

## Abundance of Harpy and Crested Eagles from a reservoir-impact area in the Low- and Mid-Xingu River

Sanaïotti, TM.<sup>a,b\*</sup>, Junqueira, TG.<sup>c</sup>, Palhares, V.<sup>d</sup>, Aguiar-Silva, FH.<sup>e,b</sup>, Henriques, LMP.<sup>a</sup>, Oliveira, G.<sup>d</sup>, Guimarães, VY.<sup>c</sup>, Castro, V.<sup>c</sup>, Mota, D.<sup>c</sup>, Trombin, DF.<sup>c</sup>, Villar, DNA.<sup>f</sup>, Lara, KM.<sup>c</sup>, Fernandes, D.<sup>c</sup>, Castilho, L.<sup>c</sup>, Yosheno, E.<sup>c</sup>, Alencar, RM.<sup>c</sup>, Cesca, L.<sup>c</sup>, Dantas, SM.<sup>g</sup>, Laranjeiras, TO.<sup>h</sup>, Mathias, PC.<sup>c</sup> and Mendonça, CV.<sup>c</sup>

<sup>a</sup>Coordenação de Pesquisas em Biodiversidade – CBIO, Instituto Nacional de Pesquisas da Amazônia – INPA, Av. André Araújo, 2936, Aleixo, CEP 69067-375, Manaus, AM, Brazil

<sup>b</sup>Coordenação de Pesquisas em Biodiversidade – CBIO, Programa de Conservação do Gavião-real – PCGR, Instituto Nacional de Pesquisas da Amazônia – INPA, Av. André Araújo, 2936, Aleixo, CEP 69067-375, Manaus, AM, Brazil

<sup>c</sup>BIOTA Projetos e Consultoria Ambiental Ltda, Rua 86C, 64, Setor Sul, CEP 74083-360, Goiânia, GO, Brazil

<sup>d</sup>Leme Engenharia Ltda, Avenida dos Andradas, 3000, 11° ao 13° andares, Boulevard Corporate Tower Santa Efigênia, CEP 30260-070, Belo Horizonte, MG, Brazil

<sup>e</sup>Coordenação de Biodiversidade – CBIO, Programa de Pós-graduação em Ecologia, Instituto Nacional de Pesquisas da Amazônia – INPA, Av. André Araújo, 2936, Aleixo, CEP 69067-375, Manaus, AM, Brazil

<sup>f</sup>Systema Naturae Consultoria Ambiental Ltda, Rua 58, 217, Qd B04, Lt 16, Jardim Goiás, CEP 74810-250, Goiânia, GO, Brazil

<sup>g</sup>Museu Paraense Emilio Goeldi – MPEG, Av. Perimetral, 1901, Terra Firme, CEP 66077-530, Belém, PA, Brazil

<sup>h</sup>Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio, Parque Nacional do Viruá, Rua Alfredo Cruz, 283, Centro, CEP 69301-140, Boa Vista, RR, Brazil

\*e-mail: tania.sanaïotti@gmail.com

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### Abstract

In the Brazilian Amazon, two monospecific genera, the Harpy Eagle and Crested Eagle have low densities and are classified by IUCN as Near Threatened due to habitat loss, deforestation, habitat degradation and hunting. In this study, we evaluate occurrence of these large raptors using the environmental surveys database from Belo Monte Hydroelectric Power Plant. Integrating the dataset from two methods, we plotted a distribution map along the Xingu River, including records over a 276-km stretch of river. Terrestrial surveys (RAPELD method) were more efficient for detecting large raptors than standardized aquatic surveys, although the latter were complementary in areas without modules. About 53% of the records were obtained during activities of wildlife rescue/flushing, vegetation suppression or in transit. Between 2012 and 2014, four Harpy Eagles were removed from the wild; two shooting victims, one injured by collision with power lines and one hit by a vehicle. Also, seven nests were mapped. The mean distance between Harpy Eagle records was 15 km along the river channel, with a mean of 20 km between nests near the channel, which allowed us to estimate 20 possible pairs using the alluvial forest, riverine forest and forest fragments. Territories of another ten pairs will probably be affected by inundation of the Volta Grande channel, which is far from the main river. The average distance between Crested Eagle records was 16 km along the river channel. The only nest found was 1.3 km away from a Harpy Eagle nest. The remnant forests are under threat of being replaced by cattle pastures, so we recommend that permanently protected riparian vegetation borders (APP) be guaranteed, and that forest fragments within 5 km of the river be conserved to maintain eagle populations.

**Keywords:** neotropical raptors, Amazon, hydroelectric power plant, environmental impact, Accipitridae.

### Abundância de Gavião-real e Gavião-real falso numa área sob impacto de reservatório no Baixo e Médio rio Xingu

#### Resumo

Na Amazônia brasileira dois gêneros mono-específicos, *Harpia* e *Morphnus*, caracterizam-se por baixa densidade e estão classificados pelo IUCN como Quase Ameaçados, porém ocorrem sobre grande parte do território nacional, suas principais ameaças são a fragmentação florestal, a degradação de hábitat e a caça. Neste estudo avaliamos a abundância destas duas grandes aves de rapina utilizando a base de dados dos programas ambientais da UHE Belo

Monte, integrando-se dois métodos para construir um mapa de distribuição ao longo de 245 km do rio Xingu. Os levantamentos terrestres pelo método RAPELD mostraram-se mais eficientes para os registros de grandes águias quando comparado aos esforços padronizados aquáticos, entretanto estes foram complementares na ausência de módulos. Cinquenta e tres por cento foram registros ocasionais durante a supressão da vegetação, afugentamento ou deslocamento. Entre 2012-2014 quatro harpias foram removidas da natureza, dois indivíduos alvo de disparos, uma por colisão com rede elétrica, e outra por atropelamento. Sete ninhos mapeados, a distância média entre os registros de harpia na calha e margens do rio foi de 15 km, 20 km distância média entre ninhos, o que permitiu estimar um total de 20 casais utilizando as florestas aluviais em uma distancia de 270 km, incluindo matas ciliares e os fragmentos fora da margem do rio. Estimamos que territórios de outros 10 casais usando a Volta Grande longe do rio principal também serão afetados pela inundação. A distância média entre os registros de *Morphnus* foi 16 km ao longo do rio, o único ninho mapeado estava distante 1.3 km do ninho de Harpia. Estes fragmentos florestais estão sendo substituídos por pastagens, ressaltando-se a importância da manutenção das áreas de preservação permanentes (APP) e a proteção destes fragmentos em diversos formatos de áreas de proteção, para diminuir a degradação dos mesmos e garantir a manutenção das populações destes grandes predadores na região do rio Xingu.

*Palavras-chave:* ave de rapina neotropical, Amazônia, hidroelétrica, impacto ambiental, Accipitridae.

## 1. Introduction

The two largest raptors in the Brazilian Amazon, Harpy Eagle, *Harpia harpyja* (Linnaeus) and Crested Eagle, *Morphnus guianensis* (Daudin) occur at low densities and are hard to detect in the rainforest (Ferguson-Lees and Christie, 2001). They occur over much of Brazil, mainly in the Amazon, and the main threats are habitat loss and hunting (Vargas-González et al., 2006). The latter sometimes results from human-wildlife conflicts due to potential livestock predation (e.g., Trinca et al., 2008; DeLuca, 2012). Both species are included in the Near Threatened (NT) category of the IUCN (IUCN, 2014). The Harpy Eagle is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2012). Both are considered as Vulnerable on the Brazilian National List of Endangered Species (Brasil, 2014b). The concern for the species has increased in Amazonia due to environment impacts that result in vegetation removal, which is higher in areas impacted by hydroelectric dams, which also have many other possible adverse effects on the environment (Fearnside, 2006). The Brazilian government plans to build 30 hydroelectric power plants in Amazonia by 2020 (Brasil, 2011).

Álvarez-Cordero (1996) estimated the mean distance between Harpy Eagle nests as 7 km for forests under timber extraction in Venezuela and about 3-5 km in forests under extractivist use in Panama. In Ecuador, Muñiz-López et al. (2007) reported that the distances between four Harpy Eagle nests ranged from 6.8 to 17 km. In Panama, a study in primary and secondary forest at Darien estimated an average distance between nests as 4.1 km (range 2.6-6.2 km) (Vargas-González and Vargas, 2011). Aguiar-Silva et al. (2011), working in the Brazilian Amazon, in areas with a mosaic of managed forest, illegal timber extraction and agricultural fields, estimated the average distance between nests as 8 km (range 5-12 km). In one Ecuadorian locality, the young stayed until two years of age within a radius of 1.3 km of the nest, within the parents' territory (Muñiz-López et al. 2012).

There are no records of density for the Crested Eagle, but the rare records of this species indicate that it can coexist with Harpy Eagle and that territories of individuals of the two species may overlap. Muñiz-López et al. (2007) found a Crested Eagle nest 2.3 km from a Harpy Eagle nest. The species use distinct strata to build their nests, with Harpy Eagles using emergent trees (Luz, 2005; Luz et al., 2010), and Crested Eagles using canopy trees (Whitacre et al., 2012; Harpy Eagle Conservation Program in Brazil-PCGR personal archive). Their diets also are distinct: Crested Eagles feed mainly on smaller prey than Harpy Eagles (Soares et al., 2008; Whitacre et al., 2012).

The first reports of Harpy Eagles on the Xingu River come from two centuries ago (Edwards, 1847), but only recently for Crested Eagle (Henriques et al., 2008). Crested Eagle records in the Brazilian Amazon are far more scattered than those of Harpy Eagles. For about 100 nests of Harpy Eagle mapped, there are only 10 of Crested Eagle (Aguiar-Silva et al., 2013, PCGR database).

Both species are part of the Brazilian National Action Plan for Raptors (Soares et al., 2008), National Action Plan for Endemic and Threatened Species from the Low- and Mid-Xingu River - PAN Xingu (Brasil, 2012) and National Action Plan for Amazonian Birds (Brasil, 2014a).

Only one Harpy Eagle nest, which was located on private land, on the border of Brazil Novo and Altamira municipalities, has previously been reported for the PAN Xingu area (Henriques et al., 2008). There were no known nests of the Crested Eagle in the area.

We evaluate the distribution of the species in the area affected by the Belo Monte Hydroelectric Complex, using two complementary methods and compare the efficiency of these methods. We analyzed the databases from the Environmental Impact studies (EIA/RIMA) and the Fauna-Monitoring Project undertaken in the Area of Influence of Belo Monte Hydroelectric Power Plant (UHE), including secondary records generated from other studies, and fauna rescue/flushing during vegetation suppression or in transit, hunting, and records of vehicle collisions, within the area of the PAN Xingu.

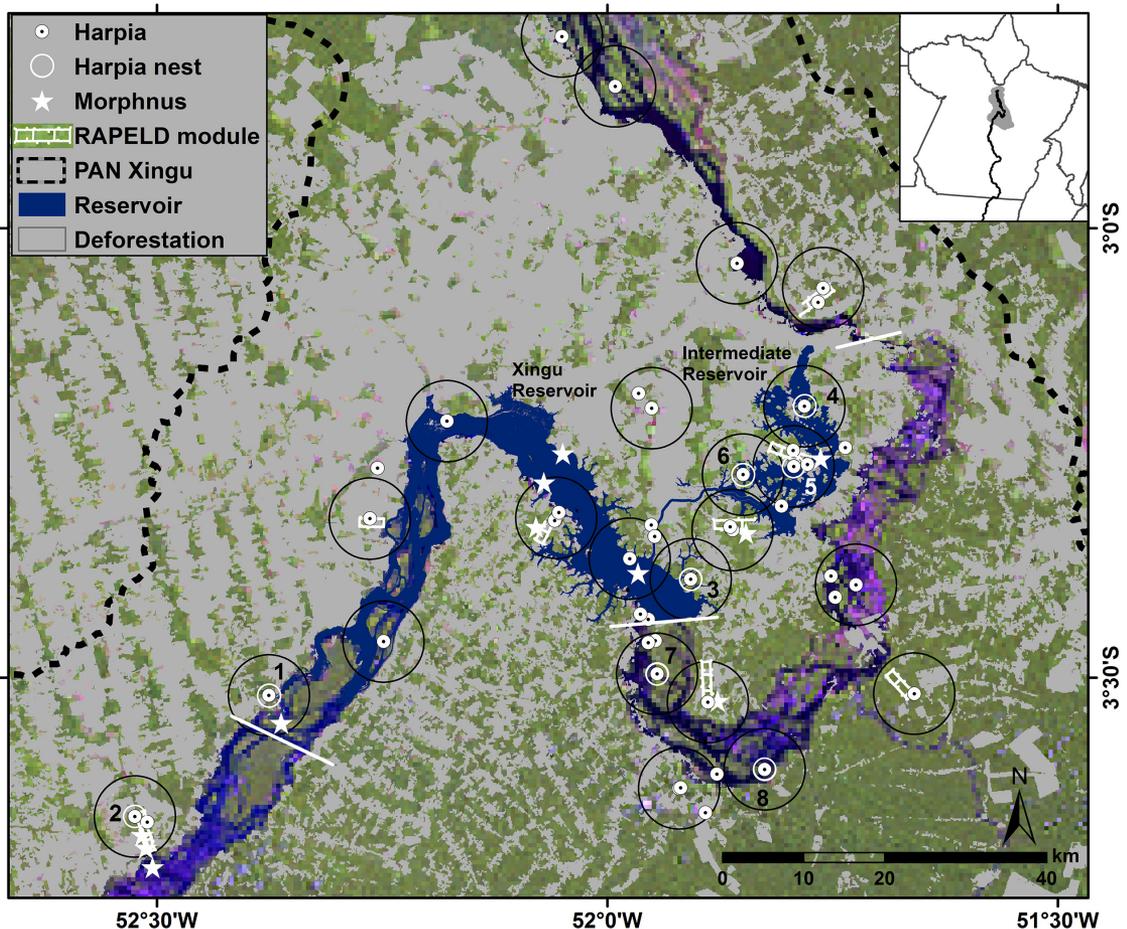
## 2. Material and Methods

The study area included the area of PAN of the Low- and Mid-Xingu River, Pará State, northern Brazil, where the Belo Monte Hydroelectric Complex is being built (Figure 1). According to the international climatic classification system of Köppen, the predominant climate in this region is humid tropical Am, mean air temperature of 26 °C, mean annual rainfall of 2289 mm, and with a short dry season occurring in August and September with average rainfall of 33.4 mm and 39.3 mm, respectively (IBAMA, 2007). The Xingu River flood season is from December to June. The image prepared for Figure 1 includes information on deforestation up to 2014 (Brasil, 2014c)

Thirty-one km, located between the headwaters of the Paquiçamba River and Belo Monte village of the 276 km

stretch of the Xingu River in the study area, were not sampled due to navigational difficulties. A total of 245 km was sampled by boat surveys in the same stretch of river in which the terrestrial surveys were distributed.

Different efforts and sample periods were used in the studies included in the database. The terrestrial and aquatic surveys were carried out during the EIA/RIMA in 2000-2002 and 2007-2008 (Henriques et al., 2008). The standardized surveys of the Terrestrial and Aquatic Fauna Monitoring Project were done from February 2012 to March 2014, according to the data available in the Fifth Consolidated Report from Norte Energia to Ibama (Norte Energia, 2014), and continued up to February 2015 (data made available by Biota and Leme). Occasional records were considered up to July 2015.



**Figure 1.** Records of Harpy Eagles and Crested Eagles in the area under the influence of Belo Monte Complex and nests mapped in the area of PAN of the Low- and Mid-Xingu River. The records for Harpy Eagle (●) combined Terrestrial Avifauna survey, Aquatic and Semi-aquatic surveys and Occasional records and (O) nests, and for Crested Eagle (☆) combined Terrestrial and Aquatic and Semi-aquatic surveys and Occasional records. Harpy Eagle active nests (1) Torrão, (2) Module 1, (3) Xingu Reservoir-CEA, (4) Intermediate Reservoir-55CTCA, (5) Intermediate Reservoir-Ticaruca, (6) Intermediate Reservoir-Paquiçamba; and inactive nests (7) Island-record 32, (8) Island-record 33. Black circles represent 5-km buffers around Harpy Eagle territories. The limits of the four Aquatic sampling areas are shown by straight white lines. The estimated reservoir areas are in black. The inset shows Pará state with the entire area of PAN Xingu highlighted in grey. (Landsat 5 mosaic 2000/deforestation up to 2014, see methods).

### 2.1. Terrestrial-habitat surveys

The Terrestrial Avifauna surveys between 2012-2015, were distributed in 8 RAPELD (Rapid Assessment Long-Term Ecological Research Program - Magnusson et al., 2005, 2013) modules. This spatial distribution of effort maximizes the probability of sampling biological communities in large areas using small sample areas (Magnusson et al., 2005). The protocol used was two observers walking simultaneously two parallel 5-km transects in each module during three consecutive days, noting visual and acoustic records. The cumulative sample effort in this study is presented as km walked \*day\*sampling period. Modules 1, 5 and 7 had 5-km parallel transects, totaling 10 km walked per day in each module. In the remaining modules, the trails were less than 5 km, so the total distance walked varied among modules (M2= 6 km; M3= 7.5 km; M4= 8 km; M6= 8.5 km; M8= 9 km). The sampling periods were (1) February to April 2012, (2) August to December 2012, (3) April to June 2013, (4) August to October 2013, (5) January to March 2014, (6) July to August 2014 and (7) January to February 2015. We excluded the first sampling period from the analysis because only 4 of the 8 modules were sampled.

### 2.2. Aquatic-habitat surveys

The Aquatic Surveys during the period 2012-2015 were standardized samples by motorboat for Aquatic and Semi-aquatic Avifauna and Aquatic (Cetacean) and Semi-aquatic Mammals (Mustelid).

#### 2.2.1. Aquatic and Semi-aquatic Avifauna surveys

Two protocols of records were combined in this study, totaling 245 km sampled, in 270 km of the Xingu River, subdivided into four sampled areas (Figure 1), with two observers over 20 days for each sampling period. The protocols included were (1) boat transects for Qualitative and Quantitative Records, in each of the four areas, 10 transects 8-km long, parallel to each edge when possible, in some cases parallel to an edge and an island (for this study, we considered the linear distance sampled by boat along the river) and (2) boat transects undertaken for Acoustic Point Counts of birds in habitats associated with and/or created by rivers, distributed in five localities within each area (approximately 2-km long), in order to sample one point every 100 m during 10 minutes, recording sightings and calls, totaling 100 points for each of the four areas of the previous protocol, totaling 400 points. The 13 sampling periods were March-April 2012, June-July 2012, August-September 2012, November-December 2012, January-February 2013, April-May 2013, July-August 2013, October-November 2013, January-February 2014, April-May 2014, July-August 2014, October 2014 and January-February 2015. The cumulative sampling effort for this study was presented as linear kilometers travelled by boat along the river\*sampling period.

#### 2.2.2. Aquatic and Semi-aquatic Mammal (Mustelid) surveys

The records for this study were combined as for the Avifauna Surveys, considering a total of 245 km sampled in 270 km along the Xingu River, subdivided into four sampling areas (Figure 1). However, the number of transects varied among the areas and among 13 sampling periods, accumulating a total of 61, 157, 149, 158, 191, 98, 154, 154, 168, 169, 167, 156, 169 transects per sampling period, respectively. The protocol consisted of two observers for 30 days per sampling period. Sampling periods were March-April 2012, June-July 2012, August-September 2012, November-December 2012, January-February 2013, April-May 2013, July-August 2013, October-November 2013, January-February 2014, April-May 2014, July-August 2014, October-November 2014 and January-February 2015. The cumulative sampling effort for this study will be presented as linear kilometers travelled by boat along the river\*sampling period.

Besides the records from the standardized samples, occasional records were included on the map. These included information from the following sources: activities for terrestrial Fauna Rescue/flushing in areas under vegetation suppression between July 2011 and March 2013 over an area of 4030 ha (Norte Energia, 2014); and in areas under suppression between 2014-2015, from photographs or call records, as well as non-documented (visual or acoustic) records during transit among areas. Only precise descriptions of the sighting that allowed us to confirm the species were included, as were records of specimens taken by hunters or hit by vehicles.

We represented territory areas with a 5-km buffer from nests or potential centers.

## 3. Results

There were 58 records of the species in different locations in the area (Harpy Eagle, n=47 and Crested Eagle, n=11 (Table 1), of those 27 (47%) came from standardized surveys and 31 (53%) from occasional encounters. There were also 13 records made during nest monitoring (3a-d, 34a, 39a-b, 43a, 45a-b, 47a, 58a-b) (Table 1).

### 3.1. Harpy Eagles

Six Harpy Eagles were recorded in the standardized Aquatic Surveys: four from the Aquatic and Semi-aquatic Mammal (Mustelid) Surveys, and two from Aquatic and Semi-aquatic Avifauna monitoring, each survey for a total effort of 245 km travelled by boat\*13 sampling periods (Table 1). The average distance among closer records was 21 km (9-28 km) (Figure 1) and one record was made during transit by boat and was categorized as occasional (Table 1, Figure 2a).

Fourteen Harpy Eagles were recorded in the standardized Terrestrial Surveys for a total effort of 69 km\*3 days\*6 sampling periods. Harpy Eagles were recorded in all eight modules, with one nest found in module 1.



**Figure 2.** (a) Adult Harpy Eagle feeding on an *Iguana iguana* seen during an Aquatic avifauna survey (record 11, photo VP Palhares), (b) Adult Crested Eagle pale morph plumage during a Terrestrial Avifauna survey (record 51, photo V Castro).

Thirty Harpy Eagle records were from occasional documented and undocumented records. Between 2001-2002, during avifauna surveys for the EIA/RIMA, one adult Harpy Eagle was reported to have been killed by hunters. An adult male was shot by Xipaia Indians between February and March 2001 in *terra firme* forest on the left bank of the Xingu River, locality Bom Jardim (Miguel Xipaia farm), Vitória do Xingu municipality (Table 1). According to the indigenous people, the species is hunted to extract the tibia, primary remiges and rectrices, to make arrows (LMPH, Henriques et al., 2008).

Between 2012 and 2014, four Harpy Eagles were removed from the wild because they were hunted or injured. An adult male, which was rescued 6 February 2014 by a Military Policeman from Altamira (C.A. Silva, pers. comm.), on the periphery of Altamira, in a forest at the edge of the road from the airport to the prison, died ten days after being shot. In the necropsy, two 5-mm diameter lead shot were detected by X-ray. At the moment of medical attention it weighed 4.4 kg, and the necropsy revealed enlarged testes, indicating breeding activity. As an environmental crime, a technical report including a shotgun pellet removed from the body was given to the Environmental Agency IBAMA, Belém, N° 02018.001564/2014-18 (TMS). This specimen was deposited at the Museu Paraense Emílio Goeldi Bird Collection (MPEG 78231) (Table 1). The second Harpy Eagle individual was found hit by a car 9 March 2012 (DFT) at km 9 of the East-West Via of the diversion channel. Apparently an adult in advanced stage of decomposition, the talons were collected (LC) and maintained at the Environmental Studies Center (CEA).

The hallux measurement (outer curvature chord = 6.1 cm) indicated it was a female (Table 1). The third, an adult female Harpy Eagle was rescued on the right bank of the Xingu River after being injured by collision with a power line (Aguiar-Silva et al., 2014b). The fourth record of a hunted individual was confirmed by a photograph of talons that were brought to the village (Aguiar-Silva et al., 2014b) (Table 1).

The active Harpy Eagle nest in a Kapok tree (*Ceiba pentandra*) mapped during the terrestrial surveys of the EIA/RIMA (Henriques et al., 2008) was monitored from May 2013 by the PCGR in partnership with BIOTA, and has been active since then with successful production of offspring (Aguiar-Silva et al., 2015); a 20-month-old juvenile was still using the nest in July 2015. The nest tree is located on private land and, according to official flooding predictions for the reservoir, the locality is not expected to flood with the filling of the Xingu Reservoir from the Belo Monte Dam, but it will be within the influence area.

Seven new nests of Harpy Eagle were mapped during field work 2014-2015. Two inactive nests on islands downstream of the dam were reported by locals (Aguiar-Silva et al., 2014b) (Table 1). Only one nest was located in the RAPELD module, found during Terrestrial surveys with a flying juvenile (Table 1). The distance between the two active nests (Torrão and module 1) was 18 km (on the same bank), and the distance between the two inactive nests on islands was about 23 km. Four active nests were mapped during vegetation suppression. All still had juveniles depending on the nest tree in July 2015. Two were on the edge of the area expected to flood when the dam is filled (nest Xingu

**Table 1.** Harpy Eagle and Crested Eagle records in the area of the Xingu River. (EIA/RIMA) Environmental Impact Studies; (PCGR) Harpy Eagle Conservation Program in Brazil; (Biota) Biota Projetos e Consultoria Ambiental Ltda.; (Leme) LEME Engenharia; (Arcadis/Naturae) Arcadis Logos/Systema Naturae Consultoria Ambiental LTDA; (WA) www.wikiaves.com; (MPEG) Museu Paraense Emilio Goeldi; (Pers. arch.) Personal archive.

(Record No.)	Author of Record	Record description	Record date/mo/year	Reference
<b>HARPY EAGLE</b>				
(1)	LMP Henriques	Photograph of an adult killed in the locality Bom Jardim (Miguel Xipaia farm), left bank of the Xingu River A3 of EIA/RIMA, municipality of Vitória do Xingu.	Feb-Mar/2001	Henriques et al. (2008)
(2)	LMP Henriques, SM Dantas	Sighting of an adult, left bank, locality Bom Jardim, A3 of EIA/RIMA, municipality of Anapu.	Apr/2008	Henriques et al. (2008)
(3)	TO Laranjeiras, LMP Henriques, SM Dantas	Photograph of an adult found in nest tree, locality Torrão, A1 of EIA/RIMA, municipality of Brazil Novo.	15/Apr/2008, Jul/2008	Henriques et al. (2008)
(3a)	TM Sanaiotti; TG Junqueira	Torrão nest monitoring and photograph of adult in the nest (same as 3).	19/05/2013	PCGR; Biota
(3b)	TM Sanaiotti; TG Junqueira; V Palhares	Torrão nest monitoring and photograph of the young about five months old.	23/03/2014	PCGR; Biota; Leme
(3c)	K Lara, TG Junqueira, FH Aguiar-Silva, Olivier Jaudoin	Photograph of the juvenile from the Torrão nest during nest monitoring (same as 3).	11/07/2014	Biota/ WA1576552 WA1569328
(3d)	TG Junqueira, Denilson Aranha	Photograph of the juvenile from the Torrão nest during nest monitoring (same as 3).	06/07/2015	Biota
(4)	DF Trombin	Photograph of a juvenile feeding on a <i>Coendou</i> sp., Serra Island.	30/10/2012	Biota, 6 <sup>th</sup> Technical Consolidate Report/ IBAMA
(5)	José Pezzi	Photograph of an adult at Serra Island, area under dam impact <i>Canteiro de Obras</i> Pimental.	Dec/2012	Biota
(6)	DF Trombin	Sighting of an adult, Pimental Island.	17/09/2012	Biota
(7)	DF Trombin	Photograph of a juvenile about 3 yrs old, attacking a group of <i>Alouatta</i> sp. during flushing.	20/09/2013	Biota, WA1119175
(8)	DAN Villar	Photograph of a sub-adult during Mustelid survey (PMASA), A3, Bela Vista Island, passing the Mucura Waterfall, above waterfall.	27/01/2013	Leme C5A3-27012013/ Naturae, 6 <sup>th</sup> Technical Consolidated Report/ IBAMA
(9)	DAN Villar	Photograph of an adult female, during Mustelid survey (PMASA) A4, Porto Seguro Island, between Viola and Santa Clara streams.	30/01/2013	Leme C5A4-30012013/ Naturae, 6 <sup>th</sup> Technical Consolidated Report/ IBAMA

Table 1. Continued...

(Record No.) Author of Record	Record description	Record date/mo/year	Reference
(10) DAN Villar	Photograph of an adult female, during Mustelid suvey (PMASA) A2, Arapuja Island.	13/02/2013	Leme C5A2-13022013/ Naturae10, 6 <sup>th</sup> Technical Consolidated Report/ IBAMA
(11) V Palhares, Vicente Medeiros	Photograph of an adult female feeding on <i>Iguana iguana</i> , during Aquatic surveys. The Avifauna Aquatic/semi (PAASA), A4, left bank Volta do Tubarão.	28/04/2013	Leme/TRQQ-6-4-T9, 6 <sup>th</sup> Technical Consolidated Report/IBAMA
(12) TG Junqueira	One remige feather found during the Terrestrial survey, M5, connecting trail T1-T2 at 5000 m.	23/09/2013	Biota
(13) D Fernandes	Photograph of a pair in the same tree, and photograph of the male during complementary study at Taboca Island.	24/10/2013	Biota, WA1132221, WA1132215
(14) G Oliveira	Sighting of adult perched on the beach and flight to a tree at Fazenda Island, during aquatic transit in A3.	02/11/2013	Leme/C8A3-021113, 6 <sup>th</sup> Technical Consolidated Report/IBAMA
(15) Rodolfo B Santos	Photograph of juvenile, during vegetation supression, at Dicks and Channels area.	22/06/2013	Biota
(16) Frederico A Raul	Photograph of adult, in phenology monitoring area, <i>Travessão 27</i> .	24/01/2014	Biota
(17) D Fernandes, L Castilho	Photograph of adult calling for few days at same place, during Terrestrial surveys M6T1 P3.	28/01/2014	Biota, WA1231122, calling WA1234862, WA1263052
(18) Roberta E Silva, Ricardo V Leone	Photograph of adult during Mustelid survey (PMASA) A2.	27/01/2014	Leme/C9A2-27-114, 6 <sup>th</sup> Technical Consolidated Report/IBAMA
(19) V Castro, L Castilho, Denilson Aranha	Photograph of adult after playback, during Terrestrial survey M7, T2, P4, and another same day (5744).	31/01/2014	Biota (V Castro pers. arch. 5724, 5744)
(20) V Castro	Photograph of adult calling perched on broken tree, during Terrestrial survey, M4, connecting trail T1-T2 at 3500 m, municipality of Anapu.	28/02/2014	Biota/ WA1258949
(21) V Castro, Denilson Aranha	Sighting of young calling right after flight during Terrestrial survey M3, T2, 1550 m and 1000 m on the next day (8).	07/02/2014	Biota
(22) R de M Alencar	Calling during Terrestrial survey M2, T2, between P2P3.	21/03/2014	Biota
(23) D Trombin, L Cesca	Hit by vehicle, late <i>postmortem</i> collected and maintained the claws at CEA, apparently an adult female.	19/03/2014	Biota

Table 1. Continued...

(Record No.) Author of Record	Record description	Record date/mo/year	Reference
(24) Wesley Barella; Rogerio Miranda	Sighting during technical visit of IBAMA in the Channel and Dicks area – km3, Intermediate Reservoir.	21/03/2014	Leme; Norte Energia
(25) Cesar A Silva, Emil Hernandez, VY Guimarães, L Cesca	An adult male injured, rescued by the Military Police close to the jail in Altamira, on 06/02/2014, on 07/2 handed to UFPA, on the same day handed over for medical care by Biota, died on 17/02/2014, and deposited at the MPEG Bird Collection #78231.	06/02/2014	This study
(26) Igor Martins	Sighting one individual with <i>Bradypus</i> , during vegetation suppression in the area under building impact from <i>Canteiro de Obras</i> Bela Vista.	Apr/2014	Biota
(27) Igor Martins	Sighting at the same place as record 26 with <i>Sapajus apella</i> , during vegetation suppression of the vegetation in the area of <i>Canteiro de Obras</i> Bela Vista.	May/2014	Biota
(28) V Palhares, Gregório Menezes	Photograph of an adult perched during Aquatic surveys. The Avifauna Aquatic/semi (PAASA), A4.	10/04/2014	Leme/ C10A4-10042014_TRQQ-10-4-T5
(29) Mauricio AM Soares	Photograph of talons from an adult female killed in the region of Itatá River, the right bank tributary of Xingu River, municipality of Senador José Porfírio.	Nov/2011	Aguiar-Silva et al. (2014b)
(30) Belo Sun Team	An adult female injured by collision with power line, rescued by Sebastião Nascimento on the road to Itatá River, municipality of Senador José Porfírio, medical care by veterinarians from Arcadis/Naturae and released at the same site by FHAS.	18/06/2014	Aguiar-Silva et al. (2014b)
(31) FH Aguiar-Silva, Olivier Jaudoin, Cicero Miranda	Sighting of an adult male crossing a road carrying prey during monitoring of a release female, municipality of Senador José Porfírio.	05/07/2014	Aguiar-Silva et al. (2014b)
(32) FH Aguiar-Silva, Olivier Jaudoin	Report by locals of a nesting site in an island about 2012 in a Kapok tree, municipality of Senador José Porfírio.	10/07/2014	Aguiar-Silva et al. (2014b)

Table 1. Continued...

(Record No.) Author of Record	Record description	Record date/mo/year	Reference
(33) FH Aguiar-Silva, Olivier Jaudoin	Report by locals of a nesting site in an island about 2012 in a Kapok tree, municipality of Senador José Porfírio.	10/07/2014	Aguiar-Silva et al. (2014b)
(34) G Oliveira, Marcelo Ribeiro	Photograph of an active nest on the edge of the Intermediate Reservoir-Trav55-CTCA.	17/07/2014	Leme, Norte Energia
(34a) FH Aguiar-Silva, Olivier Jaudoin; Ismael Martins	Photograph of a juvenile and an adult perched near the nest tree (same as 34).	15/03/2015	PCGR; Arcadis/Naturae
(35) D Mota	Sighting of an adult perched during Terrestrial survey M1, T2, 3600 m.	05/08/2014	Biota
(36) V Castro	Sighting one of a pair calling about 1 km apart, one calling and the other individual responding from the forest border, during Terrestrial survey M8, T1, 4000 m.	17/08/2014	Biota
(37) V Castro	Photograph of a sub-adult perched, while another was calling but not seen during Terrestrial survey M3, T1, 1000 m.	24/07/2014	Biota / WA1597922/ WA1395012
(38) K Lara, D Mota	Photograph of an adult perched, during Terrestrial survey M7, T2, P1.	17/01/2015	Biota / WA1610821
(39) TG Junqueira	Photograph of a juvenile carrying a Brazil Nut fruit in the new nest mapped (Module 1), during Terrestrial survey M1, T1, 3500 m.	29/01/2015	Biota / WA1625209 / WA1625204
(39a) D Mota	Photograph of an adult male bringing a <i>Coendu prehensilis</i> tail to the nest to feed the juvenile that was at the nest (same as record 39) during nest monitoring M1, T1, 3500 m.	31/01/2015	Biota / WA1610818
(39b) TM Sanaiotti; TG Junqueira, Denilson Aranha	Photograph of the juvenile at the nest tree and an adult bringing a <i>Bradypus variegatus</i> to a tree near the nest (same as 39) during nest monitoring M1, T1, 3500 m.	05/07/2015	PCGR; Biota
(40) D Mota	Photograph of an adult female crossing trail during Terrestrial survey M8, T2, 4300 m probably same individual as record 36.	10/02/2015	Biota / WA1610823
(41) E Yosheno, D Mota	Photograph of a juvenile perched during Terrestrial survey M6, T1, P4.	17/02/2015	Biota / WA1613831

Table 1. Continued...

(Record No.) Author of Record	Record description	Record date/mo/year	Reference
(42) V Palhares, Fredson Caitano, Marcelo Ribeiro	Photograph of an adult feeding on <i>Iguana iguana</i> , during transit between sites.	09/03/2015	Leme / T27-09032015
(43) FH Aguiar-Silva, Olivier Jaudoin; Carlos ED Cintra; Roberto Silva	Active nest mapped on the edge of Xingu Reservoir – CEA, female incubating.	15/03/2015	PCGR; Arcadis/Naturaes; NE
(43a) TM Sanaiotti; Ralder F Rossi	Photograph of female and nestling about 2 months old in the nest (same as 43), prey remains found under the isolated nest tree.	06/07/2015	PCGR; Arcadis/Naturae
(44) V Palhares, Marcelo Ribeiro	Photograph of an adult with alert behavior, moving around, during vegetation suppression at Intermediate Reservoir-Ticaruca (near record 45).	17/04/2015	Leme/ RI_ PENHA_17042015
(45) Danielle A Siva, Valerlan Conceição, Paulo Ferreira, Daniel Eskavron, Sebastião Rocha, Jose Pereira; Marcelo Ribeiro	Photograph of an active nest found at Intermediate Reservoir-Ticaruca during vegetation suppression (Penha); date filming nestling about 3 months old inside the nest.	27/04/2015; 30/04/2015	Arcadis/Naturae; Leme
(45a) Ralder F Rossi; Danielle A Silva	Photograph of an adult and nestling inside the nest at Intermediate Reservoir-Ticaruca (same as 45); date juvenile left nest with flying difficulties.	13/05/2015; 22/06/2015	Arcadis/Naturae
(45b) TM Sanaiotti; Ralder F Rossi	Photograph of a juvenile perched on a cut tree trunk near the ground by the isolated nest Intermediate Reservoir-Ticaruca, (same as 45). It flew 130 m to another cut tree. Reinstalling perches near forest remnants has been recommended by TMS to NE as a mitigation action.	06/07/2015	PCGR; Arcadis/Naturae
(46) Bruna K Braun	One remige feather found during Rescue activities, about 1 km from the nest Intermediate Reservoir-Paquiçamba (record 47).	01/07/2015	Arcadis/Naturae
(47) Cristiane RD Vieira, Marcos Ramalho, Elson Lima, Alciomar Araujo Wanderley Eskavron	Active nest Intermediate Reservoir-Paquiçamba found during vegetation suppression (Willy). Adult observed several days in the tree since the found and juvenile only once.	10/06/2015; 01/07/2015	Arcadis/Naturae

Table 1. Continued...

(Record No.) Author of Record	Record description	Record date/mo/year	Reference
(47a) TM Sanaiotti; Ralder F Rossi	Photograph of prey remains under the isolated nest Intermediate Reservoir-Paquiçamba (same as 47), also feces on leaves and ground, evidence of use of the nest by juvenile and adults.	06/07/2015	PCGR; Arcadis/Naturae
<b>CRESTED EAGLE</b>			
(48) LMP Henriques	Sighting, Day list, A2 of EIA/RIMA, Taboca Island.	2000	LMP Henriques pers. arch.
(49) LMP Henriques	Sighting of adult during Aquatic survey from EIA/RIMA, at A2, census 19, T6.	23/04/2008	LMP Henriques pers. arch.
(50) V Palhares, Dorinny Lisboa, José L Paula	Sighting of adult in flight, during Listening Point Aquatic and Semi-aquatic Avifauna survey A1, nearby Limão locality, below <i>Travessão</i> 17.	31/03/2012	Leme/PE-1-1-L1
(51) V Castro	Photograph adult pale morph plumage, during Terrestrial survey M5, T2.	20/09/2013	Biota/ WA1091967, WA1221499
(52) TM Sanaiotti; TG Junqueira; V Palhares	Sighting adult pale morph plumage during Aquatic transit to Harpy Eagle nest Torrão.	23/03/2014	PCGR; Biota; Leme
(53) Roberta E Silva; Cesar Leite	Photograph of an adult pale morph plumage perched during Semi-aquatic Mustelid survey, A2, right bank, Cajueiro Island.	04/05/2014	RE Silva pers. arch.; Leme
(54) V Castro, L Castilho	Sighting of adult pale morph plumage perched, that approximate after playback during, during Terrestrial survey M1, T1, 500m.	03/08/2014	Biota
(55) Jailson Xavier	Sighting of adult pale morph plumage perched, during Terrestrial survey M7, T2, near P1.	19/08/2014	Biota
(56) V Castro, E Yosheno	Photograph of an adult extreme dark morph plumage perched during Terrestrial survey M6, T1.	16/02/2015	Biota / WA1612590
(57) TG Junqueira, K Lara	Photograph of an adult pale morph plumage perched, during Terrestrial survey M3, T1, P3.	24/02/2015	Biota / WA1622326
(58) Jailson Xavier	Active nest found during Herpetofauna survey at M1, T1, 2150 m.	09/03/2015	Biota
(58a) FH Aguiar-Silva, Olivier Jaudoin; TG Junqueira, Denilson Aranha	Photograph of two adults pale morph plumage and one chick one week old in the nest (same as 58).	14/03/2015	PCGR; Biota
(58b) TM Sanaiotti; TG Junqueira, Denilson Aranha	Photograph of juvenile perched on a tree near the nest (same as 58).	06/07/2015	PCGR; Biota

Reservoir-CEA with a two-month-old nestling, and nest Intermediate Reservoir-55CTCA with a flying juvenile) and two, already isolated by the vegetation suppression, will be inundated (nest Intermediate Reservoir Ticaruca with a juvenile about six months old but with perching behavior changed because of the surrounding vegetation suppression where mitigation action is required, and nest Intermediate Reservoir Paquiçamba with a flying juvenile) (Table 1, Figure 1).

### 3.2. Crested Eagles

Of the 11 Crested Eagle records, two were found during the EIA/RIMA; one in 2000 during qualitative records on an island and the other on 23 April 2008 during Aquatic Surveys. Eight records came from the surveys from 2012-2015. During the Aquatic Avifauna Surveys, there were two records, and another record was made during transit by boat and was categorized as occasional (Table 1, Figure 2b). Five records were made during Terrestrial Surveys, recorded in 5 of 8 modules, one classified as occasional was when the nest was found 1.3 km from an active Harpy Eagle nest in the same module 1 (Table 1).

### 3.3. Comparison between species

A comparison of the RAPELD and Aquatic transects methods was carried out for the total extent of areas 1-3 and partially for area 4 (restricted to the first 19 km where module 8 is located). The effort used for each method was compared with the number of records for both species. The Terrestrial surveys revealed 14 Harpy Eagles in 69 km walked\*3 days\*6 sampling periods, and six Harpy Eagles from the Aquatic standardized methods combined. Mustelid surveys recorded four in 245 km travelled by boat\*13 sampling periods; and Avifauna surveys recorded two in 245 km travelled by boat\*13 sampling periods. Five Crested Eagles were recorded in 69 km walked\*3 days\*6 sampling periods by Terrestrial surveys, and the Aquatic standardized methods recorded two individuals, both from Avifauna monitoring of 245 km travelled by boat\*13 sampling periods.

The combined records, terrestrial, aquatic and occasional, along the river (n=58), allowed us to estimate an average of one Harpy Eagle per 15 km and one Crested Eagle per 16 km of river surveyed (including terrestrial records up to 5 km from the margin).

Harpy Eagle combined records (n=47) from all surveys Aquatic and Terrestrial, and also Aquatic occasional records (excluding 6 Terrestrial occasional >5 km from the margin) allowed us to estimate 18 pairs with territories along 245 km sampled. Assuming the same density in the 31 km of river that was not navigable, which would hold two pairs, there would be a total of 20 pairs along 276 km of the Xingu River. Three nests in the area of the Intermediate Reservoir, found during vegetation suppression far from the river (8.5-10.9 km from left margin), were separated an average distance of 8.6 km (6.2-12 km). For the Volta Grande area on the left margin up to the BR-230 using all records (nest and observations >5 km from the margin)

as center of the territories, there was a mean of 10 km between records, and the area would have been occupied by about 10 pairs (Figure 1).

Five Crested Eagle records allowed us to confirm territory overlap with Harpy Eagles. There was an average of 4.8 km (1.3-6.7 km, n=5) between active Harpy Eagle nests and Crested Eagle records. Also, within RAPELD modules (n=5), the average distance between non-simultaneous records of the two species was 1.5 km (0.02-3.2 km, n=11).

## 4. Discussion

The methods used in the present study allowed us to conclude that the Terrestrial RAPELD method for detecting Harpy Eagles and Crested Eagles appears to be more efficient in terms of distance travelled and time spent when compared to the effort from Aquatic standardized methods. Nevertheless, the aquatic effort was complementary in allowing estimates of the number of pairs in the region. It would be necessary the double the number of modules installed along the river to achieve the same information using only Terrestrial surveys. One application of results from the permanent Terrestrial Surveys database is the possibility of returning to the same sites (RAPELD modules) where breeding behavior was detected, or young were recorded (indicative of nest proximity), and further field work can be done using playback techniques, and using tree climbing for nest searches. This last tool is being used successfully in Atlantic Forest remnants in Espírito Santo state (Aguar-Silva et al., 2012) and in Bahia state (Luz et al., 2006).

The average of 4.8 km between Harpy Eagle nests and Crested Eagle records was similar to the distance found in Ecuador (Muñiz-Lopez et al. 2007). The distance between the Harpy Eagle nest and Crested Eagle nest was 1.3 km, much closer than the 2.3 km found in Ecuador (Muñiz-Lopez et al., 2007). They overlap territories and probably do not compete because Crested Eagles feed on smaller prey than Harpy Eagles (Sanaiotti et al., 2007; Soares et al., 2008; Whitacre et al., 2012; Gomes, 2014; Aguiar-Silva et al., 2011).

The average distance of 16 km between Harpy Eagle records along 276 km of the Xingu River allowed us to estimate the size of possible territories. Using each record as the territory center, gives an estimate of a maximum of 20 pairs along the surveyed extension of the Xingu River. This distance between nests is greater than expected, as 8 km apart is the average for another site in the same interfluvium (Aguar-Silva et al., 2011) and 3.8-6 km for Venezuela (Álvarez-Cordero, 1996). This greater distance between individuals results in a lower density, perhaps already a result of the lack of forest cover along the river. In a modeling study in Panama, the authors estimated a pair for every 2.6 or 6.2 km, depending on the region (Vargas-González and Vargas, 2011). Gargett (1990) considered that distance between raptor nests reflects food availability. The mean distance (8.6 km) between nests in the Intermediate Reservoir area to be inundated

was similar to that found for Pará state: 8 km (Aguiar-Silva et al., 2011).

Harpy Eagles are known to nest in managed forests (Álvarez-Cordero, 1996; Kung and Álvarez-Cordero, 1997; Aguiar-Silva et al., 2011), but the remnant forests along the Xingu River near Altamira are surrounded by pastures, which have expanded in the last 10 years (Escada et al., 2005). Forested areas within nesting territories are under pressure of being cut for pasture and timber extraction, leaving some territories only in narrow alluvial forest that will not be flooded with the filling of the Xingu Reservoir. The fauna of the region of the low-Xingu River will be subject to changes in species composition and abundance of prey species available to the Harpy Eagle due to the small flood pulse of the Belo Monte Dam (Aguiar-Silva et al., 2015). There is need for reserves on private land and, as suggested by Moura et al. (2014), we need to enforce current forest legislation and promote coordinated strategies across neighboring properties to safeguard regional biodiversity in the Amazon, including restoration of degraded forests.

The fact that a nest tree used in 2008 is still in use is a good indication that the pair is resident in the reproductive territory and will remain if not hunted and the nest tree continues to be surrounded by forest. The species shows resilience under disturbance (Álvarez-Cordero, 1996; Aguiar-Silva et al., 2014a, 2015). However, local extinction has been reported for some sites in the Amazon (Moura et al., 2014), indicating the need to maintain forest to guarantee foraging areas around the nest (Soares et al., 2008). Educational activities should be implemented with local communities and neighboring areas in a 20–30-km radius around the nest. Incorporating community education outreach has been one of the tools used by the Panamanian Harpy Eagle Conservation Program (Curti and Valdez, 2009), and the PCGR in Brazil.

For two nests (Torrão and Module 1) the territories are not expected to flood, but the four active nests mapped during this study on the reservoirs (either Intermediate or Xingu) will be impacted. The territory and the juveniles still dependent on the nest will be isolated from the continuous forest by water. Although two of the nests are not expected to flood the bases of the trees, part of the surrounding forest will be lost to flooding. The other two nests that had already been isolated by vegetation removal will be completely inundated. The juveniles, which usually stay close to and use the nest for up to two years (Muñoz-López et al., 2012), will suffer with the lack of perching trees. Thus, mitigation action of reinstalling perches near the forest remnant has been recommended (45b-Table 1). The two inactive nests, on islands downstream of the dam, will be subject to drastic decreases in the Xingu River flow, and the vegetated area is expected to decrease in size by 68% (Cunha and Ferreira 2012), with a presumed proportional decrease in territories of the pairs that made the nests.

Overall, of the 30 breeding pairs estimated to be in the study area, territories of 16 pairs will be partially or totally flooded, or subjected to drastic decrease in river flow, downstream of the dam. The remaining 14 territories

have lost forest area to ranchers and are under threat of pasture expansion. Maintenance of the present density of Harpy Eagles will require active management.

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