Fifteen Year Mangrove Hummingbird *(Amazilia boucardi)* Management Plan for Western Costa Rica

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Photo Credit: Gerry Hawkins, eBird.

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Caporale
Amazilia boucardi

Executive Summary:

The mangrove hummingbird *(Amazilia boucardi)* is a species of hummingbird that is endemic to Costa Rica. With an estimated current population of 2,500 – 10,000 individuals, and rapidly declining being considered there is a strong need for conservation of this species. Mangrove hummingbirds only utilize a section of Pacific Mangrove habitat on the Western coast of Costa Rica which is in danger of being affected by illegal logging practices. Currently, this species will likely be extinct within the next 15 years as illegal forestry practices and habitat destruction causes a lack of viable habitat for this species to persist in. While Costa Rica has already created some rigorous laws to help prevent and discourage habitat destruction, there has still been a decrease in mangrove habitat which is causing the decrease in the hummingbird's population leading to an Endangered classification according to the IUCN, and a general lack of information on this species.

The mangrove hummingbird utilizes mangrove habitats exclusively on the west coast of Costa Rica, and rarely leaves them except for feeding occasionally, but have never been found more than 200m from the edge of the habitat. Mangrove hummingbirds feed primarily on *Heliconia* sp., *Hamelia* sp., *Inga* sp., Roble de Sabana (*Tabebuia rosea*), and *Maripa nicaraquensis* which are native to mangrove habitats

When looking at what comes next for the management of this species, this plans two major goals are to understand the population ecology and population dynamics of the mangrove hummingbird, as well as to protect and maintain the existing suitable habitat in Costa Rica to ensure the further growth to reach a sustainable population. To achieve this, I have four major objectives which will help reach these goals. First, this plan aims to estimate the population size, fecundity, and mortality rates of mature individuals, along with survival rates as well. Second, we will confirm the locations of existing populations on the Pacific Coast of Costa Rica to ensure correct locations for further management. Third, we will work to conserve the existing suitable habitat to maintain and hopefully increase the overall survival rates throughout the population. Lastly, we will increase the public awareness of this species, as well as the illegal logging practices throughout the mangrove hummingbird range by 50% and set up the groundwork to increase wages for logging workers to reduce bribery.

Ultimately, the creation and implementation of this management plan will be beneficial for gaining information on the species which can be further used to protect this species directly in the future. Through implementation of the actions in this plan, I am looking to see an increase in education by 50% as well as an increase in survivorship percentages from about 5% in after hatch year individuals to at least 55% survival, which would ensure the increase in population size. This would be possible from maintaining the current estimated 41,000 hectares of mangroves in Costa Rica, with no more than a 5% decrease in number of hectares overall.

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Introduction

With an estimated 2,500 to 10,000 individuals estimated to be left in the wild, the mangrove hummingbird *(Amazilia boucardi)* is an endangered species of hummingbird exclusive to the Pacific Coast of Costa Rica inhabiting and utilizing mangroves exclusively. According to the IUCN, the mangrove hummingbird (MAHU) is listed as an endangered species with a decreasing trend in its population (Mulvihilland et al. 1992, Jones et al. 2009, BirdLife International 2020). The mangrove hummingbird is a tropical non-migrant passerine found in Western Costa Rica exclusively which occupies a very narrow range of elevation and habitat types (Jones et al. 2009, BirdLife International 2020). Long term population dynamic studies are needed in order to gain better information on this species which will aid in further management plans to aid the species. Climate change and anthropogenic activities such as habitat destruction through illegal logging practices and building new infrastructure to support tourism is causing the decrease in MAHU population (Koens et al. 2009, Miller 2011, BirdLife International 2020). While the MAHU population is in danger, there are no direct predators or migration within the population, so the main decline is due to the lack of habitat (Miller and Gass 1984, Jones et al. 2009).

This management plan is looking to gain information on this species to assess the survivorship and population size of this species more accurately, as well as proposed actions such as new protective laws for the existing habitat that could potentially save the population of existing hummingbirds in Costa Rica. The first goal is to perform estimates on the population size, fecundity, mortality rates of mature individuals (after hatch year) as well as survival rates for both hatch year and after hatch year individuals in 8 years using 10 mark and recapture assessments (Ralph et al. 1993, Hayes and Monfils 2015). Then, this management plan will look at confirming existing population locations of the mangrove hummingbird (MAHU) in relation to known locations (Figure 3) throughout the Pacific coast of Costa Rica where at least 75% of historic ranges are surveyed in 8 years with at least 10 sampling events (Ralph et al. 1993, Sánchez-Azofeifa et al. 2001). Also, this plan will aim to document health of existing mangrove habitat using GIS and other remote sensing techniques to perform NDVI (normalized difference vegetation index) analyses on the known population locations in mangrove forests (Figure 3) to estimate habitat loss over the past 20 years and every subsequent year in the future to the nearest

100 hectares (Ralph et al. 1993, Yaney-Keller et al. 2019). This will also aid in monitoring human activity in mangrove forests aerially which will help determine effectiveness of further actions (Yaney-Keller et al. 2019). This plan will also aim to maintain the current estimated 41000 hectares of mangrove habitat with no more than a 5% decrease in land area over 15 years(Solis 2018). Lastly, this plan will set the ground work to increase pay by enacting further legislation which will work with stakeholders and supervisors in the logging industry in Costa Rica to help avoid the need for illegal logging practices, as well as increasing education by 50% using educational flyers and surveys in national parks where mangrove habitat would most affect the public to decrease the chance that the Hummingbirds habitat continues to be destroyed (Arturo Sánchez-Azofeifa et al. 2007, Miller 2011, Kathiresan 2012, Brack 2013, Arroyo-Mora et al. 2014). If we can address these goals, objectives, and actions, we can expect a stabilization of the current population and a potential increase in population over 15 years which would aid in the survival of the mangrove hummingbird as well as the survival of the mangrove habitat (Jones et al. 2009, Tracewski et al. 2016, BirdLife International 2020)

Natural History

Taxonomy

The mangrove hummingbird, *(Amazilia boucardi)*, is in the order of Caprimulgiformes. Within the order of Caprimulgiformes, this species is in the family of Trochilidae and in the order of Amazilia (Amazilia boucardi, 2022). The cinnamon hummingbird *(Amazilia rutila)* and ruby-throated hummingbird *(Archilochus colubris)* were used as a surrogate species for survival rates and fecundity. The cinnamon hummingbirds are closely related to the mangrove hummingbird as they are found in the same class Aves, order Caprimulgiformes, and family Amazilia but differ in genus seeing that cinnamon hummingbird are in the genus Rutila (Amazilia boucardi, 2022). Ruby throated hummingbirds are also very widely studied and therefore have a lot of information on them to analyze.

Species Identification

Figure 1. Adult male mangrove hummingbird (Amazilia boucardi)(Luther 2020).

Figure 2. Adult female mangrove hummingbird (Amazilia boucardi)(Luther 2020).

The mangrove hummingbird, *(Amazilia boucardi)*, or MAHU is a medium sized bronze-and-green hummingbird, measuring in at around 9.5cm to 11cm. Males of this species have a pale green crown and upperparts with a turquoise-green throat and a bronze tinged rump. Their

underparts are mottled pale green, and they have a dark bill with reddish lower mandibles (Figure 1). Females are very similar to this, with a mainly white underbelly though (Figure 2) (BirdLife International 2020). Mangrove hummingbirds have a mass of around 4.5 grams and have a bill length of 18mm which may narrow the range of plants that are available for this species to use as food (BirdLife International 2020). Males have a mostly straight, medium sized bill with a slight curve downward (BirdLife International 2020).

Distribution and Home Ranges

This species is endemic to Costa Rica exclusively, having only an estimated 2,500 to 10,000 individuals in only one population (Figure 3) (BirdLife International 2020). Also, while not entirely confined to mangroves on the west coast of Costa Rica on the Pacific Ocean, the MAHU were found to venture no more than 200m from designated mangrove habitats. Nests were also found exclusively in mangroves (Jones et al. 2009). In areas of potentially dense population, a different individual hummingbird might be encountered every 50-350 meters along a section of the trail. It has been observed that this species has been found in survey sites from the Carara/Tarcoles area south to Rio Coto on the eastern side of the Golfo Dulce, except for in the Rio Terraba, where there weren't any observed. The mangroves of the Parrita area, Puerto Jimenez, Sandalo and the north end of the Gulf of Golfito currently have mangrove hummingbirds (Jones et al. 2009). MAHU are distributed in patches within larger mangrove forests, potentially due to their preference of food (Jones et al. 2009).

Habitat

Mangroves are the MAHU's habitat, which exists in tropical and subtropical climates (Pool et al. 1977). Mangroves are generally located from 9° – 26° North of the equator which lends itself to consistent daily temperatures, with the Pacific coast of Costa Rica having a distinct six-month rainy season which might produce around 1800mm of rain each year (Jones et al. 2009). Mangroves have salt tolerant trees and shrubs which form extensive coastal swamps, replacing salt marshes in tropical climates such as that of Costa Rica (Nyman et al. 2020). Unfortunately, sea-level rise is seen as a threat to mangroves throughout the world. Mangroves are also rarely managed for wildlife even though they provide valuable habitat especially to

colonial nesting waterbirds and other tropical species such as the mangrove hummingbird as they are typically difficult to manage because they are constantly changing (Nyman et al. 2020).

For the MAHU, nests have been found only in mangroves (Jones et al. 2009). They can be found mostly in mangrove forests within large stands of buttressed tea mangrove *(Pelliciera rhizophorae)* (Jones et al. 2009, BirdLife International 2020). The MAHU tend to have an irregular presence in the forests surrounding mangroves, which could be due to the flowering cycle of mangrove trees and the breeding season (Jones et al. 2009). Mangroves in Costa Rica tend to be more developed, having a taller canopy of around 16 meters which gives a larger complexity index. Mangroves in these areas have average rainfalls of around 3300mm. Pacific coast mangroves, where MAHU reside, have seasonal rainfall with six-month dry seasons, which reflect shorter canopies (Pool et al. 1977). Unfortunately, MAHU are not well suited to changing habitat, making them increasingly patchily distributed across the west coast of Costa Rica (BirdLife International 2020). Mangrove hummingbirds tend to prefer the nectar from buttressed Tea Mangrove *(Pelliciera rhizophorae)* but also eat insects (Jones et al. 2009, BirdLife International 2020). These hummingbirds are also known to supplement their diet with arthropods (Montgomerie 1979). A study on their feeding habbits also observed that these MAHU are very ritualistic, eating from the same flowers every day (Jones et al. 2009). These hummingbirds have been observed multiple times perching and feeding repeatedly on the same flowers on multiple occasions (Jones et al. 2009). Also, some preferred flowers were *Heliconia* sp., *Hamelia* sp., *Inga* sp., Roble de Sabana (*Tabebuia rosea*), and *Maripa nicaraquensis*. They have been observed feeding in a forest clearing within 200m of the edge of a mangrove (Jones et al. 2009, BirdLife International 2020).

Despite consistent deforestation here, Costa Rica is often cited as a model and example for the rest of the world as how to balance the conservation of nature and economic development within a country (Sánchez-Azofeifa et al. 2001). The Costa Rican government has set aside around one fourth of the total land area of the nation for conservation purposes. It is currently actively discussing how to use these protected lands on multiple fronts including: biodiversity inventory, ecotourism, carbon sequestration, and bio-prospecting for medicine (Sánchez-Azofeifa et al. 2001). Unfortunately, The United Nations Food and Agriculture Organization

estimated that Costa Rica has a very high deforestation rate of 3.2 percent/yr which would rank it as fifth in the world in terms of percentage (Sánchez-Azofeifa et al. 2001).

Figure 3. Drawn in green on the small map, is the current known range of the mangrove hummingbird (Amazilia boucardi) as it is endemic to the western coast of Costa Rica with an estimated 2,500 – 10,000 total individuals (Hawkins n.d., BirdLife International 2020). The red circle on the larger map shows relative location of Costa Rica to other countries.

Diet

Mangrove hummingbirds tend to prefer the nectar from buttressed tea mangrove *(Pelliciera rhizophorae)* but also eat insects (Jones et al. 2009, BirdLife International 2020). These hummingbirds are also known to supplement their diet with arthropods (Montgomerie 1979). A study on their feeding habbits also observed that these MAHU are very ritualistic, eating from the same flowers every day (Jones et al. 2009). These hummingbirds have been observed multiple times perching and feeding repeatedly on the same flowers on multiple occasions (Jones et al. 2009). Some also preferred flowers were *Heliconia* sp., *Hamelia* sp., *Inga* sp., Roble de Sabana (*Tabebuia rosea*), and *Maripa nicaraquensis*. They have been observed

feeding in a forest clearing within 200 meters of the edge of a mangrove (Jones et al. 2009, BirdLife International 2020).

Reproduction and Sex Ratio

The mangrove hummingbirds breeding season lies between October and February. Their nest is formed from balso floss, plant down, cobwebs, and lichens on the outside wall and takes the shape of a small cup. They usually place their nests on mangrove twigs one to four meters above the water and have a clutch size of two eggs where the female incubates up to three times a year (Mulvihilland et al. 1992, Jones et al. 2009, BirdLife International 2020). It has been observed that this species is ritualistic and nests in the same spot each year and perches in the same places every day, nesting on only *Pelliciera rizohorae* and *Acrosticum aureum* both of which are mangrove species (Jones et al. 2009).

Survivorship

Actual survivorship data for MAHU is non-existent. There is not enough data on this species to conduct a proper estimate of survivorship using data for this specific species. Although the Ruby—throated Hummingbird, *Archilochus colubris*, has a different habitat, they are still within the same family and are similar enough in behavior to be able to use data conducted on them to get a basis on the MAHU. Therefore, the Ruby-throated Hummingbird, *Archilochus colubris*, was used as a surrogate species to obtain data. According to a study conducted on Ruby-throated Hummingbirds in Pennsylvania, USA, a total of 4,116 individuals were tagged and studied over a 28-year period, a large majority of which were not correctly reidentified to be counted in the study correctly. Of those who were, there were 919 male hatch year birds, and 1002 female hatch year birds, with 109 male and 450 female after hatch year birds. For the purposes of this management plan, the ratios and percentages of this population was used to calculate and estimate the population size and survivorship data for the mangrove hummingbird (Mulvihilland et al. 1992).

Assuming a normal sex ratio of 1:1, the study conducted in Pennsylvania with a varying sex ratio throughout the year of 1.4:1 in the spring (April to May), 3.1:1 for adults in the summer (June-August), and 4.1:1 for adults in the fall (August to October)(Mulvihilland et al. 1992). A

1:1 is used because there is a similar sex ratio at birth and just at hatch year (Mulvihilland et al. 1992). Mangrove hummingbirds have a calculated fecundity of 3, (2 offspring/2[every other individual is assumed to be female]) * 3 broods a year. Fecundity was not calculated for hatch year individuals as they are not sexually mature until after hatch year (Mulvihilland et al. 1992, BirdLife International 2020).

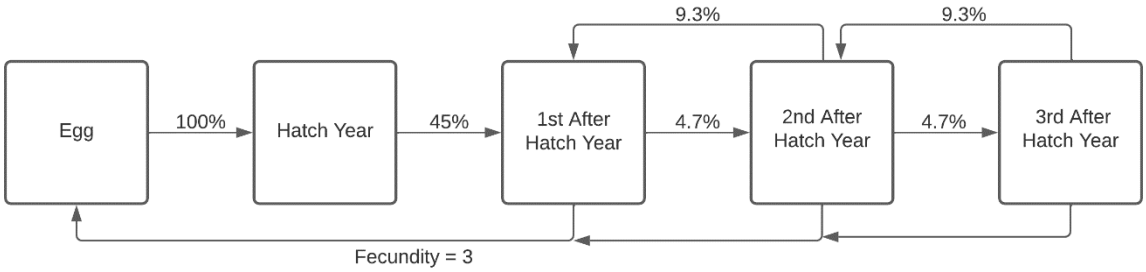

Figure 4. Calculated here is the survivorship percentages of mangrove hummingbirds (Amazilia boucardi). Each arrow shows movement of an individual onto the next life stage, where backwards arrows above hatch year boxes display the percent chance that an individual will not survive, and the arrow from after hatch year to egg displays the fecundity of individuals as they are able to breed (Mulvihilland et al. 1992). *The chart displays the total number of individuals studied, using ruby throated hummingbirds (Archilochus colubris) as a surrogate species as there is not enough information on mangrove hummingbirds to form these calculations* (Mulvihilland et al. 1992, BirdLife International 2020).

Mortality

According to a study conducted in Pennsylvania on ruby-throated hummingbirds, a survival rate of 0.14 (14%) was calculated by dividing the average of the male and female individuals throughout the study (average = 960) and the total hatch year individuals that were determined in the study were 2116 (Figure 4) (Mulvihilland et al. 1992). After hatch year individuals, those who have reached sexual maturity and are able to breed, have a survival rate of 0.45 (45%) which was calculated from finding the average male and female after hatch year individuals (average = 559), and the total after hatch year individuals found (2000) (Figure 4) (Mulvihilland et al. 1992). To obtain these survival values, assumptions that 2/3 of the population will remain in the class that they are currently in, and 1/3 will die in that class. Due to the nature of the age-based population model and life stage development, there is no percentage of individuals that will not progress on to the next stage, unless death occurs.

It is estimated that most hummingbirds have an average of a four-year lifespan, spending the first year in the hatch year stage, and the rest of their lives in the after hatch-year stage. Due to the duration of their life, there was not found to be much longer or complex life stages (Figure 4) (BirdLife International 2020, 2021).

Competition

The MAHU does not have any direct competition that has been discovered. Mainly, all of the decrease in population is due to habitat destruction (Miller and Gass 1984).

Population Goals

Considering the decline in the population of the mangrove hummingbird as noted by the IUCN, being that the population is considered endangered, the main goal of this management plan is to study this species and work to mitigate external anthropogenic factors which cause a continual decline (Jones et al. 2009, BirdLife International 2020). This management plan's final goal is to create habitat suitable for the existing population of MAHU to increase sustainably to a large enough size where there is sufficient habitat and resources for a population to survive long term while not being subject to the effects of a population too large for the area (Lebreton and Clobert n.d., Ralph et al. 1993). When looking at the decline of a population, when a species is reduced to only a handful of individuals, it behaves like the survival of a single individual where the conditional residual population tends to stabilize (Lebreton and Clobert n.d.). To obtain a sustainable population, the habitat for the MAHU is the largest portion that needs to be managed. With a stabilization of the MAHU habitat, an increase in the population of MAHU will follow as they are producing enough eggs and hatch year birds to sufficiently increase the population

(Figure 5) (Ralph et al. 1993, Jones et al. 2009). Currently, the projected population will decline to almost zero after only five years, with no management.

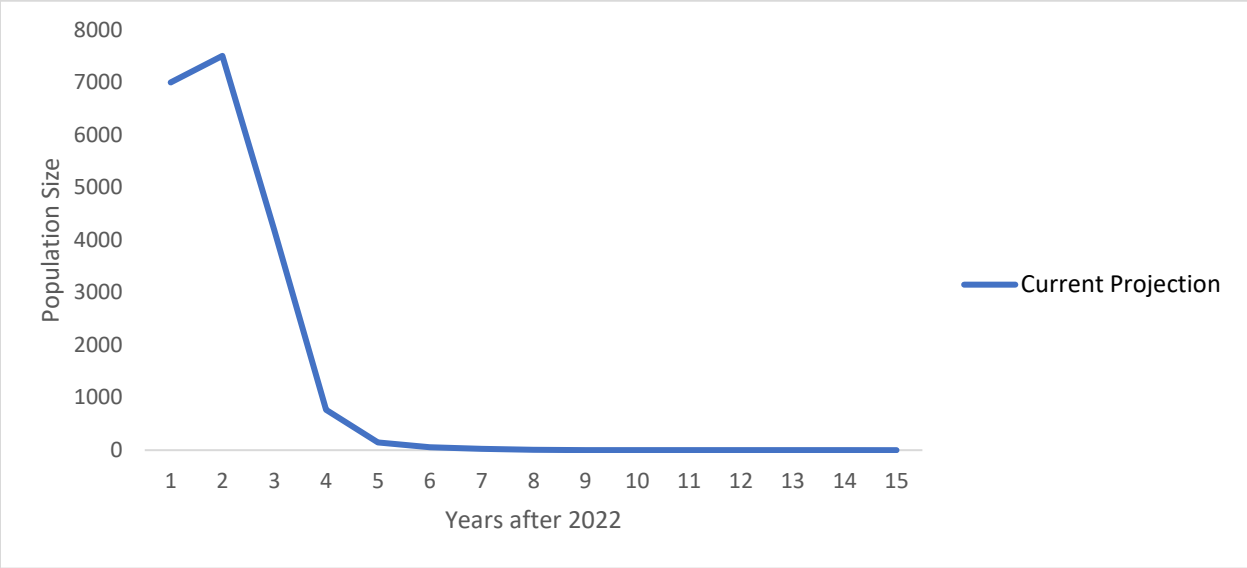

Figure 5. Pictured here is the population projection of the current status of the mangrove hummingbird (Amazilia boucardi) using an estimated 7000 individuals determined by using survivorship data for the ruby-throated hummingbird (Archilochus colubris) as a surrogate (Mulvihilland et al. 1992). *If no management is conducted, the mangrove hummingbird will likely go extinct in the next 6 years according to the data that is available.*

When considering the following management techniques, an increase in the AHY survivorship from 0.14 to 0.55 or 0.6 (55% or 60% respectively) by managing for habitat loss can significantly increase the overall survivorship and longevity of the species (Figure 6).

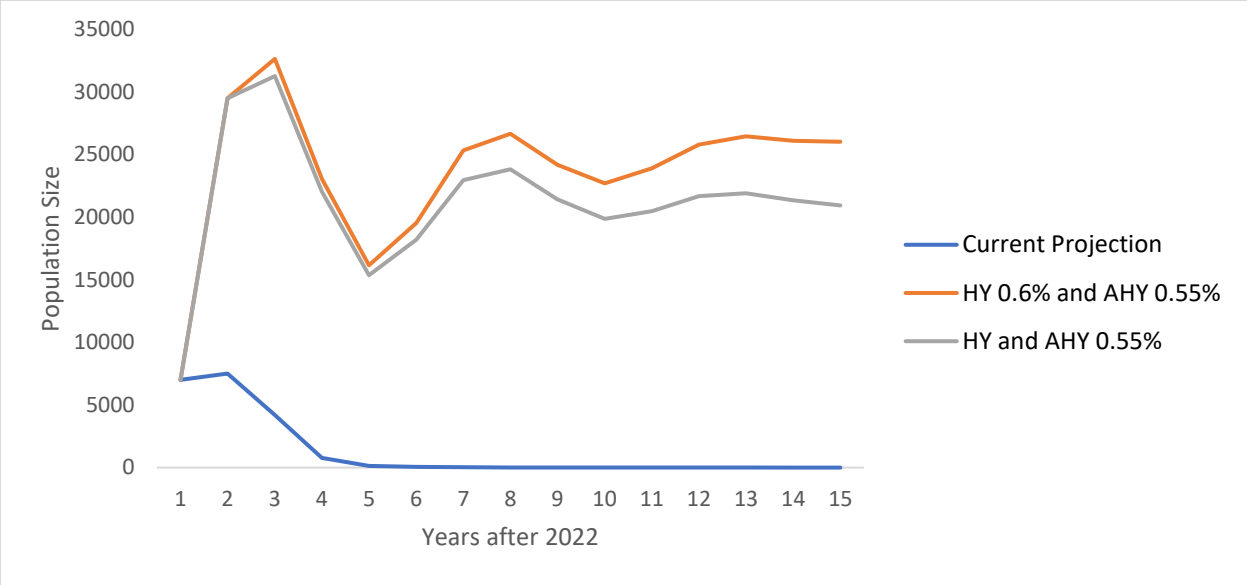

Figure 6. Pictured here is the population projection of the current status of the mangrove hummingbird (Amazilia boucardi) using an estimated 7000 individuals determined by using survivorship data for the ruby-throated hummingbird (Archilochus colubris) as a surrogate (Mulvihilland et al. 1992). *Starting with that same 7000 individuals, if we increase the baseline 4.7% survival rate for after hatch year individuals who can breed to 55% minimum, the population level will increase and eventually level out. To increase the survival rate of these individuals, further management of the mangrove habitat in western Costa Rica needs to be protected through education and an increase in laws which protect against illegal logging as this is the biggest cause for habitat destruction* (Jones et al. 2009, Miller 2011).

Considering all anthropogenic factors in following sections, further courses of action will mainly involve the management of natural resources and habitats in Western Costa Rica which will aid in the increase of the mangrove hummingbird population (Kathiresan 2012, BirdLife International 2020).

Economic

As the environment and national parks continue to grow in interest, every year more people tend to steer away from a traditional European vacation, opting for more exotic nature adventures in exotic countries (Whelan 1988). In a developing country, which focuses on their natural amenities and beauty to attract tourists, Costa Rica gains around $2.1 billion (USD) in revenue from the tourism industry which is why the protection of its natural resources is so important (Whelan 1988, Sada 2015). For a country with more than 25% of its land being protected to some degree, tourism amounts to a large portion of their economy (Whelan 1988). In all areas studied, the Manuel Antonio region, the Monteverde region, the Tortuguero region,

and the region where ecotourism is promoted by the non-governmental Asociacion Comunal para el Manjeo Forestal (ASCOMAFOR), tourism in Costa Rica resulted in benefits on the balance of the environment in these regions such as giving nature an economic value, which was found to further prevent deforestation (Koens et al. 2009).

While the development of tourism in these areas can be beneficial, the actual development of the tourism industry also has drawbacks, which may include the construction of infrastructure which includes accommodations and facilities focused on tourism, which has led to overall vegetation damage and disturbance, which can cause increased erosion, but importantly, further disturbing wildlife (Koens et al. 2009). The process of supporting the ecotourism can ultimately lead to the destruction and decline of biodiversity of Costa Rica. But, ultimately, the coastal regions of Costa Rica can experience benefits from the increase in foreign exchange due to tourists spending money. It was also found that there were definite positives and negatives associated with ecotourism, with positives such as protection of natural areas and increase in job opportunities for the people of Costa Rica, while there also were found to be drawbacks such as sewage problems, waste management issues, uncontrolled building of facilities for tourists, and sometimes the removal of the social and cultural structures of local communities (Koens et al. 2009). In some regions in Costa Rica, it was found that tourism further diversified the local economy and brought more money to the local economy (Koens et al. 2009). The tourism industry in Costa Rica is the number three foreign exchange earner in the country, making nearly US $138 millions for 1986 (over 330 million in 2022 money) (Whelan 1988).

In 1986, it was found that there was a 46% growth with a variety of different trips and events (Whelan 1988). As an alternative to tourism, another reason to protect mangroves and coastal wetland ecosystems for the mangrove hummingbird would be the potential for carbon sequestration as well as historical implications such as evidence of mangrove utilization by pre-Columbian and even pre-historic groups of humans for many purposes, including examples such as wood and energy production (Lacerda et al. n.d., Salem and Mercer 2012). It was found that these mangrove forests sequester an annual mean of 5.27 metric tons of carbon per hectare per year, making this a large carbon sink in these areas. This can potentially help with climate change and reducing the impact of carbon in the atmosphere (Salem and Mercer 2012).

Historically, mangroves have also been used as a source of wood, resins, fibers and dyes and proteins of animal origin as well including seafood and mollusks which led to semi-permanent settlements along the coast. Today, many of these goods are still collected and utilized by locals in mangrove regions, still using sticks in horticultural crops and the extraction of tannin. As of recently, mangroves have been reevaluated and are considered an ecosystem (Lacerda et al. n.d.).

Sociocultural

The mangrove hummingbird is not a particularly well-known species and provides very little immediate importance for the people of Costa Rica. While they may be crucial to their environment, there is very little known about the effects that the MAHU has on the people of Costa Rica. Unfortunately, this creates an issue for managing them as they are not well known to locals, and there is no immediate benefit for managing them. Fortunately, their habitat, coastal mangroves, are a very important part of Costa Rica, and if we can manage these ecosystems, the MAHU might follow and be indirectly supported and managed (Lefebvre et al. 1994, Miller 2011, Kathiresan 2012).

While there are often economic benefits to increasing the number of anthropogenically altered lands for human use such as agriculture and development, many parts of the world are exploiting resources and converting these mangrove ecosystems into salt evaporation ponds, aquaculture, housing developments, roads, ports, hotels, golf courses, and farms (Salem and Mercer 2012). Mangrove trees are also exploited for resources as fuel wood, timber, and charcoal as well as being cleared overall. And mangroves that survive this alteration may be threatened by oil spills, chemical pollution, sediment overload, and general disruption of the salinity balance and sensitive nature of the water (Salem and Mercer 2012). Existing forests practices from the ‘90s might have helped to preserve the forest stands near conservation areas where there was historic logging. This might be especially true when there was a transition to banning land use changes (Arroyo-Mora et al. 2014). Unfortunately, deforestation, sedimentation, and pollution can keep tourists away as Costa Rica has a high deforestation rate of 3.9% with a total of 17% of the total country being considerably eroded. Existing mangroves are being turned into salt evaporation ponds, aquaculture, housing developments, roads and other infrastructure in many parts of the world, due to the value of public-good non-market ecosystem services (Salem and Mercer 2012).

Unfortunately, we can't reasonably stop all farming and logging in fear of disrupting the economy. Consequently, Central and South America, where there are dense forests with an abundance of resources for humans, tend to be the biggest areas of the world where habitat loss and loss of forests are most common (Tracewski et al. 2016). While we might need the space for farming and wood harvesting, these coastal ecosystems also play a large role in the protection of cities and people living on the coastline (del Valle et al. 2020). Illegal logging and other activities in protected areas of Costa Rica may be a result of further corruption in government or organizations which head these operations (Miller 2011). It may often be expensive to gain a permit to legally cut or legally farm, so there is incentive to cut and farm illegally to save money, and sometimes departments are even bribed to hide illegal activity, all of this often stemming from low salaries, insufficient resources, and inadequate controls (Miller 2011). Even while legislation was being changed to further protect the existing lands integrity, large amounts of illegal logging persist across Costa Rica (Miller 2011). Because of low salaries, workers cant afford to comfortably live, so they gain additional money by taking bribes for illegal operations (Miller 2011). Further, regulators may participate in corruption due to lack of sufficient resources like equipment. This can stem back to a lack of funding and low salaries as well, and the government having weak or inadequate controls on them (Miller 2011). On the other hand though, if we irradicate these illegal practices immediately, there will almost certainly be backlash from the public who work in this sector. As they will most likely not be getting paid the same amount as before; there will be a deficit in labor (Miller 2011). To combat this, there could be an alternative such as a program modeled off of the United States Conservation Reserve Program (CRP) which would enroll farmers into a program which in exchange for a yearly rental payment, allows environmentally sensitive land to be removed from agricultural production where plant species which improve environmental health will be planted to aid the land and ecosystem (Stubbs 2014). This program has contributed to numerous environmental benefits in the United States including reduced soil erosion, improved water quality in wetlands and field buffers which would directly benefit mangroves if implemented in Costa Rica, overall reduction in fertilizer use, and an increase in wildlife habitat (Stubbs 2014).

It has been proven on multiple occasions through multiple research efforts that mangroves and other coastal wetland ecosystems can provide protection against cyclones, hurricanes, and other major natural disasters (Kathiresan 2012, del Valle et al. 2020).

Mangroves also produce large amounts of leaf litter and other natural debris, so the decomposition of this litter produces dissolved organic matter which potentially naturally enriches the coastal sea and support other ecosystems and resources (Kathiresan 2012). Lastly, mangroves have been found to prevent soil erosion and trap soil particles allowing for nutrient rich sediment particles to be trapped by mangrove vegetation, providing further protection for vulnerable ecosystems like coral (Kathiresan 2012). Using Landsat data, we can identify what areas historically have supported mangrove habitat and measure current extents of habitat. From this, we can better manage what mangrove habitat is left. It was found that the conservation of mangrove habitat can mitigate the disruption that is created to economic activity in Central America, which is why it might be in the best interest of the people who live in those regions to preserve them (del Valle et al. 2020).

Costa Rica is famous for its ecotourism and its heavy investment into its environment as increased legislation in the mid-1990s through the Payment for Environmental Services Program aims to protect the lands and habitats that allow for the $2.1 billion in tourism income each year (Whelan 1988, Arturo Sánchez-Azofeifa et al. 2007). Unfortunately, this amount of money does not transfer to its workers as expected. As of 2022, it is estimated that a logging supervisor in Costa Rica will make on average $12,417.28 USD/yr where that same position in the United States will make an average of $45,907 USD/yr (Currency Converter 2022, SalaryExpert Assessor Series 2022). For further comparison, a physician in Costa Rica is estimated to make $63,975.99 USD/yr while the same position in the United States makes $245,539 USD/yr on average (Currency Converter 2022, SalaryExpert Assessor Series 2022). Along these lines, the minimum wage in Costa Rica is set at $16.57 USD/day for an 8 hour work day (Currency Converter 2022, Minimum Wage - Costa Rica 2022).

Legal/Regulatory

At this time, there is limited resources and information available on specific legal and regulatory actions that may be taken to protect the mangrove hummingbird. Much of the devastation to the MAHU can be attributed to destruction of habitat due to exploitation of resources within these ecosystems. Costa Rica has existing legislation and protection for its tropical rainforests and other vulnerable habitat as 11% of the country is actively managed and

contains strictly protected parks, wildlife refuges, and equivalent reserves (Stiles and Clark 1989). Even so, there is widespread forest destruction and poor land use (Stiles and Clark 1989). Ideally, the best way to manage this species will be managing the surrounding area. Doing so might mean increasing accountability and increasing protection for the landscape.

Currently there are three laws in place that aid in the protection of forests in Costa Rica: the 1995 Forestry Law 7554, the 1996 Forestry Law 7575, and the 1998 Biodiversity Law (Arturo Sánchez-Azofeifa et al. 2007). They all fall under Costa Ricas Payment for Environmental Services Program which was enacted in the mid-1990s (Arturo Sánchez-Azofeifa et al. 2007). The 1995 law mandates a balanced and ecologically driven environment while the 1996 law mandates rational use for the natural resources prohibiting landcover change in forests. Lastly the 1998 law promotes the conservation and rational use of all biodiversity resources (Arturo Sánchez-Azofeifa et al. 2007).

The existing laws only protect the habitat that these birds reside in, which is very important in itself, but further policies need to be developed to combat the illegal logging and destruction of their habitat. Ultimately, further polices need to be enacted which directly protect the mangrove hummingbird as there are no current policies directly protecting resident birds. While a large portion of the protection of this species deals with their habitat, creating laws specifically protecting the MAHU or other native birds might be beneficial to the ecosystem too. The problem with this is that these birds are not a charismatic megafauna or something that are easily picked out and cherished. They are often overlooked and not many people seem to know about them, including locals. Education and protection of the existing population seems like it will be beneficial.

Suggested Legislation Changes:

1: Enforcement of Existing Laws

Being that Costa Rica is often congratulated for being one of the best countries at land conservation and ecological management, further enforcing the existing laws from ’95, ’96, and ’98 might be good option to help the mangrove hummingbird. The main problem is illegal logging and illegal destruction of habitat, specifically on private lands, occasionally on federal and public lands, where heavy thinning, and sometimes completely clearing wooded areas are

allowed to be conducted, likely due to the corruption among forestry leaders and regulators (Miller 2011). One method to protect the mangrove hummingbird would be to further enforce the existing laws that protect the mangroves and forests of Costa Rica. This would include no active management or restoration efforts, exclusively enforcement of the environmental laws and policies such as the laws created in 1995, 1996, and 1998. Possibly using drone footage or other satellite data would aid in the discovery of such illegal logging operations.

2: Creation of New Laws in tandem with existing, which better protect

Another effort to aid in the protection of the MAHU could be the enforcement of existing legislation and policies to protect existing habitat but creating stricter regulations and laws as well. Adding laws and regulations to better protect the existing and remaining habitat might dramatically increase the availability of habitat or at least maintain it if done correctly. Starting outside of Costa Rica, as a measure to discourage illegal logging, the United States or other countries might impart a law prohibiting the sale of any goods such as lumber that are considered illegal in their origin country (Brack 2013). In Costa Rica, as falsified documentation is easily available, companies importing and exporting these goods might be unaware of what they are actually managing, therefore deeper verification of the origin of lumber might be necessary to verify that the lumber was not illegally harvested (Brack 2013). A form of federally verified licenses for timber harvesting might be an option, where outside companies are not permitted to harvest in certain areas, and increased monitoring might be necessary in these areas. Another option could be a program in Costa Rica that is modeled off of the CRP program as mentioned above in the previous Sociocultural section. This program could allow environmentally sensitive land be removed from agricultural production and be planted with plants which improve the environmental health and quality of the land for a yearly rental payment (Stubbs 2014). This program in the United States has exhibited numerous benefits such as reduced soil erosion, improved water quality in wetlands and field buffers which would directly benefit mangroves if implemented in Costa Rica, overall reduction in fertilizer use, and an increase in wildlife habitat (Stubbs 2014). The benefit of this program could be that the added rent payment from the government could alleviate the stress of enforcing existing laws, which would force illegal logging practices to be shut down and the bribes and under-the-table payment that goes along with such illegal practices. It could benefit the workers, allowing them to maintain a higher

wage, while not forcing the companies to directly increase wages since the money would be coming from the government.

3: Physical replanting and physical protection and rebuilding of existing and historic Mangrove Land

Continuing further, physical intervention including replanting and rebuilding logged and historical mangrove habitat could be the ultimate option, if financially available in the future. By physically increasing the available habitat, you potentially increase the number of individuals that are able to inhabit an area (Dhondt 1988). Along with all other steps to manage mangrove habitat, increasing the amount of mangrove habitat through active management and processes like wetland restoration can return disturbed ecosystems back to a form of the original condition allows for the species in the original condition to return (Laubhan et al. 2020). Through processes like controlling problematic vegetation, increasing water quality and soil conditions as well as planting native vegetation that the mangrove hummingbird uses for habitat and cover might encourage breeding and eventually increase the population ((Jones et al. 2009, Laubhan et al. 2020).

Statement of Need

History:

The mangrove hummingbird, *(Amazilia boucardi),* is a lesser-known species of hummingbird endemic only to the pacific coast of Costa Rica (BirdLife International 2020). They are part of the Trochilidae family, having only an estimated 2500 to 10000 individuals in only one subpopulation (BirdLife International 2020). Population has been declining due to habitat destruction and exploitation of resources. Due to a lack of knowledge on the MAHU (mangrove hummingbird), there needs to be more research and protection as their population is declining and since they are considered endangered by the IUCN (BirdLife International 2020).

Economic and Sociocultural:

While there is no immediately obvious need for us to conserve a hummingbird for economic reasons such as trade or source of food for people, when we start to look at the habitat

that they live in and the impact that it has on the people surrounding it and the environment, it becomes apparent that we need to conserve these areas and by proxy, the MAHU. There is evidence of mangrove utilization by pre-Columbian and even pre-historic groups of humans for many purposes, including examples such as wood and energy production (Lacerda et al. n.d.). Historically, mangroves have also been used as a source of wood, resins, fibers and dyes and proteins of animal origin as well including seafood and mollusks which led to semi-permanent settlements along the coast. Today, many of these goods are still collected and utilized by locals in mangrove regions, still using sticks in horticultural crops and the extraction of tannin. As of recently, mangroves have been reevaluated and are considered an ecosystem (Lacerda et al. n.d.).

A destruction of MAHU habitat is one of the leading hypotheses for their decline in population size (BirdLife International 2020). Many parts of the world are exploiting resources and converting these ecosystems into salt evaporation ponds, aquaculture, housing developments, roads, ports, hotels, golf courses, and farms (Salem and Mercer 2012). Mangrove trees are also exploited for resources as fuel wood, timber, and charcoal as well as being cleared overall. And mangroves that survive this alteration may be threatened by oil spills, chemical pollution, sediment overload, and general disruption of the salinity balance and sensitive nature of the water (Salem and Mercer 2012). Unfortunately, we can't reasonably stop all farming and logging in fear of disrupting the economy. Consequently, Central and South America, where there are dense forests with an abundance of resources for humans, tend to be the biggest areas of the world where habitat loss and loss of forests are on the coastline (del Valle et al. 2020). Restoration can provide protection against cyclones, hurricanes, and other major natural disasters (del Valle et al. 2020). Using Landsat data, we can identify what areas historically have supported most common (Tracewski et al. 2016). While we might need the space for farming and wood harvesting, these costal ecosystems also play a large role in the protection of cities and people living mangrove habitat and measure current extents of habitat. It was found that the conservation of mangrove habitat can mitigate the disruption that is created to economic activity in Central America, which is why it might be in the best interest of the people who live in those regions to preserve them (del Valle et al. 2020).

Legal:

At this time, there is limited resources and information available on specific legal and regulatory actions that may be taken to protect this individual species. Much of the devastation to the MAHU can be attributed to destruction of habitat due to exploitation of resources within these ecosystems. Seeing as this is a large part missing in management, a large portion of my full management plan will be suggesting an increase and adoption of specific regulations and policies that will protect not just the MAHU and other endangered avian species, but the flora and other fauna that inhabit this ecosystem. Costa Rica has existing legislation and protection for its tropical rainforests and other vulnerable habitat as 11% of the country is actively managed and contains strictly protected parks, wildlife refuges, and equivalent reserves (Stiles and Clark 1989). Even so, there is widespread forest destruction and poor land use (Stiles and Clark 1989). Ideally, the best way to manage this species will be managing the surrounding area. Doing so might mean increasing accountability and increasing protection for the landscape.

Ecological:

The mangrove hummingbird is understood to be one of the most mangrove dependent birds in Costa Rica (Barrantes 1998). This species requires the very specific habitat and food resources that exist in these mangroves in Costa Rica exclusively in order to properly survive. Due to this need, the destruction of mangroves even though there is existing legislation prohibiting this creates a problem for this species when there is no other place for them to go. This hinders the movement of individuals and forces them to exist in isolated fragments (Barrantes 1998).

Populations of mangrove hummingbirds have been measured using GPS tracking and have been found in sites surveyed including from the Carara/Tarcoles area to Rio Coto on the east side of the Golfo Dulce, except in the Rio Terraba. In one study, the highest counts of MAHU were found in the Parrita area counting a total of 12 confirmed individuals on a 12km survey in late April (Jones et al. 2009). These hummingbirds sometimes perch for longer periods of time and repeatedly feed on the same flowers (Jones et al. 2009). Some of these individuals appeared to be territorial and stayed in the same area for extended periods of time. Also, while not entirely confined to mangroves, the MAHU were found to venture about 150m from designate mangrove habitats but were never found much further (Jones et al. 2009). Nests were

also found exclusively in mangroves (Jones et al. 2009). From observations, these MAHU are very ritualistic nesting in the same place for many years and perching in the same spot every day as well as eating from the same flowers every day (Jones et al. 2009). Some preferred flowers were *Heliconia* sp., *Hamelia* sp., *Inga* sp., Roble de Sabana (*Tabebuia rosea*), and *Maripa nicaraquensis*. Nests were also only found in mangroves on both *Pelliciera rizohorae* and *Acrosticum aureum* both of which are mangrove species (Jones et al. 2009).

Hummingbirds tend to obtain most energy from sugars in nectar from flowers, and we can assume that all the nectar that is ingested is metabolized. It has also been found that hummingbirds supplement their energy consumption with arthropods (Montgomerie 1979). It has also been noted that hummingbirds are territorial, each bird defending a feeding site, meaning that when the habitat is removed, or even a certain plant is removed, they lose their feeding grounds (Schemske 1973). Ultimately, the anthropogenic removal of habitat is one of the main causes for a decrease in population numbers of the mangrove hummingbird.

While Costa Rica is not a large country, considering the size of others in the same relative area such as Brazil or Mexico, the percentage of Mangrove ecosystems surface area in Costa Rica is only 0.08% of the country, taking up an estimated 41,330 hectares of land with a 32-mile-long coastline. In this entire 32 miles and 41,330 ha of land exists the entire population of the mangrove hummingbird (Lacerda et al. n.d., Solis 2018, BirdLife International 2020). Since this population is exclusive to this area alone, there needs to be some form of strict management to protect this species and this fragile ecosystem. Currently there are no plans to manage this species or these ecosystems in Costa Rica. Going forward, we need to take steps to mitigate the effects that this species of hummingbird feels by the increase in industrialization and utilization of resources, since it would be impossible to completely stop altogether. A detailed plan to conserve the mangrove hummingbird is severely overdue and could lead to another extinction if nothing is done to help.

Goals, Objectives, Actions and Rationale

Goal 1: Understand the population ecology and population dynamics of the mangrove hummingbird in Costa Rica.

Objective 1.1: Estimate the population size, fecundity, and mortality rates of mature individuals (after hatch year), survival rates for both hatch year and after hatch year individuals within 8 years using at least 10 mark-recapture assessments (Ralph et al. 1993, Hayes and Monfils 2015).

Action:

Action 1.1.1: Conduct a survey in areas designated on western coast of Costa Rica which currently support MAHU populations (Figure 3). We will conduct a mark and resight trapping where each individual captured will be tagged with a unique number (Ralph et al. 1993). This data will be used in occupancy modeling accounting for the probability of not seeing individuals within known habitat as well as population demographics of this species (Hayes and Monfils 2015).

Action 1.1.2: Conduct a survey in tandem with previous action in areas designated on western coast of Costa Rica which currently support MAHU populations (Figure 3). We will conduct a mark and resight trapping where each individual captured will use the unique tagged number from the previous action for after hatch year survival and line transect mark and resight sampling for fecundity and hatch year survival rates (Ralph et al. 1993). Over 8 years, we will collect data which will be used to account for survival rate of after hatch year individuals identified from first instance seen and tagged as adults to when never seen again, survival rate of hatch year individuals for number of individuals hatched to number of those individuals which fledge, and fecundity rates as number of times an individual copulates and produces a nest to number of eggs in each nest over 8 years (Clark et al. 1990, Ralph et al. 1993).

Assessment: Action 1.1.1 and Action 1.1.2 will be successful if after 8 years there are approximately 10 sampling periods that can be performed on the existing population, with an average of constant capture probabilities averaging 0.2 for the whole study. Achieving this metric would allow for reasonable identification of the model and a good level of precision for the population size estimation while using that model (Pollock n.d.).

Action 1.1.3: No action is taken, where we continue to not know any further biological information on the mangrove hummingbird include not knowing the populations size, fecundity, and survival rates of this species, where no actions to conduct population estimates or survival rate data and fecundity data is not collected (Clark et al. 1990, Bill and Miller 2003).

Assessment: Action 1.1.3 would be successful if no further studies or conservation is performed resulting a further loss of habitat and a further decrease in population size of this species (Clark et al. 1990, Bill and Miller 2003).

Objective 1.2: Confirm existing population locations of the MAHU in relation to known locations (Figure 3) throughout the Pacific coast of Costa Rica where at least 75% of the prior known MAHU population locations are sampled as described in objective 1.1 over 8 years (Ralph et al. 1993, Sánchez-Azofeifa et al. 2001).

Action 1.2.1: Using GPS and satellite imagery in a laboratory setting, determine the extent of historical ranges for the mangrove hummingbird and extrapolate the current habitat based on habitat requirements determined in previous actions (Ralph et al. 1993, Sánchez-Azofeifa et al. 2001). Using the historical range that the MAHU was able to occupy, at least 75% of historic range needs to be sampled to determine the extent of current range by using mark and recapture surveys, as described in objective 1.1 over a total of 8 years (Pollock n.d., Ralph et al. 1993, Sánchez-Azofeifa et al. 2001).

Assessment: Action 1.2.1 would be successful over 8 years, if at least 10 sampling events were used, where more than 75% of historical range as determined by historical GIS and satellite imagery was identified and studied using mark-recapture surveys according to (Figure 3) and areas extrapolated based on current data (Pollock n.d., Ralph et al. 1993, Sánchez-Azofeifa et al. 2001).

Action 1.2.2: No action is taken, where population demographics of mangrove hummingbirds are not identified further (Ralph et al. 1993). Between 2000 and 2012, 0.32% of mangroves present were deforested (López-Angarita et al. 2018). This can be extrapolated for current projections even, since the Costa Rican government is further protecting the mangroves.

Assessment: Action 1.2.2 would be successful if no further population size information was conducted and the MAHU was not further studied and deforestation of mangroves continued.

Final Course of Action and Rationale Goal 1: Actions 1.1.1, 1.1.2, and 1.2.1 will be implemented immediately. These will further allow scientists to study the MAHU and get a better understanding of the population ecology and population dynamics of this species which are both unknown factors when considering this species. All data for population models and

demographics has been pieced together from surrogate species like the cinnamon hummingbird *(Amazilia rutila)* and the Ruby-throated Hummingbird *(Archilochus colubris).* Going further, we will be able to better identify the cause of their decline in population as we better understand the population size as well as the survival rates of the mangrove hummingbird as we do not have any hard data for this species. Using the Ruby-throated Hummingbird as an example, we do have an idea of what this species should look like but there is a distinct lack of this information for this exact species (Baltosser 1986, Bill and Miller 2003).

Goal 2: Protect and maintain the existing suitable habitat in Costa Rica to ensure further growth of a sustainable population of the mangrove hummingbird in order to increase the survival of 1st After Hatch Year adults according to the Survival Rate section and (Figure 4 & 6).

Objective 2.1: Conserve and maintain existing suitable habitat using maps created in previous actions which would designate known historical activity in the MAHU classified as mangrove habitat in Costa Rica compared to current known mangrove hummingbird habitat (Figure 3). Doing so will help increase survival of 1st After Hatch Year individuals by maintaining required habitat and resources for survival by maintaining at least the current estimated 41,000 hectares of current mangrove forests with no more than a 5% decline (2,050 hectares) which can be determined by using NDVI (normalized difference vegetation index) measurements (Ralph et al. 1993, Solis 2018, Yaney-Keller et al. 2019).

Action 2.1.1: Create an estimate of the total viable habitat using GIS or other remote sensing technology such as total NDVI (normalized difference vegetation index) to document the health of mangrove forests (Figure 3) estimating total habitat loss using data from the past 20 years to the nearest 100 hectares (Ralph et al. 1993, Yaney-Keller et al. 2019). Using an NDVI analysis every year from present, estimating the total area protected and measuring the change in the rate of land loss to the nearest 100 hectares over 15 years as well as monitoring human activity in mangrove forests aerially will help determine effectiveness of further actions (Yaney-Keller et al. 2019).

Assessment: Action 2.1.1 will be considered successful if NDVI analyses of the health of mangrove forests including change in total area and change in land use in known MAHU population centers to the nearest 100 hectares for the last 20 years. A change in color in vegetation will note the health of forested areas (Yaney-Keller et al. 2019). Action 2.1.1 will

also be successful if NDVI analyses including all above criteria are monitored to the nearest 100 hectares every year after present for 15 years. Anything less than this will be considered unsuccessful (Yaney-Keller et al. 2019).

Action 2.1.2: Working with existing government law enforcement agencies, over the next 15 years, we will maintain the current estimated 41000 hectares of mangrove habitat with no more than a 5% decline in habitat (2050 hectares) (Solis 2018). Doing so will potentially slow further deforestation. Modeled off what Cancun and Mexico are doing to mitigate tourism driven impacts in their mangroves, Costa Rica will add laws which prohibit activities from individuals or government institutions which may cause any deterioration or damage to mangrove wetlands such as construction and contamination by sewage and clearing or filling land in which would eliminate existing acreage of mangroves (Brenner et al. 2018). With a combination of the existing laws under the Payment for Environmental Services Program, which was enacted in the mid-1990s to slow and eventually reverse deforestation, which has been so far successful as described in the previous Legal/Regulatory section, and a new law better protecting the land and its resources modeled off of those recently enacted in Mexico and Cancun, this would aim to discourage any further destruction (Arturo Sánchez-Azofeifa et al. 2007, Brenner et al. 2018).

Assessment: Action 2.1.2 will be considered successful if the current estimated 41,000 hectares are able to be sustained over the next 15 years with no more than a 5% decrease in land (2050 hectares)(Arturo Sánchez-Azofeifa et al. 2007, Brenner et al. 2018, Solis 2018). Action 2.1.2 will not be successful if the 41,000 estimated hectares are further destroyed more than 5% below this current estimate within the 15 estimated years.

Action 2.1.3: With such low minimum wages and salaries as detailed in the previous Sociocultural section, there is a need to increase the wages of employees within the logging industry. Doing so will aim to lessen the draw for workers accepting bribes to conduct illegal and nonethical logging practices (Miller 2011). In 15 years, this management plan will start the process of creating new legislation to increase the wages within the logging industry in proportion to the cost of living in Costa Rica as this management plan is not broad enough to manage the full scope of Costa Rica's economy (Miller 2011, Brack 2013). These new laws will be enacted while working with stakeholders and supervisors in the logging industry to ensure that actions made will be enforced (Miller 2011, Brack 2013).

Assessment: Action 2.1.3 will be considered successful if in 15 years, the groundwork for increasing wages within the logging industry are being set with new laws that protect workers and Costa Rica is working towards enforcing existing legislation (Miller 2011, Brack 2013). With the help of stakeholders and supervisors within the logging industry, this broad action will be successful if there is communication and planning laid out to aid in the increase of wages for these workers to mitigate the amount of bribery and illegal forestry practices (Miller 2011, Brack 2013).

Action 2.1.4: No action is taken where no new research is performed on the mangrove ecosystems and the health of the environment is considered in the next 15 years (Miller 2011, Yaney-Keller et al. 2019). No action to change current logging practices and no further enforcement of the existing laws and regulations which have been successful up until this point in the next 15 years (Miller 2011, Brack 2013). This would result in no further change in the mangrove ecosystem leading to further destruction which will be detrimental to the mangrove hummingbird as their biggest threat is currently deforestation (BirdLife International 2020).

Assessment: Action 2.1.4 would be successful if no further legislation is created, and no further research is conducted in the mangrove habitat in the next 15 years.

Objective 2.2: Increase public awareness and outreach for support of mangrove habitat and the mangrove hummingbird by 50% in 20 years (Arturo Sánchez-Azofeifa et al. 2007, Miller 2011, Kathiresan 2012, Brack 2013, Arroyo-Mora et al. 2014).

Action 2.2.1: First, a survey created with the intention of understanding the baseline knowledge of mangrove hummingbirds and logging practices will be distributed as an online quiz to the public for a year. This will gauge the general knowledge first, then an educational poster will be posted. This poster will be left up and altered as needed at national parks especially in areas near mangrove habitat and logging activity. After 2 years, the same quiz will be used to determine if there is a change in knowledge that we can quantify the percent increase of correct answers to show the increase in public education from our educational materials. This will aim to help deter others from overusing mangroves and their protective features (Randel III et al. n.d., Whelan 1988, Koens et al. 2009, Kathiresan 2012).

Assessment: Action 2.2.1 would be considered successful if after the second round of surveys after 2 years, there is a 50% increase in correct answers which would mean a general increase in knowledge and understanding for circumstances regarding the mangrove hummingbird and its decline in habitat(Randel III et al. n.d., Kathiresan 2012). This action would be further successful if posters were successfully distributed throughout Costa Rica's national parks (Randel III et al. n.d.).

Action 2.2.2: No action, where no effort to increase awareness and public knowledge on the benefits of mangrove ecosystems is available to the public over the next 2 years. This would decrease the chance of survival for mangrove habitats and the species within them (Whelan 1988, Koens et al. 2009).

Assessment: Action 2.2.2 would be successful if no new information is provided to the public.

Final Course of Action and Rationale Goal 3: Actions 2.1.1, 2.1.2, 2.1.3, and 2.2.1 will be all enacted immediately. The enactment of these will aid in increasing the information known about the current mangrove habitat as studies conducted on the vegetative health will provide us with a better understanding of the likelihood of survival of existing habitat if left alone and devoid of anthropogenic impact (Ralph et al. 1993, Yaney-Keller et al. 2019). These actions will also further reduce the amount of bribery that is present in current logging practices by enacting legislation that will be important in raising the wages of current logging employees (Miller 2011, Brack 2013). Lastly, these actions will increase public education which will be important for the public as there needs to be a larger understanding of the effects that mangroves have on the environment and how fragile they can be (Randel III et al. n.d., Kathiresan 2012).

Conclusion

Understanding the impact and importance of an ecosystem on the species which live in it is important to understanding the role that that ecosystem plays on a larger scale. As tropical ecosystems continue to be affected by climate change, they provide many benefits to the world and the people directly affected by these ecosystems as well (Kathiresan 2012). The mangrove hummingbird management plan for the Pacific mangroves in Costa Rica could potentially gain important new information on this critically threatened species including overall population size, actual demographic details such as birth and death rates as well as accurate survival rates for this

species and allow us to have a better understanding of the required food and habitat that would allow for a better chance at survival for this species. Anthropocentric actions such as mangrove habitat destruction due to illegal logging practices, increased implementation of new infrastructure, and climate change are large reasons for the mangrove hummingbirds decline as a species (Stiles and Clark 1989).

Considering the economic and physical benefits of mangrove ecosystems, it would benefit policy makers and naturalists to preserve them further because there is strong evidence that mangrove ecosystems protect against hurricanes and other natural disasters that can arise due to climate change (del Valle et al. 2020). These habitats are home to such a diverse range of species that it would be beneficial to further research and manage them, seeing as there is little that is addressed for management as they are not very well studied (Nyman et al. 2020). Currently, mangroves are found to be spreading and replacing existing salt marshes, most likely due to global climate change and global warming (Nyman et al. 2020). Simultaneously, the cause of change for these habitats is also a detriment to them as areas of low sediment supply tend to be in danger of destruction due to climate change (Nyman et al. 2020). Historically, mangrove ecosystems are notoriously difficult to manage and restore as they are constantly changing and tend to have a very low tolerance for disturbance and outside ecological factors. They tend to decline rapidly when outside of their tolerance range for an extended period of time (Nyman et al. 2020).

While it may be beneficial to physically manage a species to help its survival, mangrove hummingbirds will most efficiently benefit from the management of their habitat as per the analysis of data in this management plan, but further research needs to be conducted on their ecology in order to confirm this. For the time being, management of their habitat directly through physical alteration and restoration if available in the future, would be the most efficient way to maintain the mangrove hummingbird habitat in the minimum, while also benefitting countless other mangrove species which may be in danger of extinction without our current knowledge.

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Appendix

Educational Flyer