 65-73.

Hernández, C., Witter, S. G., Hall, C. A., & Fridgen, C. (2000). The Costa Rican banana industry: can it be sustainable?. In *Quantifying Sustainable Development* (pp. 563-593). Academic Press.

Honduras, B. (2021, August 28). *Electric train of Costa Rica*. Central American Bank for Economic Integration. https://www.bcie.org/en/electric-train-of-costa-rica#:~:text=The%20total%20cost%20of%20the,Costa%20Rican%20government%2C%20plus%20a

Honey, M. (2003). Ensuring Tourism Contributes to Conservation. In *Tourism and Protected Areas: Benefits Beyond Boundaries: The Vth IUCN World Parks Congress* (pp. 168-190).

Horton, L. R. (2009). Buying up nature: Economic and social impacts of Costa Rica's ecotourism boom. *Latin American Perspectives*, *36*(3), 93-107.

Huete, A. R., Didan, K., Shimabukuro, Y. E., Ratana, P., Saleska, S. R., Hutyra, L. R., ... & Myneni, R. (2006). Amazon rainforests green-up with sunlight in dry season. *Geophysical Research Letters*, *33*(6).

Effects of Deforestation on Humans and the Environment. The Humane League. (2022, October 2). https://thehumaneleague.org/article/effects-of-deforestation#:~:text=When%20companies%20cut%20down%20forests,in%20regions%20with%20tropical%20forests.

Costa Rica. ICAT. (2023, November 6). https://climateactiontransparency.org/country/costa-rica/

SINAMECC. ICAT. (2021, December 13). https://climateactiontransparency.org/our-work/icat-toolbox/sinamecc/

The International Ecotourism Society. (n.d.). *What is ecotourism - the International Ecotourism Society*. ecotourism.org. https://ecotourism.org/what-is-ecotourism/

The International Ecotourism Society. (n.d.). *The global ecotourism market*. ace.aua.am. https://ace.aua.am/files/2019/09/The-Global-Ecotourism-Market-The-Trends-How-Armenia-Can-Tap-into-Opportunities-Jon-Bruno.pdf

What is ecotourism - the International Ecotourism Society. (n.d.). Retrieved April 18, 2023, from https://ecotourism.org/what-is-ecotourism/

Full report. IPCC. (2013). https://www.ipcc.ch/report/ar5/wg1/full-report/

Global Warming of 1.5 oc. IPCC. (n.d.). https://www.ipcc.ch/sr15/

Irwin, M. T. (2007). Living in forest fragments reduces group cohesion in diademed sifakas (Propithecus diadema) in eastern Madagascar by reducing food patch size. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, *69*(4), 434-447.

Jacobson, S. K., & Robles, R. (1992). Ecotourism, sustainable development, and conservation education: Development of a tour guide training program in Tortuguero, Costa Rica. *Environmental Management*, *16*, 701-713.

Jagers, S. C., Matti, S., Crépin, A. S., Langlet, D., Havenhand, J. N., Troell, M., ... & Anderson, L. G. (2019). Societal causes of, and responses to, ocean acidification. *Ambio*, *48*, 816-830.

Jampol, G. (2014). *History in Brief: Ecotourism in Costa Rica* . globalecotourismnetwork.org.

Johnson, C. E., Tafoya, K. A., Beck, P., Concilio, A., White, K. E., Quirós, R., & Wasserman, M. D. (2023). Primate richness and abundance is driven by both forest structure and conservation scenario in Costa Rica. *Plos One*, *18*(9), e0290742.

Johnston, E. (2022, February 16). *Costa Rica: Paradise on Earth*. Kew. https://www.kew.org/read-and-watch/costa-rica-biodiversity#:~:text=How%20is%20this%20small%20country%20home%20to%20such%20a%20wealth%20of%20wildlife%3F&text=Nestled%20in%20the%20middle%20of,the%20estimated%20species%20on%20Earth.

Jones, C. B. (1985). Reproductive patterns in mantled howler monkeys: estrus, mate choice and copulation. *Primates*, *26*, 130-142.

Jones, G., & Spadafora, A. (2017). Creating Ecotourism in Costa Rica, 1970–2000. *Enterprise & Society*, *18*(1), 146-183.

Kalbitzer, U., & Jack, K. M. (Eds.). (2018). *Primate Life Histories, Sex Roles, and Adaptability: Essays in Honour of Linda M. Fedigan*. Springer.

Karmalkar, A. V., Bradley, R. S., & Diaz, H. F. (2008). Climate change scenario for Costa Rican montane forests. *Geophysical Research Letters*, *35*(11)

Kemp, L., Xu, C., Depledge, J., Ebi, K. L., Gibbins, G., Kohler, T. A., . . . Lenton, T. M. (2022). Climate endgame: Exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences of the United States of America, 119*(34), 1. doi:https://doi.org/10.1073/pnas.2108146119

Kennedy, V. S., Twilley, R. R., Kleypas, J. A., Cowan Jr, J. H., & Hare, S. R. (2002). *Coastal and marine ecosystems & global climate change*. Pew Center on Global Climate Change.

Kerr, S., Pfaff, A., & Sanchez-Azofeifa, G. A. (2003). Development and deforestation: evidence from Costa Rica. *Journal of Environment Economics and Management*, *7*(31), 1-30.

Kirkby, C. A., Giudice, R., Day, B., Turner, K., Soares-Filho, B. S., Oliveira-Rodrigues, H., & Yu, D. W. (2011). Closing the ecotourism-conservation loop in the Peruvian Amazon. *Environmental Conservation*, *38*(1), 6-17.

Kirkby, C. A., Giudice-Granados, R., Day, B., Turner, K., Velarde-Andrade, L. M., Dueñas-Dueñas, A., ... & Yu, D. W. (2010). The market triumph of ecotourism: an economic investigation of the private and social benefits of competing land uses in the Peruvian Amazon. *Plos One*, *5*(9), e13015.

Koens, J. F., Dieperink, C., & Miranda, M. (2009). Ecotourism as a development strategy: experiences from Costa Rica. *Environment, Development and Sustainability*, *11*, 1225-1237.

Langholz, J., Lassoie, J., & Schelhas, J. (2000). Incentives for Biological Conservation: Costa Rica's Private Wildlife Refuge Program. *Conservation Biology*, *14*(6), 1735–1743.

A research guide: Ecotourism, agritourism, & adventure tourism. Library of Congress. (n.d.). https://guides.loc.gov/tourism-and-travel/ecotourism

Lanier, P. (2014). The positive impacts of ecotourism in protected areas. *WIT Transactions on Ecology and the Environment*, *187*.

LePree, J. G. (2008). Certifying sustainability: The efficacy of Costa Rica's certification for sustainable tourism. *Florida Atlantic Comparative Studies Journal*, *11*, 57-78.

Levitus, S., Antonov, J. I., Boyer, T. P., & Stephens, C. (2000). Warming of the world ocean. *Science*, *287*(5461), 2225-2229.

Lienert, J. (2004). Habitat fragmentation effects on fitness of plant populations–a review. *Journal for nature conservation*, *12*(1), 53-72.

Lima, E. M., & Ferrari, S. F. (2003). Diet of a free-ranging group of squirrel monkeys (Saimiri sciureus) in eastern Brazilian Amazonia. *Folia Primatologica*, *74*(3), 150-158.

Lindsey, P. A., Alexander, R., Mills, M. G., Romañach, S., & Woodroffe, R. (2007). Wildlife viewing preferences of visitors to protected areas in South Africa: implications for the role of ecotourism in conservation. *Journal of Ecotourism*, *6*(1), 19-33.

Lindsey, R. (2023, May 12). *Climate change: Atmospheric carbon dioxide*. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Lindsey, R., & Dahlman, L. (2023, January 18). *Climate change: Global temperature*. NOAA Climate. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Link, A., & Di Fiore, A. (2006). Seed dispersal by spider monkeys and its importance in the maintenance of neotropical rain-forest diversity. *Journal of Tropical Ecology*, *22*(3), 235-246.

Lopez Gutierrez, B., Almeyda Zambrano, A. M., Mulder, G., Ols, C., Dirzo, R., Almeyda Zambrano, S. L., ... & Broadbent, E. N. (2020). Ecotourism: the 'human shield for wildlife conservation in the Osa Peninsula, Costa Rica. *Journal of Ecotourism*, *19*(3), 197-216.

MacCracken, M.C. (1985) Carbon dioxide and climate change: Background and overview. In: Maccracken, M.C. and Luther, F.M., Eds., Projecting the climatic effects of increasing carbon dioxide. U.S. Department of Energy, pp. 1-23.

Madrigal, O. (2023, March 20). *La Selva Research Station*. Organization for Tropical Studies. https://tropicalstudies.org/portfolio/la-selva-research-station/

Malavasi, E. O., & Kellenberg, J. (2002, March). Program of payments for ecological services in Costa Rica. In *Building Assets for People and Nature: International Expert Meeting on Forest Landscape Restoration, Heredia, Costa Rica* (Vol. 27, pp. 1-7).

Malhi, Y., & Wright, J. (2004) Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical Transactions of Royal Society London Series B*, 359, 311-329. http://dx.doi.org/10.1098/rstb.2003.1433

Mandl, I., Holderied, M., & Schwitzer, C. (2018). The effects of climate seasonality on behavior and sleeping site choice in Sahamalaza sportive lemurs, Lepilemur sahamalaza. *International Journal of Primatology*, *39*, 1039-1067.

Manning, A. A., & Vierck, C. J., Jr (1973). Behavioral assessment of pain detection and tolerance in monkeys. *Journal of the Experimental Analysis of Behavior*, *19*(1), 125–132. https://doi.org/10.1901/jeab.1973.19-125

Manoharan, V. S., Welch, R. M., & Lawton, R. O. (2009). Impact of deforestation on regional surface temperatures and moisture in the Maya lowlands of Guatemala. *Geophysical Research Letters*, *36*(21).

Maplecroft (2010). “Big economies of the future - Bangladesh, India, Philippines, Vietnam and Pakistan - most at risk from climate change.” http://www.maplecroft.com/about/news/ccvi.html.

Marino, L. (2010). Sentience. Encyclopedia of animal behavior, Vol. 3, M. Breed & J. Moore (Eds.)(pp. 132-138).

McKinney, T. (2014). Species-specific responses to tourist interactions by white-faced capuchins (Cebus imitator) and mantled howlers (Alouatta palliata) in a Costa Rican wildlife refuge. *International Journal of Primatology*, *35*, 573-589.

McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet*, *367*(9513), 859-869.

Milton, K. (1980). *The foraging strategy of howler monkeys: a study in primate economics*. Columbia University Press.

Montague, M. J., Disotell, T. R., & Di Fiore, A. (2014). Population genetics, dispersal, and kinship among wild squirrel monkeys (saimiri sciureus macrodon): Preferential association between closely related females and its implications for insect prey capture success. *International Journal of Primatology, 35*(1), 169-187. doi:https://doi.org/10.1007/s10764-013-9723-7

Montero, A., Marull, J., Tello, E., Cattaneo, C., Coll, F., Pons, M., ... & Vargas, M. (2021). The impacts of agricultural and urban land-use changes on plant and bird biodiversity in Costa Rica (1986–2014). *Regional Environmental Change*, *21*(2), 48.

CCT - Monteverde Cloud Forest Biological Reserve. Monteverde Cloud Forest Biological Reserve. (2023, November 29). https://cloudforestmonteverde.com/

Morera-Beita, C., Sandoval-Murillo, L. F., & Alfaro-Alvarado, L. D. (2021). Assessment of biological corridors in Costa Rica: landscape structure and connectivity-fragmentation processes. *Revista Geográfica de América Central*, (66), 106-132.

Morera, C., Sandoval, L., & Loría, A .(2015). *Dinámicas espacio temporales de los servicios ambientales en Costa Rica 2011–2015. 26 al 29 de abril del 2017*. Bolivia: Memoria del EGAL XVI. Universidad Mayor de San Andrés.

Mosdossy, K. N., Melin, A. D., & Fedigan, L. M. (2015). Quantifying seasonal fallback on invertebrates, pith, and bromeliad leaves by white-faced capuchin monkeys (Cebus capucinus) in a tropical dry forest. *American Journal of Physical Anthropology*, *158*(1), 67-77.

Muehlenbein, M. P., & Ancrenaz, M. (2009). Minimizing pathogen transmission at primate ecotourism destinations: the need for input from travel medicine. *Journal of Travel Medicine*, *16*(4), 229-232.

Mulhern, O. (2020, July 14). *Venezuela - ranked 121st in the global sustainability index*. Earth.Org. https://earth.org/global_sustain/venezuela-ranked-121st-in-the-global-sustainability-index/

Mulhern, O. (2021, January 5). *Costa rica- ranked 31st in the global sustainability index*. Earth.Org. https://earth.org/global_sustain/costa-rica-ranked-31st-in-the-global-sustainability-index/

Myers, S. S. (2009). *Global environmental change: the threat to human health* (Vol. 181). Worldwatch Institute.

Narayan, S. (1998). Below the Surface: The Impacts of Ecotourism in Costa Rica. *Course monograph: Population-Environment Dynamics. School of Natural Resources and Environment, The University of Michigan, Ann Arbor, MI*.

Deforestation. National Geographic . (n.d.). https://education.nationalgeographic.org/resource/deforestation/#

Industrial Revolution and Technology. National Geographic. (n.d.). https://education.nationalgeographic.org/resource/industrial-revolution-and-technology/

Nepstad, D. C., de Carvalho, C. R., Davidson, E. A., Jipp, P. H., Lefebvre, P. A., Negreiros, G. H., & Vieira, S. (1994). The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures. *Nature*, *372*(6507), 666-669.

Yucatan black howler, Alouatta Pigra - New England Primate Conservancy. New England Primate Conservancy - Committed to leaving a legacy of hope and tools to build a better tomorrow for all the Earth's citizens. (2023, February 25). Retrieved March 30, 2023, from https://neprimateconservancy.org/yucatan-black-howler/

Nunn, C. L., Altizer, S. M., Sechrest, W., & Cunningham, A. A. (2005). Latitudinal gradients of parasite species richness in primates. *Diversity and Distributions*, *11*(3), 249-256.

Costa Rica (CRI) exports, imports, and trade partners. The Observatory of Economic Complexity. (n.d.). https://oec.world/en/profile/country/cri

Obua, J. (1997). Environmental impact of ecotourism in Kibale national park, Uganda. *Journal of Sustainable Tourism*, *5*(3), 213-223.

Olson, S. H., Gangnon, R., Silveira, G. A., & Patz, J. A. (2010). Deforestation and malaria in Mancio Lima county, Brazil. *Emerging Infectious Diseases*, *16* (7), 1108.

Ch 8: Food, Water, and Agriculture. Open Geography Education. (n.d.). https://www.opengeography.org/ch-8-food-water-and-agriculture.html

Pasachnik, S. A., & Ariano, D. (2010). CITES appendix II listing for the Ctenosaura palearis clade: developing conservation policies in Central America. *Reptiles & Amphibians*, *17*(3), 136-139.

Pearce , F. (2023, March 21). *Lauded as green model, Costa Rica faces unrest in its forests*. Yale Environment 360. https://e360.yale.edu/features/costa-rica-deforestation-indigenous-lands

Pearce, R. (2021, October 11). *Mapped: Where "afforestation" is taking place around the world*. Carbon Brief. https://www.carbonbrief.org/mapped-where-afforestation-is-taking-place-around-the-world/

Perry, S., Baker, M., Fedigan, L., GrosLouis, J., Jack, K., MacKinnon, K., & Rose, L. (2003). Social conventions in wild white-faced capuchin monkeys: evidence for traditions in a neotropical primate. *Current Anthropology*, *44*(2), 241-268.

Perry, S. (2020). Behavioural variation and learning across the lifespan in wild white-faced capuchin monkeys. *Philosophical Transactions of the Royal Society B*, *375*(1803), 20190494.

Perry, S. (2012). The behavior of wild white-faced capuchins: demography, life history, social relationships, and communication. In *Advances in the Study of Behavior* (Vol. 44, pp. 135-181). Academic Press.

Pounds, J. A., Fogden, M. P., & Campbell, J. H. (1999). Biological response to climate change on a tropical mountain. *Nature*, *398*(6728), 611-615.

Primates-SG - primates of Costa Rica. Primate. (2007, April). Retrieved March 28, 2023, from http://www.primate-sg.org/primates_of_costa_rica/

Primates-SG - primates of Guatemala. Primate. (2007, May). Retrieved March 31, 2023, from http://www.primate-sg.org/primates_of_guatemala/

Pruetz, J. D., & Leasor, H. C. (2002). Survey of three primate species in forest fragments at La Suerte Biological Field Station, Costa Rica. *Neotropical Primates*, *10*(1), 4-9.

Radhakrishna, S., & Singh, M. (2004). Reproductive biology of the slender loris (Loris lydekkerianus lydekkerianus). *Folia Primatologica*, *75*(1), 1-13.

Raper, S. C., & Braithwaite, R. J. (2006). Low sea level rise projections from mountain glaciers and icecaps under global warming. *Nature*, *439*(7074), 311-313.

Restrepo-Coupe, N., da Rocha, H. R., Hutyra, L. R., da Araujo, A. C., Borma, L. S., Christoffersen, B., & Saleska, S. R. (2013). What drives the seasonality of photosynthesis across the Amazon basin? A cross-site analysis of eddy flux tower measurements from the Brasil flux network. *Agricultural and Forest Meteorology*, *182*, 128-144.

Riebesell, U., & Tortell, P. D. (2011). Effects of ocean acidification on pelagic organisms and ecosystems. *Ocean Acidification*, 99-121.

Rising, J., Tedesco, M., Piontek, F., & Stainforth, D. A. (2022). The missing risks of climate change. *Nature, 610*(7933), 643-651. doi:https://doi.org/10.1038/s41586-022-05243-6

Rodricks, S. (2010). *Enabling the legal framework for PES, Costa Rica*. The Economics of Ecosystems and Biodiversity. https://www.cbd.int/financial/pes/costarica-peslaw.pdf

Rojas, M. (2003). What are We Learning from Experiences with Markets for Environmental Services in Costa Rica?: A Review and Critique of the Literature.

Rutter, J. (2009). An eco-tourism case study – costa rica - squarespace. https://static1.squarespace.com/static/53109b11e4b05040160f0a8f/t/5e8d7c2ec74f165b20a94d71/1586330674654/costa+rica+ecotourism+geofile.pdf

Ryan, S. J., Starks, P. T., Milton, K., & Getz, W. M. (2008). Intersexual conflict and group size in Alouatta palliata: a 23-year evaluation. *International Journal of Primatology*, *29*, 405-420.

Salaheen, S., & Biswas, D. (2019). Organic farming practices: Integrated culture versus monoculture. *Safety and Practice for Organic Food*, 23–32. https://doi.org/10.1016/b978-0-12-812060-6.00002-7

Sanchez-Azofeifa, G. A., Pfaff, A., Robalino, J. A., & Boomhower, J. P. (2007). Costa Rica's payment for Environmental Services Program: Intention, implementation, and impact. *Conservation Biology*, *21*(5), 1165–1173. https://doi.org/10.1111/j.1523-1739.2007.00751.x

Schreier, A. L., Bolt, L. M., Russell, D. G., Readyhough, T. S., Jacobson, Z. S., Merrigan-Johnson, C., & Coggeshall, E. M. (2021). Mantled howler monkeys (Alouatta palliata) in a Costa Rican forest fragment do not modify activity budgets or spatial cohesion in response to anthropogenic edges. *Folia Primatologica*, *92*(1), 49-57.

Costa Rica – successful story of sustainable tourism. Secrets Edition. (2022, October 1). https://secretsedition.com/2022/10/01/costa-rica-successful-story-of-sustainable-tourism/

Shah, H. A., Huxley, P., Elmes, J., & Murray, K. A. (2019). Agricultural land-uses consistently exacerbate infectious disease risks in Southeast Asia. *Nature Communications*, *10*(1), 4299.

Shao, K., Liu, W., Gao, Y., & Ning, Y. (2019). The influence of climate change on tsunami-like solitary wave inundation over fringing reefs. *Journal of Integrative Environmental Sciences*, *16*(1), 71-88.

Sheffield, P. E., & Landrigan, P. J. (2011). Global climate change and children’s health: Threats and strategies for prevention. *Environmental Health Perspectives*, *119*(3), 291–298. https://doi.org/10.1289/ehp.1002233

Shinya, N., Koharu, Y., Masaaki, S., Gen, S., Ayaka, M., Noraliza, A., . . . Akiko, S. (2022). Impacts of climate change on reproductive phenology in tropical rainforests of southeast asia. *Communications Biology, 5*(1) doi:https://doi.org/10.1038/s42003-022-03245-8

Shukla, J., Nobre, C., & Sellers, P. (1990). Amazon deforestation and climate change. *Science*, *247*(4948), 1322-1325.

SINAMECC. (n.d.). http://www.sinamecc.go.cr/

Singer, P. (2019). All animals are equal. In *Ideals and Ideologies* (pp. 453-463). Routledge.

Sistema Nacional de Areas de Conservación Costa Rica . (n.d.). *Wildlife*. Wildlife. Retrieved March 30, 2023, from https://www.sinac.go.cr/EN-US/visasilves/Pages/default.aspx

Biological corridors. Sistema Nacional de Areas de Conservación . (n.d.). https://www.sinac.go.cr/EN-US/correbiolo/Pages/default.aspx#:~:text=It%20is%20a%20continental%2C%20marine,biodiversity%20and%20ecological%20processes%20and

Soeder, D. J., & Soeder, D. J. (2021). Fossil fuels and climate change. *Fracking and the Environment: A Scientific Assessment of the Environmental Risks From Hydraulic Fracturing and Fossil Fuels*, 155-185.

Solano-Rojas, D. 2021. *Saimiri oerstedii*. *The IUCN Red List of Threatened Species* 2021: e.T19836A17940807. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T19836A17940807.en. Accessed on 22 September 2023. (squirrel monkey)

Spenceley, A. (2000). Ecotourism. *Benefits for Conservation and Local People*, *3*, 16-18.

Stevenson, P. R. (1998). Proximal spacing between individuals in a group of woolly monkeys (lagothrix lagotricha) in tinigua national park, colombia. *International Journal of Primatology, 19*(2), 299-311. doi:https://doi.org/10.1023/A:1020335716853

Stone, A. I. (2007). Responses of squirrel monkeys to seasonal changes in food availability in an eastern Amazonian forest. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, *69*(2), 142-157.

Stronza, A. (2007). The economic promise of ecotourism for conservation. *Journal of Ecotourism*, *6*(3), 210-230.

Struebig, M. J., Fischer, M., Gaveau, D. L., Meijaard, E., Wich, S. A., Gonner, C., ... & Kramer-Schadt, S. (2015). Anticipated climate and land-cover changes reveal refuge areas for Borneo's orang-utans. *Global Change Biology*, *21*(8), 2891-2904.

Suárez, A., Watson, R. T., & Dokken, D. J. (2002). Climate change and biodiversity.

Surendran, A., & Sekar, C. (2011). A Comparative Analysis on the Socio-economic Welfare of Dependents of the Anamalai Tiger Reserve (ATR) in India. Margin: *The Journal of Applied Economic Research*, 5(3), 361-379. https://doi.org/10.1177/097380101100500304

Symington, M. M. (1988). Food competition and foraging party size in the black spider monkey(Ateles paniscus Chamek). *Behaviour*, *105*(1), 117-132.

Tafoya, K. A., Brondizio, E. S., Johnson, C. E., Beck, P., Wallace, M., Quirós, R., & Wasserman, M. D. (2020). Effectiveness of Costa Rica's conservation portfolio to lower deforestation, protect primates, and increase community participation. *Frontiers in Environmental Science*, *8*. https://doi.org/10.3389/fenvs.2020.580724

Talebi, M. G., & Lee, P. C. (2010). Activity patterns of Brachyteles arachnoides in the largest remaining fragment of Brazilian Atlantic Forest. *International Journal of Primatology*, *31*, 571-583.

Templeton, A. R., Shaw, K., Routman, E., & Davis, S. K. (1990). The genetic consequences of habitat fragmentation. *Annals of the Missouri Botanical Garden*, 77, 13-27.

Thelwell, K. (2020, September 3). *Economic growth and ecotourism in Costa Rica*. The Borgen Project. https://borgenproject.org/ecotourism-in-costa-rica/

Tinker, P. B., Ingram, J. S., & Struwe, S. (1996). Effects of slash-and-burn agriculture and deforestation on climate change. *Agriculture, Ecosystems & Environment*, *58*(1), 13-22.

Tiseo, I. (2023, September 25). *Latin America: CO_2 emissions per capita by country 2022*. Statista. https://www.statista.com/statistics/1066416/carbon-dioxide-emissions-per-capita-latin-america-country/

Titus, J. G. (1986). Greenhouse effect, sea level rise, and coastal zone management. *Coastal Management*, *14*(3), 147-171.

Torkkola, J. J., Chauvenet, A. L., Hines, H., & Oliver, P. M. (2022). Distributional modelling, megafires and data gaps highlight probable underestimation of climate change risk for two lizards from Australia's montane rainforests. *Austral Ecology*, *47*(2), 365-379.

Treves, A. (1999). Vigilance and spatial cohesion among blue monkeys. *Folia Primatologica*, *70*(5), 291-294.

Treves, A. (1999). Within-group vigilance in red colobus and redtail monkeys. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, *48*(2), 113-126.

Costa Rica: Sustainable pineapple. UNDP. (n.d.). https://www.undp.org/facs/costa-rica-sustainable-pineapple

10 things you should know about industrial farming. UNEP. (n.d.). https://www.unep.org/news-and-stories/story/10-things-you-should-know-about-industrial-farming

Costa Rica: The "living eden" designing a template for a cleaner, carbon-free world. UNEP. (n.d.). https://www.unep.org/news-and-stories/story/costa-rica-living-eden-designing-template-cleaner-carbon-free-world

Payments for Environmental Services Program Costa Rica. United Nations Climate Change. (n.d.). https://unfccc.int/climate-action/momentum-for-change/financing-for-climate-friendly-investment/payments-for-environmental-services-program

Report name: Food and Agricultural Import Regulations and standards. United States Department of Agriculture. (2022, May 12). https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Food%20and%20Agricultural%20Import%20Regulations%20and%20Standards%20Country%20Report_Brussels%20USEU_European%20Union_09-30-2021

University of Michigan School for Environment and Sustainability. (n.d.). *Alumni stories*. Labor of love: the father of Costa Rica's national parks . https://seas.umich.edu/alumni/alumni-stories/labor-love-father-costa-ricas-national-parks

A Global Food Crisis: World Food Programme. UN World Food Programme. (n.d.). https://www.wfp.org/global-hunger-crisis

Uren, N. (1992). About Soil Degradation. *Policy*.

Van Hulle, M., & Vaughan, C. (2009). The effect of human development on mammal populations of the Punta Leona Private Wildlife Refuge, Costa Rica. *Revista de Biologia Tropical*, *57*(1-2), 441-449.

Van Leeuwen, E. J., Cronin, K. A., & Haun, D. B. (2018). Population-specific social dynamics in chimpanzees. *Proceedings of the National Academy of Sciences*, *115*(45), 11393-11400.

Van Tassell, D. H., & Daniel, S. K. (2006). The Paradox of Ecotourism in Costa Rica: Can Economic Development and Environmental Preservation Co-Exist?. *Delaware Review of Latin American Studies*, *7*(2).

Vargas, R. (2006). Biodiversity in humid tropical banana plantations where there has been long-term use of crop protection products. *Agronomía Costarricense*, *30*(2), 83-109.

Vaughan, C. (2011). Change in dense forest habitat for endangered wildlife species in Costa Rica from 1940 to 1977. *UNED Research Journal/Cuadernos de Investigación UNED*, *3*(1), 99-161.

Vilela, S. L., & De Faria, D. S. (2004). Seasonality of the activity pattern of Callithrix penicillata (Primates, Callitrichidae) in the cerrado (scrub savanna vegetation). *Brazilian Journal of Biology*, *64*, 363-370.

Von Holle, B., Wei, Y., & Nickerson, D. (2010). Climatic variability leads to later seasonal flowering of Floridian plants. *Plos One*, *5*(7), e11500.

Waddick, K. (2017). Effects of Climate Change on Agriculture in Guatemala and Honduras. *Global Majority E-Journal*, *8*(2), 109-120.

Wallace, R. B. (2001). Diurnal activity budgets of black spider monkeys, Ateles chamek, in a southern Amazonian tropical forest. *Neotropical Primates*, *9*(3), 101-107.

Wallace, R. B. (2006). Seasonal variations in black-faced black spider monkey (Ateles chamek) habitat use and ranging behavior in a southern Amazonian tropical forest. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, *68*(4), 313-332.

Watson, J. E. M., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., Thompson, I., Ray, J. C., Murray, K., Salazar, A., McAlpine, C., Potapov, P., Walston, J., Robinson, J.

G., Painter, M., Wilkie, D., Filardi, C., Laurance, W. F., Houghton, R. A., ... Lindenmayer, D. (2018). The exceptional value of intact forest ecosystems. *Nature Ecology & Evolution*, *2*(4), 599–610. https://doi.org/10.1038/s4155 9-018-0490-x

Wearing, S., & Neil, J. (2009). *Ecotourism: Impacts, potentials and possibilities?*. Routledge.

Webb, S. E., & McCoy, M. B. (2014). Ecotourism and primate habituation: Behavioral variation in two groups of white-faced capuchins (Cebus capucinus) from Costa Rica. *Revista de Biologia Tropical*, *62*(3), 909-918.

Wikimedia Foundation. (2023, September 21). *History of Central America*. Wikipedia. https://en.wikipedia.org/wiki/History_of_Central_America

Williams-Guillén, K., Hagell, S., Otterstrom, S., Spehar, S., & Gómez, C. (2013). Primate populations in fragmented tropical dry forest landscapes in southwestern Nicaragua. In *Primates in Fragments: Complexity and Resilience* (pp. 105-120). New York, NY: Springer New York.

Wilson, M. I. (1977). Characterization of the oestrous cycle and mating season of squirrel monkeys from copulatory behaviour. *Reproduction*, *51*(1), 57-63.

Wood, M. (2002). *Ecotourism: Principles, practices and policies for sustainability*. UNEP.

Xie, S. P. (2020). Ocean warming pattern effect on global and regional climate change. *AGU Advances*, *1*(1), e2019AV000130.

Yacob, M. R., Shuib, A. H. M. A. D., Mamat, M. F., & Radam, A. L. I. A. S. (2007). Local economic benefits of ecotourism development in Malaysia: The case of Redang Island Marine Park. *International Journal of Economics and Management*, *1*(3), 365-386.

Young, C., Bonnell, T. R., Brown, L. R., Dostie, M. J., Ganswindt, A., Kienzle, S., . . . Barrett, L. (2019). Climate induced stress and mortality in vervet monkeys. R*oyal Society Open Science, 6*(11), 191078. doi:https://doi.org/10.1098/rsos.191078

Zhan, X., Long, Y., Zhan, X., & Mu, Y. (2017). Consideration of statistical vs. biological significances for OMICS data-based pathway network analysis. *Med One*. https://doi.org/10.20900/mo.20170002

Zipperer, W. C., Foresman, T. W., Walker, S. P., & Daniel, C. T. (2012). Ecological consequences of fragmentation and deforestation in an urban landscape: a case study. *Urban Ecosystems*, *15*, 533-544.