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BIOLOGÍA Y CONSERVACIÓN DEL ÁGUILA HARPÍA (*Harpia harpyja*)  
EN ECUADOR

Ruth Muñiz López



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**TESIS DOCTORAL**

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**RUTH MUÑIZ LÓPEZ**

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**Facultad de Ciencias**

**Departamento de Ciencias Ambientales y Recursos Naturales**

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**BIOLOGÍA Y CONSERVACIÓN DEL ÁGUILA HARPÍA (*Harpia harpyja*)  
EN ECUADOR**

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En Alicante, junio de 2016.

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*Churulla, Cunsi Pindo, Kenguiwe, Chorongo wamani, Nasó wiwé... Águila Harpía*



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Hembra de águila harpía partiendo de su árbol del nido en la Reserva Faunística Cuyabeno.

Foto: P. Oxford/PCAHE-SIMBIOE

*A los ojos de Etsá vuela el espíritu del aire en la selva y, de la mano de Arutam,  
guía los pasos de los nungkánmayas acogidos por Ikiam*

Foto de portada: P. Oxford /PCAHE-SIMBIOE



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## CAPÍTULO 1



Figura precolombina de águila harpía, 1600 a.C - 600 d.C. Frontera occidental Panamá-Costa Rica.  
Foto: Universidad Vanderbilt. TN. EE.UU.

*Que las palabras sigan vivas, las ideas no pernocten, las imágenes dancen al son de los tambores, la música sea sonidos sonoros que lleguen al corazón de Iwia.*

Extraído del poema “Como puma herido”  
María Clara Sharupi, poeta indígena de la Amazonía ecuatoriana.



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## CAPÍTULO 1

### 1.1. Introducción.

La palabra Neotrópico (del griego *neos* = “nuevo”) hace referencia a la región tropical del continente americano. Este término fue acuñado por Peter Martyr d’Anghiera en 1493 poco después del primer viaje de Cristóbal Colón a América (O’Gorman 1972). Tal y como hoy se define abarca desde la región central de México hasta el sur de Brasil, incluyendo Centroamérica, las islas del Caribe y la mayor parte de Suramérica (Schultz 2005). En ella, la precipitación y la temperatura media son generalmente elevadas (Antonelli & Sanmartín 2011), aunque existe una alta variación entre las distintas subregiones, por ejemplo, mientras que al oeste de Colombia el nivel de precipitación es uno de los más altos del mundo con casi 9000 mm/año (Antonelli & Sanmartín 2011) en la Amazonía la precipitación varía entre 1500 y 3000 mm / año (Salati & Vose 1984).

Los ecosistemas tropicales son los más diversos del mundo (Wilson 1988) siendo el Neotrópico la región biogeográfica con mayor diversidad de rapaces en la tierra y el centro de origen de la familia Falconidae y del género *Buteo* (Escobar-Acosta *et al.* 2006). De las aproximadamente 292 especies de aves rapaces diurnas que existen, 222 se encuentran en los trópicos y 96 en el Neotrópico, de los que 18 son endémicas (Bildstein *et al.* 1998), habiéndose identificado 67 en Ecuador (Ridgely & Greenfield 2001).

Las aves rapaces son sensibles a la contaminación y a los cambios en la calidad del hábitat, por lo que pueden desempeñar un papel importante como indicadores funcionales de la salud ambiental (Leck 1979, Newton 1979, Peakall & Kiff 1988). Para conservar las rapaces y sus hábitats deben comprenderse sus ciclos biológicos, requerimientos de hábitat y las condiciones ecológicas y humanas en las que viven de forma que se logre preservar tanto como sea posible su distribución natural (Stotz *et al.* 1996).

Tanto el tamaño como la distribución de las poblaciones de aves rapaces pueden verse limitados por la disponibilidad de lugares adecuados para criar, la existencia de recursos tróficos, factores climáticos y presiones antrópicas (Newton 1979). En general,

poseer gran tamaño, baja fecundidad y longevidad son señales que predicen propensión a la extinción, pero sólo para aquéllas especies que evitan hábitats modificados (Laurance 1991). Las grandes aves de presa que son relativamente especializadas en cuanto a su hábitat y dieta generalmente desaparecen cuando se aíslan en hábitats (Thiollay 1989). Estas aves, después de las típicamente cinegéticas - es decir, frecuentemente utilizadas para la cacería- son las primeras en desaparecer durante el proceso de crecimiento de la población humana y el aumento de la explotación de los bosques lluviosos (Harris 1984).

### **1.1.2. Antecedentes en la investigación del águila harpía.**

Una de las observaciones iniciales sobre esta especie en estado silvestre fue publicada por Bond (1927) en donde reportó el descubrimiento de un nido de águila harpía en el noreste del Brasil a aproximadamente 64 km del estado de Pará, en abril de 1926. En el nido se encontraron dos huevos y se observó el comportamiento de un individuo adulto, posiblemente la hembra.

Los primeros trabajos acerca de la ecología reproductiva del águila harpía fueron llevados a cabo en la región Rupununi, en la República de Guyana durante los años 60 (Fowler & Cope 1964). En esta ocasión se descubrieron dos nidos que fueron descritos y en donde se monitoreó su actividad para estudiar de forma básica los hábitos de las aves adultas y juveniles, su dieta y las variaciones en su plumaje. Más tarde, en esa misma región, Brock (1972) realizó observaciones acerca del plumaje de dos águilas que habían sido capturadas.

Hasta el trabajo de Neil Rettig, realizado entre los años 1974 y 1975 (Rettig 1978), apenas se conocía el comportamiento reproductivo del águila harpía. Éste regresó a uno de los nidos encontrados por Fowler y Cope en el año 1960, y describió el lugar de nidificación, la construcción del nido, el período de cópula, la puesta de huevos, la incubación, la alimentación de adultos y cría, los cuidados parentales y el comportamiento de la cría en las distintas etapas de desarrollo. Más tarde, Izor (1985) realizó un estudio de las presas aportadas a un nido también en la República de Guyana y posteriormente, entre los años 1987 y 1988 se describió por primera vez la anidación de esta especie en la Provincia de Misiones (Argentina) (Chébez *et al.* 1990). Aún así, hasta la tesis doctoral realizada por Álvarez-Cordero en la región Guayana de

Venezuela y en la provincia de Darién en Panamá (Álvarez-Cordero 1996) no se presenta información detallada acerca de esta especie, incluyendo su rango ecológico y geográfico, biología de la anidación, independencia del área natal, dieta, y amenazas, así como propuestas para apoyar su conservación.

Tras el estudio de Álvarez-Cordero, en Panamá se realizaron algunas investigaciones complementarias acerca de su biología reproductiva, distribución histórica (Mosquera *et al.* 2002, Aparicio 2003) y tamaño de población (Vargas & Vargas 2011).

En Perú los trabajos sobre esta águila son casi inexistentes, excepto por aquéllos realizados por Piana (2007) acerca de la nidificación, distribución y abundancia del águila harpía en la provincia amazónica Madre de Dios.

En Brasil existen trabajos acerca de su comportamiento durante el periodo de cría (Sanaiotti 2002) y hábitos alimenticios (Aguiar-Silva 2014).

Otros datos puntuales se pueden encontrar en la bibliografía acerca de su comportamiento y ecología del aprovisionamiento alimenticio a lo largo de su rango de distribución (Eason 1989, Peres 1990, Touchton *et al.* 2002, Rotenberg *et al.* 2012) o de especímenes reintroducidos (Muela & Curti 2005). Por otra parte, es interesante señalar la existencia de estudios genéticos para esta especie, en los que se describe su cariotipo (Felipe *et al.* 2001, De Oliveira *et al.* 2005), se muestra el origen no monofilético del grupo Harpiinae (Lerner & Mindell 2005) y se concluye que existen niveles moderadamente altos de diversidad genética entre subgrupos de águila harpía a lo largo de su distribución (Lerner *et al.* 2009)

- En Ecuador:

La primera vez que se recogieron datos de campo acerca de la distribución del águila de manera formal fue en los años cuarenta, encontrándola al oeste de Ecuador (Orcés 1944).

En 1990 se afirma que el águila harpía se distribuye en el bosque húmedo tropical bajo los 600 m s. n. m., tanto en la región occidental (costera) como en la oriental (región amazónica) (Ortiz-Crespo *et al.* 1990) del país.

Álvarez-Cordero (1996) recogió en su tesis datos de museos que poseían pieles de águilas ecuatorianas que databan de 1880 (en el British Museum of Natural History, Reino Unido), 1925 y 1926 (en el American Museum of Natural History, EE. UU.). Los

ejemplares procedían de la localidad de Balzar (provincia de Guayas), de la desembocadura del río Cotapino (suroccidente de la provincia de Orellana) y la desembocadura del río Curaray (provincia de Pastaza) respectivamente. Los colectores o referentes para estos restos fueron, siguiendo el orden cronológico, Illingwroth y Olalla e hijos.

Mauricio Guerrero realizó su tesis de licenciatura con el águila harpía en la Universidad Central de Ecuador (Quito). Los objetivos fueron realizar una evaluación del estado poblacional de esta especie en el país y determinar el valor cultural o mítico que le asignan al águila diferentes grupos humanos en Ecuador (Guerrero 1997). Se trató de un estudio preliminar en el que tomó algunos datos de ejemplares capturados o tiroteados, profundizando su enfoque en el ámbito etnozoológico. Según ese trabajo, la distribución del águila harpía al occidente ecuatoriano es muy restringida, limitándose actualmente al noroccidente, en la provincia de Esmeraldas, en la región que comprende la parte noroeste de la Reserva Ecológica Cotacachi-Cayapas, en donde obtuvo un registro visual en abril de 1991. Concluía que en el oriente o región amazónica ecuatoriana su distribución es más amplia, coincidiendo con bosques poco perturbados y escasa presencia humana.

Guerrero registró 16 individuos entre 1989 y 1995, gran parte de ellos en los ríos Cuyabeno, Záballo y Pacayacu, afluentes del río Aguarico, en la provincia de Sucumbíos, nororiente de Ecuador. Otros registros se localizaron en la provincia situada al sur, Orellana, en los alrededores de los ríos Yasuní y Cononaco, lagunas de Garzacocha y Jatuncocha, así como en las riberas del río Tiputini. Llegó a localizar tres nidos, todos en el oriente ecuatoriano, pero ninguno activo en ese momento. En su tesis, analizó el interés que el águila harpía provocaba en el grupo étnico huaorani (propio de la provincia de Orellana) en donde coronas y brazaletes de guerra son generalmente adornados con plumas de esta águila con el objeto de lograr la protección y fuerza que consideran ofrece esta ave. Literalmente cita: “Ellos la admiran por su fuerza y su destreza cazadora, deseando imitarla para el mismo fin. La consideran un símbolo protector de sus comunidades y niños, por lo que las capturan para mantenerlas junto a ellos; eso significa adquirir un estatus superior y una posición privilegiada, pues consideran que en el ser del cazador ha sido encarnada toda la sabiduría y habilidad del águila”.

En la región occidental, en donde los bosques ya han sido fragmentados, el águila harpía parece estar prácticamente desaparecida (Ridgely & Greenfield 2001). Leck

(1979) ya hizo referencia a la prácticamente nula existencia de registros de la especie en esta región, y sugería que probablemente estuvieran sufriendo extinciones locales.

En el año 2001 se publicó el libro “Aves del Ecuador” (Ridgely & Greenfield 2001) en el que se señala que esta especie se encuentra relativamente extendida al este del país, en donde todavía permanecen bosques de forma extensiva y añadiendo que, a pesar de que su territorio sea considerable, los individuos observados siempre son muy pocos. Según el mismo libro, se ha encontrado por debajo de los 400 m s.n.m. (salvo en un registro en Tinalandia, un hotel a unos 700 – 800 m s.n.m. al oeste de la cordillera andina). Al noreste casi todos sus registros son de aves disparadas o que han sido capturadas para mantenerlas en cautividad a pesar de que está penado por ley (salvo en casos de tradición cultural ancestral como el de la etnia huaorani, en el oriente ecuatoriano). En la región occidental sólo obtuvieron un único registro de dos aves en 1983, cerca de Tinalandia.

Más tarde, ya en el año 2004, se encontró el primer y único nido activo de esta especie localizado hasta el momento al oeste de la cordillera andina (Muñiz-López 2007).

El águila harpía no es considerada como una especie abundante, aún en áreas sin habitar (Ridgely & Greenfield 2001). En comparación con la región occidental, se encuentran de forma más regular en la región del bajo río Aguarico (provincia Sucumbíos, nororiente de Ecuador), en donde aún así existen escasísimos avistamientos (Ridgely & Greenfield 2001).

La tenencia de esta ave en cautividad se describe desde 1971, en donde Stummer relata en un artículo la captura de un águila harpía en el occidente ecuatoriano y su posterior traslado a Seattle, EE. UU. (Stummer 1971). Otras informaciones sugieren la captura y sacrificio de un ejemplar de esta especie en la comunidad afroecuatoriana de Mataje (provincia de Esmeraldas, noroccidente de Ecuador), en el área del río Mataje, a principios de 1991 (Jaime Cevallos, en Guerrero 1997). Además, se determinó que un águila cautiva con plumaje de juvenil, que se encontraba en una residencia privada cerca de la Reserva Manglares-Churute (provincia de Guayas, suroccidente del país), murió en 1995 a causa del ataque de otra harpía cautiva adulta al intentar reproducirlas en cautividad (Mireya del Pozo, en Guerrero 1997).

La comercialización fue evidente en un local privado en la provincia de Esmeraldas. Allí habían mantenido tres ejemplares de águila harpía en diferentes años. De los tres individuos, uno había estado cautivo en las inmediaciones de la Reserva Manglares-

Churute, y se desconoce su destino; el segundo individuo formaba parte de la colección del zoológico de Salango (provincia de Manabí, occidente de Ecuador), aunque después fue integrado al programa de reproducción en cautividad de esta especie desarrollado por la institución “The Peregrine Fund”, regresando a un centro de fauna privado de Ecuador al finalizar el mismo, en el año 2006 (The Peregrine Fund 2006). Del tercer ejemplar no se tiene información exacta, ya que se declaró que desapareció en 1991, no descartándose su posible comercialización (Guerrero 1997).

En el año 2007 fue localizada otra águila harpía de unos dos meses de edad que se encontraba mantenida en cautividad en una casa de la comunidad San Pablo de Katetsiyá, perteneciente a la nacionalidad indígena Secoya o Siecopai, en la región amazónica ecuatoriana. Según la persona que la había capturado, derribó el árbol en donde se encontraba el nido para recoger al pollo y vendérselo a un traficante que meses antes pasó por el lugar ofreciéndose para comprar una. Sin embargo, de acuerdo con el captor y al contar el ejemplar con poca edad, se reintegró con éxito de nuevo al bosque, en donde la pareja adulta de águilas silvestres continuó cuidado de este pollo hasta al menos un año después de su liberación (Muñiz-López *et al.* 2008).

El primer nido activo de águila harpía que fue monitoreado en Ecuador fue encontrado en el año 2002, al noreste del país (Muñiz-López 2007). Desde entonces, quince nidos más han sido localizados en la región amazónica ecuatoriana y uno en la región occidental de este país.

### 1.1.3. El águila harpía: la especie.

El águila harpía (*Harpia harpyja*) es el accipítrido de mayor tamaño del continente americano (Collar 1989) y una de las cuatro águilas más grandes del mundo, junto con el pigargo de Steller del este de Siberia (*Haliaeetus pelagicus*), el águila marcial de las sabanas africanas (*Polemaetus bellicosus*) y el águila pitecófaga (*Pithecopaga jefferyi*) que habita en cuatro de las islas de Filipinas (Collar 1989, Sick 1997). De todas ellas, es la que posee las garras de mayor longitud del mundo (Brown & Amadon 1968), estando considerada como la más poderosa de todas las de su grupo (Collar 1989).

El águila harpía se distribuye a lo largo de bosques tropicales y subtropicales, en general por debajo de los 900 msnm (Stotz *et al.* 1996) desde el sur de México hasta el

norte de Argentina (Hilty & Brown 1986), aunque la población desde México hasta Costa Rica se encuentra muy debilitada (Vargas *et al.* 2006).

En Ecuador su presencia se encuentra restringida a algunos parches de bosque al noroeste del país, pero más homogéneamente en la región amazónica (Guerrero 1997, Ridgely & Greenfield 2001, Muñiz-López 2003) en donde la temperatura oscila alrededor de los 25° C y las precipitaciones se calculan entre los 2.000 a 4.000 mm anuales, siendo el promedio de humedad ambiental entre un 96-100%. (Sierra *et al.* 1999).

El águila harpía cría un polluelo cada dos años y medio o tres años y se presume que permanece en el territorio de los padres durante al menos dos años antes de independizarse del área paterna (Rettig 1978, Ruschi 1979, Álvarez-Cordero 1996).

Su alimentación se basa fundamentalmente en mamíferos arborícolas, complementándose por aves y algunos reptiles (Fowler & Cope 1964, Rettig 1978, Álvarez-Cordero 1996, Muñiz-López *et al.* 2007).

Estas águilas son especialmente longevas. En la República de Guyana se estima que una pareja utilizó el mismo nido durante más de 30 años (Fowler & Cope 1964).

El águila harpía es una rapaz forestal. Raras veces se le ha visto planeando por encima del bosque (del Hoyo *et al.* 1994). En vuelo las alas se notan cortas en proporción con el resto del cuerpo (180 a 200 cm), así como muy anchas y redondeadas (del Hoyo *et al.* 1994).

Poseen un disco facial que puede aumentar su capacidad auditiva y ojos muy frontales que son útiles para localizar con facilidad sus presas y medir las distancias a éstas con efectividad, pues se mejora su visión tridimensional (Ferguson-Lees & Christie 2001). No adquieren su plumaje definitivo hasta los cinco años de edad (Ferguson-Lees & Christie 2001).

Como en muchas otras rapaces, la hembra es de mayor tamaño y peso que el macho (del Hoyo *et al.* 1994). La primera puede pesar hasta 9 kg (6,0 – 9 kg), a diferencia del macho que llega como mucho a los 5 kg (4 – 5 kg) (del Hoyo *et al.* 1994). La longitud de su cuerpo oscila entre los 89 a 105 cm (del Hoyo *et al.* 1994).

Su gran tamaño hace difícil la confusión con otras especies si se la ha visto alguna vez. Sin embargo, a veces pueden existir problemas para discernirla del águila crestada (*Morphnus guianensis*), aunque esta última es más pequeña, posee una cresta sin bifurcar y sus tarsos resultan mucho más finos a simple vista (del Hoyo *et al.* 1994).

Actualmente, se cataloga de forma global como “Casi Amenazada” en todo su rango (Collar *et al.* 1994, BirdLife International 2013) pero en Ecuador es considerada “Vulnerable” (Granizo *et al.* 1997), aunque en la región occidental del país podría incluirse en la categoría de “Peligro Crítico” (Ridgely & Greenfield 2001).

#### **1.1.4. Relación con la cultura y reconocimientos nacionales.**

La relevancia a nivel cultural del águila harpía es, en general, un campo poco conocido. Sin embargo, está considerada como una “Especie Integral” (especie con valor para la biodiversidad y para la cultura) (Muñiz-López 2002).

Se han reportado registros de tallas, representaciones y figuras en la cultura Olmeca de México (1500-500 d. C.) (Pool 2007), en la cultura Veraguas de Panamá (500-1200 a. C.) (Newton 1987), en la cultura Tairona de Colombia (1000-1400 a. C) (Mason 1931), en la cultura Saladoide-Barrancoide (ver Figura 1) de Venezuela (500-280 a. C.) (Silverman & Isbell 2008), en las culturas Tolita (400 a. C.) (DeBoer 1996) y Chorrera (1200 a. C.-500 d. C.) (Gutiérrez-Usillos 2002) de Ecuador y en la cultura Chavín de Perú (900-200 d. C.) (Fagan 1996).



**Figura 1: Cerámica barrancoide del Bajo Orinoco. Cabeza dimófica superpuesta con un águila harpía (Silvermand and Isbell 2008)**

En las culturas indígenas amazónicas, el águila harpía representa al espíritu del aire y es el alter ego de los shamanes en el cielo, tal y como el jaguar lo es en la tierra y la anaconda en el agua (Beltrán 2013). Los shamanes son los líderes intelectuales de las

culturas nativas americanas. En sus trances se transforman en águila harpía para que éstas sean las mensajeras desde el mundo espiritual al terrestre. Entre otras muchas habilidades, pueden negociar con los dueños del mundo animal a través de su espíritu para lograr que la cacería o pesca sea abundante (Muñiz obs. pers.). Un shamán puede ser iniciado por el águila harpía, adquiriendo la capacidad de volar, que a su vez le brinda una cosmovisión del universo; sus plumas les conferirán fuerza y poder (Reina & Kensinger 1991).

Algunos países han dado un reconocimiento especial en su patrimonio al águila harpía. El 22 de Agosto de 1996 fue declarada Monumento Natural de Argentina de acuerdo a la Ley Nº 2932 de Áreas Naturales Protegidas y de Interés Público. Posteriormente, fue nombrada Ave Nacional de la República de Panamá, amparada por la Ley 18 del 10 de Abril de 2002. Ese mismo año, en el mes de julio, el águila harpía pasaba a ser el “Ave Representativa de la Diversidad Biológica del Ecuador”, mediante el Acuerdo Ministerial número 089, y Registro Oficial número 635.

Tras esto, en Ecuador se escribe la “Estrategia Nacional para la Conservación del Águila Harpía” que, validada y reconocida a través de un Acuerdo Ministerial en marzo de 2007, y tras ser publicada en el Registro Oficial número 24 un año después, forma actualmente parte de la legislación ambiental del país (Muñiz-López *et al.* 2008).

## **1.2. Justificación de la Tesis Doctoral.**

Suramérica contiene aproximadamente 92 especies de aves rapaces diurnas, siendo Ecuador uno de los cuatro países con mayor diversidad del continente americano (67 especies) (Chébez 2001). A pesar de ello, todavía se desconoce la historia natural, distribución, abundancia, ecología y necesidades de muchas de ellas, lo que dificulta el diseño de acciones útiles para su conservación. Existe la necesidad urgente de documentar estas especies desde diferentes puntos de vista, particularmente en los trópicos en donde se encuentra la mayor parte de aves rapaces amenazadas y en donde la destrucción de hábitat ocurre a mayor velocidad (Bildstein *et al.* 1998)

El águila harpía es una especie de costumbres reservadas que habita bosques húmedos de zonas remotas de parte de Centroamérica y Suramérica, y por ello es difícil de detectar (Álvarez-Cordero 1996). Obtener los suficientes datos o un tamaño de muestra adecuado para estudiarla es particularmente complicado y requiere una fuerte

inversión de tiempo (Bednarz 2007), lo que ha resultado en un escaso número de investigaciones que la hayan abordado a pesar de su amplia distribución (Vargas *et al.* 2006). Dentro del grupo de los accipítridos, existen nueve especies catalogadas como “Críticamente Amenazadas”, ocho como “Amenazadas” y 26 como “Vulnerables”, entre las que se encuentra el águila harpía (BirdLife 2015). La mayoría de ellas se ven seriamente afectadas por la destrucción de hábitat y la persecución humana (Remsen *et al.* 2011).

Antes de crear e implementar un plan de manejo o conservación de cualquier especie, ésta debe ser estudiada y comprendida. Su estudio es el primer paso para su protección. Con esta tesis se documentan aspectos de la historia natural, características que definen su vulnerabilidad y necesidades de conservación de un ave carismática pero apenas conocida en Ecuador, aportando información que puede ser utilizada para recomendar acciones que favorezcan su protección. En base a lo anterior, la carencia de conocimiento biológico de esta especie en el país justifica la elaboración del presente estudio.

### **1.3. Objetivos de la Tesis Doctoral.**

Esta Tesis Doctoral tiene como objetivo principal contribuir al conocimiento del águila harpía proporcionando información biológica que caracterice a esta especie en Ecuador y aportando propuestas para la gestión y conservación de sus poblaciones (Capítulos 2, 3, 4, 5 y 6).

Objetivos específicos:

1.3.1. Caracterizar la dinámica de movimiento de individuos juveniles y establecer su periodo de dependencia del área natal. Investigar la hipótesis de que la dependencia juvenil supera el año desde el nacimiento del pollo. Se plantean las siguientes preguntas (Capítulos 2 y 3):

- ¿Cuánto tiempo permanecen los juveniles en el territorio paterno?
- ¿Cuánta distancia recorren los juveniles durante sus primeros dos años de vida?

- ¿El distanciamiento se produce de forma progresiva o repentina?
  - ¿La dispersión de los distintos individuos ocurre de forma similar?
  - ¿Qué recomendaciones surgen para la conservación de esta especie?
- 1.3.2. Determinar el comportamiento de dispersión juvenil. Contrastar la hipótesis de que a partir de los dos años y medio de edad los juveniles abandonan el área paterna para comenzar su dispersión (Capítulo 3).
- ¿A qué edad comienzan los juveniles sus movimientos de dispersión?
  - ¿Qué distancia alcanzan desde su área de cría?
  - ¿Qué área llegan a ocupar mientras se dispersan?
  - ¿Existe algún lugar de asentamiento en el área que exploran los juveniles durante su primera etapa de dispersión?
- 1.3.3. Describir la dieta y ecología trófica durante el periodo de cría en distintas áreas de nidificación. Testar la hipótesis de que la mayor contribución a la dieta del águila harpía proviene de mamíferos arborícolas (Capítulo 4).
- ¿Cuál es el espectro de especies que caza el águila harpía cuando está criando y qué características tienen?
  - ¿Es el águila harpía especialista en cuanto a su alimentación?
  - ¿Cuándo y por quién se producen los aportes de alimentación al pollo? ¿Varían según las distintas parejas y del estado de desarrollo en el que se encuentren los pollos?
  - ¿Qué preferencias de caza poseen los parentales?
- 1.3.4. Estimar la densidad de nidos en una región del nororiente de Ecuador describiendo las características del paisaje en donde el águila harpía establece su área de nidificación, de lo que se genera un mapa de distribución potencial en Ecuador. (Capítulo 5).
- ¿Cuántas parejas de águila harpía puede contener un área protegida como la Reserva de Cuyabeno en Ecuador?

- ¿Cuáles son las características del paisaje en donde las águilas harpías establecen sus áreas de cría en el área de estudio? ¿Qué elementos influencian más la presencia de nidos?
- ¿En qué áreas de Ecuador podrían tener un hábitat adecuado para criar? ¿De cuántas hectáreas disponen?

1.3.5. Examinar las causas de mortalidad en el norte de la región amazónica de Ecuador (Capítulo 6).

- ¿Cuál es la tasa de mortalidad detectada en el área de estudio para adultos y juveniles?
- ¿Existe algún momento crítico en el desarrollo de los juveniles que pueda hacerlos más sensibles a fallecer?
- ¿Qué condiciones y razones originaron la muerte de los ejemplares localizados?
- ¿Cuáles pueden ser las acciones para disminuir la mortalidad de esta especie?

1.3.6. Identificar los factores de amenaza que pueden afectar al águila harpía a lo largo de su rango de distribución en Ecuador y proponer lineamientos que puedan contribuir a su conservación (Capítulos 2, 3, 4, 5 y 6).

- ¿Qué acciones pueden emprenderse para reducir el impacto y grado de presión antrópica hacia el águila harpía?

#### **1.4. Estructura de la Tesis Doctoral:**

La presente memoria doctoral se compone de un capítulo introductorio y de resumen de memoria de tesis y cinco capítulos estructurados en formato de publicación científica. De forma adicional se incluye un anexo fotográfico para ilustrar el trabajo de campo realizado.

A este capítulo (**Capítulo 1**), le siguen los **Capítulos 2, 3, 4 ,5 y 6** que reproducen el contenido de artículos publicados, en revisión o encaminados hacia su publicación en diferentes revistas científicas, por lo que se presentan en inglés, con sus correspondientes secciones de introducción, material y métodos, resultados y discusión. Al inicio de cada capítulo se presenta el resumen del artículo traducido al castellano. Cada capítulo tiene su propia sección de referencias y el formato de las citas puede no ser concordante entre ellos.

A continuación se describe el contenido de los siguientes capítulos:

En el **Capítulo 2** (Muñiz-López, R., R. Limiñana, G.D. Cortés and V. Urios. 2012. Movements of Harpy Eagles *Harpya harpia* during their first two years after hatching. Bird Study 59 (3): 1-6) se describen por primera vez los movimientos águilas harpías silvestres durante sus primeros dos años de vida. Para ello se capturaron dos individuos y se equiparon con un transmisor de satélite con GPS y panel solar, obteniéndose posiciones geográficas para cada uno de ellos. Se evaluó cómo ocurría el distanciamiento al árbol del nido con el paso del tiempo y se compararon los dos casos para determinar diferencias en esta tendencia.

El **Capítulo 3** (Urios V., R. Muñiz-López and J. Vidal-Mateo. Harpy Eagle *Harpia harpyja* juvenile dispersion) complementa la información obtenida para los individuos equipados con emisores GPS del capítulo 2, analizándose cuándo ocurre el momento de dispersión juvenil y de qué manera progresó su distanciamiento del área natal. Además, se estudian las distancias horarias antes y después del comienzo de la dispersión y el área que ocuparon los juveniles durante su periodo de dispersión mientras el emisor se encontró en funcionamiento.

A lo largo del **Capítulo 4** (Muñiz-López R. Trophic ecology of the Harpy Eagle (*Harpia harpyja*) in Ecuador) se examinan los hábitos y preferencias alimenticias del águila harpía durante su periodo de cría, analizando su grado de especialización y la estrategia trófica que adopta en diferentes áreas de nidificación. Además se estudia la contribución de los parentales a la alimentación del juvenil a lo largo de su desarrollo y las preferencias de caza de los adultos según los hábitos de sus presas.

En el **Capítulo 5** (Muñiz-López R. & H. Alcántara. Harpy Eagle breeding habitat and nesting density estimation in Cuyabeno Wildlife Reserve, Ecuador) se analizan las características a nivel de paisaje de las áreas de cría de águila harpía en la región nororiental de Ecuador y se realiza una estimación de la densidad de nidos que puede existir en el área estudiada. Además, se genera un mapa que perfila la distribución potencial a nivel de país y se examina el grado de alteración por causas antrópicas que existe en las áreas en donde parejas de águila harpía pudieran estar criando. Asimismo se sugieren algunas acciones que pueden tomarse en cuenta para mejorar o mantener las condiciones idóneas de su hábitat.

En el **Capítulo 6** (Muñiz-López R. Harpy Eagle mortality in Ecuador) se analizan las causas de muerte registradas durante el periodo de estudio. Se recopilan los casos de individuos fallecidos tanto por muerte natural como por razones antropogénicas y se examinan los motivos que pudieron dar origen a cada una de ellas, señalando algunas recomendaciones para disminuir su mortalidad.

## 1.5. Área de estudio, resultados generales y discusión general.

La presente tesis recoge aspectos generales pero inéditos de la biología del águila de mayor tamaño del continente americano, el águila harpía (*Harpia harpyja*), realizando un recorrido por aspectos como su dispersión juvenil- desconocido en el mundo hasta la presente investigación-, ecología trófica, hábitat, densidad poblacional, mortalidad y recomendaciones para su conservación.

El estudio fue realizado en Ecuador (Mapa 1), principalmente en la Reserva Faunística Cuyabeno y su área de amortiguamiento, situada en la región amazónica al nororiente del país, y en un área dentro del territorio afroecuatoriano al noroccidente (Mapa 2).

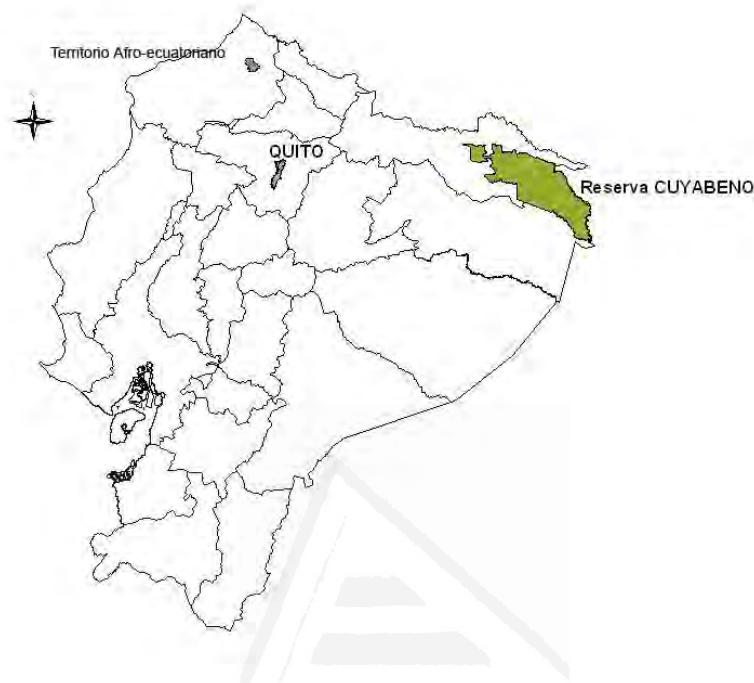
Mapa 1: Localización geográfica de Ecuador (área de color marrón) en el continente americano.



La Reserva Cuyabeno, localizada entre las provincias de Sucumbíos y Orellana, es fronteriza con Colombia y Perú, y se encuentra en la región amazónica ecuatoriana (Sierra *et al.* 1999), a una altitud entre 250 y 326 m s. n. m. (Cañas 1983), con una temperatura media entre 24,6 y 26,3 °C y una precipitación media de entre 2093,8 y 2728,2 mm al año (Cañas 1983). La riqueza biológica de esta reserva es extraordinaria, contando con la mayor densidad de especies arbóreas del mundo (Valencia *et al.* 1994). Cinco nacionalidades indígenas reparten sus territorios en esta área, conformando una amalgama cultural que caracteriza socialmente a la reserva (ICCA 2010).

En la región occidental, el área de estudio se concentró en la provincia de Esmeraldas, que forma parte de la región del Chocó ecuatoriano en donde existen bosques tropicales húmedos y muy húmedos (Sierra *et al.* 1999). La humedad relativa media supera el 90%, la temperatura media varía de 23 a 25 °C y la pluviosidad media anual comprende de 3.500 a 4.000 mm (Jahn 2011). Esta área contiene una rica biodiversidad, calculándose unas 830 especies de aves y unas 6.000 especies de plantas (Critical Ecosystem Partnership Fund 2001). Los habitantes de esta región corresponden a la cultura afroecuatoriana (Minda-Batallas 2002).

Mapa 2: Coloreadas de verde se muestra la localización del área de estudio en la Reserva Faunística Cuyabeno al oriente y territorio afroecuatoriano al occidente de Ecuador



La información de esta tesis proviene de los datos recogidos en las áreas de cría de águila harpía, localizados en colaboración con las comunidades locales y siguiendo sus rutas de cacería o pesca. Próximo a algunos de los nidos se armaron torres de observación de aproximadamente 28 – 30 m de altura para mejorar las condiciones de visibilidad, puesto que las plataformas de los nidos son construidas en árboles emergentes como ceibos (*Ceiba pentandra*) o cedrelingas (*Cedrelinga cateniformis*). Para obtener los datos de dispersión juvenil, dos águilas fueron capturadas y equipadas con emisores satélite con GPS de 70 g. El seguimiento se realizó hasta que los juveniles contaron con 27 y 39 meses de edad.

Según nuestros resultados, la dispersión juvenil del águila harpía no comienza hasta el mes 28 de edad, siendo uno de los períodos más largos de dependencia de los parentales que se conoce para aves rapaces. Su área de dispersión, que se calculó en 386 km<sup>2</sup>, y las distancias recorridas, 1,07 km/día como media llegando como máximo a 35,1 km del nido con 39 meses de edad, son menores que las observadas para otras especies de grandes águilas, probablemente debido a las condiciones de homogeneidad del hábitat que les ofrece el bosque tropical en el que se encuentran. Uno de los juveniles seguido a través del emisor satélite y que no se desplazó de su área de cría a

pesar de haber llegado el momento en el que era esperable que comenzase su dispersión, murió tras haberse observado que semanas antes era atacado por uno de los adultos. Es la primera vez que se advierte este comportamiento en el águila harpía, aunque ya ha sido reportado para otras especies, ya que la agresión hacia los juveniles favorece la independencia y el comienzo de la dispersión.

A pesar de que el águila harpía puede depredar sobre una variedad de especies, mayoritariamente mamíferos arborícolas, existe especialización en su dieta, prefiriendo monos (diversas especies) y perezosos (*Choloepus spp.* y *Bradypus variegatus*) como parte de su alimento. Las águilas harpías capturan preferiblemente animales que utilizan habitualmente el estrato más alto del bosque, y son los machos los que alimentan a su cría de forma más frecuente, entregando el alimento en la primera fracción del día y cada 3,8 días. Aunque en todos los nidos estudiados los perezosos siempre formaron parte de la dieta y fueron la presa más común, los monos podrían ser la presa preferida en condiciones de alta disponibilidad, como en áreas en donde no sufran presión de cacería por parte de humanos y su hábitat esté bien conservado.

No se encontraron diferencias en la tasa de aporte de alimento ni en el tipo de presas entregadas según las diferentes edades de los pollos, a pesar de que en algunos estudios con aves rapaces se observó que, a medida que las crías se desarrollan y sus necesidades energéticas aumentan, los padres aumentan su tasa de entrega de alimento o el tamaño de las presas que capturan. Nuestros datos pueden sugerir que en el área de estudio las águilas obtienen presas que exceden los requerimientos de los juveniles a lo largo de su periodo de cría, puesto que el peso y tamaño de las especies capturadas es, en general, considerablemente alto y suficiente para cubrir sus necesidades.

Todas las especies identificadas que formaron parte de la dieta del águila harpía están dentro de alguna categoría de amenaza, ya sea a nivel nacional, internacional o ambos, lo que supone que además de sus propias características biológicas, como la de criar un único pollo cada tres años, la pérdida de hábitat y la persecución humana, la estabilidad de las poblaciones de águila harpía se encuentra también amenazada porque los recursos de los que depende también lo están.

Se calculó que la distancia mínima entre nidos más cercanos es de  $4,9 \pm 0,7$  km, ocupando cada pareja un área de  $19,6 \pm 5,7$  km<sup>2</sup>, resultados parecidos a los obtenidos en Panamá, en donde las condiciones de conservación del hábitat son similares a las de Ecuador. En general, las especies tropicales poseen requerimientos territoriales menores que las de las regiones temperadas (Keran 1978), tal y como ocurre con las dimensiones

del área de cría reportadas para el águila real (*Aquila chrysaetos*), un águila de gran tamaño de la región temperada que requiere 285,7 km<sup>2</sup> por pareja (Carrete *et al.* 2001). Sin embargo, en hábitat alterados como los que ocupan algunas parejas de águila pitecófaga (*Pithecophaga jefferyi*) en Filipinas, los tamaños de territorio pueden ser mayores, puesto que si debido a la alteración del ambiente los recursos que necesita son más escasos, los territorios se conformarán por áreas más amplias (Bueser *et al.* 2003).

Aunque teóricamente pueden encontrarse áreas de cría al menos hasta los 1.200 m s. n. m., los nidos encontrados en nuestro estudio se ubicaron a  $219 \pm 11.7$  m s. n. m., ya que la altitud del área de estudio comprende altitudes entre 250 y 326 m s. n. m. A diferencia de Perú, en donde la mayor parte de los nidos que fueron identificados se hallaron en bosques de Tierra Firme (Giudice 2005), en este trabajo las áreas de cría se localizaron especialmente en bosques Inundables. Aunque en algunos estudios se ha encontrado que los bosques de Tierra Firme poseen mayor riqueza de especies que los anteriores (Balslev *et al.* 1987, Peres 1997, Patton *et al.* 2000, Haugaasen & Peres 2005 a, b), parece que la densidad y biomasa total tanto de primates como de perezosos es menor que en los bosques Inundables (Haugaasen & Peres 2005 a, b), por lo que éstos ofrecen condiciones favorables para que el águila pueda obtener suficientes recursos. Por otra parte, los nidos se encontraron en áreas de baja presión antrópica, aunque éste es un dato esperable debido a que el área de estudio se sitúa en un área protegida y sus alrededores inmediatos. Asentamientos indígenas se encontraron muy próximos a las áreas de cría, lo que sugiere que éstos mantienen sus territorios en condiciones que al menos son aceptables como para que no interfieran con las necesidades de cría del águila harpía. Así, la presencia de estas comunidades no es un factor desventajoso para esta especie, siempre y cuando no sufran de persecución humana.

El hábitat potencial disponible para el águila harpía en Ecuador se estimó en 77.849,86 km<sup>2</sup>. El rápido avance de monocultivos, de la frontera agrícola y de las consecuencias sociales y ambientales de la explotación de crudo en la Amazonía ecuatoriana pone en riesgo la estabilidad de las parejas de águila harpía que se encuentran en el límite del bosque. Sin embargo, si esto se controla, el futuro de las poblaciones de esta especie es alentador en esta región del país, pero ocurre lo contrario al occidente de la cordillera andina, en donde la fragmentación y pérdida de hábitat son mucho más evidentes.

Detectar individuos muertos de águila harpía es extremadamente complicado, especialmente si los ejemplares no cuentan con marcas de identificación o seguimiento, por lo que es fácil subestimar el número de estos eventos. La mortalidad de adultos registrada en este estudio (9,4%) fue menor que la mortalidad juvenil (28,6%) y, en todos los casos, debida a persecución humana. Miedo a la especie, consideración de depredadora de animales domésticos, uso de sus elementos corporales con motivos mágicos y venganzas personales fueron las razones detectadas para justificar los disparos que sufrieron los distintos ejemplares, entre los que se incluye un juvenil. Los conflictos antropogénicos juegan un papel importante en el declive de algunas poblaciones de rapaces (Raptor Research Foundation 2016), y está considerada como una de las causas de disminución de la especie estudiada (Vargas *et al.* 2006)

La mortalidad juvenil en este estudio es menor a la observada para 13 especies de aves rapaces europeas (Newton 1979), aunque no se conocen estudios que cuantifiquen este aspecto en este grupo y en la región Neotropical. El momento de aprendizaje del vuelo es un periodo crítico para la supervivencia de los juveniles, puesto que durante éste pueden ocurrir accidentes que provoquen su muerte. Tal y como también se observó en Venezuela (Álvarez-Cordero 1996), durante esta etapa, adoptan posturas que les desequilibran y, si no son capaces de corregirlas, pueden caer al estrato más bajo del bosque con el riesgo de quedarse atrapados en éste y no poder volver a ascender, tal y como probablemente ocurrió en cuatro de las seis muertes descubiertas.

Debe continuarse el seguimiento de adultos y juveniles para determinar con mayor certeza las principales causas de su muerte, ya que conocer cuáles son los elementos que afectan a su éxito reproductor es esencial para entender la dinámica poblacional de esta especie y, de esta manera, desarrollar estrategias de conservación más eficientes.

Los esfuerzos para conservar no solo al águila harpía, sino a la biodiversidad existente en el área donde se encuentra, deberían estar integrados con un desarrollo social y económico respetuoso con el ambiente y con las necesidades locales, haciendo partícipe a la población en los proyectos que se ejecutan en sus distintas etapas y ejerciendo control sobre la utilización de recursos naturales a través de incrementar la voluntad política para ello. La educación ambiental y la sensibilización tanto a nivel local como nacional son elementos necesarios e ineludibles para disminuir los conflictos gente-fauna y para obtener el apoyo social que requieren las acciones de conservación. El concepto de “Especie Bandera” puede ser una forma útil de aumentar el alcance e

interés de la población acerca de la importancia de conservar la biodiversidad, pudiéndose obtener resultados favorables para emprender acciones que la beneficien.

### **1.6. Conclusiones generales de la Tesis Doctoral.**

1. Se describen por primera vez los movimientos de juveniles de águila harpía utilizando telemetría vía satelital con GPS. Esta especie posee un prolongado periodo de dependencia juvenil que se extiende hasta al menos los dos años de edad, en donde sólo ocurren desplazamientos cortos dentro del territorio paterno sin evidenciarse tendencia dispersiva alguna.
2. Se estima en 28 meses la edad en la que un juvenil comienza su dispersión juvenil. Antes de este momento, las distancias que recorren son cortas y siempre dentro del área natal.
3. En sus movimientos exploratorios de dispersión, el juvenil recorre una distancia media de 1,07 km al día, llegando a alejarse como máximo 35,1 km de su área natal a los 35 meses de edad, mientras que para otras especies de águilas estas distancias son considerablemente mayores.
4. El águila harpía presenta hábitos tróficos especialistas aunque es capaz de predar sobre cierta diversidad de especies que habitualmente se encuentran en el estrato más alto del bosque. Durante el periodo de cría, los machos son los que más frecuentemente acuden con alimento al nido y ambos padres se presentan preferentemente por las mañanas y cada 3,8 días de media.
5. Los perezosos son las presas más seleccionadas por los adultos. Sin embargo, en áreas en donde existe menos presión de cacería de primates, los parentales aportan en los nidos más monos que perezosos pudiendo ser los primeros la presa preferida en condiciones de alta disponibilidad de este recurso.

6. Existen condiciones adecuadas para que el águila harpía establezca su área de cría desde 0 hasta al menos 1200 m s. n.m. en Ecuador siempre y cuando el bosque se encuentre en buen estado.
7. La densidad de áreas de cría de águila harpía en nuestra área de estudio es relativamente alta, estimando una densidad de 5 nidos/100 km<sup>2</sup> en esta región amazónica y, por el momento, de forma similar a la densidad existente en Panamá, aunque mayor información se requiere para el continente Suramericano.
8. Los bosques Inundables en buen estado ofrecen condiciones favorables para que sirvan como áreas de nidificación de águila harpía, siendo el tipo de bosque en donde más frecuentemente se localizaron los nidos en este estudio.
9. El éxito de cría de águila harpía puede ocurrir cerca de comunidades humanas que conservan sus territorios y no tienen conflictos con esta especie.
10. El futuro del águila harpía en la región oriental de Ecuador cuenta con buenas previsiones siempre y cuando se mantengan controladas las presiones de pérdida de hábitat que comienzan a afectar a esta parte del país. En la región occidental su situación se encuentra más comprometida debido a la desaparición de la mayor parte de su hábitat original. En total, estimamos 77.849,86 km<sup>2</sup> de hábitat potencial para esta especie en Ecuador.
11. Se detectó que la etapa juvenil es la de mayor mortalidad, superior a la del estado adulto y debida sobre todo a causas naturales. El momento de aprendizaje del vuelo es un periodo crítico para la supervivencia de los juveniles puesto que durante éste pueden ocurrir accidentes que provoquen su muerte.
12. Los casos registrados de mortalidad adulta se originaron por disparos a causa de temor hacia la especie, de su consideración como depredadora de animales domésticos, utilización de partes de su cuerpo como elementos mágicos y elemento con el que saldar venganza de conflictos intracomunitarios.

13. Las áreas de cría deben ser tenidas en cuenta en una estrategia de conservación no sólo durante el tiempo en el que el pollo se encuentra en el nido, sino al menos un año después de su nacimiento.
14. La educación ambiental y la sensibilización son acciones fundamentales para disminuir los casos de mortalidad no natural del águila harpía. Los casos de mortalidad juvenil debido a accidentes pueden reducirse con un monitoreo más acentuado durante esta etapa. Utilizar a esta especie como “Especie Bandera” puede favorecer el acercamiento a la sociedad de las consecuencias a las que se enfrenta la biodiversidad a causa de los problemas de conservación que existen en las diferentes áreas del país.
15. Comprender mejor las circunstancias, intereses, conflictos y cultura de las comunidades que conviven con los recursos naturales y aumentar su participación en todas las fases de desarrollo de las distintas iniciativas de conservación puede ser una estrategia útil para aumentar las posibilidades de alcanzar los objetivos de esas intervenciones.
16. Una mayor cantidad de estudios son necesarios para comprender la biología y las necesidades de esta especie y para poder concretar de la forma más adecuada posible los mecanismos apropiados para su conservación.

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**CAPÍTULO 2**

Juvenil de águila harpía en la Reserva Cuyabeno. Foto: R. Muñiz López

Los espíritus que protegen a los Cunsi Pindo:

El águila harpía (*Cunsi pindo* en lengua Aí o Cofán) suele criar en grandes árboles, uno de ellos el llamado Ceibo (*Ceiba pentandra*). Según los Cofanes, en cada Ceibo vive un espíritu, llamado “Atsatábahe Kukuya”, y cuando ese espíritu abandona su árbol éste comienza a marchitarse hasta morir. “El *Atsatábahe Kukuya* protege y mezquina al águila que esté criando sobre esta especie, impidiendo cualquier daño que los humanos pudieran hacerle. Así, cuando necesiten capturar un pichón de Águila harpía para colocarle su “mochila” (refiriéndose al transmisor satelital-GPS) necesitan pedir permiso al espíritu del Ceibo para que éste comprenda y autorice nuestra tarea” (Osvaldo Criollo, indígena Aí / Cofán, com. pers. 2005)



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## CAPÍTULO 2

### MOVIMIENTOS DE ÁGUILAS HARPIAS *Harpia harpyja* DURANTE LOS DOS PRIMEROS AÑOS DESDE SU NACIMIENTO

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Muñiz-López Ruth, Rubén Limiñana, Gonzalo D. Cortés and Vicente Urios. 2012. Movements of Harpy Eagles *Harpia harpyja* during their first two years after hatching. Bird Study 59 (3): 1-6.

#### Resumen

Dos águilas harpías juveniles fueron equipadas con transmisores satélite cuando se encontraban en sus nidos. Durante los dos primeros años los desplazamientos de ambas aves ocurrieron hasta distancias muy cortas, registrándose una distancia máxima de 1.3 km desde el nido. Durante el periodo de estudio, ninguna de las dos comenzó la dispersión juvenil pero en una de ellas se detectó un incremento en el distanciamiento medio mensual al nido con la edad, mientras que para el otro individuo esto no ocurrió. Proteger los territorios de los adultos de águila harpía puede favorecer así mismo la protección de los juveniles durante un largo periodo e tiempo.

## MOVEMENTS OF HARPY EAGLES *Harpia harpyja* DURING THEIR FIRST TWO YEARS AFTER HATCHING

RUTH MUÑIZ-LÓPEZ<sup>1,2</sup>, RUBÉN LIMIÑANA<sup>1,3</sup>, GONZALO D. CORTÉS<sup>4,5</sup> and VICENTE URIOS<sup>1</sup>

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This chapter reproduced entirely the text of the following manuscript:

Muñiz-López Ruth, Rubén Limiñana, Gonzalo D. Cortés and Vicente Urios. 2012.

Movements of Harpy Eagles *Harpia harpyja* during their first two years after hatching.  
Bird Study 59 (3): 1-6.

**Capsule:** Two juvenile Harpy Eagles were tagged at their nests with satellite transmitters. During the first two years after hatching both birds moved very short distances, with a maximum recorded distance of 1.3 km from the nest. During the study period, neither bird started juvenile dispersal, but while one of the birds showed a significant overall increase in mean monthly distance from nest with age, the other bird did not. Protecting territories of adult Harpy Eagles may enhance the protection of juveniles for a long period of time.

In large, long-lived raptors with delayed maturity, the period between fledgling and recruitment to the breeding population may take several years and is usually poorly understood (Whitfield et al. 2009). Juvenile dispersal represents the movements undertaken by juveniles, once they become independent from their parents, to find a breeding site (Clobert et al. 2001).

The onset of juvenile dispersal is not easy to detect and usually it has been more or less arbitrarily defined. Nevertheless, a simple and adequate approach to estimate the onset of dispersal considers that this stage of bird's life-cycle starts when juveniles abandon their parental territory (sometimes based on when juveniles reach the mid-distance between adjacent nests in the region and remain beyond that distance for a given period of time; e.g. Ferrer 1993, Soutullo et al. 2006a, Cadahía et al. 2008). The period between the first flights and the onset of juvenile dispersal is known as the post-fledgling dependency period, when juveniles are still dependent on their parents (e.g. Soutullo et al. 2006a). The fate of juvenile birds during these periods may have important consequences for population trends and, thus, they are of particular importance from a conservation point of view

(Ferrer 2001, Whitfield et al. 2004, Penteriani et al. 2006, 2011, Soutullo et al. 2008a). However, because of the difficulty of obtaining adequate data during these periods, little is known on the juvenile stage of most raptor species (Penteriani & Delgado 2009).

The Harpy Eagle *Harpia harpyja* is one of the largest raptors of the American continent, being distributed from southern Mexico to northern Argentina (Ferguson- Lees & Christie 2001). Currently, the species is threatened across its whole distribution range and population numbers are declining, mainly due to human persecution and habitat loss and fragmentation (Vargas et al. 2006, BirdLife International 2012). For this reason, the Harpy Eagle is globally listed as Near Threatened (BirdLife International 2012). In Ecuador (where this study was conducted) it is listed as Vulnerable (Granizo et al. 2002).

Although several aspects of its biology and ecology have been studied at several areas across its distribution range, such as Brazil (e.g. Galetti & de Carvalho Jr 2000, Lenz & Marajo dos Reis 2011), Ecuador (Muñiz-López 2007, 2008), Panama (e.g. Vargas & Vargas 2011), Peru (Piana 2007) and Venezuela (Álvarez-Cordero 1996), the Harpy Eagle is one of the least-known

raptor species of the world. Most of the information available on the species is related to diet and adult behaviour at their breeding areas (Rettig 1978, Álvarez-Cordero 1996, Muñiz-López 2008) and recently also on population genetics (Banhos et al. 2008, Lerner et al. 2009). The species feeds primarily on tree-dwelling mammals, particularly monkeys and sloths, as well as on large birds and reptiles (Fowler & Cope 1964, Rettig 1978, Álvarez-Cordero 1996, Galetti & de Carvalho Jr 2000, Piana 2007, Muñiz-López 2008, Springer et al. 2011).

The Harpy Eagle has probably the longest breeding period of any raptor, usually breeding once every two and a half or three years (Rettig 1978, Álvarez-Cordero 1996). According to the few studies conducted on this species, adult home-ranges are generally large, ranging between 16 and 79 km<sup>2</sup> (Álvarez-Cordero 1996, Muñiz-López 2007, Vargas & Vargas 2011).

Juvenile Harpy Eagles have rarely been monitored and the only data regarding their first movements suggest that fledgling occurs when birds are between 120 and 160 days old (Rettig 1978, Álvarez-Cordero 1996, Muñiz-López 2007). After that, juveniles are mostly inactive, making only short flights within the nest-tree or nearby

trees, and being fully dependent on parents in terms of feeding (Álvarez-Cordero 1996). Harpy Eagles are supposed to be in this post-fledgling dependency period for a long time (Álvarez-Cordero 1996), although no quantitative data to confirm this have been obtained to date.

In recent years, the use of satellite telemetry has become widespread and predominant in the study of migratory movements of several raptor species (e.g. Limiñana et al. 2007, 2012a,b, Strandberg et al. 2010, López-López et al. 2010, Mellone et al. 2011), as well as in detailed studies of juvenile dispersal and habitat use (e.g. Urios et al. 2007, Soutullo et al. 2008b, Cadahía et al. 2010). Here, we use GPS-satellite telemetry to describe the movements of two freeranging juvenile female Harpy Eagles in Ecuador during the first two years after hatching.

This study was conducted within the reserve ‘Reserva de Producción Faunística Cuyabeno (-0.117° N, -75.833°E, northeastern Ecuador). This reserve is dominated by rainforest, although habitats range from evergreen forests to flooded lowlands (Cerón et al. 1999, Palacios et al. 1999). There, two juvenile Harpy Eagles (‘Masakay’ and ‘Tava’) were trapped at their nests. ‘Masakay’ was tagged on 15 July 2006

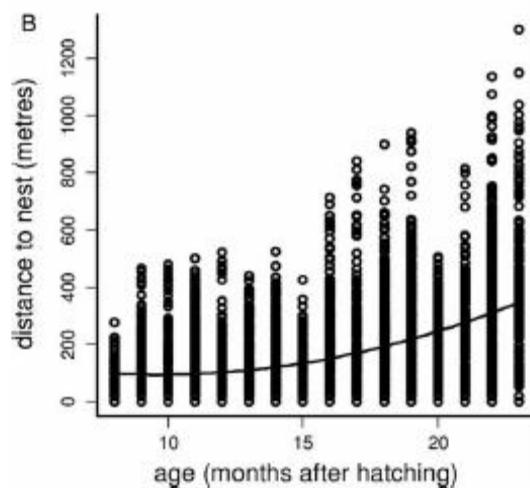
in its third month after hatching, and ‘Tava’ on 28 March 2009 in its seventh month after hatching. Age of birds at tagging was known because the nests were monitored before the eggs hatched by Cofanes natives, who collaborated in the project and recorded hatching date.

Both birds were sexed as females by means of body size and weight measures, according to reference values for juveniles in del Hoyo et al. (1994). Eagles were tagged with 70-g Argos/GPS satellite transmitters (Microwave Telemetry Inc.), which were affixed to their backs using a Teflon harness. The full transmitter equipment did not exceed 1.5% of the juveniles’ body mass, which is considerably below the 3% suggested to minimize the effects of additional mass on birds’ movements (Kenward 2001). Satellite transmitters were programmed to record one GPS position (nominal accuracy + 18 m) every hour between 09:00 and 03:00 for ‘Masakay’ and between 11:00 and 03:00 for ‘Tava’ (local time). Data were recorded until both individuals reached the age of two years (i.e. the last day of their 23rd month after hatching, taking into account age of birds at tagging). For both birds, we excluded data from the tagging month from the analyses, because it was only partially recorded.

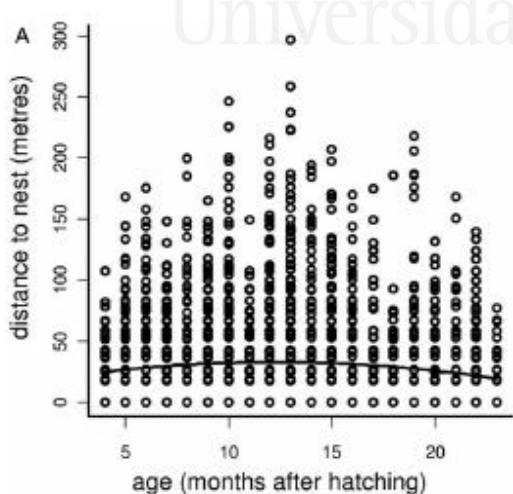
During the study period, a total of 7170 GPS locations were obtained for ‘Masakay’ and 6337 for ‘Tava’.

Locations were transformed from Geographic Coordinate System to UTM coordinates for calculations. For each individual, we calculated the loxodromic distance from every recorded position to its nest. We evaluated the relationship between the distance to nest and age of birds (months after hatching) using linear and quadratic regression analysis (distance to the nest ~ bird age  $\times$  bird identity + bird age squared  $\times$  bird identity). Since these initial models presented heterogeneity of variances, we then conducted Generalized Least Square (GLS) regression models to overcome this analytical issue (Pinheiro & Bates 2000, Zuur et al. 2010). Therefore, considering the possible existence of proportional or potential structures of variances and also considering that different variance structures could emerge for each bird, these alternative variance structures were evaluated for each one of the independent variables (Zuur et al. 2009). In order to find the optimal variance structure we computed the same model using different variance structures and compared each GLS model using Akaike’s Information Criterion (AIC) (Burnham & Anderson

2002, Zuur et al. 2009). All these models were fitted with the `gls` function from the NLME package (Pinheiro et al. 2011) for R software (R Development Core Team 2011). When doing this, the best model (lowest AIC value) was the one that included the second-order polynomic variable ( $\text{distance to nest} \sim \text{bird age} \times \text{bird identity} + \text{bird age squared} \times \text{bird identity}$ ) and included a power variance structure ( $\text{varPower} \sim \text{bird age} | \text{bird identity}$ , in R), thus taking into account differences in monthly spread of data for each bird. As interactions in this model were significant ( $P < 0.001$  in all cases), these results show that during the study period the two tracked juvenile eagles exhibited significantly different behaviours.



**Figure 1. Movements of two Harpy Eagles (A: ‘Masakay’ and B: ‘Tava’), tracked by satellite telemetry during two years after hatching. Open dots represent every recorded distance to nest forevery month within this two-year period. The line represents the quadratic model that better described the movements of both eagles in the study period (see text for details and parameter estimates).**



To deconstruct the movements pattern of each individual, we conducted GLS models separately to test if distance to nest showed a linear or quadratic trend for each individual ( $\text{distance to nest} \sim \text{bird age} + \text{bird age squared}$ ), also accounting for the observed heterogeneity of variances. The best individual GLS models (according to AIC) included the age squared term, but a different variance structure. The selected model for

‘Masakay’ included a power variance structure of the quadratic covariate ( $\text{varPower} \sim \text{bird age} + \text{squared bird age}$ , in R) (parameter estimates: intercept = 16.1,  $P < 0.001$ ; age = 2.7,  $P < 0.001$ ; age squared = -0.1,  $P < 0.001$ ). The selected model for ‘Tava’ included a variance structure proportional to the quadratic covariate ( $\text{varFixed} \sim \text{bird age} + \text{squared bird age}$ , in R) (parameter estimates: intercept = 110.0,  $P < 0.001$ ; age = -10.6,  $P < 0.001$ ; age squared= 0.8,  $P < 0.001$ ). These differences in parameter estimates revealed different individual trends in distance to nest during the study period (Fig. 1).

Whereas ‘Tava’ showed an overall increasing trend in its monthly distances to nest, ‘Masakay’ first showed a slight increase in distances from the nest but then it began to reduce the extent of its movements from the nest, spending more time closer to the nest (Fig. 1).

During the study period, maximum distance to the nest achieved by ‘Tava’ was 1300 m when it was 23 months old, whereas for ‘Masakay’ this maximum distance was 296 m at the age of 13 months (Fig. 1).

Juvenile dispersal is the ecological process that leads juvenile birds to find a site for breeding (Clobert et al. 2001). In large bird species with delayed maturity and relatively large home-

ranges and breeding territories, this process may take several years until a breeding territory is occupied (e.g. Urios et al. 2007, Cadahía et al. 2009, Whitfield et al. 2009). Given the extent of the adult home-ranges in the Harpy Eagle, ranging between 14 and 79 km<sup>2</sup> (Álvarez-Cordero 1996, Vargas & Vargas 2011), and considering the movements reported here, it is clear that none of the tracked juveniles left the parental territory during the study period. Therefore, the onset of the juvenile dispersal in the species does not take place within the first two years after hatching, and the stage of life reported here corresponds to the post-fledgling dependence period (Soutullo et al. 2006a, Cadahía et al. 2008).

Similar results for the Harpy Eagle were found by Álvarez- Cordero (1996), who reported distances to the nest of 300–600 m for juveniles 2 years old; however, the data of Álvarez-Cordero (1996) are based on direct observations, which, in the closed-canopy forests where Harpy Eagles live, may have precluded getting observations at larger distances from nest.

The individual eagles showed a different behaviour during the study period. ‘Tava’ showed a progressive distancing from nest during the study period, while ‘Masakay’ first showed a

distancing from nest but then began to spend more time near the nest (see Fig. 1).

Progressive distancing from the nest during the post-fledgling dependency period is common in several large raptors (e.g. O'Toole et al. 1999, Soutullo et al. 2006a,b, Cadahía et al. 2008). However, during this dependency period, juvenile birds are mostly fed by parents, which may explain the constant return of both birds to their nests observed here. However, during this period, juvenile raptors also make their first hunting attempts within parental territories (e.g. Ferrer 1993, Kitowski 2009), and this has been also observed for Harpy Eagles (Muñiz-López 2007). Therefore, differences in prey abundance or availability in the areas used by these Harpy Eagles may explain, at least partially, the different behaviour of these individuals, with the eagle moving closer to its nest possibly being in a less-productive area.

Large, tropical birds usually show reduced clutch sizes and long breeding seasons due to the relative environmental stability of their habitats (Russell & Rowley 2000). As a consequence of the reduced brood size, parental care is usually longer and juveniles spend more time at the parental territory to enhance their

survival probability (Skutch 1976) or to be in better condition at the onset of dispersal (Young 1996).

Age of first reproduction for Harpy Eagles breeding in captivity has been estimated as 4 years; however, taking into account that the onset of juvenile dispersal for freeranging individuals in undisturbed environments takes place at ages older than 2 years, age of first reproduction in the wild is likely to take place at ages probably much older than 4 years (see also Shaner 2011), which would represent one of the longest dispersal periods among raptors. However, as Harpy Eagles live in habitats that are largely homogeneous and undisturbed, there may be little need to cover very large distances to find a breeding site, contrary to other species in temperate heterogeneous habitats (e.g. Urios et al. 2007, Cadahía et al. 2009, Whitfield et al. 2009), which would reduce the overall time spent dispersing.

Future tracking studies of individuals should focus on these aspects, because this floating period of large raptors is of great importance from a conservation point of view (Penteriani et al. 2006, 2011, Soutullo et al. 2008a).

Our results and conclusions are limited because of the small sample size that is often associated with such

satellite-tracking studies. However, this approach has the advantage of obtaining spatially explicit information about raptors' movements, which is of great importance from a conservation point of view, even if only a few birds are tracked (e.g. Urios et al. 2010). In the case of the Harpy Eagle, this is exacerbated by the secretive nature of the species, the difficulties in finding their nests, as well as carrying out the fieldwork in remote dense forests.

Results presented here indicate that territories occupied by adults are also important for juvenile birds for at least 2 years after hatching. Therefore, conservation actions at these areas should not only be focused during the pre-fledgling period, but also throughout the year, given that the juveniles are actively using the same areas used by parents for a long time. Juvenile survival is one of the most important parameters determining population trends in long-lived raptors (Soutullo et al. 2008a). Hence, protecting these adult territories would also not only directly affect adult survival but also juvenile survival, which would be of paramount importance for conservation of the Harpy Eagle.

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## CAPÍTULO 3



“Tava”, hembra juvenil de Águila harpía que fue equipada con emisor satélite. Foto: A. Blanco /PCAHE-SIMBIOE

*Águila que va volando, no dice a dónde... ni cuándo.*

Anónimo



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## CAPÍTULO 3

### DISPERSIÓN JUVENIL DEL ÁGUILA HARPÍA *Harpia harpyja*

VICENTE URIOS, RUTH MUÑIZ-LÓPEZ & JAVIER VIDAL-MATEO

**Palabras clave:** rapaces, telemetría satélite, ecología del movimiento, agresión parental.

#### Resumen

Los movimientos de dos águilas harpía juveniles antes y durante el periodo de dispersión son estudiados mediante telemetría satelital GPS. Una de las harpías comienza la dispersión durante el mes 28 de edad, mientras que la otra en esas fechas permanece en las cercanías del nido y fallece a los 30 meses de edad. El juvenil que se dispersa se aleja un máximo de 35.1 km durante el periodo de estudio y ocupa un área de 386 km<sup>2</sup> según kernel fijo del 95%.

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**JUVENILE DISPERSAL OF HARPY EAGLE *Harpia harpyja***

VICENTE URIOS, RUTH MUÑIZ-LÓPEZ & JAVIER VIDAL-MATEO

**Key words:** raptors, satellite telemetry, movement ecology, parental aggression.

**Capsule:** Movements of two juvenile Harpy Eagles before and during the dispersal period were studied by GPS satellite telemetry. One of the eagles started the dispersal during the month 28 of life, while on the same dates the other juvenile remained in the surrounding area of the nest, suffering parental attacks that might cause its death.

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The Harpy Eagle *Harpia harpyja* is one of the largest and heaviest birds of prey in the world (Brown & Amadon 1968). This species usually lives in lowland rainforests, with a distribution range from southern Mexico to northern Argentina discontinuously (Ferguson-Lees & Christie 2001).

Due to habitat loss and human persecution, the populations of this eagle are declining (Alvarez-Cordero 1996, Vargas *et al.* 2006, BirdLife International 2016). Its long breeding interval, not studied in depth and estimated between two and a half and three years (Rettig 1978, Álvarez-Cordero 1996), makes it even more vulnerable. Currently, for these reasons, it is considered a Near Threatened species by the International Union for Conservation of Nature and Natural Resources (IUCN 2013), and in Ecuador it is included within the category Vulnerable (Granizo *et al.* 1997).

Different aspects of the biology of the Harpy Eagle have been studied, as its trophic ecology (Piana 2007, Lenz & Marajó dos Reis 2011, Aguiar-Silva *et al.* 2014) or its breeding behaviour (Rettig 1978, Álvarez-Cordero 1996, Muñiz-López 2007, Rotenberg *et al.* 2012). However, due to the difficulty of observation of this species, its

movement ecology is still poorly known (Muñiz-López *et al.* 2012), in particular its juvenile dispersal period. Juvenile dispersal comprises the movements undertaken by juveniles in their search for a breeding area once they are independent from their parents (Greenwood & Harvey 1982, Clobert *et al.* 2001). In large raptors this process may take several years (Cadahía *et al.* 2009, Whitfield *et al.* 2009), and it is preceded by a period of parental dependence called post-fledging period. This post-fledging period takes place from the first flights of the bird until the onset of the dispersal (Soutullo *et al.* 2006). The onset of dispersal period is not easy to detect, and it has been seen that it can be influenced by a reduction of the parental investment in their offspring (e.g. decreasing the food supply), even with presence of parent-offspring aggressions (Alonso *et al.* 1987) or between siblings (Holleback 1974).

Here we study the movements before and during the dispersal period of two juveniles Harpy Eagles tracked by GPS satellite telemetry.

Two juvenile female Harpy Eagles were trapped and tagged: ‘Masakay’ (# 49178) and ‘Tava’ (# 48179). Both eagles were tagged at their nest tree (for more details of the capture see Muñiz-

López *et al.* 2012), in the ‘Reserva de Producción Faunística Cuyabeno’ (Sucumbíos province, northeastern Ecuador). Located in the Amazon region of Ecuador, this is one of the most biodiverse places on the planet, dominated by primary lowland tropical moist forest between 250 and 300 m, and flooded tropical evergreen forests (Cañas 1983, Stotz *et al.* 1996, Cerón *et al.* 1999, Palacios *et al.* 1999).

Eagles were tagged with 70 g Argos/GPS satellite transmitters (Microwave Telemetry Inc.), which were affixed to their backs using a Teflon harness. This equipment did not exceed 1.5% of body mass, which is within the recommended limits (Kenward 2001). One GPS position (nominal accuracy  $\pm$  18 m) was recorded every hour between 09:00 and 03:00 (local time) for ‘Masakay’ and between 11:00 and 03:00 for ‘Tava’. ‘Masakay’ was tagged on 15 July 2006 in its third month of age, and ‘Tava’ on 28 March 2009 in its seventh month of age. In addition, in collaboration with the natives of nationality A'i / Cofan, an observation tower 30 m high was built, which allowed also take visual records of the eagles.

Muñiz-López *et al.* (2012) described the movements of these two

Harpy Eagles until they reached the age of two years. In this study we track their movements since that date (first day of the 24th month of age) onwards: in ‘Masakay’ until month 27 and month 39 in ‘Tava’ (4 and 15 months of tracking respectively).

During the months of study, a total of 1320 locations for ‘Masakay’ and 3761 for ‘Tava’ were received. Data were retrieved and managed by Satellite Tracking and Analysis Tools (STAT; Coyne & Godley 2005). The distances covered every day for each eagle were calculated, selecting a location per day and trying to approach as much as possible to midnight. We also calculate the distance to the nest from every recorded position.

Using the Mann-Whitney U test, we evaluated the differences in these daily distances and distances to nest between ‘Masakay’ and ‘Tava’ during the months that data are available for both birds. In the case of ‘Tava’ we also analyzed the differences between the daily distances before the onset of dispersal when he was in the natal area, and the distances covered once started the dispersal period. Daily distances calculated between non-consecutive days (for lack of data) were excluded from the analysis.

In addition, with all obtained GPS locations, we estimated the hourly distances as the straight distance between two locations corresponding to consecutive hours. These distances could be calculated between 09:00 and 3:00 hours (local time), the time period in which the locations were obtained. We used the Kruskal-Wallis test to examine whether there were differences in the hourly distances according to the time throughout the day, and the multiple comparison Games-Howell test to check whether there was any peak of activity.

All statistical analyses were performed with IBM SPSS Statistics ver. 22.0. Significance level was established at  $P < 0.05$ .

We estimated the home-range of both Harpy Eagles during the period in the natal area and during the dispersal period using a fixed kernel approach (Worton 1989), including all GPS locations. We calculated the 95%, 75% y 50% fixed kernels using the Animal Movement extension for ArcView 3.2 (Hooge & Eichenlaub 1997).

We used the least squares cross validation (LSCV) procedure to calculate the smoothing parameter H (Silverman 1986). To estimate the real size of home-ranges we transform the kernel polygons in geographic

coordinates to an Equal-Area Cylindrical projection using the Projector! Extension for ArcView 3.2. We also calculated the Minimum Convex Polygon (MCP) encompassing all the locations obtained for the different periods (post-fledging and dispersal period), performing the same transformation as for the kernel analyses.

The individual eagles showed a different behaviour. ‘Tava’ remained in the natal area until the beginning of the month 28 of age: on 6 December 2010 began to move away from the nest towards the North and started its juvenile dispersal (Fig. 1). All available GPS data of ‘Masakay’ (from month 24 of age to 27) were located in the natal area, without leaving it. Coinciding with the second month of dispersal of ‘Tava’, ‘Masakay’ in the middle of the month 29 of age begins to suffer attacks by one of the parents, presumably the male, as we became aware thanks to the visual observations carried out from the tower. These attacks consisted in quick flights showing the claws and approaching the juvenile who was perched on the branch of a tree adjacent to the nest tree. ‘Masakay’ was found dead on the next month (October 2008) a few meters from the nest tree. Furthermore, the daily distances covered by ‘Tava’ and

'Masakay' during the months for which data are available for both birds (in their natal area) were significantly different ( $Z = -10.72, P < 0.000$ ), making shorter displacements 'Masakay': 0.03 km on average ( $\pm$  sd) compared to 0.48 km of 'Tava'. In the same way it happens with the distances to the nest measured for each day ( $Z = -34.29, P < 0.000$ ): 'Masakay' moved away an average distance of 0.03 km and 'Tava' 0.35 km before the onset of the dispersal (their maximum distance were 0.24 and 2.2 km respectively; Fig. 2).

In the case of 'Tava', the daily distances covered before and after the onset of the dispersal were significantly different ( $Z = -8.72, P < 0.000$ ), with an average of 0.48 ( $\pm 0.46$ ) km while the eagle remained in the natal area and 1.47 ( $\pm 0.90$ ) km during the dispersal. The maximum daily distance recorded was close to 4 km, although during the dispersal period it was less than 2 km in most cases (69.03%). Only in 3.87% of the daily segments, the distance exceeded 3 km. During the study period 'Tava' moves away from the nest a maximum of 35'1 km (in the 35th month of age; Fig. 2).

The hourly distances were only calculated for 'Tava' because 'Masakay' remained static most of the time making only short displacements.

The hourly distances changed significantly throughout the day ( $\chi^2 = 65.61, df = 11, P < 0.000$ ), although there was no a prominent peak of activity, moving on average 0.11 ( $\pm 0.14$ ) km/h. The maximum distance recorded in one hour was 0.99 km, although in 95% of the hourly movements it was below 0.42 km. There was activity during all daylight hours.

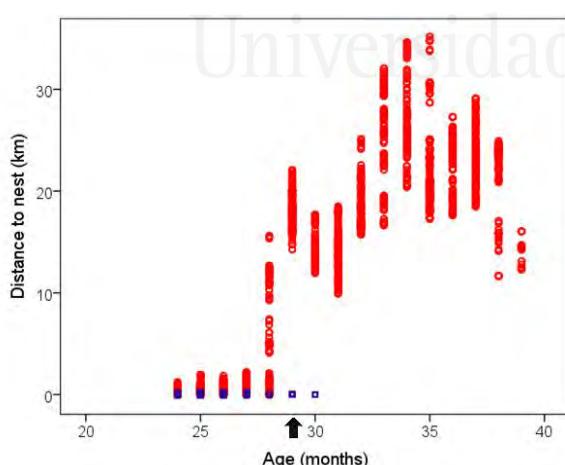
During the time that 'Tava' remained in the natal area (zone A in Fig. 1), it occupied an area of 0.387 km<sup>2</sup> according to 95% fixed kernel (0.071 and 0.031 km<sup>2</sup> for 75% and 50% kernels respectively, and 6.064 km<sup>2</sup> for MCP). The estimated area during the eleven months of dispersal (zone B in Fig. 1) that have been studied was 386 km<sup>2</sup> according to 95% fixed kernel (137 and 42 km<sup>2</sup> for 75% y 50% kernels, and 579 km<sup>2</sup> for MCP). The 95% kernel for 'Masakay' encompassed 2783 m<sup>2</sup> (793 and 370 m<sup>2</sup> for 75% and 50% kernels, and 0.112 km<sup>2</sup> for MCP).

The Harpy Eagle presents the highest record of permanence in the natal area and duration of post-fledging dependence period between raptors together with the Philippine Eagle *Pithecophaga jefferyi* (del Hoyo *et al.* 1994, Álvarez-Cordero 1996, Muñiz-López *et al.* 2012). According to our

data, although we only based on tracking of two individuals, the Harpy Eagle begins its juvenile dispersal period and left its natal area around the 28th month of life.

This age is greater than that has been seen in other eagles in which was studied the end of the post-fledging dependence period (Wood *et al.* 1998, Soutullo *et al.* 2006a, Cadahía *et al.* 2008). There is a coincidence between the onset of the dispersal of ‘Tava’ and the aggressive behaviour by one of the adults that the other juvenile suffers. On the same dates as ‘Tava’ began to disperse, ‘Masakay’ remained in the surrounding area of the nest making shorter displacements (Fig. 2).

**Figure 2:**



In our view, for this reason, possibly it suffered the parental attacks that might cause the death. Although it

is not common in all raptors (Bustamante & Hiraldo 1990, Bustamante 1994, Boileau & Bretagnolle 2014), parental aggression toward the juveniles has been observed in other species (Alonso *et al.* 1987). This conflict between adults and offspring (Trivers 1974), promoted by parents that reduce the food supply or increase their aggressive behaviour toward juveniles, favours the independence and the onset of the dispersal (Hiraldo *et al.* 1989, Arroyo *et al.* 2002, Balbontín & Ferrer 2005).

Once initiated the dispersal, ‘Tava’ remained north of the natal area and exploring the territory without stopping permanently in any zone. At 39 months old, the transmitter stops emitting signal, but it is likely to continue these movements until establishing in a breeding territory and incorporating into the breeding population, a process that could take several years (Urios *et al.* 2007, Cadahía *et al.* 2009, Whitfield *et al.* 2009).

Although the studies on juvenile dispersal for large forest eagles are scarce, estimated dispersal area and the distances covered in the first months after the start of the dispersal are lower than in other species. For instance, Golden Eagle *Aquila chrysaetos* (Haller 1994, Soutullo *et al.* 2006b), Spanish

Imperial Eagle *Aquila adalberti* (González *et al.* 1989, Muriel *et al.* 2015), Bonelli's Eagle *Aquila fasciata* (Cadahía *et al.* 2005, 2010) or Crowned Eagle *Harpyialeatus coronatus* (Urios *et al.* 2014) reach hundreds of km away from the nest and explore large areas before occupying a territory.

These differences could be due to the homogeneity of the habitat that occupies the Harpy Eagle (Muñiz-López 2008) and allows it to have a suitable conditions and sufficient availability of preys in a smaller surface than in the more heterogeneous habitats in which these eagles live. Abaño *et al.* (2015) also reported larger movements for the Philippine Eagle *Pithecophaga jefferyi*, a species similar to Harpy Eagle in size and biology (del Hoyo *et al.* 1994). However, the results are not comparable because they involved released individuals. The New Guinea Harpy Eagle *Harpyopsis novaeguineae*, smaller in size, inhabits tropical forests of great homogeneity where it has been seen that also occupies relatively small areas of territory, of several tens of km<sup>2</sup> (Watson & Asoyama 2001).

There are no quantitative data for other large forest eagles, as the Crested Eagle *Morphnus guianensis* and the African Crowned Eagle *Stephanoaetus coronatus*.

Although in the future it will be necessary to conduct more studies of the dispersal of other juvenile Harpy Eagles and improve the knowledge of their movements, important implications for the conservation of this species can be discerned from our results. The reduced clutch size and long breeding period (Rettig 1978), together with the long post-fledging and dispersal period underline the importance of directing conservation plans not only to adults but also to juveniles. Therefore, understanding the movements of juvenile dispersal, a period with relevant demographic consequences, can be of great importance for the conservation of the species (Clobert *et al.* 2001, Soutullo *et al.* 2008, Penteriani *et al.* 2011).

The long period spent in the nesting area and the dispersal movement located not far away from it, facilitate the delimitation of areas for protection of the Harpy Eagle.

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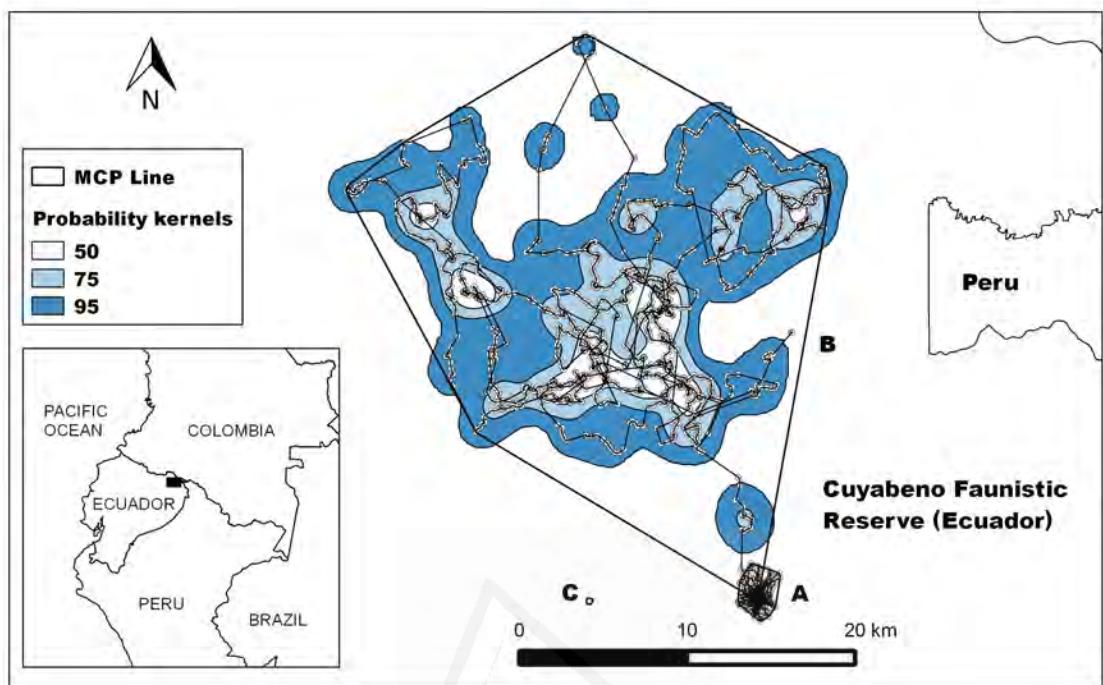
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**Figure 1:**

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## CAPÍTULO 4



Juvenil de águila harpía alimentándose en la plataforma del nido.

Foto: P. Oxford/PCAHE-SIMBIOE

*“Uno de nuestros principales símbolos venerados es ‘kenguiwe’. Ella es admirada por nosotros tanto por ser majestuosa y avisarnos cuando hay peligro, como por tener extraordinaria habilidad para cazar a través de su fuerza, velocidad y astucia”.*

Manuela Omari Ima Omene, indígena Huaorani de Ecuador\*.

\* Ima Omene M.O. 2012. Saberes Waorani y Parque Nacional Yasuní: plantas, salud y bienestar en la Amazonía del Ecuador. Iniciativa Yasuní ITT. Ministerio Coordinador de Patrimonio, Ministerio del Ambiente, Programa de las Naciones Unidas para el Desarrollo (PNUD) y Fondo para el Medio Ambiente Mundial (FMAM). Quito. Ecuador. 118 pp.



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## Capítulo 4

### ECOLOGÍA TRÓFICA DEL ÁGUILA HARPÍA (*Harpia harpyja*) EN ECUADOR.

RUTH MUÑIZ-LÓPEZ

#### Resumen

Se analizó el aporte de presas en siete nidos de águila harpía (*Harpia harpyja*) en el noreste y el noroeste de Ecuador entre 2002 y 2010. Se encontraron al menos 18 especies diferentes pero índices de diversidad relativamente bajos en cada muestra. El índice de nicho trófico fue relativamente bajo ( $B_{sta} = 0.28$ ) lo que denota especialización en la dieta del águila. Los machos entregaron presas más frecuentemente que las hembras y ambos prefirieron cazar especies ubicadas en el estrato más alto del bosque. El perezoso de dos uñas (*Choloepus spp.*) fue la especie que más contribuyó a la dieta del águila harpía estando presente en todas las muestras. El peso medio de las especies aportadas fue de 4.01 kg. El grupo taxonómico de las presas aportadas y la frecuencia de entregas no fueron diferentes a lo largo de las distintas edades de los pollos, ocurriendo preferentemente entre las 7:00 y las 10:00 am. Todas las especies que forman el espectro de la dieta del águila se encuentran en alguna categoría de amenaza.

**Palabras clave:** Águila harpía, dieta, Ecuador, *Harpia harpyja*, nido.

**TROPHIC ECOLOGY OF THE HARPY EAGLE (*Harpia harpyja*) IN  
ECUADOR****RUTH MUÑIZ-LÓPEZ**

**Capsule:** We examined prey delivered to seven Harpy eagle (*Harpia harpyja*) nests in northeast and northwest Ecuador between 2002 and 2010. At least 18 different species were found but a relatively low diversity indexes were detected in every sample. For our study area we found a relatively low niche breath ( $B_{sta} = 0.28$ ) that means diet specialization. Males delivered more prey to the nests than females and both preferred species that were located at the highest forest stratum. Two-toed sloth (*Choloepus* spp.) was the species that contributed most to the Harpy eagle diet and it was always present in all the samples. The mean adult weight of the prey species delivered was 4.01 kg. The taxonomic group of prey provided and the frequency of deliveries were similar for all juvenile age classes and prey delivery occurred preferably between 07:00 to 10:00 H. We determined that all the species delivered were found under some degree of threat or conservation pressure at a national level and all but one at an international level.

**Key words:** Diet, Ecuador, *Harpia harpyja*, Harpy eagle, nest.

## Introduction

The Harpy eagle (*Harpia harpyja*) is considered one of the most powerful birds of prey in the world, as well as one of the largest (Brown and Amadon 1968, Collar 1989). It formerly inhabited tropical and subtropical rainforest to about 900 m (Stotz *et al.* 1996) from southern Mexico to northern Argentina (Hilty and Brown 1986). In Ecuador, the species distribution is restricted to several small patches of forest in the northwest of the country and more consistently with an elevation range below 400 m a.s.l. in the east, where Ecuadorian Amazon Basin starts (Guerrero 1997, Ridgely and Greenfield 2001, Muñiz-López 2002). The Harpy eagle is currently considered Near-threatened throughout its range (Collar *et al.* 1994, Birdlife International 2013). In Ecuador it is believed to be a Vulnerable species (Granizo *et al.* 1997).

Harpy eagles breed every 2.5 to 3 yr and the resulting offspring, usually one per pair, remains in the natal area for at least two years before dispersing (Rettig 1978, Ruschi 1979, Álvarez-Cordero 1996). The first active nest of a Harpy eagle to be monitored in Ecuador was found in 2002 in the northeast

(Muñiz-López 2003). Since then, fifteen more nests have been found in the Ecuadorian Amazon Basin, but only six of them have been monitored to collect data for this study. One additional nest was discovered at the west of the country and this was the only one found in that area during this study.

In some of its distribution area there are few published records about diet of this species and most of them are based upon sporadic observations of Harpy eagle hunting attempts in the field or descriptions of provisioning behaviour to nests: British Guiana (Fowler and Cope 1964, Rettig 1978, Izor 1985), Peru (Eason 1989, Sherman 1991, Piana 2007), Brazil (Peres 1990, Galetti *et al.* 1997, Ferrari and Port-Carvalho 2003), Venezuela (Álvarez-Cordero 1996), Panama (Álvarez-Cordero 1996, Touchton *et al.* 2002, Aparicio 2003) and Belize (Rotenberg *et al.* 2012). There is a more comprehensive study that analyzes the Harpy eagle food habits in Brazil (Aguiar-Silva *et al.* 2014). One study examined captive-bred and released Harpy eagles diet and hunting (Touchton *et al.* 2002; Muela and Curti 2005). All these studies show that this eagle feed mainly on arboreal mammals such as sloths, monkeys, rodents, carnivores and less frequently

on reptiles and birds (Fowler and Cope 1964, Rettig 1978, Eason 1989, Álvarez-Cordero 1996, Sanaiotti *et al.* 2001, Touchton *et al.* 2002, Ferrari and Port-Carvalho 2003, Muñiz-López 2007, Piana 2007, Rotenberg *et al.* 2012 and Aguiar-Silva *et al.* 2014).

Here I present the first study of the Harpy eagle trophic ecology of Ecuador.

### Study area

This study was conducted in two different regions, one at the east and one at the west of Ecuador. The Cuyabeno Faunistic Reserve is located in the eastern region of the country and it belongs to Sucumbíos and Orellana provinces, close to Colombia and Peru borders. This reserve has 590,112 hectares (Ministerio del Ambiente 2012) that means about 1% of the country's land area. Five indigenous groups live and use natural resources for hunting and cultivating familiar properties, but overall the human density is low (0.002 inhabitans per hectare; ICCA Consortium 2010). The area is dominated by primary lowland tropical moist forest between 250 and 326 m a. s. l. (Cañas 1983), and flooded tropical evergreen forests (Stotz *et al.* 1996, Cerón *et al.* 1999, Palacios

*et al.* 1999). The temperature averages 25°C and environmental moisture is 96-100%; annual rainfall fluctuates between 2,000 to 4,000 mm (Cañas 1983). There is a distinct dry season from December to March, a rainy season from April to July and an intermediate season from August to November (Cañas 1983) but the dry season does not occur in some years (Geenen *et al.* 2000). Biodiversity level is high in the Reserve, including around 490 species of birds, 165 of mammals (10 of them are primates), and around 470 plant species per hectare (Geenen *et al.* 2000).

At the western region of the country the study was concentrated in the Esmeraldas Province. This province lies in the Chocó biogeographic region which includes western Ecuador, southeast of Panama, western Colombia and Ecuador down to the northwest of Peru (Critical Ecosystem Partnership Fund 2001). Relative humidity is more than 90% on average, mean temperature ranges 23 to 25°C and mean annual rainfall varies between 3,500 to 4,000 mm/year (Jahn 2011). Annual rainfall is unimodal, with a dry season from May to November and a rainy season from December to April (Neil and Möller-Jorgensen 1999). The study area belongs to the "Cayapas-Santiago-

Wimbi" Important Bird Area that encompasses 60,000 hectares of humid and very humid tropical forest (BirdLife International 2015). It is calculated that this area contains about 6,000 species of vascular plants, 830 of birds and 142 mammal species (Critical Ecosystem Partnership Fund 2001). It also includes afro-ecuadorian communities that in our study area have 0.03 inhabitants per hectare (Minda Batallas 2002).

### **Methodology:**

Prey delivered to seven Harpy eagle nests from 2002 to 2010 were analyzed. One nest was in the western region of the country (nest 3) and the rest were in the eastern region. They were occupied with one juvenile each that were different ages. The age of the juveniles occupying each nest was based in the first visit according to their plumage pattern (Fowler and Cope 1964, Ferguson-Lees *et al.* 2001) and behavior (Rettig 1978). To facilitate the analysis of data we divided the age of the juveniles in two classes of ages depending on their development status: one class from 0 to  $\leq 3$  months old (nestling) and the other  $> 3$  months old (fledgling).

The number and identification of items in nests were known using both direct observation of prey delivery by adults at the nest to feed the young in combination with analyses of prey remnants and regurgitated pellets dropped under the nest tree to confirm or complete the observation data. In one case, the species were identified when uneaten parts of the prey were collected from the nest platform in nest 1. Climbing equipment was used to reach the nest tree.

The monitoring period for each nest was the following: For nest 1: 52 days, Nest 2: 156 days; Nest 3: 87 days, Nest 4: 84 days, Nest 5: 77 days; Nest 6: 15 days; Nest 7: 77 days; in total 548 observation days. Data from nest number 6 were only used to complete the spectrum of prey species since it provided very little information as it was monitored during a short period of time.

Direct observations were conducted using 10x40 binoculars from 07:00 to 16:30 H from the ground or from a camouflaged 28 m observation tower, 34-50 m from the nest tree.

Days between consecutive prey deliveries were calculated only when observations happened during continuous periods of  $\geq 10$  d. Prey species and hour of prey delivery

attempt were recorded. Prey were individually identified to genus or species using a field guide (Emmons and Feer 1990) when the adult left them on the nest platform or when the juvenile was feeding on it.

Prey bones and pellets dropped on the ground were collected during each visit to the nest area and saved in zipped plastic bags. The date, number of bones and nest location was noted on each plastic bag. After that they were identified to genus or species level by comparison to the remains of animals hunted by people of the community near the nest and comparing bones to a reference animal collection at the Ecuadorian Museum of Natural Sciences in Quito, Ecuador.

Mann-Whitney U Test was used to determine the existence of any bias in regard to the probability of finding more remnants of some species than others under the nest trees.

Prey diversity was estimated using the Shannon-Weaver function (Shannon-Weaver 1949) and Sheldon correction (Sheldon 1969) for variable sample sizes. This index indicates the average degree of uncertainty in predicting species to which an individual belong if it is chosen at random from a sample. A high value of H would be a representative of a diverse

and equally distributed community and lower values represent less diverse community. A value of 0 would represent a community with just one species. It is explained by the formula:

$$H_{\text{Shannon/corr}} = \sum_i (p_i \ln p_i) \ln N$$

where  $p_i$  is the frequency of the  $i$ th element and  $N$  is the size of the sample.

Statistical differences in the values of diversity between pairs of nests were evaluated by the procedure proposed by Solow (1993) which consists of the randomization of combined data of pairs, followed by the calculation of the difference in the value of diversity between the pairs of samples and the repetition of the procedure 10000 times from which it is estimated the significance ( $p$ ).

Niche breath was calculated by standardized Levins index (Colwell and Futuyma 1971):

$$B_{\text{sta}} = (B-1)/(n-1)$$

where  $B$  is the Levins index ( $B = 1/\sum p_j^2$ ),  $p_j$  is the proportion of occurrence of each prey species and  $n$  the number of prey species. Standardized Levins index values range between 0 (minimum niche breadth and, consequently, maximum selectivity) and 1 (maximum niche breadth, minimum selectivity; Krebs 1999).

Prey weight were estimated based on values published in previous

literature (Oliveira 1998, Taube *et al.* 1999, Kays 2000, Poloskey 2000, Robinson and Bennet 2000, Trovati *et al.* 2010, Catania 2011, Tirira 2011, BirdLife International 2013, Pinto and Nicolalde 2015). Only adult weights were available for all the species, consequently only adult prey types were considered for this purpose.

To facilitate comparisons of prey contribution, species were classified into six different categories: sloths, large monkeys, medium and small monkeys, other mammals, birds and reptiles.

Intervals of prey delivery hour were distributed in three categories: 07:00 to 10:00 H; >10:00 to 13:00 H and > 13:00 to 16:00 H.

To allocate the prey to a specific forest stratum the forest was classified based on height classes or elevation above the ground to select three different layers:

Layer /stratum 1 (low): height from 0 to  $\leq$  12 m;

Layer/stratum 2 (medium): height from > 12 to  $\leq$  24 m;

Layer/stratum 3 (high): height from > 24 m.

The tree canopy in our study area reaches 30 to 40 m in height (Sierra *et al.* 1999). The species were catalogued in different levels in order to

bibliographic references (Pinto *et al.* 2015, BirdLife International 2013)

The conservation and threat status of the prey was taken into account. Prey were classified by degree of conservation threat in national and international categories and were used to consider the possible linked pressure on their predator.

## Results

Prey of seven nests were analyzed. Different development stages of the juvenile were found for each nest: juvenile of nest 1 was monitored from 9 to 12 months old juvenile, juvenile of nest 2 from 6 to 12 months, in nest 3 it was monitored from 15 to 18 months, in nest 4 from 8 to 11 months, in nest 5 from 2 to 4 months, in nest 6 from 18 to 19 months and in nest 7 from 1 to 4 months.

For this study 158 prey records were analyzed. Diet included 18 identified species (Table 1). Additionally, six individuals were recognized within the group of birds, and fourteen more items could not be identified.

Nests 1, 2 and 5 were those that contain the highest diversity index (Table 2), and no significant differences

were found between them ( $H'1 < H'2$ ;  $P=0.85$ ;  $H'1 > H'5$ ;  $P= 0.93$  y  $H'2 > H'5$ ;  $P=0.81$ ).

Niche breath was  $B_{sta}= 0.28$  that is a low value which shows an especialization of the diet of the harpy eagle.

The sample was clearly dominated by mammals which comprised 85.2% of prey numbers.

Related with prey contribution it was found that in nests 1 and 2 there were a bias toward the probability of finding more remnants of sloths than other prey species under the nest trees, so we decided to take into account only the observation records of prey delivery to the nest (See table 4). Table 3 shows filtered prey records.

In general and taking into account the taxonomic level (Order and Species), the Order Pilosa and the Two-toed sloth species (*Choloepus didactylus* at the east of the country and *C. hoffmannii* at the west side) were who contributed in a highest percentage to the diet of the Harpy eagle (Order Pilosa: 49,6%; from which *Choloepus* spp. contributed with 43.1% and Three-toed sloth (*Bradypus variegatus*) contributed with 6.5%), followed by Order Primate (39.8%) where Squirrel monkey (*Saimiri macrodon*, 14.6%) and Red howler monkey (*Alouatta*

*seniculus*, 8.9%)) were the most common species registered. However the highest contribution of prey in the nest 1 was the Order Primate (Kruskall-Wallis  $H_{Nest1}=5.48$ ;  $df=1$ ,  $P= 0.019$ ) and for nests 2, 3 and 7 it was the Order Pilosa ( $H_{Nest2}= 5.18$ ,  $df=1$ ,  $P= 0.023$ ;  $H_{Nest3}= 8.16$ ,  $df= 1$ ,  $P= 0.04$ ;  $H_{Nest7}= 6.1$ ,  $df= 1$ ,  $P= 0.014$ ).

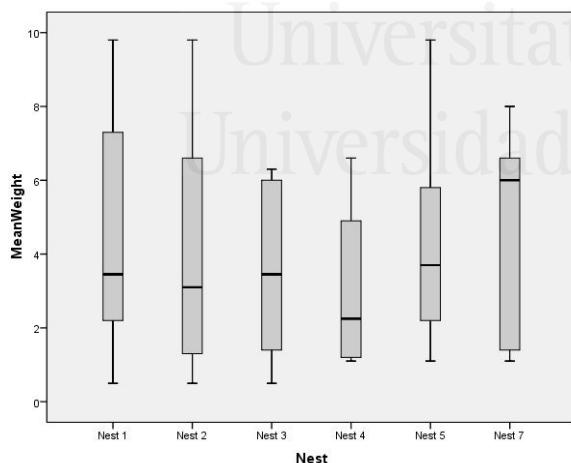
There were no significant differences between species group of prey delivered by adults and development stage of the juvenile in the nest (Pearson Chi-square= 9.82;  $df= 5$ ;  $P=0.081$ ) and sloths and primates were the principal type of prey for both nestlings (87.8 %,  $n= 41$ ) and fledglings (90.4 %,  $n= 94$ ).

Data on prey left on the nest platform were collected only once, in September 2002 at nest 1. The platform was composed of a mixture of unidentified old bones and sticks on a Kapok tree (*Ceiba pentandra*). A young half-bodied Three-toed sloth that was delivered one day before weighed at the time 300 g and its length was 19 cm from the head to the thorax. The lower extremities had already been consumed.

The other prey on the platform was a Blue and Yellow Macaw (*Ara ararauna*), that was delivered the same day of the collection. The juvenile did not eat it until measurements were done.

It weighed 1,400 g and measured 45 cm from its cervical vertebrae to the end of the synsacrum or the beginning of the caudal vertebrae. It was decapitated by the adult.

Mean weight of delivered prey species was 4.01 kg (range 0.5 - 9.8 kg, S.D.= 2.8, n= 44; Graph 1) and there were no significant differences between the averaged weights of species delivered in different nests (Chi-Square =3.97, df= 10; P= 0.9). In addition, the weight of prey species provided by adults to the nest is similar regardless to the juvenile age (nestling or fledgling) (Mann-Whitney U= 1668.5, P = 0.15) when they are grouped in light-medium weights ( $\leq$  4 kg) and heavy prey ( $>$  4 kg).



**Graph 1: Distribution and dispersal of the Harpy Eagle species prey weights in each of the nests.**

On average, adults delivered one prey every 3.8 days (range 1- 7; S.D.=

1.7; n= 63). Related with juvenile development, adults delivered a prey item every 3.3 days ( $\pm$  1.4; n = 15) when the juvenile was  $\leq$  3 months old, and every 3.9 days ( $\pm$  1.8; n= 53) when it was  $>$  3 months. There were no significant differences in delivery rates comparing juveniles with different development degree (nestling or fledgling) (U=318, P = 0.2; n = 68).

Adults delivered prey preferably during the morning from 07:00 to 10:00 H (Kruskal-Wallis  $H=$  12.6, df=2; P= 0.002; n= 103), and the main prey (sloths) were delivered preferably during the morning ( $U =$  437; P = 0.001). Males were who contributed more to the prey delivery (74.8% n= 103; Wilcoson Signed Ranks Test = -2.201; P = 0.03). Contribution of males and females was maintained for each juvenile age group (Chi-Square= 3.47; df=1; P = 0.06).

Sloth prey deliveries were negatively correlated to primate deliveries (Pearson Correlation Coefficient= -0.86; P= 0.05). A lineal regression was conducted showing that sloths prey delivery influences in a 66.1% primates deliveries. Increasing sloths prey deliveries lead to lower primate consumption and viceverse (Adjusted  $R^2=$  0.66; p= 0.05).

The model will fit as:

$$Y = 68.9 + (-0.72)x$$

Where Y = sloths prey deliveries and x= primate prey deliveries.

The forest stratum that was more commonly used to hunt by the Harpy eagle was the highest level (Level/stratum 3) (Kruskall Wallis Test; H= 17.3, P = 0.004, n = 139)

Combining the prey data from all the nests, all the species delivered except two were found under some degree of threat or conservation pressure at a national level and all but one at an international level (See Table 1).

depending on prey community structure, abundance and availability of those. Diet would be supplemented with prey that would be hunted opportunistically.

Niche breath was higher for our study than for central Amazonian in Brazil ( $B_{sta} = 0.17$ ) (Aguiar-Silva 2014) although specialization is evident for both. In our study area all nests were located in the influence area for community hunting activities. We might expect that opportunistic behaviour for hunting is greater in areas where there is greater pressure on the preferred Harpy eagle prey as monkeys are.

#### *Species contribution:*

### **Discussion**

#### *Niche breath:*

Existing Harpy eagle reports indicate that it preys on a considerable variety of species, most of which are arboreal mammals (Rettig 1978, Álvarez-Cordero 1996, Aparicio 2003, Piana 2007, Muñiz-López 2008, Aguiar-Silva 2014). Although in our study we found a diversity of prey for all nests, values of diversity index were relatively low. These data make us suspect the existence of preferred prey and the use of replacement prey

As in the majority of previous provisioning behaviour reports, we found that Two-toed Sloth was always part of Harpy eagle diet and the most common prey (Rettig 1978 and 1995, Álvarez-Cordero 1996, Galetti and Carvalho 2000. Sanaíotti et al. 2001, Touchton et al. 2002, Piana 2007, Aguiar-Silva 2014).

Something different happened in Belize where the most frequent food items were Common opossum (*Didelphis marsupialis*) and White-nosed coatiundi (*Nasua narica*), and no sloths were found. In this study

authors argued that the reason of this difference with other Harpy eagle prey reports could be that they were breeding at the fringe of sloths natural range where prey choice and availability may be limited. In addition, Belize only supports two primate species (Rotenberg *et al.* 2012). These data suggest that in case there is sufficient density of sloths these would be selected by the Harpy eagle as the main part of their diet and it would be able to respond to changes in the availability and abundance of prey across variations in their diets. When abundant, the Harpy eagle should eat only the most valuable prey type that seems to be sloths and monkeys. Inclusion of other prey types in the diet should depend on the scarcity of preferred prey and abundance of more profitable prey. As preferred prey abundance declines, diet diversity should increase as happened in nest 1, 2 and 5. These nests were located where indigenous communities have their regular hunting routes so humans would be competing with the Harpy eagle for food as indigenous people hunt preferably large size primates (de la Montaña 2013). The persistence of hunting may come along with a decrease in the relative importance of large primates (Zapata 2001, de la Montaña 2013) and this

could lead to an eagle underexploitation of monkeys in territories where humans and eagles compete for same prey. Only for the area around nest 1 the indigenous prohibit to hunt “animals with hands”, which includes monkeys. This situation is reflected in the proportion of big monkeys captured by the eagles that is higher for nest 1 (see Table 3).

Related with this we could hypothesize that if sloths are the preferred prey delivered on Harpy eagle nests they should be the most frequent prey provisioned even if monkeys are more abundant in the foraging area. However we have found that in the area where humans do not hunt monkeys Harpy eagles delivered more primates than sloths to the nest. That could suggest that our results fit with the predictions made for Schluter (1981) about the original optimal diet model: Frequencies of alternate prey in the diet may be related not to their own densities but inversely with the densities of the preferred prey; when prey are abundant, predators should eat only the most valuable prey type and as prey abundance declines, diet diversity should increase.

Models based on the Optimal Foraging Theory (OFT) (Svanbäck and Bolnick 2005) established the

connection between intrapopulation diet variation and resource availability. Such models are useful for our study because they represent a few examples of the possible rules that describe how individual niches could vary with resource availability. In the competitive refuge model (CRm), for instance, the preferred prey is also the same. For low and high resource availability this model predicts that when resource availability is high, all the individuals feed on the preferred prey, but as resource availability decreases, individuals begin to include alternative prey in their diet in a similar order, as could happen with large monkeys as preferred prey and sloths as alternative. If resource availability decreases further, all the prey become scarce, and individuals expand their diets and tend to consume all the prey.

Future studies need to evaluate intrapopulation variation in different ecological scenarios and the relative importance of human hunting on prey diversity of Harpy eagles to reveal how individuals adapt to variations in different environmental conditions.

Remains of Margay (*Leopardus wiedii*) were found as a new record for Harpy eagle prey species at genus level although it has a widespread distribution throughout the American

continent, occurring in a diversity of environments that includes rainforests (Emmons and Feer 1997) where Harpy eagle is allocated. Nails and hair were found in a pellet under the tree where nest 7 was located. The few studies on the Margay suggest that its diet is mainly composed of arboreal mammals (de Oliveira *et al.* 2009) including species as Capuchin monkeys (*Cebus spp.*) (Beebe 1925, Mondolfi 1986) so Harpy eagles and Margays could occasionally overlap their diet causing encounters that could origin an opportunistic capture of the eagle on the feline.

#### *Prey weight and provisioning rate:*

The Harpy Eagle is known to take a variety of larger-bodied species ( $\geq 2.5$  kg) (Barnett *et al.* 2011) and thanks to its massive body size which is for males 4.0 - 4.8 kg and for females 7.6 - 9.0 kg (Fowler and Cope 1964, Bierregaard 1994) it can prey on species that weight more than its own body mass, as Wooden monkeys. The peak in food demand is likely to occur in the middle stages of brood development when growth rates are highest and it decreases slightly when broods are close to fledgling (Newton 1979). In some raptor studies, greater nestling

needs lead to increased provisioning rates (Green and Ydenberg 1994, Jenkins 2000, Masman *et al.* 1989, Olsen *et al.* 1998, Tolonen and Korpimaki 1994); in other studies, parents respond by increasing prey size (Newton 1986, Palmer *et al.* 2004). Our results about Harpy eagle provisioning preferences may suggest that in our study area they could obtain prey that exceed the needs of the juvenile throughout the breeding period as the mean species prey weight is considerably high during all the months covering our study.

The frequency with which prey items were delivered to the nest (prey delivery rate) in our observations is slightly longer than data collected in other studies. Harpy eagles showed the lowest feeding rates yet found among raptors (Rettig 1978). On average, our rate in Ecuador is longer than for British Guyana where observed rate is one prey every 2.5–3.5 days (Rettig (1978) and for Venezuela it is every 2.1–2.4 days (Seymour *et al.* 2010). Those differences could be due to different provisioning tactics as result of variation in prey availability as a consequence of influences of their seasonal distribution or human hunting pressures that keeps some of the prey away from important foraging sites as

all nest were in the hunting influence ratio of an indigenous /afroecuadorian community. Rettig (1978) and Seymour *et al.* (2010) reported fewer days per delivery as the nestling grew. Rotenberg *et al.* (2012) observed the opposite trend in Belize. In our study we did not detect any difference in the provisioning rates throughout the development of the juvenile. However, sample sizes may have been too low to detect statistical relationships between prey delivery rates and nestling development at an alpha level of 0.05.

Eagles probably hunt during the morning or late in the evening and save prey to leave it on the nest the next morning. In our study prey delivery rate is higher for males as happened in nests studied in British Guyana (Rettig 1978) and Venezuela (Seymour *et al.* 2010) but this is an opposite trend to reports from Belize (Rotenberg *et al.* 2012) and Serra da Bodoquena National Park in Brazil (Martins Pereira and Salzo 2006) where females had a greater role. Both parental care and time-activity budgets of male and female raptors may vary as result of several biotic (e.g., brood size, age of adults, food availability, competition with other predators, hunting skills) and abiotic (e.g., day length, topography, weather) factors (Boulet *et al.* 2001, Palmer *et al.* 2001).

Females are much larger than males, and only periodically join in the hunting, mainly during the late nestling and postfledgling period (Newton 1973, Eldegard *et al.* 2003). We will need more data to determine sex contribution to assess a trend in prey delivery rates through juvenile development.

*Hunting preferences:*

Ground and medium-level vegetation may affect the ability to detect prey and hence may influence the success of particular foraging behaviours (Bechard 1982, Janes 1985). With a wingspan of 176 to 224 cm it should probably be more difficult to maintain the required maneuverability for hunting as in lower strata there are more density of obstacles due to the thick vegetation. Harpy eagle predatory habits occurring more in the upper canopy may facilitate the accessibility to the prey, decrease the risk of collision and do more successful any attempt of hunting.

*Endangered prey:*

In this study it was shown that all the identified Harpy eagle prey were suffering some kind of threat or pressure. That means that, additional to

its own breeding characteristics (one juvenile every 3 years), habitat loss and hunting pressure (Álvarez-Cordero 1996), Harpy eagle population stability is also endangered because the resources which they are depending on are threatened as well.

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Table 1: Relative abundance, estimated body mass, habits and conservation status of prey delivered on seven Harpy eagle nests from 2002 to 2010 in Ecuador.

Order	Family	Species	Estimated body mass (kg)	Habits	Forest stratum	National Conservation Status (Red List Ecuador)	International Conservation Status (Red List IUCN)
Carnivora	Felidae	<i>Leopardus wiedii</i>	6.0	Crepuscular and nocturnal	All	Near Threatened	Near Threatened
	Procyonidae	<i>Nasua nasua</i>	5.0	Diurnal	Low and medium	Least Concern	Least Concern
	Potos flavus	<i>Potos flavus</i>	3.0	Crepuscular and nocturnal	High	Least Concern	Least Concern
Pilosa	Bradypodidae	<i>Bradypus variegatus</i>	3.7	Crepuscular	High	Least Concern	Least Concern
	Megalonychidae	<i>Choloepus didactylus</i>	6.6	Crepuscular	High	Least Concern	Least Concern
		<i>Choloepus hoffmannii</i>	6.3	Crepuscular	High	Least Concern	Data deficient
Primates	Atelidae	<i>Alouatta seniculus</i>	8.0	Diurnal	Medium and high	Least Concern	Least Concern
		<i>Lagothrix lagotricha</i>	9.8	Diurnal	Medium	Vulnerable	Vulnerable
	Callithricidae	<i>Saguinus nigricollis</i>	0.5	Diurnal	Low and medium	Least Concern	Least Concern
	Cebidae	<i>Cebus yuracur</i>	3.2	Diurnal	All	Least Concern	Vulnerable
		<i>Saimiri macrodon</i>	1.1	Diurnal	Low and medium	Least Concern	Least Concern
	Pitheciidae	<i>Callicebus lucifer</i>	1.3	Diurnal	Low and medium	Least Concern	Least Concern
		<i>Pithecia milleri</i>	2.5	Diurnal	Medium and high	Least Concern	Data Deficient
Rodentia	Scoirotidae	<i>Sciurus spp.</i>	0.5	Diurnal	Medium and high	Least Concern	Least Concern
	Erethizontidae	<i>Coendou bicolor</i>	4.5	Crepuscular	High	Least Concern	Least Concern
Psittaciformes	Psittacidae	<i>Ara ararauna</i>	1.4	Diurnal	High	Least Concern	Not categorized
Galliformes	Cracidae	<i>Pipile cumanensis</i>	1.4	Diurnal	Medium and high	Least Concern	Not categorized
Squamata	Iguanidae	<i>Iguana iguana</i>	6.0	Diurnal	Medium	Not evaluated	Least Concern

Table 2: Shannon's diversity index for species of prey found in each nest. Nests 1, 2 and 5 shows higher diversity values.

Nest 1 (n=25)		Nest 2 (n=37)		Nest 3 (n= 21)		Nest 4 (n= 7)		Nest 5 (n= 23)		Nest 6 (n=2)		Nest 7 (n= 29)	
H'	SD	H'	SD	H'	SD	H'	SD	H'	SD	H'	SD	H'	SD
1.93	0.17	1.99	0.17	1.23	0.22	1.15	0.32	1.91	0.25	0	0	1.14	0.14

Table 3: Relative abundance of Harpy eagle prey species delivered in each of the nests after bias correction for nests 1 and 2.

Species delivered	Nest 1	Nest 2	Nest 3	Nest 4	Nest 5	Nest 6	Nest 7
<i>Leopardus wiedii</i>	-	-	-	-	-	-	1
<i>Nasua nasua</i>	-	-	-	-	2	-	-
<i>Potos flavus</i>	2	1	-	-	-	-	-
<i>Bradypus variegatus</i>	2	2	3	-	1	-	-
<i>Choloepus didactylus</i>	1	11	-	4	10	2	12
<i>Choloepus hoffmannii</i>	-	-	13	-	-	-	-
<i>Alouatta seniculus</i>	5	3	-	-	1	-	2
<i>Lagothrix lagotricha</i>	2	1	-	-	1	-	-
<i>Saguinus nigricollis</i>	1	3	-	-	-	-	-
<i>Cebus yuracus</i>	1	3	-	1	2	-	-
<i>Cebus spp</i>	-	-	1	-	-	-	-
<i>Saimiri macrodon</i>	-	3	-	1	-	-	13
<i>Callicebus lucifer</i>	-	1	-	1	1	-	-
<i>Pithecia milleri</i>	-	1	-	-	-	-	-
<i>Sciurus spp.</i>	-	-	-	-	-	-	-
<i>Coendou bicolor</i>	-	-	-	-	2	-	-
<i>Ara ararauna</i>	1	-	-	-	-	-	-
<i>Pipile cumanensis</i>	-	-	-	-	-	-	-
<i>Iguana iguana</i>	-	-	1	-	-	-	-
Not identified bird	-	-	2	-	1	-	1
Not identified mammal	-	2	1	1	-	1	1

Table 4: Mann-Whitney U Test to assess the bias in the probability of presence of each prey class depending on the method of data collection (Pr= Probability collecting rests under nests; Pob= Probability using direct observation of prey delivery) . The table shows significative P-values (\*) in Nest 1 (for sloths and large monkeys) and Nest 2 (for medium and small monkeys).

Nest	Sloths		Large monkeys				Medium and small monkeys				Other mammal				Birds			Reptiles			Not identified		
	Pr (n)	Pob (n)	U	Pr	Pob	U	Pr	Pob	U	Pr	Pob	U	Pr	Pob	U	Pr	Pob	U	Pr	Pob	U		
1	0.6 (12)	0.2 (15)	55.5 p=0. 04 (*)	0.1	0.5	55.5 p=0.0 3 (*)	0	0.1	78 p=0. 19	0	0.1	78 p=0. 19	0.2	0.1	81 p=0. 42	0	0	1 p=1	0.2	0	75 p=0. 1		
2	0.4 (9)	0.4 (31)	136 p=0. 89	0.2	0.1	126.5 p=0.4 9	0	0.4	90 p=0. 038 (*)	0.1	0	128.5 p=0. 34	0.1	0	124 p=0. 06	0	0	1 p=1	0.1	0.1	133 p=0. 6		
3	0.7 (7)	0.7 (15)	45.5 p=0. 72	0	0	49 p=1	0.1	0	42 p=0. 15	0	0.1	45.5 p=0. 48	0.1	0.1	42 p=0. 16	0	0.1	45.5 p=0. 48	0	0.1	45.5 p=0. 48		
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
5	0.5 (11)	0.4 (18)	92.5 p=0. 73	0.1	0.1	95.5 p=0.7 2	0.2	0.1	92 p=0. 59	0.2	0.2	97.5 p=0. 92	0.1	0	90 p=0. 2	0	0	1 p=1	0	0.3	71.5 p=0. 06		
6	1 (1)	0.5 (2)	0.5 p=0. 48	0	0	1 p=1	0	0	1 p=1	0	0	1 p=1	0	0	1 p=1	0	0.5	0.5 p=0. 48	0	0.5	0.5 p=0. 48		
7	0.4(1 5)	0.4(1 5)	112.5 p=1	0	0.1	97.5 p=0.1 5	0.5	0.4	105 p=0. 71	0.1	0	105 p=0. 32	0	0	105 p=0. 32	0	0	1 p=1	0.1	0	105 p=0. 32		
Total	0.51 (55)	0.43 (104)	2641. 5 p=0. 36	0.07	0.13	2683 p=0.2 4	0.18	0.23	2720 p=0. 47	0.07	0.07	2844. 5 p=0. 89	0.09	0.03	2682. 5 p=0. 09	0	0.01	2832. 5 p=0. 46	0.07	0.1	2793 p=0. 62		



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## CAPÍTULO 5



Pollo de águila harpía en su nido sobre un ceibo (*Ceiba pentandra*) rodeado de un bosque típico de tierras inundadas de la Amazonía. Foto: P. Oxford /PCAHE-SIMBIOE

Ñanda gi ña'me ñotssia tsampi jin'ttima isu. Tse'ttini tsu osha'cho aña'cho'qque jin, toya'caen na'en'su'qque.

Seje'pa'qque, ingi semanqque'su'qque. Toya'caen tsu ande'qque sisipa andepa ñotssi tsuipa jacañe'qque, mingae asapa'chosa'ne. Tsa'cansi gi antte'fayambi cocama tsa andema itsaye'ja.  
In'jamba'qque tsendeccu jipa ingi andembe na'suve dasa'ne.

Guillermo Quenamá, indígena A'i / Cofán de Ecuador



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## Capítulo 5

### HÁBITAT DEL ÁREA DE NIDIFICACIÓN Y ESTIMACIÓN DE LA DENSIDAD DE NIDOS DEL ÁGUILA HARPÍA EN LA RESERVA FAUNÍSTICA CUYABENO, ECUADOR.

RUTH MUÑIZ-LÓPEZ y HÉCTOR ALCÁNTARA

#### Resumen

A través de la información obtenida de 15 nidos de águila harpía (*Harpia harpyja*) localizados en la región nororiental de la Amazonía ecuatoriana estimamos la densidad de lugares de cría utilizando el método de Densidad Máxima de Nidos. La altitud media de los lugares de nidificación fue de 219 m s. n. m. ( $\pm 11.7$  m) y todos los nidos se construyeron sobre árboles emergentes. La distancia mínima entre nidos más cercanos fue de  $4.9 \pm 0.7$  km y un área de cría de  $19.6 \pm 5.7$  km<sup>2</sup> por cada pareja. La densidad de nidos en nuestra área de estudio se estimó en 5 nidos / 100 km<sup>2</sup>. La mayoría de las áreas de cría se localizó en bosques inundables y relativamente lejos de áreas urbanas. El hábitat potencial del águila incluye bosques al este y oeste de la cordillera andina pero los bosques de la región occidental poseen un alto grado de alteración por lo que las condiciones para mantener una población sana de águila harpía en esa zona son más limitadas. Algunas acciones para conservar el hábitat del águila harpía incluyen programas de educación y sensibilización, integración de la población local en los planes de conservación y desarrollo y voluntad política para controlar la explotación de los recursos naturales.

**Palabras clave:** Águila harpía, área de cría, densidad, Ecuador, hábitat.

**HARPY EAGLE BREEDING HABITAT AND NESTING DENSITY ESTIMATION IN CUYABENO WILDLIFE RESERVE, ECUADOR.**

RUTH MUÑIZ-LÓPEZ y HÉCTOR ALCÁNTARA

**Capsule:** Using the information obtained from 15 Harpy eagle (*Harpia harpyja*) nests located in the Northeastern region of Amazonian Ecuador we estimated the density of breeding areas applying the Maximum Packed Nest Density method. Altitude of the nesting sites averaged 219 m.a.s.l. ( $\pm 11.7$  m) and all nests were built on emergent trees. Nearest-neighbour distances averaged  $4.9 \pm 0.7$  km and an area of  $19.6 \pm 5.7$  km<sup>2</sup> per breeding pair. Estimated nest densities was 5 nests/ 100 km<sup>2</sup> in our study area. There is a regular distribution of breeding territories which have an extension of  $19.6 \pm 5.7$  km<sup>2</sup>. Most nesting areas were located in Flooded forests and relatively far from urban areas. Potencial habitat includes forests at east and west of the Andean mountains but Western Region forests are highly disturbed and the conditions to sustain a healthy Harpy eagle population are more restricted than in the Eastern region. Some Harpy eagle habitat conservation actions include educational and awareness programs, integration of local communities in conservation and development plans and political will to control natural resources exploitation.

**Key words:** Harpy eagle, breeding area, density, Ecuador, habitat.

## Introduction

South America has the highest absolute number of living species among the seven continents, by a substantial margin (Stotz *et al.* 1996). The major waves of extinctions in the Neotropics are occurring among species that have evolved ecological specializations that limit their ability to adapt to human modifications of their habitats (Stotz *et al.* 1996).

For many tropical raptors, habitat loss and fragmentation have contributed to population declines (Thiollay 1993, Bildstein *et al.* 1998). Rainforest fragmentation occurs when habitat loss results in an area of continuous forest being dissected into smaller, isolated areas, or ‘fragments’; simultaneously increasing the amount of forest edge whilst reducing forest area (Broadbent *et al.* 2008, Ewers and Didham 2005, Ranta *et al.* 1998). Edge effects can strongly influence the structure, ecology, species composition and biodiversity of a fragment though a series of effects (Broadbent *et al.* 2008, Laurance *et al.* 1998, Murcia 1995), placing many specialized species at great risk of extinction (Cordeiro and Howe 2003). Human population size, areal extent of reserves, and isolation of ecosystems are strong predictors of

species extinction (Brashares *et al.* 2001, Parks and Harcourt 2002, Woodroffe and Ginsberg 1998).

As fragmentation rates continue to rise in conjunction with expanding human populations (Bierregaard *et al.* 1992, Laurance and Curran 2008), the fate of tropical rainforests is dubious.

The most pressing conservation goal today is to reduce these extinction waves to a minimum. Effective conservation of species requires information about the location of suitable habitats and the environmental factors affecting them (Guisan and Thuiller 2005). Despite of that our level or knowledge about species distribution and abundance in Neotropics is still rudimentary for all but a few groups of animals and plants.

Birds of prey are notoriously difficult to survey in tropical forests, especially in tall, dense, large unbroken tracts of humid lowland forests. In addition, ecological theory predicts that tropical top predators as raptors are occur at low densities (Forsman and Solonen 1984, Thiollay 1989b) and study areas of 500 ha or more may contain less than one full territory for most species (Robinson and Wilcove 1989). However, many rain forest raptors are now threatened by habitat destruction, disturbance or

fragmentation (Thiollay 1985). There is still an urgent need of basic data on natural distribution and density of rain forest raptors because of a concern about the suitability of many reserves which may well prove to be too small for long term survival of some raptor species supported originally (Thiollay 1989b).

Like many birds, raptors are usually highly selective with respect to their habitats, especially regarding the availability of suitable nesting areas, although foraging habitats may also have an important effect at the time of choosing a site during the breeding season (Newton 1998). Breeding habitat (which include both nesting and foraging habitats) may limit species productivity or distribution (e.g. Benton *et al.* 2002, Soh *et al.* 2006). In these cases, increasing availability or suitability of preferred habitats (e.g. restoring nesting habitats or increasing the availability of foraging habitats) may potentially lead to increasing population sizes (Carrete *et al.* 2002, Hiraldo *et al.* 1996). Understanding the strength of the relationships between habitat and species distribution or breeding success may be important to manage protected areas and to predict how changes in habitat may influence population dynamics, and thus

contribute to the development of successful conservation programmes (López-López *et al.* 2006, 2007).

The Harpy eagle is the largest and most powerful raptor found in the Americas (Collar 1989) and one of the biggest eagles in the world (Collar 1989, Sick 1997).

It inhabits tropical and subtropical lowland rainforests (Stotz *et al.* 1996). These large raptors apparently occur in relative low density and are difficult to detect in the dense forest canopy (Álvarez-Cordero 1996). Although not particularly shy, the Harpy eagle is very secretive and spends long periods perched motionless (Thiollay 1989b). It feeds mainly on arboreal mammals, specially sloths and monkeys (Álvarez-Cordero 1996, Piana 2007, Muñiz-López *et al.* 2007, Aguiar-Silva *et al.* 2014).

The Harpy eagle range extends from Southern Mexico to Northeastern Argentina between 0 to 800 m a. s. l. (Ferguson-Lees and Christie 2001, Vargas *et al.* 2006) but in Ecuador one pair was reported at 1,100 (Pilataxi and Salagaje 2014 through Jocotoco Foundation comm. pers) and one individual at 1,650 m a. s. l. (Navarrete 2004).

Harpy eagles have been extirpated from several locations, and are currently

declining in various countries (Vargas *et al.* 2006, BirdLife 2013). It is considered that the main reasons of its population decline are human persecution and deterioration of its habitat (Ferguson-Lees and Christie 2001, Vargas *et al.* 2006, BirdLife 2013), although there is little information about how Harpy eagles are affected by these (Gorzula and Medina 1986, Álvarez-Cordero 1996, Guerrero 1997, Trapé-Trinca *et al.* 2007).

At a global level it is catalogued as Near Threatened (BirdLife 2013) but as Vulnerable for Ecuador (Granizo *et al.* 1997).

There are few studies about Harpy eagle nesting density. Vargas and Vargas (2011) estimated 16-24 km<sup>2</sup> per pair depending on the method used in one area of Darien region in Panama and extrapolated results from 18 breeding selected pairs to assess the population size for all the country. They also roughly described some landscape characteristics as most nests ( $n= 30$ ) were located below 310 m in primary forest. In Peru, Piana (2007) calculated an area of 43 km<sup>2</sup> per pair ( $n = 3$  nests) and Álvarez-Cordero (1996) determined 45-79 km<sup>2</sup> for Venezuela ( $n= 9$  nests). Thiollay 1989 a,b, considered 100 km<sup>2</sup> per pair in French Guiana but this was based on individuals observations

opposite to inter-nest distances used in other countries.

There is no published studies about quantitative descriptions of Harpy eagle breeding areas features at a landscape scale. Before this study Álvarez-Cordero (1996) described the ecological and geographical range of the Harpy eagle in Venezuela and Panama showing that it is adapted to a wider array of forest environments from Lowland Rainforest to Tropical Dry Forests; On the other hand, Giudice (2005) described forest structure and nest tree architecture for nine Harpy eagle pairs in Madre de Dios (Peruvian Amazon). He concluded that in the Terra Firme forests of the lower basin of Tambotata river Harpy eagle nests were determined by a lower basal coverage (average amount of an area occupied by the cross-section of tree trunks and tree stems) than in randomly selected areas. After that, a study in a region of Panama correlated vegetation structure with presence of Harpy eagle nests finding that number of tree families and average tree height were the best predictors of nest site selection (Vargas *et al.* 2014).

Here we present preliminary spatial landscape-scale analyses of Harpy eagle breeding areas and an estimated nest density in a region in the northeastern

Amazon Basin in Ecuador. Assuming homogeneity it can be useful for providing a crude description of the distribution patterns without any underlying assumption. Thus we present a map of the potential distribution of this species in Ecuador.

### Study area

The study area comprised approximately 590,112 hectares and it was composed of some sectors of the Cuyabeno Wildlife Reserva in the northeast of Ecuador, bordering Colombia and Peru, and the northwestern Reserve boundary that is occupied by Secoya indigenous group and colonist (Ministerio del Ambiente 2012). The Cuyabeno Wildlife Reserve is one of the most important protected areas in Ecuador (Balslev *et al.* 1998) comprising about 12% of national protected land (World Resource Institute 2005). Located in the northeastern portion of the Ecuadorian Amazon, between 250 y 326 m a. s. l., it is categorized as a Humid Tropical Forest bioma with an annual mean precipitation that ranges from 2093.8 to 2728.2 mm and annual average temperature from 24.6 to 26.3 °C (Cañas 1983, Ministerio del Ambiente 2012). This is the most

widespread type of vegetation in the country, which covers more than a third of the continental Ecuador (Neill 1999). The percentage of relative humidity is about 72% (61.8 - 76.7 %) and average canopy height reaches  $35 \pm 9$  m (Rivadeneira-Roura 2007).

Its seasonal variation consist of a dry season - defined as the months that receive less than 250 mm of rain per month and includes from late December through March; a rainy season - defined as the months receiving more than 250 mm of rain per month, that runs from April to July- and the time of fluctuation ranges from August until mid-December (Rivadeneira-Roura 2007).

Cuyabeno Reserve embodies an extraordinary degree of biological richness (Araya and Peters 2000). This Reserve has registered the greatest density of tree species in the world, 473 species per hectare (Valencia *et al.* 1994). Some taxa are extremely biodiverse as well: 500 species of birds, 165 species of mammals, and 135 species of amphibious and reptiles (Ministerio del Ambiente 2012). Cuyabeno Reserve was designed to protect the Cuyabeno Lakes District, an ecosystem with unique hydrologic characteristics comprising 14 interconnected lakes and seasonally

inundated lands located at the confluence of the Ecuadorian Amazon's black and white water river systems (Coello-Hinojosa 1992). It was also planned to be a tool to increase the income of local people by improving wildlife management and tourist facilities.

Cuyabeno river, with its headwaters in the Andes, is the main river that flows through the area and drains into Aguarico river, that flows in the southeastern region of the Reserve; it joins Napo river at the Peruvian boundary and eventually flows into the Amazon River.

The forest in our study area has two distinctive subtypes according to local hydrology (Valencia *et al.* 1994):

- Flooded forest: Irregularly and almost permanently inundated forests flooded by white and black-water rivers (Asanza 1985, Pires and Prance 1985). Flooded palm swamps occurs along depressions and stream valleys with a vegetation dominated by Morete palms (*Mauritia flexuosa*).

- Terra Firme forest: This forest occur on low ridge slopes and crests that are never flooded, known as Terra Firme. They are well-drained forests located on small hills in the upper watershed and the areas between the semi-inundated planes.

The Reserve is also home to several indigenous communities (see Table 1): Siona, Secoya/Sieco'pai, Cofán/ A'i, Kichwa, and Shuar that all have different histories of migration to the area and different degrees of acculturation and market integration (Holt *et al.* 2004).

**Table 1: Indigenous communities population in the study area.**

Community Name	Indigenous Nationality	Population
Puerto Bolívar	Siona	111
Tarapuy	Siona	100
Playas de Cuyabeno	Kichwa	242
Siecoya Remolino	Secoya/Sieco Pai	150
Charap	Shuar	42
Zábaló	Cofán/A'i	71
Zancudo	Kichwa	100
Poocoya*	Secoya/Sieco'	9
Wajosará*	Secoya/Sieco'	7
	Pai	

Data from UCODEP (ICCA 2010)

\* Muñiz-López R. Pers.obs.

Indigenous communities and petroleum development existed in the area prior to the designation of the Reserve boundaries. The indigenous

groups (e.g. Secoya/Sieco'pai) also established communities within the current Reserve boundary. Colonists have established themselves in the area as well.

Human activities that take place within the Reserve, therefore, range from oil exploration and tourism to agriculture (Erlien *et al.* 2005). Annual rates of deforestation within the Cuyabeno Reserve was 0.08% /year<sup>-1</sup> for 1996-2002 loosing 1,300 ha of primary forest during 1986-2002 for agricultural, livestock and infrastructure construction (Mena *et al.* 2006).

## Methodology

### *Nest searches and nesting density:*

Nests were located by the local population in their hunting or fishing routes in the framework of the Harpy eagle Conservation Program in Ecuador (PCAHE in spanish) between the years 2000 and 2011. The PCAHE team confirmed the species that was nesting and organized training activities to help people identify this species of other eagles with crest feathers in the study area as Ornate hawk eagle (*Spizaetus ornatus*) and Crested eagle (*Morphnus guianensis*) as they were sometimes

confused and made mistakes in recognition of the species.

Bigger efforts in searching nests were made in the lower Aguarico river as the PCAHE worked more intensely in A'i/Cofán territory.

Finding Harpy eagle nests in the short term is a work that can hardly be done without the cooperation of the local people, because they are the ones who best know their own territory.

We estimated the number of territorial pairs per unit area. We based these estimates on the spacing amount neighboring pairs, indicated by active nests.

Since our study nests were not generally in predetermined study plots that had been exhaustively searched for them, we used the average distance between neighboring nests to estimate densities of territorial pairs. Nests position were recorded with a hand-held GPS and plotted on a digital map.

Nearest-neighbour distances (NNDs) between pairs were used as a measure for the Maximum Packed Nest Density (MPND) method to set an upper limit on the density that could be possible for the available habitat under a given mean inter-nest distance. To calculate distances, each of a group of  $n$  nests is joined by a straight line to its nearest neighbor, yielding  $n-1$  inter-nest

distances and a single mean inter-nest distance (Gower and Ross 1969; Selas 1997). NNDs were calculated using known occupied nests.

To avoid inflating estimates with sites that were obviously not, or might not be, ‘nearest’ neighbours, only was used adjacent, closest or clearly neighbouring sites in contiguous or nearly contiguous habitat. We excluded nests that were separated by large expanses of open landscape or which, if within the same block of forest, were so far apart (arbitrarily defined as 2.5 times the minimum inter-nest distance as used for Philippine eagle (*Pithecophaga jefferyii*) distribution and nesting study in Mindanao Island (Bueser *et al.* 2003) that they might include other, undiscovered, territories.

GMASD statistic of Brown (1975) was used to test whether nests were more evenly distributed than if sites were selected by the birds at random. To do that we take the ratio of the squares of the geometric and arithmetic means of nearest-neighbour distances. Values of this ratio greater than 0.65 indicate regular spacing, while lower values indicate randomness (Nilsson *et al.* 1982).

The area per nesting pair ( $A$ ) is given by:

$$A = \pi r^2 * 1.158$$

where  $r$  is half the mean inter-nest distance, adjusted by multiplying by a constant that includes the portion of the non-overlapping area between neighboring territories (Brown 1975, Whitacre 2012). This equation assumes that spacing is completely regular and that the maximum possible packing of nesting territories is achieved.

Neighbor nest distances offered a way of estimating overall carrying capacity in areas of known suitable habitat. An estimate of pair spacing can be used to extrapolate population carrying capacity if the area of suitable habitat is known. Carrying capacity may be an important estimate for setting a target population size for endangered species.

#### *Habitat characteristics:*

A circular plot (radius = 1/2 NND), using the mean NND, was drawn around all nests and pair locations, including additional isolated or non-neighbouring sites. The extent of each type of vegetation cover (Flooded forest, Terra Firme forest and Degraded landscape) was determined within each circular plot using GIS software (ArcGIS® by ESRI). Degraded landscape included roads, oil palm plantations and residential

lands. We also took into account physiographic features such as elevation, vegetation cover, distribution of water or human development. Altitude was taken in account and it was estimated by a hand-held GPS.

Habitat-related terms follows Hall *et al.* (1997). In brief, *habitat* is an area suitable for an organism to use. Habitat composition in the study area was determined using the 1: 250,000 digital map of Ecuador geographical features generated by Ministerio del Ambiente del Ecuador and EcoCiencia (2005) and the 1: 1,000,000 vegetation structure created by Sierra (1999).

Nine variables were taken into account for analysis: altitude (A), percentage per circular plot of rivers (Rv), Terra Firme forest (TF), Flooded forest (FL) and degraded landscape (FD), distance to indigenous settlements (Di), distance to forest edge (Dfe), distance to urban areas (Dua), and distance to roads (Dr) (see Table 2) . A modified Kolmogorof-Smirnov test was used for testing normality of the data distribution (Massey 1951). Data were analyzed using descriptive and non parametric statistics. Spearman's correlation coefficient measured dependence between variables. Spearman correlation of +1 or -1 occurs

when each of the variables is a perfect function of the other (Spearman 1904).

Kruskal-Wallis one-way analysis of variance tested whether samples originate from the same distribution. A significant Kruskal-Wallis test will indicate that at least one sample stochastically dominates one other sample (Kruskal and Wallis 1952).

Factor analysis (Thurstone 1931) using Principal Component Analysis (PCA) with variance maximizing (varimax) rotation was used to detect structure in the relationships between forests subtypes and spatial location of the nests. The goal in varimax rotation is to maximize the variance (variability) of the "new" variable (factor), while minimizing the variance around the new variable.

The thematic layers of vegetation types that were located below 1200 m.a.s.l. were superposed using GIS software (ArcGIS®) to create a digital map of potential areas in Ecuador where Harpy eagles breeding pairs could be located.

## Results

### *Nest searches and nesting density*

Locations of all nests are shown in Map 1. From 2002 to 2011 we located 17 Harpy eagle nests. One of them was an inactive alternative nest and one different was an old nest that was not used by eagles in the study period of time. All nests were built on emergent trees: 16 nests were in Kapok trees (*Ceiba pentandra*) and the remaining in a Cedrelinga tree (*Cedrelinga catenaeformis*). Only active nests (n= 15) were considered for the following analysis.

All but four nests were located in the Cuyabeno Wildlife Reserve.

Altitude of the nest sites ranged from 206 to 244 m a. s. l., averaging 219 m a. s. l. ( $\pm 11.7$  m, N= 15).

Nearest-neighbour distances (NNDs) between closest pairs averaged  $4.9 \pm 0.7$  km (n= 6; range 4.2- 5.9; N= 6).

The GMASD statistic value was 0.98 that means a high degree of regular distribution of breeding territories.

The resulting circular plots averaged  $19.6 \pm 5.7$  km<sup>2</sup> per breeding pair that means a maximum theoretical

nesting density of 5 nests/100 km<sup>2</sup> in continuously suitable nesting habitat.

Nests were found at different distances from indigenous communities and average separation was  $5.9 \pm 4.9$  km (range 1.3-20.1 km).

### *Habitat types*

Forests (both Flooded and Terra Firme) contained more than 90% (90.2  $\pm 7.3$  %, N=15) of the vegetation types used by the Harpy eagle in its breeding area. Those that were closer to human settlements (nests 1, 7, 9, 11, 12 and 13) were the nests which contained some proportion of degraded forest defined as mosaics of forests at various stages of degradation and human-induced modification characterized by oil palm plantations and roads (5  $\pm 2$  %). Rivers occupied the rest of the area calculated.

A Chi-Square test showed significative differences in forest type contribution to the nests (Chi-square = 25.707; d.f.=2; P= 0.00). Flooded forest (67  $\pm$  6.1 %) was the most representative type of forest in the Harpy eagle breeding area studied, followed by Terra Firme forest type (23  $\pm$  5.6%) (see Graph 1).

Six nests were located within  $18.6 \pm 2.8$  km of urban areas ( $> 1000$  inhabitants).

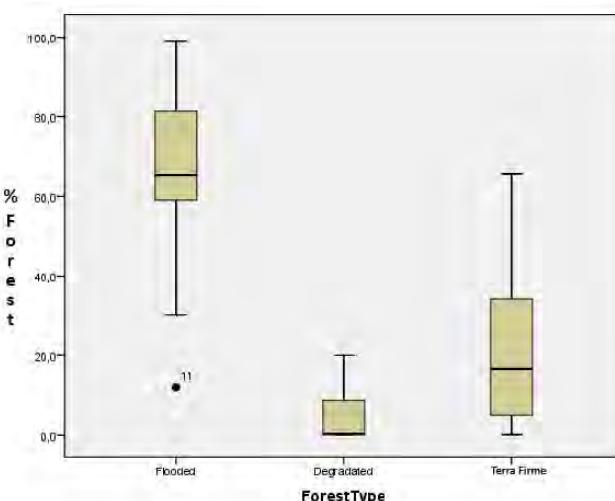
Correlations between degraded forest proportion in a breeding area and distance from the nest to an urban zone resulted in a negative relationship (Spearman's rho = -0.758; P=0.001).

No correlation was found for degraded forest in a breeding area and distance to an indigenous settlement (Spearman's rho = -0.172; P = 0.541).

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	4.946	54.960	54.960
2	2.245	24.946	79.906
3	.763	8.476	88.381
4	.648	7.201	95.582
5	.329	3.657	99.239
6	.046	.511	99.749
7	.014	.160	99.909
8	.008	.091	100.000
9	.000	.000	100.000

**Table 3: Distribution of the variance by component**

The factor analysis showed that the nest-site variables included in this study are highly related and therefore can be reduced as evidenced by the index of Kaiser Meyer Olkin (K.M.O.= 0.6).



**Graph 1: The boxplot displays a significative different contribution of forest types to Harpy eagle breeding areas. Flooded Forest is the most representative vegetation type for nesting sites. Note right-skewed data and an outlier in Flooded Forest type.**

This correlation between the variables is confirmed by the Barlett's Sphericity test since its value is statistically significant (Chi-square = 246.136; df: 36; P = 0.000 ) so that the procedure of analysis of factors applies for this study.

The distribution of the variance explained by the components of the model is showed in Table 3. Two factors explained 79.9% of the original data variance. Table 4 allows to compare the relative overruns of each variable by factor; the first factor is formed by the variables: Distance to urban areas (Dua), degraded landscape (Df) and distance to road (Dr). All these variables saturated in a single factor

because they constitute a distinct group of variables within the matrix of correlations. This factor seems to reflect the constraints of existing anthropic influence.

The second factor collects the variables designated as Flooded forest (FL) and Terra Firme forest (TF), which would come to represent the forest type around nests (See Table 4).

Variable	Component	
	1	2
Dfe	.986	.121
Dua	.982	.144
Dr	.957	.215
Rv	.791	-.289
A	-.756	-.257
FD	-.706	-.162
FL	.116	.952
TF	.055	-.944
Di	.318	.687

Table 4: Rotated component matrix.

A component plot of the rotated factors (Figure 1) shows how the variables associated with the same factor appear next to each other in the common factor space.

Map 2 displays a map of available habitat showing an hypothetical distribution of Harpy eagle breeding pairs in Ecuador assuming that the entire vegetation types of the circular

plots are representing the vegetation type used by pairs and 1,200 m.a.s.l. is the maximum altitude. Counting both areas at the west and east of the Andean mountains a potential area of 77,849.86 km<sup>2</sup> could be suitable for nesting Harpy eagles in Ecuador.

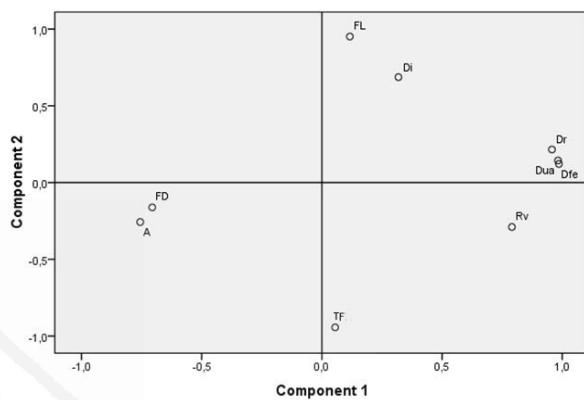


Figure 1: Component plot in rotated space.

If the entire areas of the circular plots are used as representing the spacing needed by territorial birds between each other, and these are fitted into Cuyabeno Reserve (5,901.12 km<sup>2</sup>), the simple estimates for the total maximum number of breeding pairs drop to 295 pairs. These calculation assume that the birds are maximally packed into the available habitat, ignoring all "edge" and territory shape considerations.

## Discussion

### *Altitudinal pattern*

Altitude data for nest in our study are similar to altitude levels reported for Amazon Basin of Peru (below 202 m a.s.l.; Giudice 2005) and Brazil (below 150 m a.s.l.; Aguiar-Silva 2014). In Center America altitude was reported below 310 m a.s.l. (Vargas and Vargas 2011) and in Argentina below 515 m a.s.l. (de Lucca 1996). Taking into account that the maximum altitude of our study area is 360 m a.s.l. (Ministerio del Ambiente 2012) we would expect this result in altitudinal range for our nest sites.

Parker *et al.* (1996) assembled a database of ecological and distributional information for Neotropical birds. They assigned the Harpy eagle to the Tropical Lowland Evergreen Forest type, broadly characterized as <900 m in elevation and >2,000 mm rainfall per year (Stotz *et al.* 1996). Although our nest locations are included in this description, it is necessary to sample forests at higher altitudes in order to elucidate the presence of Harpy eagle breeding areas as might foreseeable for the presence of a couple at 1,100 m a.s.l. in Ecuador, included in Tropical Montane Cloud Forests

vegetation type (Sierra 1999). A landscape level transect for the Harpy eagle distribution in the eastern portion of the Venezuelan Guayana shows lands where the eagle was present that surpasses 1,000 m elevation (Álvarez-Cordero 1996).

A study in Panama came to the conclusion that tree height was one of the factors that determined the nesting place of the Harpy eagle, resulting in an average value of 16.2 m high (Vargas *et al.* 2014). In our study area the most common tree selected for this species to build the nest is the kapok tree (*Ceiba pentandra*). The Kapok tree is a heavily buttressed, canopy-emergent tree. It can reach 70 m in height and it is limited by elevation (it does not exist above 1,500 m.a.s.l.) (Dick *et al.* 2007).

There is a significant decline in tree height with increasing elevation in Ecuador (Girardin *et al.* 2014). Most published studies report structural and functional differences in Tropical Montane Cloud Forests compared with Lowland Rainforests, showing an increase in stem density, basal area and soil organic matter depth and a decline in tree height, leaf area index and tree species richness with altitude (Tanner 1980, Raich *et al.* 1997). All of the studies associate these trends with cooler temperatures, fog, reduced light

incidence and higher relative humidity. At 1,200 m a. s. l. in Ecuador tree height ranges 10-21 m (Girardin *et al.* 2014) so this altitude would contain trees with height enough to be selected for the Harpy eagle if tree architecture is appropriate.

The distribution patterns of most animal species reveal clear altitudinal preferences and limits, which can usually be related to their thermal physiology. Food webs may be altered by elevational shifts (Beck *et al.* 2008). Sixty-nine species of mammals, birds and reptiles have been described as part of the Harpy eagle diet from Central to South America (Fowler and Cope 1964, Rettig 1978, Izor 1985, Chebez *et al.* 1990, Álvarez- Cordero 1996, Touchton *et al.* 2002, Muñiz-López *et al.* 2007, Piana 2007, Rotenberg *et al.* 2012, Aguiar-Silva 2014) but sloths were the most frequent prey in their diet followed by primates (Aguiar-Silva 2014, Miranda 2015)

Sloths genus *Choloepus* and *Bradypus* ranges from sea level up to 2,400 m a. s. l. (Britton 1941, Ureña *et al.* 1986). Although primates as capuchins (genus *Cebus*) or red-howler monkeys (genus *Alouata*) are mostly lowland species both have been recorded up to 2000 m a. s. l. (Berton *et*

*al.* 2008, Hernández-Camacho and Cooper 1976).

According to these data it can theoretically be said that it should not be unusual to find Harpy eagle breeding areas at least at altitudes of 1,200 m a. s. l. as they have availability of food resources and nesting trees if habitat is undisturbed.

#### *Nesting density*

Raptors nests that are located in relatively continuous habitat are often separated from one another by roughly equal distances in a fairly regular manner (Brown 1970, Newton *et al.* 1977). Such distributions permit population density and size estimates via sampling and various spatial statistics such as nearest neighbour distances (e.g. Clark and Evans 1954, reviews in: Ripley 1985, Krebs 1999). Opposite to the results reported by Thiollay in French Guiana (Thiollay 1989b) we found a regular distribution of breeding territories. Thiollay concluded that Harpy eagles have extremely low densities and patchy distributions. This difference in regularity of nest spacing may be due to the very small sample size (three observed individuals and no nest) in his study as he worked in an unbroken

rainforest where there should not exists constraints that could affect the regular distribution of the eagles.

The use of methods based on the distance to the nearest nest is a very helpful approach to the determination of the patterns of distribution of species. At the theoretical level, it is predicted that the territory size is inversely related with the abundance of food so that individuals will establish territorial sizes that contain adequate resources to maintain their energy needs (Dunk and Cooper 1994). NND offer a direct way of estimating overall carrying capacity in areas of known suitable habitat.

In previous studies about Harpy eagle nest density it was found that neighbour nests distances averaged 3.8 km and density 10-20 km<sup>2</sup> per pair ( $n= 5$ ; Álvarez-Cordero 1996) and 4.1 km and 16-24 km<sup>2</sup> per pair ( $n=18$ ; Vargas and Vargas 2011) in Panama (Darien region), 6.3 km and 45-79 km<sup>2</sup> per pair in Venezuela ( $n = 5$ , calculated for sites < 8 km apart considered to be nearest neighbors; Álvarez- Cordero 1996), 7.4 km and 43 km<sup>2</sup> per pair in Amazonian Peru ( $n= 3$ ; Piana 2007), and 5 km with no density estimation ( $n=2$ ) in a Brazilian Atlantic Forest reserve- one found in 1992 and other in 2010- but it was no clear if both nests were used by the same pair (Aguiar-

Silva *et al.* 2012). Thiollay (1989b) estimated an average of 100 to 300 km<sup>2</sup> per pair (3.1 individuals/100 km<sup>2</sup>) based on three observed records in French Guiana. We will not consider this two last reports for analysis because uncertainty of data.

Our results do not differ too much from those of Panama found for Vargas and Vargas but distances are smaller than observed for Amazonian region in Peru and for Venezuela.

These differences may be due to different availability of resources between particular study areas. When resources are scarce territories became larger (Pyke *et al.* 1977). Assuming that raptor breeding territories are determined, in part, by food availability (e.g. Marquiss and Newton 1981, Village 1982) habitats with greater productivity should be, then, in a higher density of breeding Harpy eagle events and a reduction in the size of territory (Yosef and Grubb 1994). On the other hand, success finding the shortest internest distance and sample size in different studies might be causing these discrepancies. In addition, differences in estimates of nesting density may appear as result of different methodological approaches. Álvarez-Cordero (1996), Piana (2007) and this study applied Maximum Packed Nest Density method

while Vargas and Vargas (2011) compared this procedure with the polygon method resulting in a higher area per pair with the second technique ( $16 \text{ km}^2$  vs.  $24 \text{ km}^2$ ). Thiollay did not use inter-nest distances as he did not find any Harpy eagle nest in his survey but he concluded density using three observed encounters.

Our estimates are similar to reported in Panama with the Maximum Packed Nest Density method. Analogous undisturbed Lowland Evergreen Rainforest were reported for both study areas. A homogeneous distribution of resources both trophic and suitable places for nesting, lack of competitive interactions between sympatric species with similar ecological demands (Begon *et al.* 1996) and the absence of human habitat alterations or persecution could explain a regular and similar distribution in both areas.

There seems to be a general pattern in breeding-range size in areas that offers enough resources and have carrying capacity to maintain this density of Harpy eagle pairs suggesting that phylogenetic and behavioural factors could be influential in spatial territorial use. Harpy eagle has specific morphological features such as a big body size, very robust tarsi, wide wings

and long tail that may influence its foraging behaviour and selection of breeding sites. Although individual and environmental factors may influence the use of space patterns shown by Harpy eagles, these birds are also apparently limited by their own morphological and phylogenetic characteristics.

Large species have high energetic requirements and presumably must occupy large home ranges to obtain sufficient food (Zachariah Peery 2000) but tropical species have lower territorial requirements than those of temperate regions (Keran 1978). For example, Crowned eagle (*Stephanoaetus coronatus*) is the only large eagle in sub-Saharan Africa found in primary forest. It has similar skeletal morphology to the Harpy eagle (del Hoyo *et al.* 1994) and its NND averages  $1.8 \pm 0.43 \text{ km}$  (range  $1.1 - 2.5 \text{ km}$ ) with an estimated density of  $6.5 \text{ km}^2$  per pair (Shultz 2002). This distance is even smaller than closest pairs of neighbors found for Harpy eagles ( $2.3 \text{ km}$  in Panama; Álvarez-Cordero 1996) and density is higher than all Harpy eagle reported data. On the contrary and to illustrate differences with temperate regions, Golden eagle (*Aquila chrysaetos*) may serve as an example because it is a Holarctic distribution species that is similar to the previous in

terms of size and weight but its mean NND is  $9.7 \pm 3.8$  km and density estimation is  $285.7 \text{ km}^2$  per pair for a southeastern region in Spain (Carrete *et al.* 2001).

However the Philippine eagle (*Pithecophaga jefferyi*) that is other big sized raptor species which lives in tropical geographical range and occupies forest habitat, has nest neighbour distances much higher than Harpy eagles (mean inter-nest distance was calculated at  $12.6-12.7 \pm 0.9$  km with the minimum at 8.3 km and  $130 \text{ km}^2$  per pair; Bueser *et al.* 2003). This difference may be due to anthropogenic habitat alteration and disturbance in their breeding habitat (Bueser *et al.* 2003). As suitable habitat is reduced due to fragmentation, resources became more restricted and eagles will need bigger territories (Zachariah Peery 2000).

Breeding areas are used continuously by Harpy eagles as juveniles until a new reproductive cycle starts (Álvarez-Cordero 1996, Muñiz-López *et al.* 2012). Thus it would be desirable to regulate disturbing activities (lodging, overhunting, major infrastructures and urban development, etc.) all year round.

### Habitat:

Studies on the habitat of the Harpy eagle are still scarce. The presence of nests in our study area was influenced by two main elements: anthropic pressure and structure of the forest. Results of habitat analysis in our study indicates that Harpy eagle breeding areas occurs especially in Flooded Forests which are usually originated along river sides. However it has to be taken into consideration that this result could be biased as most nests were found near the edges of rivers or streams, probably due to the ease of access they provide to the nesting areas.

Flooded Forests comprise the second major vegetation type in the Amazon (Ferreira 1997). The low-lying topography of the basin and seasonality of rainfall inundate these floodplains for up to six months of the year, and the annual water level fluctuation of the rivers can reach 14 m in amplitude (Ferreira 1997). Although Terra Firme is found to be consistently more species-rich than Flooded Forests (e.g. Balslev *et al.* 1987, Peres 1997, Patton *et al.* 2000, Haugaasen and Peres 2005 a, b), the aggregate primate density in Terra Firme Forests seems to be considerably lower than that in the species-poor Flooded (Haugaasen and

Peres 2005 a, b). Consequently, the total biomass estimated will be much higher in Flooded compared to Terra Firme Forest. (Haugaasen and Peres 2005b). Many arboreal folivores (which account for more than half the biomass of non-volant mammals in Neotropical forests) show an abundance gradient increasing from Terra Firme to Flooded Forests; species exhibiting this pattern include sloths (Peres 1997; Eisenberg and Thorington Jr. 1973) that are the main prey for Harpy eagles (Álvarez-Cordero 1996, Piana 2007, Muñiz-López *et al.* 2007, Aguiar-Silva *et al.* 2014). In addition, Howler monkeys (*Alouatta* spp.) are the second main prey for this eagle and their population density is positively correlated with forest structural heterogeneity, soil fertility, and degree of seasonality, all of which are higher for Flooded Forests (Peres 1997).

Flooded Forests hold canopy-emergent trees. Fourteen Harpy eagle pairs selected Kapok tree (*Ceiba pentandra*) to establish the nesting platform. This is a heavily buttressed tree than can reach 70 m in height and one of the most common tree species inhabiting the Flooded Forests. It has a worldwide tropical distribution growing in the Caribbean, northern Mexico to northern South America and in many

countries of tropical West Africa. (Dick *et al.* 2007). Kapok commonly colonizes riverbanks, but is able to grow in both Floodplain soils and Terra Firme soils that exist above the average inundation level.

One nest was built on a cedrelinga tree (*Cedrelinga cateniformis*) in a Terra Firme area. This is a characteristic tree of the upper canopy that is restricted to Terra Firme land; however, it is possible to find it also in flooded habitats and on hills in the Peruvian, Colombian, Brazilian and Ecuadorian Amazon and in Suriname (Duke 1981). Considering this information habitat features of Flooded Forests may offer good conditions for nesting trees and food availability for Harpy eagles.

The records for Venezuela (i.e. Caura River and Orinoco Delta; Álvarez-Cordero 1996), and some areas in Amazonian Peru (Piana 2007), indicate that Harpy eagles routinely utilize flooded and river-edge forests; In Peru five of nine nests were found in Terra Firme Forests (Giudice 2005). That study suggested that this preference may be due to the fact that from that forests eagles would have a best place to locate potential prey and to get greater protection against predators. Opposite to that conclusion our study adduces that Flooded Forests can be at

least as suitable and advantageous as Terra Firme Forests could be. Harpy eagle may be able to nest or to forage from any of the emergent trees that are found both in Terra Firme and Flooded Forests but as an specialist raptor it might prefer areas that offer a greater amount of preferred prey, i.e. greater abundance of certain species and not so much greater diversity, so that Flooded Forests may be the best option.

Nests were located in areas with low anthropic pressure and relatively far away from urban areas. It was expected to find this type of result in our study as we worked at Cuyabeno Reserve and boundaries and it is a well conserved area where degraded forest percentage is still small (0.1 %) (Rodríguez and de Vries 1994, Ministerio del Ambiente 2015).

Indigenous communities were relatively close of the Harpy eagle nests found in this study. In other investigation in Amazonian Brazil there were found 15 nests averaging 1.5 km (0.6-2.5 km) away from local communities (Aguiar-Silva 2014).

This proximity could be a reflection of favorable or acceptable conditions kepted in their territories for years that allowed Harpy eagles to share their breeding areas close to this kind of human settlements. If this conserved

forests keep resources available for eagles and if they do not suffer pressures or anthropogenic disturbances, then the presence of communities may not be converted into a factor that disadvantage the presence of eagles. On the other hand, competition of resources used both for humans and eagles (e.g. food as primates or timber species as cedrelinga or kapok trees) may decrease the availability of nearby feeding areas or nesting trees and this could foment the displacement or disappearance of Harpy eagle breeding pairs that are sharing territories with humans.

Shootings, persecution and other direct human impairment of Harpy eagles as removal of live eagles from their habitat could happen the more near the villages are and may impact on their population stability.

In our study area indigenous communities have coexisted since their origin with the eagles. These form part of their worldview and the Harpy tend to be respected by their condition of mythological beings that represent forces of nature. It is not usual to have news of shooting or any other disturbance in their territories but colonist do not have the same relationship with this species and conflicts have been reported.

Educational and awareness programs could bring the local people to a better appreciation and knowledge about this species and help to reduce this kind of pressures not only on Harpy eagles but on wildlife.

A few nests were located outside the Reserve boundaries and all were successful. In spite of the fact that the area in which they were found has a higher degree of Earth's surface transformation (deforestation and agricultural extensification) compared with lands inside Cuyabeno Reserve the state of the forest is still in a relatively good situation and well conserved probably due to the low density of human population and a non massive exploitation of natural resources in that area. Habitat degradation is not yet evident but the advance of African Palm plantations, new and more populated human settlements are arriving and the construction of infrastructure to develop the oil industry is increasingly growing in the province.

Specialist species tend to be located in less fragmented and less disturbed landscapes than generalist (Devictor *et al.* 2008). They are expected to benefit from environments that are relatively homogeneous whereas ecological generalists should benefit from environments that are heterogeneous

(Kassen 2002, Marvier *et al.* 2004, Östergård and Ehrlén 2005).

The fact that habitat degradation should negatively affect specialists is predicted by niche evolution theory: the more specialist a species, the more negative its spatial response to landscape fragmentation and disturbance (Holt and Gomulkiewicz 2004).

The Harpy eagle is a specialist raptor (Álvarez-Cordero 1996; Fam and Nijman 2011) and this could be an argument to expect this species to be negatively affected by landscape disturbance as natural selection has favored their development in stable environments (Kassen 2002). Empirical findings suggest that the decline of specialist species observed worldwide is likely to be related to human-induced landscape degradation (Devictor *et al.* 2007).

Álvarez-Cordero (1996) suggested that the eagles were quite tolerant of human landscapes as long as the forest matrix remained. In Venezuela large portions of the habitat of this raptor reverted to production forests managed by logging companies. In his study area he described a breeding area surrounded by an intensive logging activity where one pair successfully completed incubation and hatched a nestling that

later fledged. He monitored six nests where eagles completed 1-2 breeding cycles while the immediate habitat was undergoing logging. In an study in Amazonian Peru there were reported six Harpy eagle nests and four were located in a land that was heavily used by the local settlers in order to subsistence hunting and collection of palm leaves and fruits. Additionally two nests were found abandoned in areas that were less than 100 m of roads and surrounded by activities of non-mechanized forest extraction and palm exploitation (Piana 2007). Other study in Panama found 30 nests, 25 were located in primary forest, and five were in areas of human use (agriculture or fallow farmland > 2 ha were agriculture had ceased less than 10 yr ago) (Vargas and Vargas 2011).

It is known that habitat loss affects the survival not only of the Harpy eagle but other species of raptors that depend on forests (Burnham *et al.* 1988, Stotz *et al.* 1996) and perhaps this examples only indicate a short to mid-term resiliency of the Harpy eagles in the face of massive intervention (Álvarez-Cordero 1996). Long-term evaluation of this land management and related breeding success should continue to determine to what extent the adaptability of these eagles can hold

different degree of particular human activities.

Habitat loss and human persecution were identified as the main threats that affects Harpy eagle populations at an international level (BirdLife International 2015). Ecuador exemplifies the challenges in balancing conservation and development, with the highest deforestation rate in South America over the last 15 years (Pinter *et al.* 2015) but it has about 20% of its territory (excluding marine reserves) under some degree of protection (Ministerio del Ambiente 2015), and this situation positions it as one of the Latin American countries with the most area under some type of protected status (Elbers 2011).

The conflict between conservation and development is evident in the Ecuadorian Amazon, where deforestation has been closely linked to the oil industry (Kimerling 1990, 1993; Uquillas 1984) and where more oil industry growth is expected due to the large oil reserves in this region (Energy Information Administration 2005).

Zones of conflict within or surrounding the protected areas emerge where there are trade-offs and inconsistencies between development and conservation, especially in cases where colonist and indigenous residents

have competing land uses and needs. The main threat that affects the integrity of the Reserve and boundaries and its biodiversity corresponds to the existing pressure in the buffer zone and the header of the Cuyabeno river by the use of natural resources due to extractive activities such as oil, timber and monocultives, in addition to the expansion of the agricultural frontier and colonization (Mena *et al.* 2006).

Large-scale studies provide greater understanding of species habitat characteristics by revealing the nature of upper level constraints. The future of Harpy eagle population at the east of the country has a good projection if deforestation processes and land cover changes are brought under control. At the west of the Andean Mountains the circumstances are different. Unfortunately, the West Ecuadorian region is one of the places in the world where biodiversity is considered most at risk (e.g. Myers 1988, Parker and Carr 1992). This region is greatly threatened by habitat loss and fragmentation caused by rural-urban development, agricultural activities, uncontrolled logging, and an inadequate management of natural resources (Sierra 1996). This is an area that has been severely deforested and less than 4% of the

original western Ecuadorian forests remain (Cerón *et al.* 1999).

The western region has only 5.1 % of its territory protected by the Government through four state reserves that comprise 101,434 ha. Although this region has experienced extensive transformation of the original ecosystems by intensive agriculture (Sáenz and Onofa 2005) small patches of natural vegetation still remain in this heavily altered zone and they could be a shelter of species as Harpy eagle but high habitat degradation, small extension of protected forests, and few protected areas reduces the chances of finding areas with high biodiversity conservation feasibility.

An active Harpy eagle nest was found in 2004 in the northwest of Ecuador (Muñiz-López 2005) but the nest tree was destroyed five years later because of the incursion in the nesting area of informal mining activity. Despite visits of ornithologists to this forests and the sporadic interviews of this research team to the local people we did not have any report of sightings from the year 2006, which suggests that couples remnants may have been moved to the most inaccessible places and that this species has a very low population density that makes them difficult to discover at the west. Although in

Ecuador the Harpy eagle is considered as a vulnerable species, in the coastal region it may be considered as Critically Endangered (Ridgely and Greenfield 2001).

Human persecution may be reduced with educational and awareness programs. Giving indigenous peoples legal rights to their ancestral lands seems to be a good way to ensure that substantial areas of tropical rain forest survive.

Individual species cannot be protected effectively outside the biological context afforded by the community they occupy but “Flagship” species concept (“*popular charismatic species that serve as symbols and rallying points to stimulate conservation awareness and action*”; Heywood 1995) is an important public relations device. It provides a way of communicating to a wide audience the plight of a local ecosystem. Using this technique could be useful to accomplish ecosystem conservation (Stotz *et al.* 1996).

Managing populations largely depends on managing or maintaining habitat (Anderson and Gutzwiller 1994). Habitat quality is involved in the regulation of the raptor populations and determines the species’ settlement pattern (Newton 1998). Further investigation of the habitat requirements

of this endangered species is crucial to many aspects of its conservation (Manly *et al.* 1993, Noss *et al.* 1997) as both nesting and foraging habitats may play an important role in limiting bird population numbers or distribution (e.g. Newton 1998).

Tropical rainforest habitat degradation and fragmentation are one of the most pervasive threats to the conservation of biological diversity. Efforts to conserve Harpy eagle habitat may include to link biodiversity conservation in protected areas with local, social and economic development (Brown 2002, Hulme and Murphree 1999) involving Integrated Conservation and Development Projects (ICDPs), community-based conservation, political will and extractive reserves control that may be of great help to safeguard the survival not only of the eagles but the vastness biodiversity that refuge the forests where they live.

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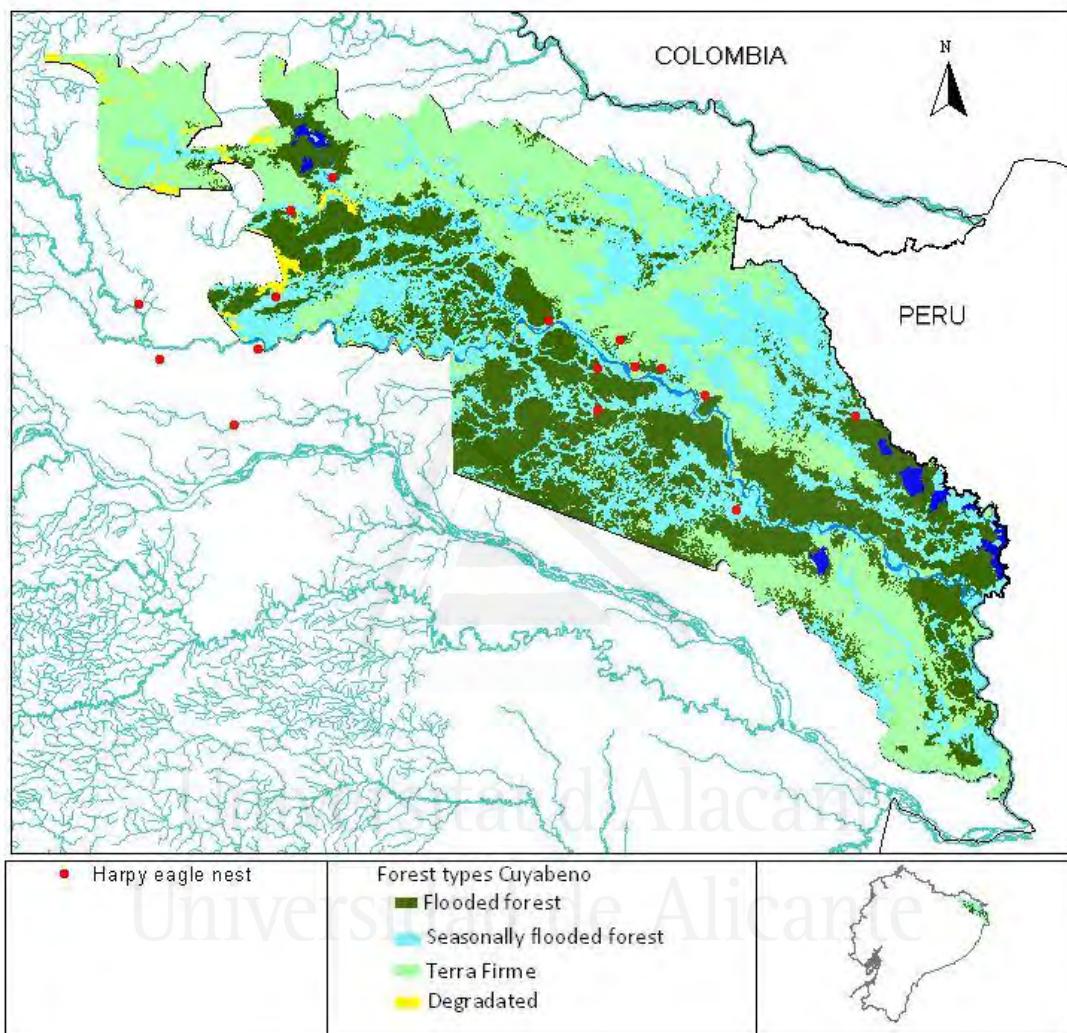
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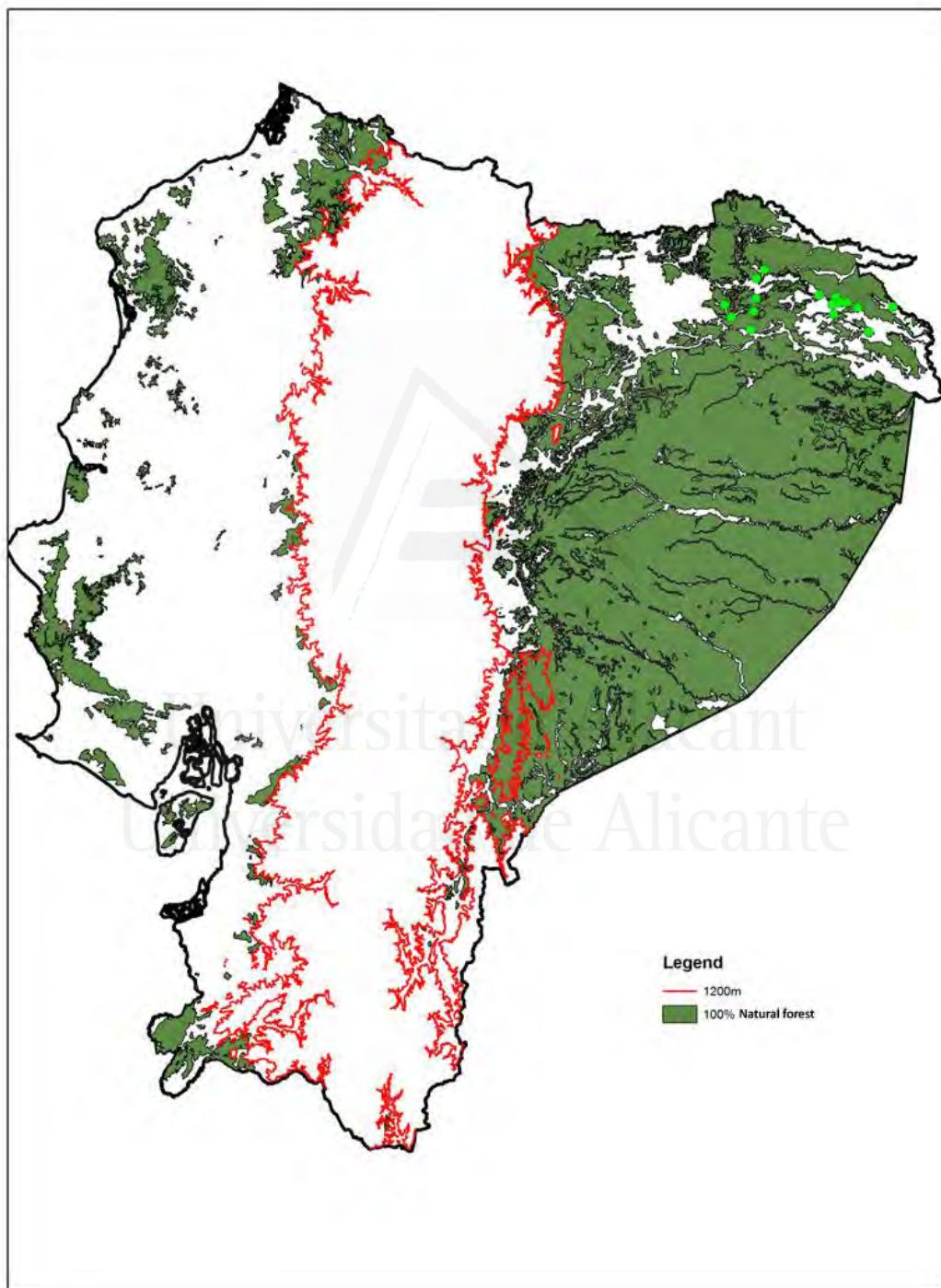
**Table 2: Harpy eagle breeding areas variables in a plot of 4.2 km radius from the nest site.**

<b>Variables</b>	<b>Description</b>	<b>Code</b>	<b>Nest 1</b>	<b>Nest 2</b>	<b>Nest 3</b>	<b>Nest 4</b>	<b>Nest 5</b>	<b>Nest 6</b>	<b>Nest 7</b>	<b>Nest 8</b>	<b>Nest 9</b>	<b>Nest 10</b>	<b>Nest 11</b>	<b>Nest 12</b>	<b>Nest 13</b>	<b>Nest 14</b>	<b>Nest 15</b>
Topography	Altitude	A	243	210	213	216	210	206	220	212	224	211	230	218	244	225	212
Habitat	Terra Firme forest (%)	TF	35.3	0	64.7	34.9	33.7	0.02	12.6	10	0	11.2	65.7	16.7	29.1	0	28.4
	Degradated forest (%)	DF	3.4	0	0	0.3	0.1	0	18.4	0	20	3.1	18.4	13.8	2.7	0	0.1
	Flooded forest (%)	FL	59.2	97	30.2	58.9	59	93.9	65.4	84	76.5	78.6	12	68.2	63.4	98.9	64.7
	Distance to forest-field edge	D <sub>fe</sub>	10.9	77	70.5	75	82	101	19.2	68.6	2.1	52.4	6.3	9.4	17.1	12.9	75.5
	Distance to roads	D <sub>r</sub>	6.2	81	58.8	63.7	70.1	88	13.4	50.1	3.9	43.3	1.4	4.9	14.1	13.2	53.3
	River area	Rv	2.1	3	5.1	5.8	7.2	6.1	3.6	6	3.4	7.1	3.9	1.3	4.8	1.1	6.8
Settlements	Distance to indigenous settlements (< 1000 inhabitants)	D <sub>i</sub>	3.8	14	3.1	6.4	3.5	20.1	4.6	3.6	2.8	3.5	1.9	7.5	6.7	5.2	1.3
	Distance to urban areas (km)	D <sub>UA</sub>	16	68.5	67.3	74	81	94.6	20.4	65.5	22.9	56.1	16.4	17	20.9	28.6	68.5
Ethological	Min Inter-nest distance (km)	D <sub>IN</sub>	8.2	5.7	3.6	4.8	8.4	18.2	5.9	4.9	8.9	10.7	9.1	20.1	8.2	8.9	3.6

**Map 1: Harpy Eagle nest location and Cuyabeno Reserve forest types.**



**Map 2: Potential breeding habitat of Harpy Eagle in Ecuador in dark green colour. Note light green points showing nest locations.**





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## CAPÍTULO 6



Macho de Águila Harpía muerto por disparo cerca de la comunidad de Dureno. Sucumbíos. Ecuador.  
Foto: F. Solórzano.

### Historia de los Shiwiar de Pastaza:

*“El día en el que Ramón Gualinga iba a pasar la prueba para superar la transición de joven a adulto, su tío tuvo un sueño premonitorio. En él visualizó un águila harpía que se le aparecería en el camino y que se lanzaría hacia él atacándole. En ese momento, Ramón no se podría amedrentar, por lo que allí mismo tendría que matar al águila con su cerbatana. Ramón salió al bosque y sucedió todo tal y como le había dicho su tío. Ocurrió el encuentro con el águila y éste la mató con una flecha. Ésa era la prueba que tenía que superar. Conservó los huesos en una pequeña bolsa de piel y las guardó para que le acompañaran el resto de su vida. Éstos le darían fuerza, poder y entereza, cualidades que le siguen hasta hoy día. Salvo en esa ocasión, nunca había matado un águila harpía, pues para ellos encontrarse con una de ellas en el bosque les confiere suerte para la cacería. Si las matan, esa misma suerte se les vuelve en su contra”.* (Mayo 2001. Entrevista con Ramón Gualinga-dirigente de ONSHIPAE (Organización de Nacionalidad Shiwiar de Pastaza-Ecuador)\*

\* Muñiz R. 2001. Memoria del estudio Biología y conservación del Águila Harpía en Ecuador. AECI (Agencia Española de Cooperación Internacional. España.)



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**Capítulo 6****MORTALIDAD DEL ÁGUILA HARPÍA EN ECUADOR.**

RUTH MUÑIZ LÓPEZ

**Resumen**

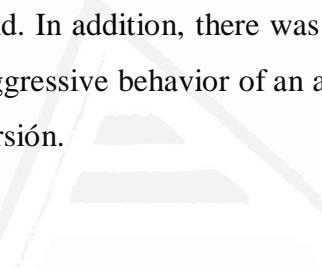
Como resultado del monitoreo continuado de la actividad en los nidos de Águila Harpía en Ecuador se obtuvo información que documenta los eventos de muerte de individuos de esta especie y sus causas en el área de estudio. Los registros de mortalidad adulta fueron menos frecuentes que los de mortalidad juvenil (9.4% mortalidad adulta y 28.6% mortalidad juvenil) y en todos esos casos las muertes se debieron a persecución humana (disparos). En los juveniles se encontró que las caídas durante el tiempo de aprendizaje de vuelo pueden provocar el resultado fatal. Además, se anota un caso de disparo y otro de muerte tras un comportamiento agresivo de un adulto hacia el juvenil en el momento en el que éste debía comenzar su dispersión.

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**HARPY EAGLE MORTALITY IN ECUADOR.**

RUTH MUÑIZ LÓPEZ

**Capsule:** Information about death incidents of harpy eagle in Ecuador were documented as a result of prolonged monitoring of their breeding activity. Adult mortality was recorded less frequently than juvenile mortality (9.4% and 28.6% respectively) and all adults were killed due to human persecution (shots) for different causes. It was found that juveniles could die if they fall or lose height from the canopy while learning to fly and become trapped near the ground. In addition, there was a case of shooting on a juvenile and another of death after an aggressive behavior of an adult toward the youth at the time that it should start its dispersión.



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## Introduction

Mortality rate is an important parameter for understanding the structure of a species' population and its population dynamics. At the individual level, the estimation of this rate is based mainly on information from ring recoveries and other identification marking tools such as wing tags, colour rings or satellite and radio tracking (Meyburg & Meyburg 2009). In most cases, however these records do not serve to detect causes of death.

In most of the large birds of prey, the mortality rate during the first year of life approaches or exceeds 50%, during the second year it drops to approximately 38 %, and amounts to less than 10% after that (Fish & Wildlife Service 2004). In general mortality is higher for younger birds than for adults in both passerine and larger and long-lived bird populations (Newton 1998).

Generally sources of natural mortality are rarely reported and are poorly known. The information presented in this work is the first about the natural and non-natural mortality of

the harpy eagle (*Harpia harpyja*) gained from continuously monitoring their breeding areas. The harpy eagle is a long lived tropical forest raptor that is considered one of the most powerful birds of prey in the world, as well as one of the largest (Collar 1989; Sick 1997). It is intermittently found from southern Mexico to northern Argentina (Vargas *et al.* 2006) in tropical and subtropical rainforests (Stotz *et al.* 1996). It feeds mainly on arboreal mammals, especially sloths and monkeys (Alvarez Cordero 1996; Galetti & Carvalho Jr. 2000; Piana 2007; Muñiz Lopez *et al.* 2007; Aguiar Silva *et al.* 2014). Harpy eagles breed every 2.5 to 3 yr and the resulting offspring, usually one per pair, fledge at about five months of age (Rettig 1978; Alvarez Cordero 1996; Muñiz Lopez 2007) and remains in the natal area under the parental care for at least two years before dispersing (Rettig 1978, Ruschi 1979, Alvarez Cordero 1996; Muñiz Lopez *et al.* 2012). The first active nest of a harpy eagle to be monitored in Ecuador was found in 2002 in the northeast of the country (Muñiz Lopez 2005). Its longevity in the wild is estimated to be 35 years

(Lerner *et al.* 2009).

In Ecuador, the species distribution is restricted to several small patches of forest in the northwest of the country and more consistently in the east, where Ecuadorian Amazon Basin starts (Guerrero 1997, Ridgely and Greenfield 2001, Muñiz Lopez 2002). The harpy eagle is currently considered “Near-Threatened throughout its range” (BirdLife International 2013). In Ecuador it is classified as “Vulnerable” (Granizo *et al.* 1997).

It is thought that the main reasons for population decline of the harpy eagle are human persecution and habitat deterioration (Vargas *et al.* 2006; BirdLife International 2013), although there is little information about how the species is affected by these (Gorzula & Medina Cuervo 1986; Alvarez Cordero 1996; Guerrero 1997; Ghomeshi *et al.* 2005; Vargas *et al.* 2006; Trape Trinca *et al.* 2008).

This paper presents the registration and causes of death of individual harpy eagles between 2002 and 2011.

### **Study area, materials and methods.**

The study was developed in two different areas. The first one was the Reserve Cuyabeno and its buffer zone in Sucumbios province in northeast

Ecuador. This zone included 15 of 16 nesting areas that were monitored. This reserve comprises 590,112 ha (Ministerio del Ambiente 2012) of humid tropical forest (Cañadas 1983). Culturally, it is divided into territories of the indigenous nations of Siona, Siecopai, Shuar, Cofan or Ai and Kichwa, which are located close to the main rivers.

The second one belongs to the coastal region of Esmeraldas province, in northwest Ecuador, where one nesting area was located (number 6; see Table 1). This zone lies in the Choco biogeographic area where the Afroecuadorian culture is present.

Our data were collected by direct observation by members of the Harpy Eagle Conservation Program in Ecuador (PCAHE in Spanish) and biomonitoring which are trained indigenous people or peasants located near the sixteen nesting areas. All nesting areas were visited at least once a week. Observations were made using binoculars from the ground or from towers 25 to 30 m in height. All dead specimens were found during these monitoring activities in the vicinity of their corresponding breeding areas.

## Results

We monitored 53 individual harpy eagles which consisted of 32 adults and 21 juveniles continuously throughout the 10 years of study. Nine cases of death were detected, which represents 17 % of the total individuals monitored.

We found that 9.4 % (n=3) of the monitored adults died during the study period. As shown in Table 1, all adult deaths were caused by non natural causes (gunshot). On the other hand 28.6% (n= 6) of monitored juveniles died during the study period which is 67% of the deceased eagles reported in this study (n=9). On five occasions (records 5, 8, 12, 13 and 16, see Table 1) juveniles fell to the ground and dead. There is one case (record 12; see Table 1) of a juvenile that was found dead on the ground a few meters away from the nest tree located in a flooded forest with water level of one meter approximately. At the age of its death (30 months) it could fly with skill and was beginning its independence from its parents and its first movements of dispersion (Muñiz Lopez *et al.* 2012). Days before, an observer noted one of the adults, presumably a parent, performing demonstration flights of attack toward this juvenile that was perched in a tree adjacent to the nest tree. This attack appears that caused an imbalance of the

youth in the canopy and its fall to a lower and flooded stratum.

In other case, a biomonitor discovered an eight month old juvenile on the ground that was weak but still alive. A veterinary review detected that it was too skinny (pronounced breastbone) as to have forces to return to fly. This individual was recovered and reintegrated to its nest tree successfully and we were able to verify that the juvenile was alive at least six months after being placed back in the breeding area.

Starvation and drowning can be identified as causes of death of juveniles that fall to the ground and cannot return to the canopy.

## Discussion

### Adult mortality

In parts of their geographic range, large predators such as harpy eagles come into conflict with humans. Most often this consists of harpy eagle predation on livestock (Thirgood *et al.* 2005) and this results in the predator being persecuted, trapped, or killed, with corresponding negative effects on its population (Etheridge *et al.* 1997).

Through informal conversations with the local indigenous communities we collected information about why

people wanted to kill the harpy eagles. Their reasons fell into four categories:

1- Fear of the species: Many people in the local communities believe that harpy eagles will attack humans, especially children. Because of its large size, its attentive gaze and its reluctance to flee when found by humans, it gives the impression that it is going to pounce. In addition, people compare the ease of a harpy eagle catching a large monkey with that of capturing a young child.

2- Predation of domestic animals: Domestic animals are exposed in cleared areas around homes close to forests which makes them easy to prey for harpy eagles. Because of this, eagles are shot, which occurred in the areas of agricultural frontier in northern Mato Grosso in Brazil (Trape Trinca *et al.* 2008). In our study we found no livestock remains in prey delivered by adults to nestlings (Muñiz-López 2011).

3- Use of harpy eagle body ornaments: The enormous claws and the long and wide feathers

have attracted attention from the antiquity to the human being (Reina & Kensinger 1991). In one case a harpy eagle was shot to obtain the its claws as a trophy and feathers as a Shaman ornament.

4- Reprisal for intra-community conflict: rivalries between people in a community can sometimes have negative consequences for harpy eagles. For example, one of the PCAHE biomonitor had an altercation with another community member. In retaliation, the community member killed the chick that the biomonitor was monitoring.

Hunting, or other forms of direct human persecution may play an important role in the decline of some raptor populations and it is a significant conservation issue worldwide (Raptor Research Foundation 2016). In Venezuela, Álvarez-Cordero (1996) documented at least 45 harpy eagles shot in a ten year study. Reasons for shooting varied and included fear, pleasure hunting, and tribal use as “power medicine” (a case in Panama). In Brazil, reasons for shooting included

fear, lack of knowledge, predation of livestock or fear of livestock predation, and revenge against environmentally conscious landowner (Trape-Trinca *et al.* 2007). Thiollay (1984) estimated that 50 villagers in French Guiana shot 50 raptors per year of multiple species (Whitacre 2012). Other tropical eagles, such as the African crowned eagle (*Stephanoaetus coronatus*) face persecution over much of their range because of witchcraft, food, ornaments and threats to humans (BirdLife 2016, Thomsett 2011). For example, the African crowned eagle is specifically targeted by hunters in the Ebo forest, Cameroon (Whytock & Morgan 2010) and appears in fetish markets in West Africa (Nikolaus 2001). Human conflict due to predation of livestock is common and raptors are often shot to protect farm animals from predation (Newton 1979). However, a study on the crowned eagle (*Buteogallus coronatus*) in Argentina found that contrary to local beliefs, these eagles rarely preyed on domestic animals (Sarasola *et al.* 2010). Unfortunately, human persecution is the most important cause of mortality of crowned eagles in Central Argentina. Although we also did not find any remains of livestock in our monitored harpy eagle nests, further research is needed to

clarify the degree to which raptor predation on livestock is exaggerated in different communities.

Large biomass raptors such as the harpy eagle are particularly sensitive to hunting pressure (Redford & Robinson 1987; Silva & Strahl 1991) as it was found in this study where all adult deaths were directly due to man induced causes. The importance of human-induced mortality should also be considered in the context of population dynamics (Lopez Lopez *et al.* 2011).

The main threat to Neotropical bird species is habitat loss (Marzluff & Sallabanks 1998), although other factors, such as pollution, persecution, and the live-bird trade, have negative consequences for conservation for a number of species (Marzluff & Sallabanks 1998). Large biomass raptors such as the harpy eagle are particularly sensitive to hunting pressure (Redford & Robinson 1987, Silva & Strahl 1991). Governments and NGOs should undertake awareness campaigns and public education among local populations where this problem is especially acute.

#### *Juvenile mortality:*

Although no data are available regarding harpy eagle or other tropical eagle mortality in the first years of life,

our observed 28.6% juvenile mortality is below the 50-83% reported for 13 European raptor species (Newton 1979) but similar to the 15-29% reported for Bonelli's Eagles (*Hieraetus fasciatus*) in Europe (Cadahia *et al.* 2005).

Except in one case (record 1; see Table 1) all cases of death of juveniles happened by natural causes. Juveniles who are learning to fly or perfecting their flying techniques when they are one year old or less perform exploratory flights and sometimes land in difficult positions (see Figure 1) when they try to grab a new perch (Muñiz Lopez 2007). They must be able to correct these positions properly to avoid accidents such as falling to the ground. This behaviour was also reported by Álvarez-Cordero (1996) in Venezuela where a branching harpy eagle nestling lost altitude and crashed into the lower forest canopy when it was learning to fly. This juvenile returned to perch on the nest tree within a few hours however. Álvarez-Cordero described a similar event in Panama with a juvenile continually crashing into the vegetation while attempting to fly but finally returning to its nest.

Physical capabilities of young birds increase with a resulting decrease in mortality rates during the course of development (Ricklefs 1969), but there

is probably a brief period of increase in losses while the young gain experience immediately after leaving the nest.

We were able to verify that on three of the days when juveniles fell (records 5, 8 and 13 in Table 1) there were strong gusty winds that are typical of this season of the year (November-December) which could have caused the instability of these juveniles. If they fell to the ground or to a lower stratum of the forest, they may not have been able to propel themselves to a higher perch from which they could achieve enough height to fly again staying trapped under the canopy without the possibility of being fed by their parents as we have not detected any adults descending to feed or take care of the juveniles on the ground. In addition if the nest is located in a flooded forest, a juvenile that falls to the ground is at risk of drowning or getting wet and with wet feathers they will not be able to fly.

In other long-lived birds of prey, such as the Iberian imperial eagle (*Aquila adalberti*), 45% of reproductive failures are due to falls to the ground not only of the juveniles, but also of the eggs or nest platforms. This happens due to moderately strong winds (Calderon *et al.* 1987).

Adult raptors such as the Iberian imperial eagle or the tawny eagle

(*Aquila rapax*) perform aggressive displays to their own offspring, (Simmons & Mendelsohn 1993) during the period when the parents discontinue food contributions to the offspring which begins the stage of dispersion (Alonso *et al.* 1987). Although this behaviour is not described for harpy eagles belligerent conduct may have caused the death of the juvenile that was being seen attacked by its parents (reference 12; Table 1).

The detection of dead harpy eagle individuals is extremely difficult, especially without identification markings or tracking tools so it is easy to underestimate the number of mortality events. Comprehensive monitoring of individuals through direct observation can reveal valuable information including the way deaths occur on an individual level as well as their causes.

Efforts should be made to monitor the survival of juveniles in both the breeding and non-breeding areas, since studies focused only on adults may not detect a decline due to death of juveniles before they become part of the breeding population (Kokko & Sutherland 1998; Kenward *et al.* 2000). Understanding the elements that affect the reproductive success of this species is essential for population dynamics

studies and to develop conservation strategies.

In summary, this study revealed that the short period during which young harpy eagles are learning to fly is critical and can be dangerous. All records for dead adults were by anthropogenic causes, but the majority of juveniles that were found death in the vicinity of their nests were due to accidents during the post-fledging period. Not taking this into account could result in inaccurate estimates of population viability. Detailed studies using more sophisticated methods such as telemetry are needed to fill knowledge gaps concerning temporal and spatial patterns of mortality rates. In addition, formal and informal awareness and education programs are essential to mitigate or eliminate the causes of mortality due to hunting and misinformation in local communities.

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Reference number	Breeding area name (Territory)	Number of breeding seasons monitored	Number of individuals to reach their dispersion period	Year of nest discovery	Date of death	Estimated age at the time of death	Sex	Cause of death
1	Zábala	2	1	2002	December 2002	13 months	Female	Shot. Conflict within the human community.
2	Zancudococha	2	2	2002	-	-	-	-
3	Treiki	1	1	2002	-	-	-	-
4	Tarapuy	1	0	2003	June 2003	Adult	Unknown	Shot in fear. Eagle close to the vegetable garden.
5	Pakuyo	2	1	2003	November 2010	12 months	Male	Fall from a tree.
6	Junco	1	1	2004	-	-	-	-
7	2 de Agosto - Dureno	1	0	2005	July 2005	Adult	Male	Shot because the eagle approached to domestic animals.
8	Churuyacu Playas de Cuyabeno	2	1	2006	November 2006	3 months	Male	Fall from tree
9	Tsechueki	2	2	2007	-	-	-	-
10	Cocaya	1	1	2007	-	-	-	-
11	Nueva Vida	1	0	2008	February 2008	Adult	Unknown	Shot for trophy
12	Masakay	1	0	2008	October 2008	30 months	Female	Natural/loss of balance due to parental display?
13	Charap 1	1	0	2009	November 2009	13 months	Unknown	Fall from tree
14	Puñuna	1	1	2010	-	-	-	-
15	Arutam	1	1	2010	-	-	-	-
16	Charap 2	1	0	2011	Enero 2011	9 months	Unknown	Fall from tree

**Table 1: Harpy eagle breeding territories in chronological order according to their discovery year, including number of breeding seasons and chicks monitored, and causes of death.**

**Figure 1: A young harpy eagle in a dangerous position practicing its flight habilities. Photo:  
PCHAE/SIMBIOE**



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A. Tentets, joven de la nacionalidad Achuar del Ecuador y biomonitor del PCAHE  
Foto: Enrique de la Montaña / <https://vagandomundos.wordpress.com>

*A las águilas harpías que nos permitieron disfrutar y aprender de ellas, por embaucarnos y llevarnos de las garras hacia su mundo... por habernos regalado tantas experiencias inolvidables.  
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Garras de águila harpía, el ave rapaz más poderosa del planeta. Foto: P. Oxford/PCAHE-SIMBIOE



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