Spring 2020

An Apex Predator in Peril in the Western Lowlands of Ecuador: Mapping the Population Distribution of Harpy Eagles (Harpia harpyja) in a Highly Deforested Region

Samuel Zhang

SIT Study Abroad

An Apex Predator in Peril in the Western Lowlands of Ecuador

Mapping the Population Distribution of Harpy Eagles (*Harpia harpyja*) in a Highly Deforested Region

Samuel Zhang

Juvenile Harpy Eagle with sloth in Esmeraldas Province © Ana Vanegas, 2019

Academic Director: Xavier Silva Ph.D.

Project Advisor: Ruth Muñiz López Ph.D.

Amherst College: Biology

South America, Ecuador

SIT: Comparative Ecology and Conservation Spring 2020

Submitted in partial fulfillment of the requirements for Ecuador SIT Study Abroad, Spring 2020

Abstract

The Harpy Eagle (*Harpia harpyja*) is a highly threatened bird of prey in Ecuador. While they are already elusive in the Ecuadorian Amazon, they are even lesser known in the coastal lowlands, and their existence is threatened by rapid deforestation. This study mapped their potential distribution by examining satellite images to find intact humid forest, their ideal habitat. Habitat areas were quantified using ImageJ. The only sites found to be adequate for sustaining Harpy Eagle populations were the primary forests in the vicinities of Reserva Ecológica Mache Chindul and Reserva Ecológica Cotacachi Cayapas. The two reserves are expected to be able to support a maximum of 4 and 29 breeding pairs, respectively. 11 additional pairs may occupy intact forest patches surrounding Cotacachi Cayapas. Vortex simulations showed that, in the best case scenario where all the subpopulations in western Ecuador are well connected and where forest cover stops decreasing, a minimum of 64 individuals are required for the metapopulation to remain viable for the next century. Any potential Mache Chindul colony is not expected to last for that amount of time if it remains isolated from Cotacachi Cayapas. The rapid shrinking of intact forest at both sites despite their protected statuses signal an urgent call for active intervention, especially in the political sector, as the lack of regulation on human activities can eventually leave the remnant forests too small and fragmented for this large bird of prey. Future studies must conduct intensive, on-ground surveys of these two sites to assess their quality and their specific conservation needs. A deeper understanding of the Pacific lowlands and the eagle's dispersal behaviors, both understudied topics, is required to properly support any Harpy Eagles that remain in western Ecuador.

Resumen

El águila arpía (Harpia harpyja) es un ave rapaz altamente amenazada en Ecuador. Mientras ya son escurridizos en la Amazonía, son aún menos conocidos en las tierras bajas costeras, y su existencia se ve amenazada por deforestación rápida. Este estudio mapeó su distribución potencial por examinar imágenes satelitales para encontrar bosques húmedos intactos, el hábitat ideal. Los áreas de hábitat se cuantificaron por ImageJ. Los únicos sitios que acabaron adecuados para mantener las poblaciones de águila arpía fueron los bosques primarios en los alrededores de las Reserva Ecológica Mache Chindul y Reserva Ecológica Cotacachi Cayapas. Se espera que las dos reservas puedan soportar un máximo de 4 y 29 parejas reproductoras, respectivamente. 11 pares adicionales pueden ocupar parches de bosque intactos que rodean Cotacachi Cayapas. Las simulaciones de Vortex mostraron que, en el mejor de los casos donde todas las subpoblaciones en el oeste de Ecuador están bien conectadas y donde la cubierta forestal deja de disminuir, se requiere un mínimo de 64 individuos para que la metapoblación permanezca viable durante el próximo siglo. No se espera que ninguna colonia potencial de Mache Chindul dure ese tiempo si permanece aislada de Cotacachi Cayapas. La rápida reducción del bosque intacto en ambos sitios a pesar de sus estados protegidos indica un llamado urgente a una intervención activa, especialmente en el sector político, ya que la falta de regulación sobre las actividades humanas puede eventualmente dejar los bosques remanentes demasiado pequeños y fragmentados para esa gran ave rapaz. En el futuro, se deben realizar estudios intensivos en el terreno de estos dos sitios para evaluar su calidad y sus necesidades específicas de conservación. Se requiere una comprensión más profunda de las tierras bajas costeras y de los comportamientos de dispersión del águila, ambos temas poco estudiados, para apoyar adecuadamente a las águilas arpías que quedan en el oeste de Ecuador.

Acknowledgements

I would like to thank Xavier Silva, Ana María Ortega, Diana Serrano, and Javier Robayo for their academic guidance that led to my decision to choose the topic on Harpy Eagles. A big thank you to my project advisor, Ruth Muñiz López, whose expertise in this field is indispensable and unrivaled. I also thank my Quito homestay family, the López's, and all my SIT classmates for the amazing abroad experience as well as the virtual company. Finally, thank you to my family at home for being a welcome constant in these tumultuous times.

Introduction

Context and background

The Neotropical realm is known both for its ecological importance for the natural world and for its economic value to human civilization. The struggle between the two fronts is all too common throughout the globe, and the work to strike balances is always ongoing. Ecuador is no stranger to these struggles, and, as is the case in most other places, locals are the ones who suffer the most. The Harpy Eagle (*Harpia harpyja*) is one of the community members that have been adversely affected by human activity, owing to its specialist life history and sensitivity to disturbance. The species is historically found in Ecuador's lowlands, including the Pacific coast and the Amazonian region (Muñiz-López 2016). Both areas have undergone increasing deforestation for agriculture, mining, and oil drilling, but conditions are a lot more severe in western Ecuador compared to the east. A study tracking deforestation in Ecuador reported that agricultural lands started growing in the Amazon in the 1950s, so the impact is relatively new; however, more than two million hectares of the coastal lowlands had already been cleared for agriculture by 1954 (Sierra 2013). Another study analyzing NOAA satellite images found that Ecuador's overall forest cover dropped from 48.1% to 36.8% in the period 1986-2008, with an annual deforestation rate that has increased from about 1% to 2% over a decade; the pacific lowlands had notably higher deforestation rates than the Andes or the Amazonia, so its local rate must be higher than the national value (González-Jaramillo et al. 2016). Compared to the global publicity and scrutiny that the Amazon receives for ecology and conservation-related themes, there is very little literature for the Pacific lowlands.

Western Ecuador can be roughly divided into Tumbesian dry forest to the south, Chocó humid forest to the north, and the Tropical Andes to the east. Since Harpy eagles prefer lowland humid forests, this study will focus on the Chocó region. It is deemed one of the most biodiverse places in the world, with extreme levels of endemism (Faber-Langendoen and Gentry 1991, Critical Ecosystem Partnership Fund 2001). The area contains a number of protected areas, some of which are discussed later in this study (Image 1). Thanks to the region's geographic location at the equator and its proximity to the Andes, rain shadow effects cause a humid climate not unlike the Ecuadorian Amazon, another region known for its high biodiversity.

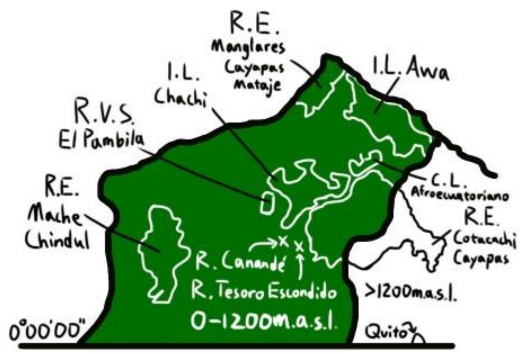


Image 1. Northwestern Ecuador
R.=Reserva, R.E.=Reserva Ecológica, R.V.S.=Refugio de Vida Silvestre, I.L.=Indigenous Land, C.L.=Community Land

The Harpy Eagle is often considered the heaviest and most powerful extant eagle in the world, with large females weighing up to 9kg (Ferguson-Lees and Christie 2001). Their talons are the longest of any raptor, even surpassing bear claws in length (Brown & Amadon 1968). Their relatively short, rounded wings enable more maneuverability through the forest canopy, indicating their specialization to and dependence on extensive forest cover (del Hoyo et al. 1994). The species is partial to nesting in T-shaped trees in the emergent layer, especially Kapok (*Ceiba pentandra*), highlighting a need for primary forest with mature trees, a habitat type that is rapidly disappearing (Banhos et al 2016). The composition of its diet varies by region, but it chiefly feeds on arboreal mammals, especially sloths and monkeys, which are themselves sensitive to threats like deforestation and human disturbance (Aguiar-Silva et al 2014, Muñiz-López 2007, de Luna 2010, Miranda 2015). The Harpy Eagle's status as aerial apex predator makes it a keystone species that can regulate the lower trophic levels. The nature of its biology requires resource-rich territories for sustenance. While this makes the species sensitive to disturbance, it also gives the eagle the title of an umbrella species, whose own focused protection would naturally extend to all the other species, including its prey, that live in its area.

Harpy Eagles have the lowest reproductive rate of any living bird (Rettig 1978). A single chick is raised every 2.5 to 3 years, and eaglets require parental care for at least two years before dispersing, taking up to five years total to reach sexual maturity, and even more years to reproduce for the first time (Álvarez-Cordero 1996, Ferguson-Lees & Christie 2001). Nesting behavior in Ecuador had been poorly studied until the country's first monitored nest was found in the Amazonian region in 2002 (Muñiz-López 2003). Nesting is typically at low elevations, around 200-300m.a.s.l., but nests can be found at up to 1200m.a.s.l. where resources are abundant (Muñiz-López 2016, Giudice 2005, Cerón et al. 1999).

The species holds cultural significance to local peoples. They were worshipped by the Chorrera culture, which existed in the Pacific lowlands in pre-Columbian times (Gutiérrez-Usillos 2002). The bird is now revered as a sort of deity among the Waorani of the Amazon, who would decorate their war spears with eagle feathers (Colleoni 2016). The Waorani would capture live individuals and keep them tethered to their houses as a status symbol, and the birds would be allowed to go free if they could break the string, as a sign of respect for their physical strength (Colleoni 2016, Guerrero 1997).

Image 2. Harpy Eagle global distribution (IUCN 2017)

In 1944, distribution data of the Harpy Eagle was formally recorded in Ecuador for the first time, with a few records in the northwest (Órces 1944). Mapping species distribution has come a long way since then. Remote sensing and GIS tools have been used extensively to study avian habitat relationships. A review of 109 studies from 1973 to 2004 concluded that satellite imagery is a reliable alternative to on-ground surveys. While former may lack the detail achievable by the latter, satellite images provide rough approximations of spatial-temporal relationships in a much more time- and cost-efficient manner (Gottschalk et al. 2005). One of the referenced studies was conducted in the Ecuadorian Amazon, assessing the relationship between avian guilds and habitat variations; this study found that different guilds or species were best associated with different resolutions of satellite imagery analysis (Pearman 2002). Relevant to this study, ImageJ is a versatile tool that has been utilized in many fields, including remote sensing (Ricotta et al. 2014). Satellite imagery has been used extensively for ecological studies in the Amazon, but there is a lack of relevant literature for Ecuador's Pacific lowlands.

The IUCN has designated the Harpy Eagle as Near Threatened globally. Within Ecuador, the populations seem to be completely separated by the Andes, with very few individuals in the Chocó lowlands and more in the Amazonian zone (Lerner et al 2009). The birds west of the Andes are of particular concern due to the massive scale of unregulated forest clearing in the last few decades, leading to the species' extirpation from most known localities (Leck 1979). The eagle's rarity progresses from Near Threatened at the global level, to Vulnerable at the national level, to Critically Endangered in western Ecuador (Granizo et al. 2002, Ridgely & Greenfield 2001). Many years of searching had turned up very few individuals, and the first active nest ever recorded in western Ecuador was not discovered until 2004 (Muñiz-López 2007). Harpy Eagles are so rare in the region that the range map provided by IUCN does not even acknowledge their presence there (Image 2, IUCN 2017).

South America is home to various large Accipitrine species that are just as rare as – if not rarer than – the Harpy Eagle (Zuluaga 2018). In fact, besides the *Spizaetus tyrannus* and *S. melanoleucus*, all South American eagles have been designated a status worse than Least Concern. According to the IUCN, these species include *S. isidori* (EN), *S. ornatus* (NT), *Morphnus guianensis* (NT), *Buteogallus solitarius* (NT), and *B. coronatus* (EN) (IUCN 2017). All but the *B. coronatus* have been recorded in Ecuador (eBird). Well known around the world for its size, power, and charisma, the Harpy Eagle has beat out its relatives to become a symbol of the Neotropics (Muñiz-López 2002). Being a keystone species, an umbrella species, and an ambassador species all at once, the Harpy Eagle is an essential player in terms of ecology, conservation, and culture.

Research Question and Objectives

This study attempts to answer the following main question: What is the potential distribution and population size of the Harpy Eagle in western Ecuador?

As most Harpy Eagles live in the Amazon Basin, there are understandably many published studies on birds east of the Andes. Attention to populations in Ecuador is relatively recent, but knowledge and conversation about this species are still mostly confined to the Amazon, where there are more birds to work with. While observations have been logged in western Ecuador, Muñiz-López is one of the few Harpy researchers conducting complete studies there. There is no practicum organization that focuses on raptor conservation in western Ecuador, but a number of conservation groups have done work in this sector. One goal of this study is to make predictions about the Harpy Eagles of western Ecuador despite the scarcity of direct, empirical data. The study aims to use satellite imagery to pinpoint locales that are good candidates as breeding habitats for Harpy Eagles. As an alternative tool to conventional remoting sensing software, ImageJ is tried out for analyzing satellite imagery. A hypothetical population will be modeled using Vortex to determine its long-term viability under the present conditions of deforestation. The study aims to raise suggestions about conservation plans pertaining to the connection of currently isolated patches of intact forest, whether they are protected or not.

Ethics

Since this project was conducted remotely, no physical contact was made with persons, wildlife, or habitats. Exact nest locations have been omitted from this manuscript to prevent risks of harm to breeding eagles. The other studies referenced here also abided by ethical guidelines. However, conservation-themed studies like this could have negative implications for local communities in the short term. If concessions are achieved down the road for the protection of natural habitats, it would be a win for Harpy Eagles and conservation, but human communities that live in the target areas could potentially be adversely impacted by the change in ownership and land use. There may also be some degree of intervention with the traditional harvesting of Harpy Eagle individuals by local peoples. On top of providing education on the importance of living sustainably, it is important to negotiate with people whose livelihoods may be at stake. If opportunities are available to local communities for them to benefit from conservation, such as on-site employment, their participation could garner public support and political leverage to keep conservation efforts afloat.

Vortex PVA software (Lacy & Pollak 2020) is provided under a CreativeCommons Attribution-NoDerivatives International License, courtesy of the Species Conservation Toolkit Initiative.

Methods

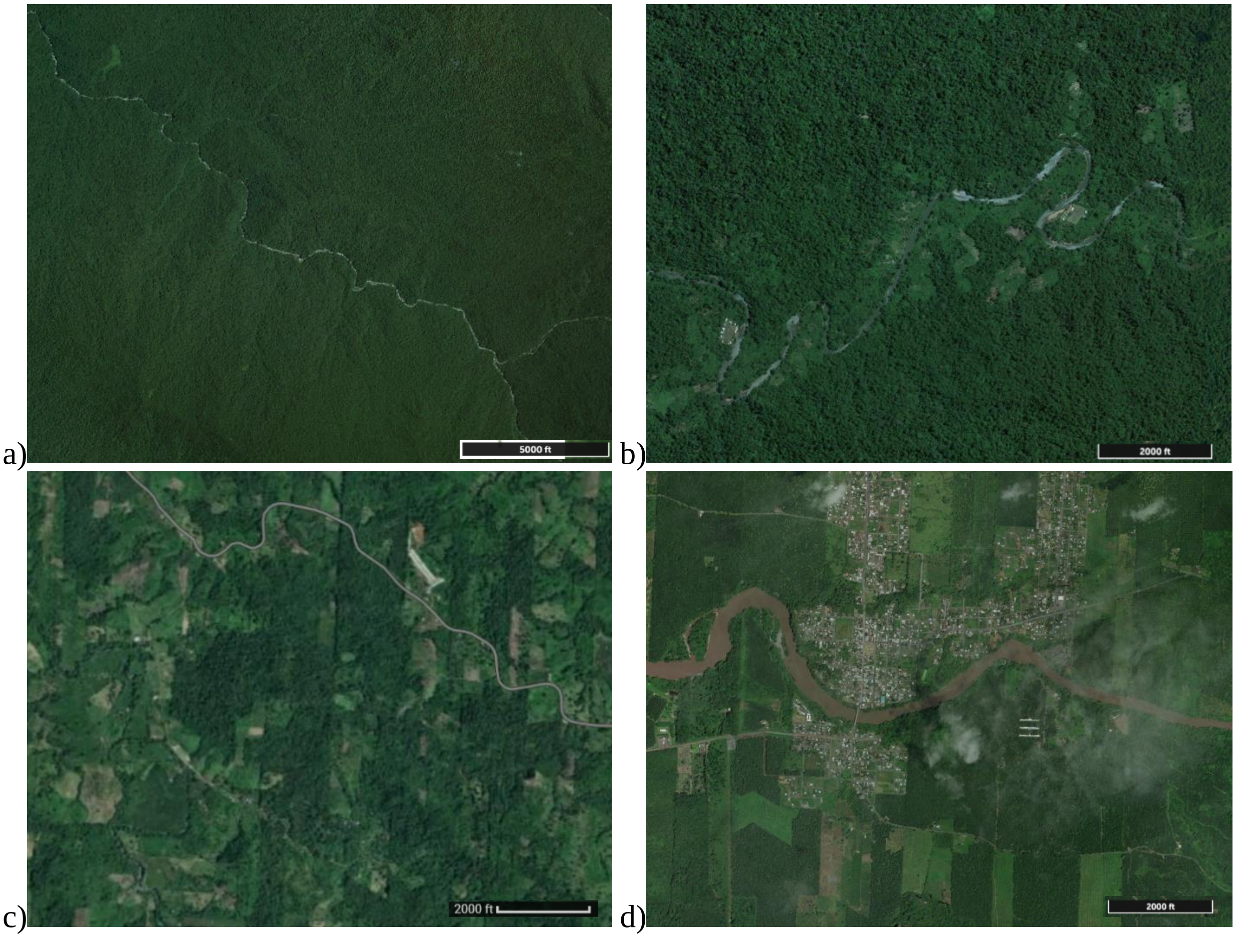


Image 3. Varying degrees of land use in the western humid lowland forests (Google Earth)
a) intact primary forest with no visible human activity
b) small-scale agricultural properties lining rivers and roads
c) Forest fragments surrounded by converted landscapes
d) urban centers surrounded by palm oil plantations, without any native forest cover

Very few recent, cloudless satellite images are available for western Ecuador, so a mixture of maps provided by Google Earth and Zoom Earth are examined for forest cover. Remote sensing and GIS data provided by various studies were displayed on Global Forest Watch, which served as guidelines for determining the presence of intact forest habitats.

A preliminary examination of Ecuador's Pacific lowlands found that almost the entire region has been deforested, save for a few patches in the northwest and southwest. The cordillera Chongón-Colonche and Parque Nacional Machalilla include some patches of intact forest, but these are dry forests in the arid zone and are therefore not suitable for Harpy Eagles. Once this area was excised from the study, only the northwestern corner was usable, so everything south of the equator (0°00'00'') was cut out.

For the remaining area, landmass of altitudes 0-1200m.a.s.l. was outlined free-hand with the aid of Google Earth's elevation coordinates. Cloudless images by Google Earth from the 2000-

2001 period were used for broader analysis. ImageJ was used for analyzing forest coverage in satellite imagery. The resolution of satellite images used in this procedure are all 0.652km^2. Humid forest, representing the most saturated greens in the images, was approximately enclosed by adjusting color threshold parameters to the following: Hue 62-70, Saturation 159-255, and Brightness 0-41. Similar procedures were also performed for deforestation and reforestation, whose data were provided by other studies. After setting the scale manually, the total enclosed area was calculated directly by ImageJ.

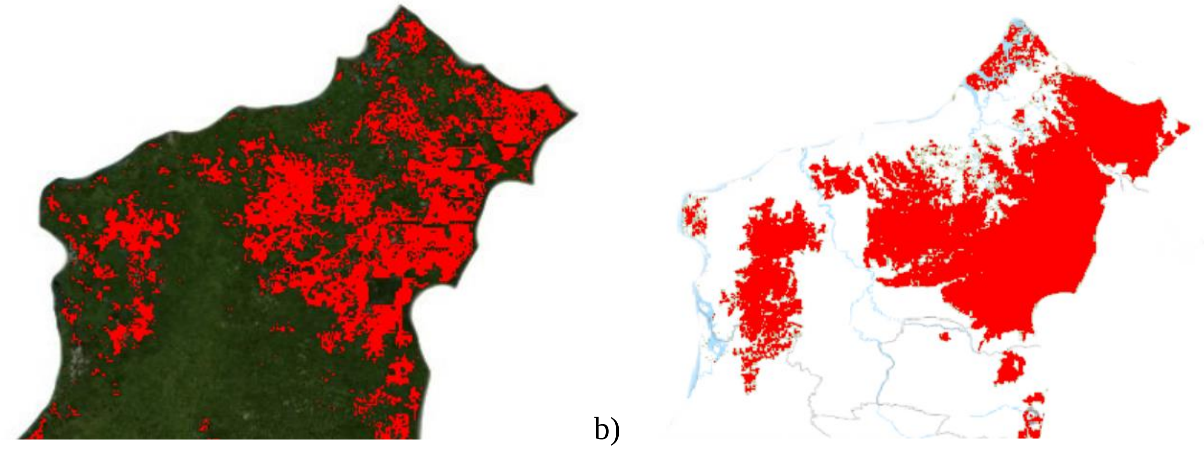
From dark green patches highlighted by ImageJ, intact forest patches were picked out by visual analysis of more recent satellite images provided by Zoom Earth from the period 2016-2018. The areas of interest were further examined for signs of agriculture, habitation, or other human activities (Image 3). Special attention was given to palm oil plantations, which sometimes present as dark green on satellite images and can be mistaken for native forest (Image 3d). All these areas were avoided when the potential distribution of Harpy Eagles was determined.

Distance between neighboring nests and estimated breeding territory size were calculated in several countries by other studies. These measurements were averaged to be used in this study's predictions of eagle distribution in northwestern Ecuador, as no observations of neighboring nests exist in this region itself. Predicted breeding distribution maps were made with IbisPaintX, a drawing app. If the average territory size is greater than the average inter-nest distance, then territory radius is used to ensure that territories do not overlap. The resulting territory circles were crammed side-by-side into regions of continuous forest cover to demonstrate carrying capacity, with each circle representing 1 nest, 2 adults, and 1 offspring.

There is only one instance of juvenile dispersal tracked by satellite telemetry, and its data served as a guide for this study's dispersal distribution map despite the extremely small sample size (Muñiz-López 2016). The predicted distribution map of juvenile dispersal was drawn with dispersed individuals at exactly 35.1km from their natal areas, and the direction of dispersal was selected by a random number generator. If a dispersed individual ended up an area above 1,200m.a.s.l. or in the ocean, then directions are regenerated until the individual was placed at lower elevations.

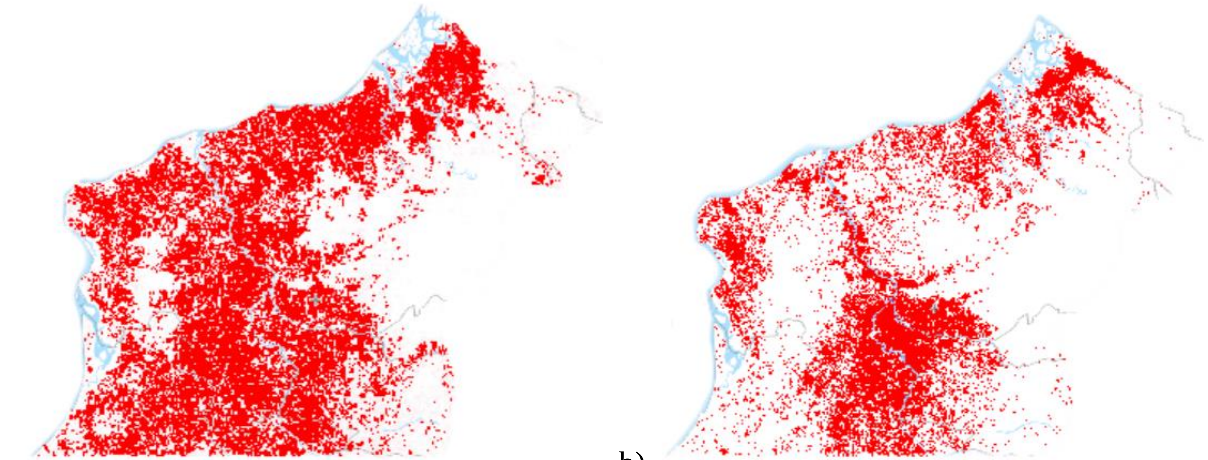
Vortex 10, a population viability analysis software, was used to model future trends of the potential population in northwestern Ecuador. Simulations were performed using the following inputs: Mortality rates of 9.4% for adults and 28.6% for juveniles (Muñiz-López 2017); life span of 35 years (Lerner et al. 2009); dispersal; maximum of 1 brood and 1 chick per year (Rettig 1978). The rest of the inputs were informed by other results of this study. Simulations were run for 100 years with 1000 iterations. The initial population size was increased until the probability of extinction is less than 5%, at which point the population is considered viable for the next century.

Results



a) b)

Figure 1. Primary forest cover at 0-1200m.a.s.l. in the year 2001, calculated using two data sources. a) 5529.097km^2 from direct color analysis of satellite imagery and b) 8518.117km^2 based on data provided by Turubanova et al. 2018 via Global Forest Watch.



a) b)

Figure 2. a) 10,849.177km^2 of forest cover lost between 2001 and 2018. b) 5,446.521km^2 of forest cover gain between 2001 and 2012. Both based on data provided by Hansen et al. 2013 via Global Forest Watch.

Table 1. Estimated inter-nest distance and breeding territory size as reported from different countries

Study	Country	Sample size	Distance b/w neighboring nests (km)	Territory size (km^2)
Álvarez-Cordero 1996	Panamá	5	3.8	10-20
Vargas & Vargas 2011	Panamá	18	4.1	16-24
Muñiz-López 2016	Ecuador	15	4.9+/-0.7	19.6+/-5.7
Aguiar-Silva et al. 2012	Brazil	2	5	\
Álvarez-Cordero 1996	Venezuela	5	6.3	45-79
Piana 2007	Perú	3	7.4	43
Average	\	8	**5.25**	**31.92**

Note: no estimate for territory size was provided for Brazil (Aguiar-Silva et al. 2012).

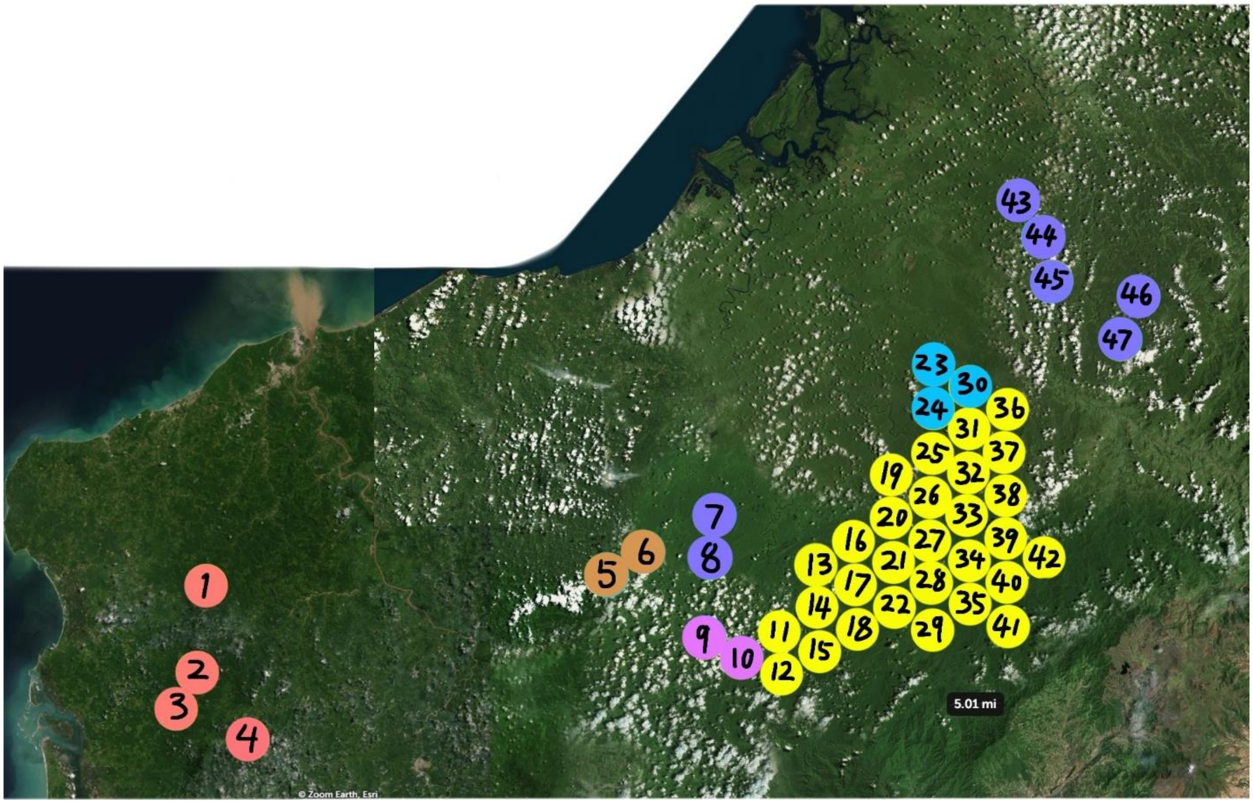


Figure 3. Predicted maximum distribution of Harpy Eagle nests or breeding pairs in northwestern Ecuador. Nests are placed in the vicinity of:

Red - Reserva Ecológica Mache Chindul

Yellow - Reserva Ecológica Cotacachi Cayapas

Orange - Refugio de Vida Silvestre el Pambilar

Magenta - Reserva Canadé and Reserva Tesoro Escondido

Purple - government-acknowledged Chachi (southwest) and Awa (northeast) indigenous land

Blue - government-acknowledged Afro-Ecuadorian community land

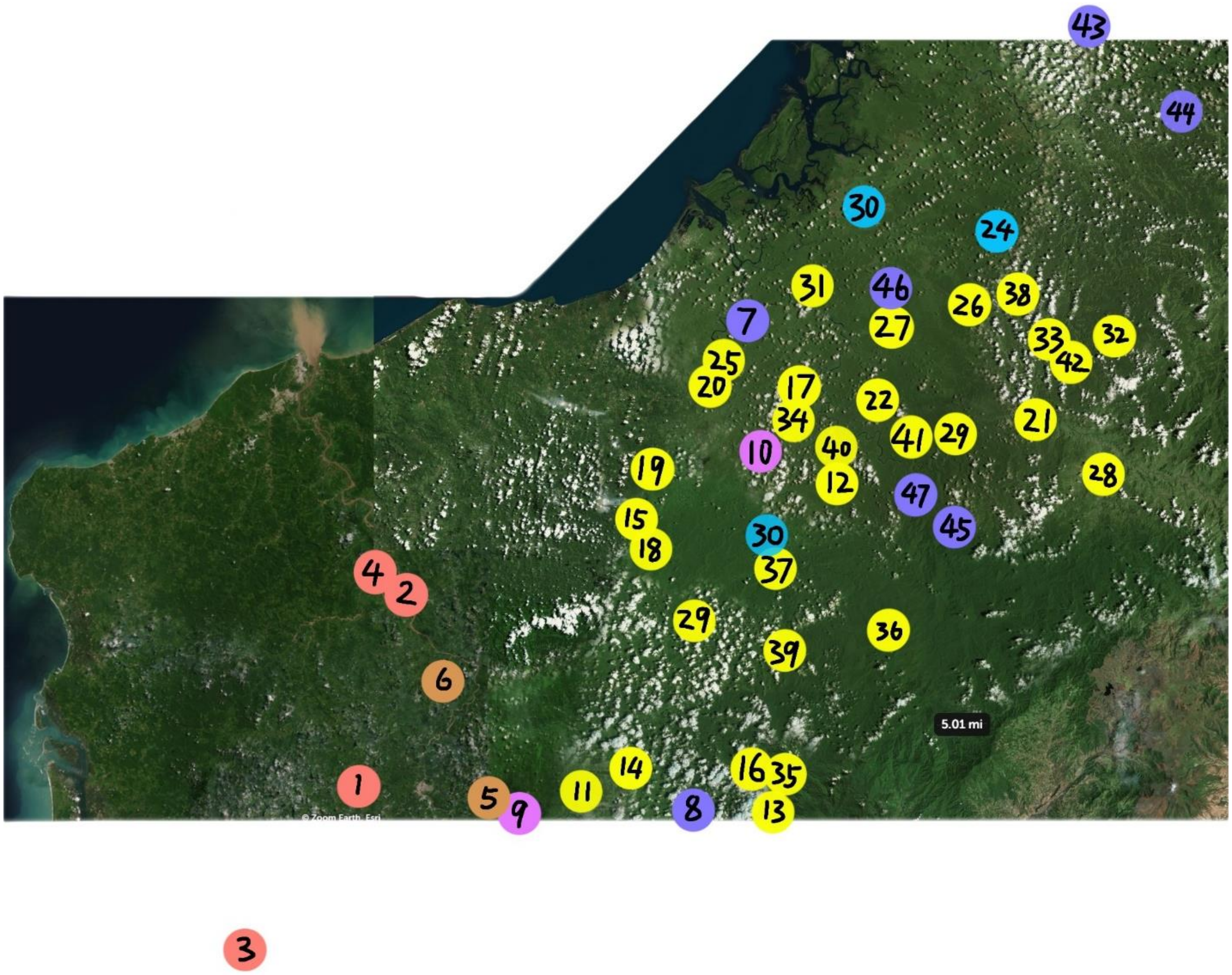


Figure 4. Predicted dispersal distribution of juvenile Harpy Eagles in northwestern Ecuador. Individuals originate from natal areas of:

Red - Reserva Ecológica Mache Chindul

Yellow - Reserva Ecológica Cotacachi Cayapas

Orange - Refugio de Vida Silvestre el Pambilar

Magenta - Reserva Canadé and Reserva Tesoro Escondido

Purple - government-acknowledged Chachi (southwest) and Awa (northeast) indigenous land

Blue - government-acknowledged Afro-Ecuadorian community land

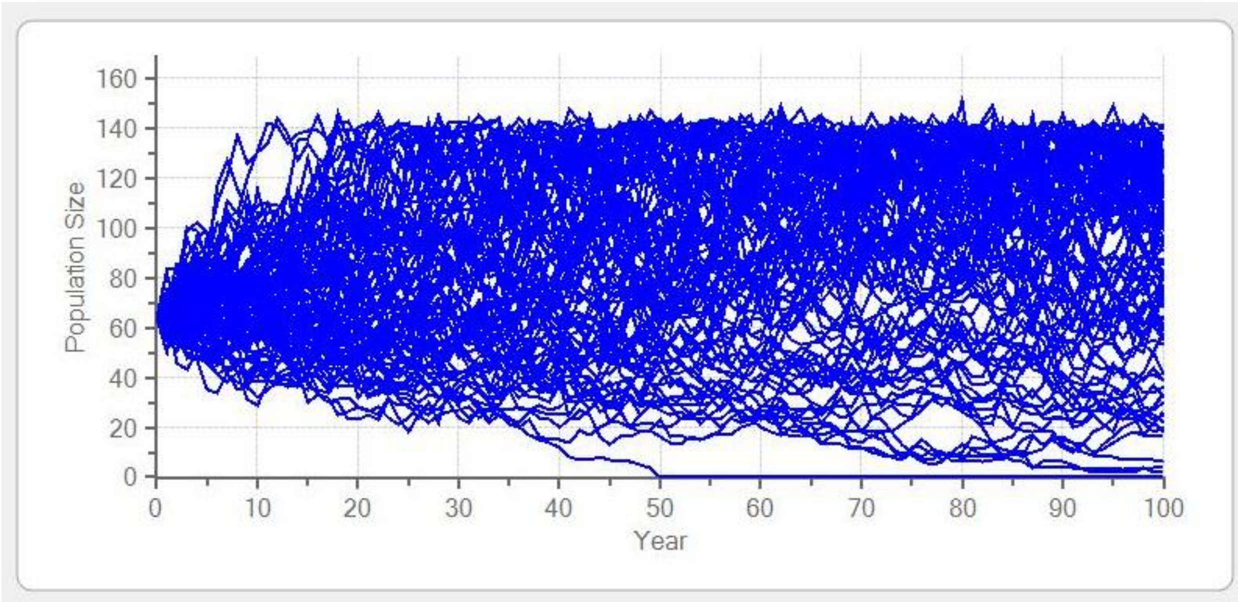


Figure 5. Potential Harpy eagle population modeled for 100 years for 1000 iterations. Initial population size: 64.

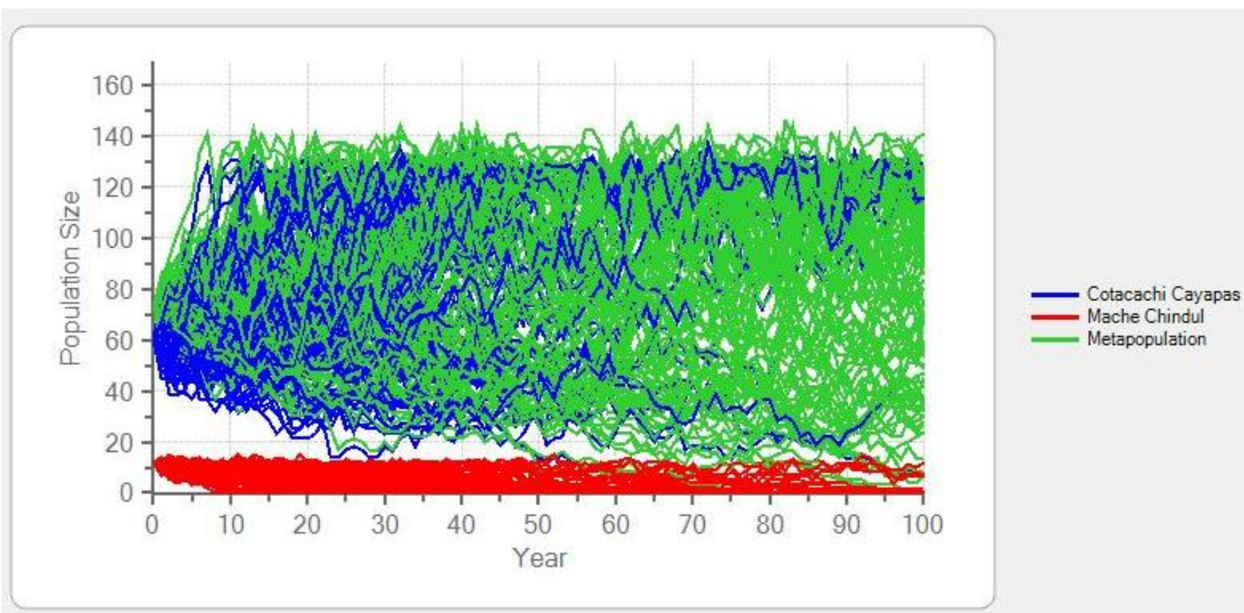


Figure 6. Potential Harpy Eagle population modeled for 100 years for 1000 iterations, without gene flow between Mache Chindul and other sites (Cotacachi Cayapas plus surrounding area). Initial population sizes: 12 at Mache Chindul, 61 at Cotacachi Cayapas and surroundings

Discussion

Image analysis performed with ImageJ found 5529.097km^2 of darkest green patches at a resolution of about 0.653km^2 in northwestern Ecuador below 1200m.a.s.l. and north of the equator (Figure 1a). This value is substantially less than 8518.117km^2, the primary forest coverage of the same area determined by ArcGIS technology (Figure 1b, Turubanova et al. 2018). Despite the discrepancy, the resulting maps show fairly similar distributions of color patches, concentrating in the vicinity of R.E. Mache Chindul, R.E. Cotacachi Cayapas, and R.E. Manglares Cayapas Mantaje. This indicates that ImageJ can be a somewhat precise but inaccurate alternative to conventional remote sensing methods.

After examining satellite images, the general impression is that the western lowland humid forests have been mostly converted to a mosaic of agricultural properties. The only areas that show any amount of continuous primary forest are in the vicinity of R.E. Mache Chindul and R.E. Cotacachi Cayapas (Image 1, Figure 1). In 1992 several more southern sites showed promising levels of contiguous forest cover, and surveyors urged immediate protection of these lands (Parker & Carr 1992). After reviewing current satellite images, there is little left of that intact forest, and the habitat degradation is now so severe that the entire southern half of the western lowlands have been eliminated from the consideration of Harpy Eagle habitat. Historically, Harpy Eagles were known to occur that far south. A museum specimen was collected in the Guayas Province in 1880, and a few other sparse records exist, but no more have been observed in recent memory (Álvarez-Cordero 1996). The mangrove forest of R.E. Manglares Cayapas Cataje in the northwestern corner of the country appeared promising initially (Image 1, Figure 1). Further examination revealed that the allegedly protected area is heavily deforested, and the nature reserve is surrounded by urban development (Figure 2a). This site appears significantly less suitable for eagles compared to the other forest patches even without a conversation about the presence of emergent trees for nesting or large mammals for consumption.

ImageJ was also used to quantify deforestation and reforestation, found to be 10849.177km^2 during 2001-2018 and 5446.521km^2 during 2001-2012 respectively (Figure 2a,b). Since the image analyses were done at a low resolution (about 0.653km^2 per pixel), the actual number of hectares of deforestation could not be calculated. Instead, this study shows the number of hectares of land that were affected by deforestation. Forest cover loss is visibly concentrated along the northern coast and between R.E. Mache Chindul and R.E. Cotacachi Cayapas, making disperser crossings unsafe and unlikely for all transient animals, including the Harpy Eagle (Figure 2a). The forest cover gain is deceptive, as the highlighted area is almost entirely newly matured palm oil plantations (Image 3d, Figure 2b). While agricultural lands might cast a healthy green hue on satellite images, they are most likely low in biodiversity due to massive monocultures and the extensive use of harmful pesticides. This is a difficult hurdle for conservation to overcome since palm oil is one of Ecuador's most important products. Compared with the deforestation visualization, there seems to be very little 'reforestation' around major reserves (Figure 2b). This could be evidence that newer deforestation events are rolling towards and into reserves, such that these newly formed plantations have yet to produce a false forest cover. Additionally, some of the blank spaces could represent mining activity, which is more likely to occur closer to reserves since the other areas have already been occupied by agriculture for a century (Sierra 2013).

Deforestation is happening so rapidly that any eagles that manage to breed near the edge of an intact forest will likely lose their nests soon. This is already the case, as the site of one of the few known nests in western Ecuador had already been destroyed by mining activities, and the eagles are no longer present there (Muñiz-López). The health and environmental crises caused by mineral mining have been reported by scientific studies as well as media coverage (Knee & Encalada 2013). The Ecuadorian government has authorized mining concessions all over the country, with some even in protected areas; R.E. Cotacachi Cayapas is now surrounding by mining concessions in addition to the other mechanisms of habitat disturbance, undermining the reserve's function as a corridor connecting other protected areas; R. Canandé and R. Tesoro Econdido are also directly subject to exploratory mining concessions (Roy et al. 2018). Since the government cannot promise protection to the supposedly federally protected reserves, the future of Harpy Eagles and other threatened species hangs precariously. This calls for multiple layers of protection, with national reserves overlapped by private reserves and indigenous land, which is the case at R.E. Mache Chindul, in which a Chachi indigenous property and a private Bilsa research station are embedded (LandMark 2019). GLAD Alerts, which track deforestation, have identified extensive deforestation throughout Mache Chindul in the last five years, but a few intact pockets remain (Hansen et al. 2016). Considering the extreme levels of deforestation in the immediate area, it is likely thanks to efforts of these overlapped protected properties that R.E. Mache Chindul still has any intact forest left.

Harpy eagles are known to successfully raise offspring in disturbed and fragmented forests, but there are little data on long term survival of a nest under disturbance from human activity (Álvarez-Cordero 1996). Since the Harpy Eagle is a specialist species, this study assumed that it will not be able to tolerate human disturbance long-term, allocating only intact forest patches to the potential distribution. The predicted maximum distribution crammed breeding territories as closely together as possible into intact forest patches visible on satellite images taken in 2017-2018. The average territory across the Harpy Eagle's range is about 31.92km^2, whose diameter 6.38km was more than the average distance between neighboring nests (5.25km), but the former was given precedence for drawing the maximum distribution map, since larger territories allow for a more conservative estimate of the maximum eagle population (Table 1). The average inter-nest distance was still reported for the possibility of its utility for future studies. The present resulting total of 47 nests covered around 1500.24km^2 (Figure 3). For simplicity, only territory areas that showed no visible signs of human disturbance were accepted, so More than 7000km^2 of the primary forest identified in 2001 had disturbance levels from clearings to fragmentation to complete disappearance (Figure 1b).

An ArcGIS study demonstrated clustered hotspots of statistically significant primary forest loss in the period 2002 to 2018, amounting to 3736.030km^2 in northwestern Ecuador (Image 4, Harris et al 2017). Potential nesting areas 1, 5, 6, and 43 fall in these hotspots, so these could be the first to disappear as deforestation advances (Figure 3). A recurring pattern observed in this study is the expansion of human development along rivers, with newly cleared areas appearing upstream and clearings expanding

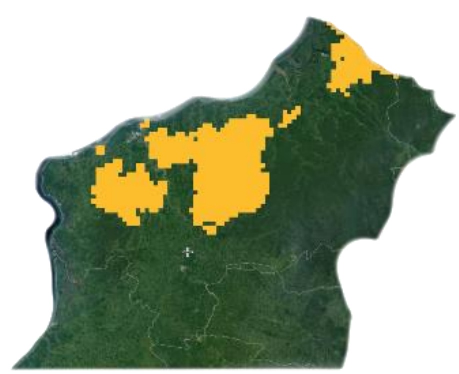


Image 4. Hotspots of primary forest loss. Harris et al. 2017 via Global Forest Watch

downstream. Where there are many rivers close to each other, the clearings divide the forest into wedge-shaped fragments with rapidly receding tips, eliminating them from the pool of acceptable breeding areas (Image 3b).

The protection of breeding territories not only benefits the adults, but also the juveniles, as they remain within their parents' territory for up to 28 months; the learning stages of flight and hunting put these young birds at heightened risk to harm (Urios et al. 2017, Álvarez-Cordero 1996). This calls for protection of the territory year-round instead of only when the nest is occupied. Since the eagles do not reach sexual maturity until age 4, their dispersal period is at least two years, during which they have the capacity to wander large distances; however, this is compensated by the relative homogeneity and rich resources of their habitat, so they do not need to travel very far from their birthplace (Muñiz-López 2016, Cerón et al 1999).

The predicted dispersal distribution map was made based on a vast number of assumptions and simplifications. The dispersal distance was rather arbitrarily set at 35.1km, based on the maximum displacement recorded by a juvenile that was tracked until 39 months of age, which is only a fraction of its total dispersal period (Muñiz-López 2016). The dispersal direction was also randomized and only limited by the ocean or high elevations. Since there are no complete studies of multiple juveniles tracked throughout their dispersal periods, there is no way to simulate variations in dispersal distance or direction. Any interaction with established breeders or other dispersers was ignored, and all land areas below 1200m.a.s.l. were accepted regardless of the amount of forest coverage. This map could be plausible during a time when the entirety of northwestern Ecuador was covered in intact forest, but in the current state, only about 9 of the 47 simulated juveniles landed in suitable habitat. Furthermore, this distribution highlights the geographical isolation of Mache Chindul birds from other sites, which are able to overlap extensively (Figure 4). The map also raises the possibility of dispersal into the Colombian Chocó (dispersers 43 and 44, Figure 4), so future conservation efforts could potentially involve international collaborations.

Censuses conducted in R.E. Mache Chindul in the periods 1998-1999 and 2004-2011 yielded 360 bird species, of which 130 were observed exhibiting breeding behavior (Carrasco et al. 2013). Harpy Eagles were not detected at all, but the rich avian diversity in the area highlights the reserve's potential to support these large raptors. Despite being a protected property on paper, Mache Chindul contains a large population of human inhabitants, who actively engage in deforestation and defaunation for agricultural practices. Since the communities are scattered, they cause fragmentation throughout the reserve (Sierra et al. 1999). By 1992, much of the Bilsa area had been severely fragmented, and the researchers who carried out the assessment warned of the imminent disappearance of that patch of forest (Parker & Carr, 1992).

Even with viable habitat, R.E. Mache Chindul may be too isolated to support a population long-term. If eagles were to be placed in this forest in its present state, the birds may be able to be successful on their own, but inbreeding depression will likely render the colony obsolete. Vortex simulations show that, at low dispersal levels (~5% in both directions), the Mache Chindul colony would not be safe from local extinction (>5% chance) in the next hundred years (Figure 6). Expansive wildlife corridors would be essential for connecting insular populations and promoting gene flow, A study proposing new protected areas for terrestrial wildlife outlined the possibility of forming corridors between R.E. Cotacachi Cayapas and R.V.S. el Pambilar. Comparing to other potential conservation areas in Ecuador, the authors designated this corridor at medium priority and maximum feasibility. A corridor is also proposed between R.E. Mache Chindul and the neighboring estuary reserve. Like R.E. Manglares Cayapas Mataje, the latter is probably less suitable for breeding Harpy Eagles, but the birds may benefit from the effective expansion of protected areas bordering the Mache Chindul property. The authors placed this corridor at medium priority and medium feasibility (Lessmann et al. 2014). Regenerated forest in disturbed areas have been found capable of supporting high diversity, provided that there is intact habitat nearby and that the prior disturbance was not too severe, so there may be some hope reforesting agricultural land over the long term (Durães et al. 2013). According to Vortex simulations, the potential breeders in and around Cotacachi Cayapas are viable for the next hundred years (chance of extinction <5%) if they remain completely connected (Figure 6). If these are also well connected with the Mache Chindul birds, then a metapopulation starting out at a minimum of 64 individuals will be viable for the next hundred years (Figure 5). That is 9 less than the number of individuals required when the Mache Chindul colony is isolated, citing an importance to keep all the spatially separated populations connected promote gene flow and reduce inbreeding depression. To simulate the effects of present deforestation rates, the carrying capacity was lowered by 1% per year, and all Vortex simulations with this parameter showed guaranteed local extinction of Harpy Eagles within the century, since a carrying capacity of 141 is low to begin with. As deforestation rates are likely higher than 1% in the study area, Harpy Eagles could be wiped out from western Ecuador in even less time.

Some primary forest can be found outside of Cayapas National Park but close to its borders. The Ecuadorian government acknowledges these patches as indigenous land for the Chachi and Awa nationalities and community lands for Afro-Ecuadorians, all of whom have some degree of authority and autonomy over the usage of their land (Image 1, Figure 3, EcoCiencia 2013, LandMark 2019). These properties are sparsely populated in general, and traditional lifestyles allow for the existence of intact forest cover despite human habitation (EcoCiencia 2013). The trade-off is that some Harpy Eagles may be removed from the population for ritualistic practices (Guerrero 1997). Studies have also shown that deforestation is increasing in Awa indigenous lands, albeit at a much lower rate that the rest of northwestern Ecuador (Pavón Cevallos 2011). R. Canandé, R. Tesoro Escondido, and R.V.S. el Pambilar are some of the few smaller reserves that contain intact forest. Pambilar is federally protected, but there is active logging within the refuge; Canandé and Tesoro Escondido, which are privately owned, have hosted breeding eagles this year (Image 5), but mining, loggings, and palm oil activities also loom over these properties (eBird, Roy et al. 2018, Rainforest Trust). In fact, the few recent observations of Harpy Eagles in northwestern Ecuador all occur in at-risk areas (Image 5). In 2014, several conservation foundations teamed up to purchase land around Reserva Canandé. The reserve grew from 2000ha to about 2500ha (Erickson-Davis 2014). It was a step towards expanding the protection of natural habitat and connecting to other nature

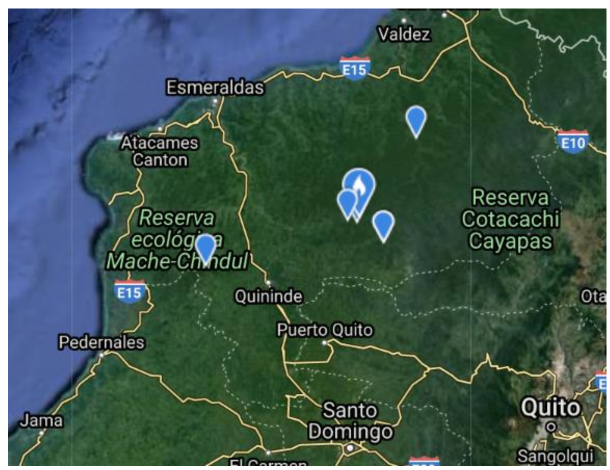


Image 5. eBird records of Harpy Eagle in NW Ecuador. Note that all the markers on the right refer to the same family unit, but pinned locations are deliberately misplaced to protect the birds (eBird)

reserves. The reserve now spans over 5000ha, and newly purchased properties that were previously cleared are now being reforested, showing that it is possible to significantly expand protected areas (Fundación Jocotoco Ecuador).

The distribution of preferred prey was not taken into account for the selection of Harpy habitat. Brown-throated sloth (*Bradypus variegatus*), Hoffman's two-toed sloth (*Choloepus hoffmanni*), Colombian white-faced capuchin (*Cebus capucinus*), Mantled howler (*Alouatta palliata*), and Brown-headed spider monkey (*Ateles fusciceps fusciceps*) all live within range in the northwestern corner of Ecuador and may serve as potential and preferred prey (IUCN 2017). All of these species are designated Least Concern globally except for the Chocó endemic *A. f. fusciceps*, whose species complex is critically endangered due to hunting and human disturbance, and for whom protected areas with intact forest are critical strongholds (Tirira 2003). It is highly probable that the other listed prey species are also in severe decline in northwestern Ecuador, but local vulnerability may be masked by the sound status of their global populations (Lynch Alfaro et al. 2014, Muñiz-López 2016). It does not seem like a good idea to impose targeted predator pressure on them, but the Harpy Eagle is an umbrella species; conservation of its habitat means collateral protection of the other resident species, including endangered primates. Harpy Eagles have been found to be versatile in their prey choice when monkeys and sloths are less available, with an extreme case in Belize targeting *Didelphis marsupialis* and *Nasua narica* (Aparicio 2003, Piana 2007, Rotenberg et al. 2012). While *C. hoffmanni* were found to be the primary prey item in northwestern Ecuador, the eagles living there would be expected to hunt opportunistically if prey abundance decreases (Muñiz-López 2016).

The caveat to opportunism is the possibility that eagles would take domestic animals from neighboring human communities, which they have been known to do very rarely. This could spark animosity against the species and conservation efforts. Historically, eagle poaching is not as serious a threat in western Ecuador as it is in the Amazon, where the bird is regularly poached for reasons such as fear, blame for killing domestic animals, trophies, feathers for ritualistic practices, etc., and such killings are considered a significant factor in this species' decline in addition to habitat loss (Vargas et al. 2006). One study found that all observed instances of adult mortality were caused by gunshots (Muñiz-López 2017). The unnecessary loss of even a single bird would be significant for a species that is slow to mature and slow to reproduce. Therefore, despite the eagle's potential ability to live in disturbed habitats, his project emphasized the importance of distancing from human habitation.

If a sustainable population were to be established in northwestern Ecuador, there might be a higher likelihood of observing Harpy Eagles in very deforested areas due to intraspecific competition rather than the intrinsic lack of food. A sizeable portion of Harpy observations south of the Amazonian basin occur in categorically unsuitable habitat – tiny forest fragments in urban areas, open spaces, etc., but that is not to say that these birds are successful (Miranda et al. 2019, eBird). Researchers have insisted that birds appearing at such sites are vagrants, and that few signs of breeding have been found (Miranda et al. 2019). Increased contact with humans and domestic animals would also be problematic for these transient birds. Hunting might be a lesser issue for eagles in northwestern Eucador simply because there are already so few of them, but ritual sacrifices and commercial trade involving this bird was still known to occur in Afro-Ecuadorian communities in Esmeraldas Province (Guerrero 1997). Successful conservation efforts could potentially increase encounters with wandering young eagles. Therefore, it is imperative that large areas of suitable habitat are maintained to reduce the pressure on the eagles to forage near human habitation.

Despite apparent shortcomings in the legislature for habitat protection, all the suitable breeding areas were coincidentally found in areas with some degree of protection, be it federal, private, indigenous, or communal (Figure 3). Perhaps it was not a coincidence after all. While none of the protected areas were completely safe from mining concessions or other exploitative activities, any intact forest patch at least the size of a potential breeding territory was still only found on land with some degree of protection. Therefore, there is still hope that protected statuses can serve as an obstacle against deforesting activities.

Reintroduction of the Harpy Eagle may involve the artificial addition of new individuals to an existing population or the recolonization of areas where the eagle was previously extirpated. Genetic diversity is one of the most important considerations. Studies have had somewhat conflicting views on the level of genetic diversity across populations, with some stating low levels and inferring a grim outlook and others stating high levels and showing more optimism (Banhos et al. 2016, Lerner et al. 2009). Elsewhere in the Harpy Eagle's global distribution, various sites have been considered for reintroduction. Some forest fragments in the Serra do Mar region of southeastern Brazil have been considered good candidates for establishing a new colony (Miranda et al. 2019). Thorough assessments need to be done in northwestern Ecuador in order to make reintroduction a possibility in the near future.

Conclusion

Main findings

A carrying capacity of 141 individuals, or 47 breeding pairs and their offspring, may be supported in northwestern Ecuador, with each territory averaging 35.1km^2 and the total distribution covering 1500.24km^2 of intact forest, with 29 within the bounds of R.E. Cotacachi Cayapas and 4 within R.E. Mache Chindul. The remaining 14 family units are divided among small entities around R.E. Cotacachi Cayapas, namely, Awa indigenous land (5), Afro-Ecuadorian community land (3), Chachi indigenous land (2), R.V.S. el Pambilar (2), and private reserves Canandé and Tesoro Escondido (2) (Figure 3). Small forest patches and peripheral areas are at highest risk to forest cover loss and fragmentation in the near future.

If all the northwestern birds are well connected, a minimum of 64 individuals is required for the population to be viable for the next 100 years (Figure 5). R.E. Mache Chindul is very geographically isolated from the other sites, and a colony there is not expected to survive this century if there is no consistent gene flow from the greater Cotacachi Cayapas area (Figure 6).

With deforestation accelerating at an uncontrollable rate, the future appears rather bleak for all biodiversity in western Ecuador, let alone the Harpy Eagle. But there is still hope for a self-sufficient population of this large raptor in northwestern Ecuador if the remaining forests are actively protected and if new wildlife corridors are established.

Limitations

This study's main issues to overcome are the low amount of information on some aspects of the Harpy Eagle's history, such as juvenile dispersal dynamics, and the general lack of comprehensive studies in western Ecuador compared to other parts of the eagle's distribution.

These directly impact the quality of this study's assessment of suitable habitats in the study area. Another technical limitation is the lack of high-resolution, cloudless satellite imagery for the desired locations. While cloudless images exist for miscellaneous dates, these were not enough to make direct analyses on how forest cover changed over the years; instead, these time-dependent data had to be sourced from other studies to discuss the rapid forest coverage loss in the peripheral and core areas of intact forest patches.

Future recommendations

Any future studies attempting to use ImageJ to analyze satellite images should do so at higher resolutions to yield more accurate calculations of forest cover areas and their change over time. Focused analyses on the vicinities of R.E. Mache Chindul and R.E. Cotacachi Cayapas are recommended as the former is critically threatened while the latter's core regions are relatively safe so now, so a comparative study between the two sites might yield more insights to deforestation patterns and habitat suitability for Harpy Eagles..

It is simply unknown how many eagles are currently left in western Ecuador. If future on-ground surveys find suitable habitat but no presence of Harpy Eagles, reintroductions plans must not be formed hastily, as there could be debilitating reasons that the available habitat was unoccupied. Factors like the presence of wildlife corridors connecting to existing populations or the availability of prey species might significantly affect the independent survival of a reintroduced colony. More long-term studies are needed to show how Harpy Eagles respond to increasing deforestation within their breeding territories. A mathematical function could show how territory size changes as distance to disturbance increases; it makes sense that birds living in more disturbed areas would require larger territories to obtain enough resources. These adjustments can improve this study's distribution maps. Besides habitat disturbance, bioaccumulation of pesticides from agriculture and residual chemicals from mining should also be studied to assess any immediate health risks to Harpy Eagles. With more details about species life history in the context of local environments, the Vortex software would also be able to perform more realistic simulations of future population trends, which may contribute to formulating conservation goals for specific populations.

Since mining and palm oil plantations cause severe levels of habitat loss and fragmentation in the western lowlands, much of the future work should involve diplomacy with local communities, private companies, and the government. Rare and charismatic species tend to be drivers of the ecotourism industry, so the presence of Harpy Eagles in northwestern Ecuador may become a potential source of funding to keep local conservation efforts afloat. Its qualities as a keystone, ambassador, and umbrella species make it a powerful mediator.

This study demonstrates the mutual dialogue between ecology, conservation, culture, economy, and politics. The successful conservation of any entity, be it a plant, animal, or habitat, requires multifaceted approaches that involve more than just the target's life history. All relevant literature on Harpy Eagles referenced in this study have ties to the above themes, and politics are an especially important component in the conversation about conservation, as policies and how they are reinforced have significant impact on how natural resources are managed. The Harpy Eagle is only one of the many vulnerable species that are subject to how humans use land, so the collaborative efforts of a network of research organizations, private businesses, local communities, government agencies, and funding patrons are needed to carry out effective conservation.

Bibliography

Aguiar-Silva, F.H., Sanaiotti, T.M., & Luz, B.B. (2014). Food Habits of the Harpy Eagle, a Top Predator from the Amazonian Rainforest Canopy. *Journal of Raptor Research*, 48(1):24-35.

Álvarez-Cordero, E. (1996). Biology and Conservation of the Harpy Eagle in Venezuela and Panama. PhD. Thesis, University of Florida, Gainesville, Florida, U.S.A.

Aparicio, K. (2003). Ecología, participación comunitaria y conservación del águila harpía (*Harpia harpyja*) en la República de Panamá. Tesis de Posgrado. Universidad Nacional, Costa Rica.

Banhos, A., Hrbek, T., Sanaiotti, T.M., & Farias, I.P. (2016). Reduction of Genetic Diversity of the Harpy Eagle in Brazilian Tropical Forests. *PloS one*, 11(2):e0148902. https://doi.org/10.1371/journal.pone.0148902

Brown, L. & Amadon, D. (1968). *Eagles, hawks and falcons of the world*. McGraw-Hill, New York, U.S.A.

Carrasco, E., Berg., K.S., Litz., J., Cook, A., & Karubian, J. (2013). Avifauna of the Mache Chindul Ecological Reserve, Northwest Ecuador. *Ornitologia Neotropical*, 24:321-334.

Cerón, C., Palacios, W., Valencia, R., & Sierra R. (1999). Las formaciones naturales de la Costa del Ecuador. In R. Sierra (Ed). Propuesta preliminar de un Sistema de clasificación de Vegetación para el Ecuador Continental.

Critical Ecosystem Partnership Fund. (2001). Corredor de conservación Chocó-Manabí. Ecorregión Terrestre prioritaria del Chocó-Darién-Ecuador occidental (Hotspot). Colombia y Ecuador.

Colleoni, P. (2016). Becoming Tamed. The Meaning of “Becoming Civilized” among the Waorani of Amazonian Ecuador. *Tipití: Journal of the Society for the Anthropology of Lowland South America*, 14(1):5:72-101.

de Luna, A.G., Sanmiguel, R., Di Fiore. A., & Fernandez-Duque, E. (2010). Predation and Predation Attempts on Red Titi Monkeys (*Callicebus discolor*) and Equatorial Sakis (*Pithecia aequatorialis*) in Amazonian Ecuador. *Folia Primatol*, 81:86–95.

del Hoyo, J., Elliot, A., & Sargatal, J. (1994). *Handbook of the Birds of the World: (Vol. 2).* Lynx Editions, Barcelona.

Durães, R., Carrasco, L., Smith, T.B., & Karubian, J. (2013). Effects of forest disturbance and habitat loss on avian communities in a Neotropical biodiversity hotspot. *Biological Conservation*, 166(2013):203-211.

EcoCiencia. Consejo de Desarrollo de las Nacionalidades y Pueblos del Ecuador - CODENPE. (2013). Quito, Ecuador.

Erickson-Davis, M. (2014). ‘A remarkable conservation achievement’: Ecuador reserve expands as forest disappears. Mongabay. https://news.mongabay.com/2014/10/a-remarkable-conservation-achievement-ecuador-reserve-expands-as-forest-disappears/

Faber-Langendoen, D., & Gentry, A. (1991). The Structure and Diversity of Rain Forests at Bajo Calima, Choco Region, Western Colombia. *Biotropica, 23*(1):2-11. doi:10.2307/2388682

Ferguson-Lees, J., Christie, D. A. (2001). *Raptors of the world*. Houghton Mifflin Harcourt. pp. 717–19. ISBN 978-0-618-12762-7.

Fundación Jocotoco Ecuador. Canandé. https://www.jocotoco.org/wb#/ES/Canande

Giudice, R. (2005). Arquitectura de árboles y estructura de vegetación del bosque como factores determinantes en la anidación del águila arpía (*Harpía harpyja* Linnaeus 1878) en la cuenca baja del río Tambopata. Tesis de licenciatura, Universidad Nacional Agraria La Molina, Lima, Peru.

Global Forest Watch. World Resources Institute. https://gfw.global/2XRttSd

González-Jaramillo, V., Fries, A., Rollenbeck, R., Paladines, J., Oñate-Valdivieso, F., & Bendix, J. (2016). Assessment of Deforestation during the Last Decades in Ecuador Using NOAA-AVHRR Satellite Data. *Erdkunde, 70*(3):217-235.

Google Earth. Google. http://earth.google.com/web/

Gottschalk, T.K., Huettmann, F., & Ehlers, M. (2005). Review article: Thirty years of analysing and modelling avian habitat relationships using satellite imagery data: a review. *International Journal of Remote Sensing*, 26(12):2631-2656, DOI: 10.1080/01431160512331338041

Granizo, T., Pacheco, C., Ribadeneira, M.B., Guerrero, M., & Suárez, L. (2002). Libro rojo de las aves de Ecuador. SIMBIOE Conservación Internacional-Ecociencia-Ministerio del Ambiente-UICN, Quito.

Guerrero, M. (1997). Evalucación del estado poblacional y etnozoología del águila harpía (*Harpia harpyja*) en el Ecuador. Tesis de Grado previa a la obtención del título de licenciatura en Biología. Facultad de Filosofía, Letas y Ciencias de la Educación. Universidad Central del Ecuador, Quito, Ecuador.

Gutiérrez-Usillos, A. (2002). *Dioses, Símbolos y alimentación en los Andes. Interrelación hombre-fauna en el Ecuador prehispánico*. Ediciones Abya-Yala. Quito. 473 pp.

Harris, N., Goldman, E., Gabris, C., Nordling, J., Minnemeyer, S., Ansari, S., Lippmann, M., Bennett., Raad, M., Hansen, M., & Potapov, P. (2017). Using spatial statistics to identify emerging hot spots of forest loss. *Environmental Research Letters*. 12. 10.1088/1748-9326/aa5a2f.

Hansen, M.C., Krylov, A., Tyukavina, A., Potapov, P.V., Turubanova, S., Zutta, B., Ifo, S., Margono, B., Stolle, F., & Moore, R. (2016). Humid tropical forest disturbance alerts using Landsat data. *Environmental Research Letters*, 11(3). Accessed through Global Forest Watch on 06/05/2020.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., & Townshend., J.R.G. (2013). High-Resolution Global Maps of 21st-

Century Forest Cover Change. *Science*, 342(November 2013):850–53. Accessed through Global Forest Watch on 06/05/2020.

IUCN Red List. (2017). http://www.iucnredlist.org/

Knee, K.L. & Encalada, A.C. (2014). Land use and water quality in a rural cloud forest region (Intag, Ecuador). *River Res. Applic*., 30:385-401. doi:10.1002/rra.2634

Lacy, R.C., & J.P. Pollak. (2020). Vortex: A stochastic simulation of the extinction process. Version 10.3.8. Chicago Zoological Society, Brookfield, Illinois, USA.

LandMark. (2019). Indigenous and Community Lands. www.landmarkmap.org. Accessed through Global Forest Watch on 06/05/2020.

Leck, C. F. (1979). Avian Extinctions in an Isolated Tropical Wet-Forest Preserve, Ecuador. *The Auk*, 96(2):343–352. https://doi.org/10.1093/auk/96.2.343

Lerner, H.R., Johnson, J.A., Lindsay, A.R., Kiff, L.F., & Mindell, D.P. (2009). It's not too late for the harpy eagle (*Harpia harpyja*): high levels of genetic diversity and differentiation can fuel conservation programs. *PloS one*, 4(10):e7336. https://doi.org/10.1371/journal.pone.0007336

Lessmann, J., Muñoz, J., & Bonaccorso, E. (2014). Maximizing species conservation in continental Ecuador: A case of systematic conservation planning for biodiverse regions. *Ecology and Evolution*. 4(12). 10.1002/ece3.1102.

Lynch Alfaro, J.W., Izar, P., & Ferreira R.G. (2014). Capuchin monkey research priorities and urgent issues. *American Journal of Primatology*, 76:1-16.

Miranda, E.B.P. (2015). Conservation implications of harpy eagle *Harpia harpyja* predation patterns. *Endang Species Res*, 29:69-79. https://doi.org/10.3354/esr00700

Miranda, E.B.P., Menezes, J.F.S., Farias, C.C.L., Munn, C., & Peres, C.A. (2019). Species distribution modeling reveals strongholds and potential reintroduction areas for the world's largest eagle. *PLoS ONE* 14(5): e0216323. https://doi.org/10.1371/journal.pone.0216323

Muñiz-López, R. (2002). Especies Integrales (Nexus species): El águila harpía como ejemplo de especie Integal. Pg 23 en: The Peregrine Fund y Fondo Peregrino-Panamá (Eds.). Libro de resúmeses de la Conferencia de rapaces neotropicales y simposio del Águila Arpía. Ciudad de Panamá. 122 pp.

Muñiz-López, R. (2003). Ecuador y el águila harpía: El reto de conocer al águila más ponderosa del mundo. Nuestra Ciencia, 5. Pontificia Universidad Católica del Ecuador (PUCE). Facultad de Ciencias Exactas y Nacturales. Quito, Ecuador.

Muñiz-López, R. (2007). Ecología, biología y habitat del águila harpía (Harpia harpyja). En: Tufiño, P. (Ed.) Cunsi Pindo. Conservación del Águila harpía en Ecuador. Editorial SIMBIOE. Quito, Ecuador.

Muñiz-López, R. (2016). Biología y Conservación de la Águila Harpia (*Harpia harpyja*) en Ecuador. Tesis Doctoral. Facultad de Ciencias, Departamento de Ciencias Ambientales y Recursos Naturales. Universidad de Alicante.

Muñiz-López, R. (2017). Harpy Eagle (*Harpia harpyja*) mortality in Ecuador, *Studies on Neotropical Fauna and Environment*, 52(1):81-85. DOI: 10.1080/01650521.2016.1276716

Muñiz-López, R., Limiñana, R., Cortés, G.D., & Urios, V. (2012). Movements of Harpy Eagles *Harpia harpyja* during their first two years after hatching. *Bird Study*, 59(4):509-514. DOI: 10.1080/00063657.2012.722190

Órces, V.G. (1994). Notas sobre la distribución geográfica de algunas aves neotrópicas (del Ecuador y noroeste del Perú). *Flora*, 4:103-123.

Parker, T.A., III, & Carr, J.L. eds. (1992). Status of forest remnants in the Cordillera de la Costa and adjacent areas of southwestern Ecuador. Conservation International, RAP Working Papers 2.

Pavón Cevallos, F. M. (2011). *Evaluación de los cambios en la cobertura vegetal en las comunidades del territorio Awá en el Ecuador a través de sensores remotos* (Bachelor's thesis, Pontificia Universidad Católica del Ecuador)

Pearman, P.B. (2002). The scale of community structure: habitat variation and avian guilds in tropical forest understory. *Ecological Monographs*, 72(1):19–39.

Piana, R.P. (2007). Anidamiento y dieta de *Harpia harpyja* en la Comunidad Nativa de Infierno, Madre de Dios, Perú. *Revista Peruana de Biología*, 14(1):135-138.

Rainforest Trust. Rio Canandé Reserve. https://www.rainforesttrust.org/projects/rio-canande-reserve/

Rettig, N. (1978). Breeding behaviour of the Harpy Eagle (*Harpia harpyja*). *Auk*, 95:629-643.

Ridgely, R. & Greenfield, P. (2001). *The Birds of Ecuador. Vol. I: Status, Distribution and Taxonomy and Vol. II Field Guide*. Cornell University Press.

Ricotta, E.E., Frese, S.A., Choobwe, C., Louis, T.A., & Shiff, C.J. (2014). Evaluating local vegetation cover as a risk factor for malaria transmission: a new analytical approach using ImageJ. *Malaria journal*, *13*(1):94.

Rotenberg, J.A., Marlin, J.A., Pop, L., & Garcia, W. (2012). First Record of a Harpy Eagle (*Harpia harpyja*) Nest in Belize. *The Wilson Journal of Ornithology*, 124(2):292-297.

Roy, B.A., Zorrilla, M., Endara, L., Thomas, D.C., Vandegrift, R., Rubenstein, J.M., Policha, T., Rios-Touma, B., & Read, M. (2018). New mining concessions could severely decrease biodiversity and ecosystem services in Ecuador. *Tropical Conservation Science*, *11*, 1940082918780427.

Sierra, R., Cerón, C., Palacios, W., & Valencia, R. (1999). Mapa de vegetación del Ecuador continental. 1:1b000.000. Proyecto INEFAN/GEFBIRF, Wildlife Conservation Society & EcoCiencia, Quito, Ecuador.

Sierra, R., Campos, F., & Chamberlin, J. (1999). Áreas Prioritarias para la Conservación de la Biodiversidad en el Ecuador Continental. Un Estudio Basado en la Biodiversidad de Ecosistemas y su Ornitofauna. Ministerio de Medio Ambiente, Proyecto INEFAN/ GEFBIRF, EcoCiencia y Wildlife Conservation Society. Quito.

Sierra, R. (2013). Patrones y factores de deforestación en el Ecuador continental, 1990-2010. Y un acercamiento a los próximos 10 años. Conservación Internacional Ecuador y Forest Trends. Quito.

Tirira, D. (2003). Estado actual del mono araña de cabeza café (Ateles fusciceps) (Primates: Cebidae) en el Ecuador. *Lyonia*, 13:1-6.

Turubanova, S., Potapov, P.V., Tyukavina, A. & Hansen, M.C. (2018). Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. *Environmental Research Letters*, 13(7):074028. Accessed through Global Forest Watch on 06/05/2020. www.globalforestwatch.org.

Urios, V., Muñiz-López, R., & Vidal-Mateo, J. (2017). "Juvenile Dispersal of Harpy Eagles (*Harpia harpyja*) in Ecuador." *Journal of Raptor Research*, 51(4):439-445.

Vanegas, A. (2019). eBird checklist: https://ebird.org/checklist/S64967329. eBird: An online database of bird distribution and abundance. eBird, Ithaca, New York. Available: http://www.ebird.org. (Accessed: May 2, 2020).

Vargas, J.J., Whitacre, D., Mosquera, R., Alburquerque, J., Piana, R., Thiollay, J.M., Márquez, C., Sánchez, J., Lezama-López, M., Midence, S., Matola, S., Aguilar, S., Rettig, N., & Sanaiotti, T. (2006). Estado y distribución actual del Águila Arpía (Harpia harpyja) en Centro y Sur América. *Ornitología Neotropical*, 17:39-55.

Zuluaga, S., Grande, J.M., Schulze, M., Aristizabal, D.F., Vargas, F.H., & Aguiar-Silva, F.H. (2018). Nest Records of Two Large Eagles in Colombia and Ecuador. *Journal of Raptor Research*, 52(4):522-527. https://doi.org/10.3356/JRR-17-60.1