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Short communication

Harpy eagles (*Harpia harpyja*) nesting at Refugio Amazonas, Tambopata, Peru feed on abundant disturbance-tolerant species

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ABSTRACT

The harpy eagle (*Harpia harpyja*) is one of the main predators of arboreal mammals in the neotropics, affecting the ecology and behaviour these species. Knowledge of harpy eagle diets across their geographical range is patchy, the ability of harpy eagles to adapt to changing habitats is still open to question. The three main species in the diet of harpy eagles nesting at Tambopata were porcupines (*Coendou* sp.) (n = 7) howler monkeys (*Alouatta sara*) (n = 6) and two-toed sloths (*Choloepus didactylus*) (n = 4), all species that do well in disturbed forests. We conclude that harpy eagles can reproduce in secondary forests, feeding on abundant disturbance-tolerant species, if they themselves are not hunted and their nesting trees are conserved. Harpy eagle nests have a high value for tourism, and strategies that allow landowners to benefit from harpy eagles nesting on their property through revenues from tourism may be instrumental in incentivising the conservation of forests and emergent trees, and the regeneration of forests in anthropogenic landscapes.

The harpy eagle (*Harpia harpyja*) is the heaviest eagle on the planet. Historically, it inhabited a wide range of lowland forests and forest enclaves at altitudes of 0 to 800 m, from the forests of southern Mexico to northeast Argentina (Miranda et al., 2019; Vargas-González et al., 2006). Globally, the harpy eagle is considered Near Threatened (Sarasola et al., 2018). It has been extirpated from habitats across Mexico and Central America and populations have decreased in South America due to the destruction, fragmentation and degradation of forests (Banhos et al., 2016; Miranda et al., 2019). Deforestation clearly limits the range of harpy eagles, while selective logging of the emergent trees that they breed in and the shortage of prey animals due to hunting may also reduce breeding potential (Giudice et al., 2007; Luz, 2005). Additionally, direct persecution may contribute to population declines in some areas (Trinca et al., 2008).

Breeding success in raptors will ultimately depend on the availability of suitable nest sites and the eagles' success in finding and capturing prey. Harpy eagles use firm forks to build their nests, and large eagles typically select emergent trees that are separated from others by position and height (Giudice et al., 2007; Luz, 2005). These requirements may mean that they are dependent on a few emergent species in Amazonian forests, such as *Dipteryx micrantha* and *Ceiba pentandra*, and to a lesser extent trees like the Brazil nut tree *Bertholletia excelsa* which have a more restricted range (Miranda et al., 2020; Thomas et al., 2014). The density of prey species is thought to affect the eagles' breeding success and ultimately distribution, and the breadth and flexibility in the diet of harpy eagles will affect their density and breeding success in impacted forests (Miranda, 2015). The first step in assessing harpy eagle feeding ecology is to determine which species are preyed upon. We examined the diet of harpy eagles nesting at Refugio Amazonas, a site where emergent trees are still abundant and eagles and their prey are protected by tourism activities, but where historical hunting and habitat degradation have created an impacted forest structure and mammalian community.

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We focused on a single harpy eagle nest in Tambopata National Reserve's 'Buffer Zone' (Fig. 1), near the Refugio Amazonas Lodge (Rainforest Expeditions), and close to several small settlements. The area around the nest is a matrix of forests of which 9 ha are regenerating from clearance in 2000, while the rest of the forest, although historically selectively logged for high value timber species, is relatively pristine, with occasional emergent trees such as *Dipteryx micrantha* and *Ceiba pentandra,* and areas of Brazil nut concession with frequent emergent Brazil nut trees that are still managed for Brazil nut production by local people. The area has not been hunted, logged or used for agriculture or any other economic activity beside ecotourism and Brazil nut harvesting since 2004. The area has an apparently complete mammalian community, but the abundance of the larger primates, specifically spider monkeys (*Ateles chamek*) is lower than at more remote sites up the Tambopata River (Rosin and Swamy, 2013).

The harpy eagle nest was 25 m from the ground in a *Dipteryx micrantha* tree, at the branching point of three major boughs. Almost directly below was a clay lick frequented mostly by mammals such as peccaries (*Tayassu pecari* and *Pecari tajacu*), red brocket deer (*Mazama americana*), lowland tapir (*Tapirus terrestris*), howler monkeys (*Alouatta sara*), and prehensile-tailed porcupines (*Coendou prehensilis*).

As part of a citizen science program called Wired Amazon managed by Rainforest Expeditions S.A.C., we observed the harpy eagle nest for nine months, from shortly after hatching. Observations were made using binoculars from the ground, and a remote surveillance camera with telephoto zoom lens (Dahua PTZ 4MP 30× Network Dome IP Camera) installed in a second *Dipteryx micrantha* tree, 30 m from the nest at a similar height. This camera sent a signal to a network video recorder (NVR) and digital display at a hide below, where researchers and tourists could view in real time. The system was powered by a solar panel and battery system. Due to constraints of the battery and solar power charging of the system, the camera was not recording continuously each day, but because prey items were in the nest for extended periods, we believe most larger prey items were detected within these periods. In total, 995.49 h of recordings were made.

We recorded the diet of the eagles on a total of 143 days (Table 1). A total of 53 kills were recorded. In 36 events, the sex of the bird bringing

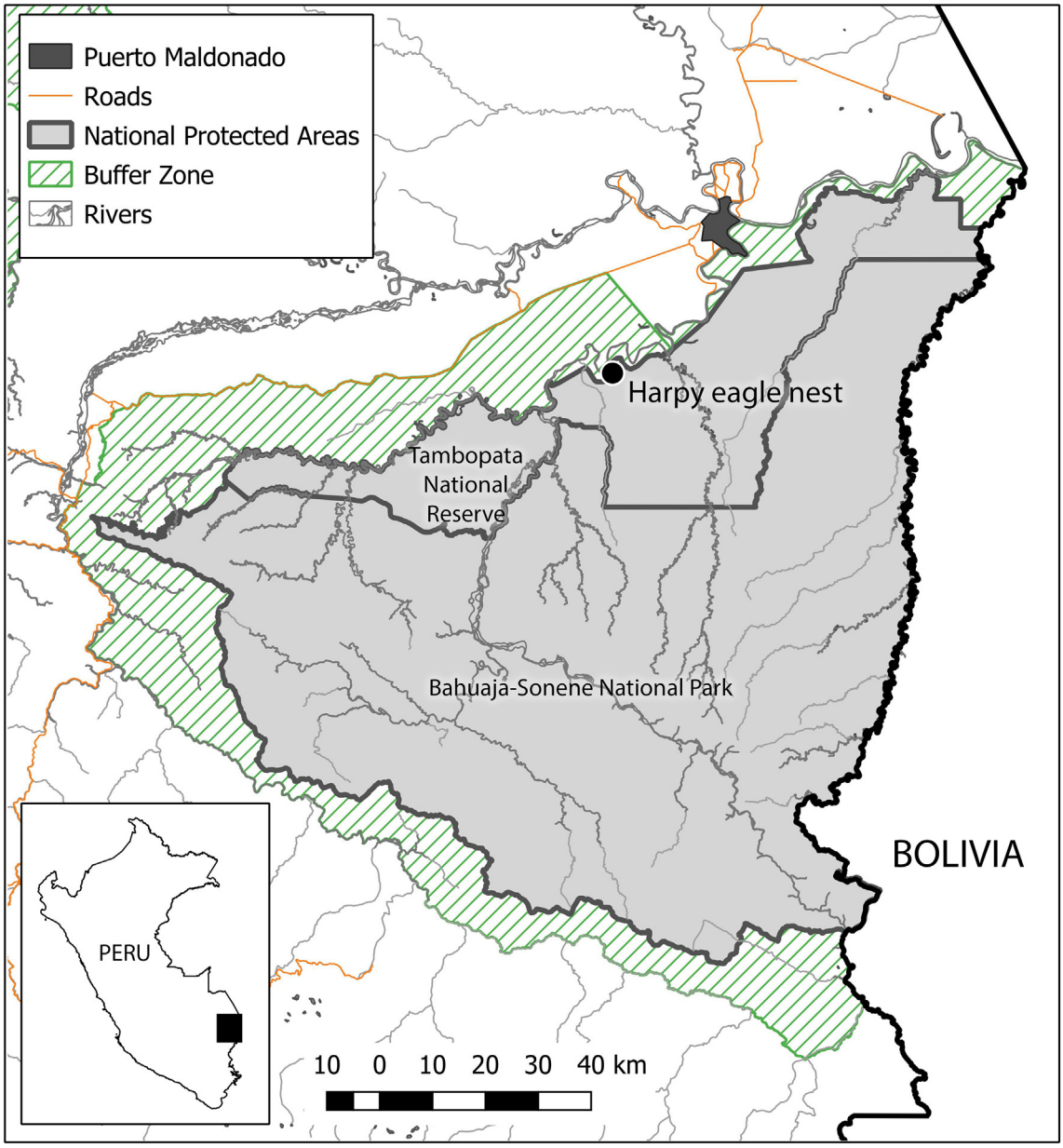

Fig. 1. Location of the harpy eagle nest under study near Refugio Amazonas on the edge of the Tambopata National Reserve, Peru.

Table 1
Harpy Eagle nest monitoring period.

Start	End	Total (days)	Nestling age
1st July 2017	12th July 2017	12	Hatchling
2nd Aug 2017	11th November 2017	101	Unfledged
28th November 2017	5th December 2017	9	Fledged
1st March 2018	21st March 2018	21	Fledged

the prey could be determined due to the larger size of the female (Fig. 2.); the female was identified bringing prey 15 times, and the male 21 times. When prey delivery was observed well enough to inspect the item brought, on 24 of 34 of occasions (71%) the prey was partially consumed by the time it was brought to the nest.

The prey species could be identified for 28 kills (52.8%, Table 2). The most common species were porcupines (*Coendou* sp.;.n = 7) of which two species are present at the site; the prehensile-tailed porcupine *Coendou prehensilis* and a much smaller dwarf porcupine (*Coendou* cf. *ichilus*). Except when the chick was almost fully grown, porcupines were brought to the nest with most of the spines removed. Howler monkeys (*Alouatta sara*) (n = 6) and two-toed sloths (*Choloepus didactylus*) (n = 4) were the second and third most important species respectively.

Fig. 2. Harpy eagles with prey at the nest near Refugio Amazonas Lodge on the edge of the Tambopata National Reserve, Peru. A. Female harpy eagle with red howler monkey *Alouatta sara*. B. Male (left) harpy eagle bringing Bolivian black-capped squirrel monkey *Saimiri boliviensis* to female. C. Female (left) harpy eagle with two-toed sloth *Choloepus didactylus* and juvenile harpy eagle (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Frequency of prey items observed at a harpy eagle nest at Refugio Amazonas, Tambopata, Peru.

Rank	Species	Common name	Frequency	Activity
1	*Coendou* spp.	Tree porcupines	7	Nocturnal
2	*Alouatta sara*	Red howler monkey	6	Diurnal
3	*Choloepus didactylus*	Two-toed sloth	4	Nocturnal
4	*Nasua nasua*	Coati	2	Diurnal
5	*Saimiri boliviensis*	Bolivian black-capped squirrel monkey	2	Diurnal
6	*Tamandua tetradactyla*	Tamandua anteater	2	Cathemeral
7	*Potos flavus*	Kinkajou	1	Nocturnal
8	*Bassaricyon alleni*	Allen's Olingo	1	Nocturnal
9	*Sapajus macrocephalus*	Large-headed capuchin monkey	1	Diurnal
10	*Cebus cuscinus*	Shock-headed capuchin monkey	1	Diurnal
11	*Eira barbara*	Tayra	1	Diurnal
		Unidentified	25	
		n=	53	

Parent birds brought prey to the eaglet until early 2019. Around March 2019, the parent birds removed all the sticks from the nest, while the young bird persisted in the vicinity. The young bird continued to bring prey to the branching point where the nest had been at least until August 2019. It is not clear if the young bird was catching its own prey or being previsioned since no hunts or exchanges were observed.

Rarefaction curves show that at least 25 samples are needed to identify the four main prey species of harpy eagles at a site (Miranda, 2015). In our case three species tied for fourth place, so we are confident in ranking the three main prey species at Refugio Amazonas. At other sites, harpy eagles ate larger proportions of primates and sloths (Miranda, 2015). Although most harpy eagles at other sites consumed porcupines, they were only a main prey item in one other study, which was also in the Tambopata National Reserve's 'Buffer Zone' (Piana, 2007). In common with most studies of harpy eagles to date (see Miranda, 2018), the Refugio Amazonas nest was in a human-modified landscape, dominated by old regrowth forest. Porcupines are abundant in secondary forest (Chiarello, 1999), and are not hunted by humans due to their strong odour (Emmons and Feer, 1997). Both the two-toed sloth and the red howler monkey probably also benefit where forest disturbance occurs and hunting is low (Lopes and Ferrari, 2000). Furthermore, the two-toed sloth is protected from hunting by its cryptic and largely nocturnal habits (Superina et al., 2010) and their low muscle to body mass ratio (Beebe, 1926; Endo et al., 2010; Peres, 2000).

We concur with Miranda (2015) that the harpy eagle's apparently opportunistic and adaptable diet enables them to live in impacted forests, feeding on abundant disturbance-tolerant prey items. If harpy eagles are indeed scarce outside expansive pristine areas, this may have more to do with a lack of nest sites or direct persecution than with changes to mammal communities (Muñiz-López et al., 2012; Vargas-González et al., 2006). Refugio Amazonas has persisting emergent *Dipteryx micrantha* and *Ceiba pentandra* nesting trees, but these are increasingly rare in accessible parts of the Amazon (Asner et al., 2006; Putzel, 2010). Harpy eagles are probably rarely persecuted in the local area around Refugio Amazonas, due to their value to tourism. Elsewhere, harpy eagles are killed to protect livestock (e.g. Brazil, Trinca et al., 2008) or for food (Freitas et al., 2014; Rio Napo, Peru, M. Bowler *unpublished data*).

Harpy eagles preyed mostly on canopy folivores, as shown in previous studies (Aguiar-Silva et al., 2014). Those are probably the species of

greatest abundance in the canopy (Alho, 2011). Four nocturnal species made up 34% of the diet of the harpy eagles, which may suggest nocturnal hunting. On the other hand, harpy eagles may prey on sleeping animals during the day. Although porcupines often sleep in tree cavities, porcupines and two-toed sloths can be found sleeping in the forks of branches during the day (Emmons and Feer, 1997), where they are at risk from diurnal predation by harpy eagles. Nocturnal, cavity sleeping night monkeys (*Aotus nigriceps*), one of the most common primate species in Amazonian forests and abundant at Refugio Amazonias (M. Bowler *unpublished data*), were not recorded as prey. However, the presence of strictly nocturnal kinkajou (*Potos flavus*) and olingo (*Bassaricyon alleni*) in the diet, which sleep only in tree cavities, does suggest that harpy eagles are able to hunt in very low light in the early mornings or late evenings, and on bright full moon nights (Miranda et al., 2020).

The adult harpy eagles taking sticks from their nest after their chick had fledged is a behaviour that has been seen previously at other sites in the region (E. Nycander *unpublished data*). It is possible the parent birds were stimulating chick dispersal, removing the platform used to eat. Harpy eagles are known to have alternative nests (Vargas-González and Vargas, 2011), and have been recorded killing offspring unable or unwilling to disperse (Muñiz-López, 2017). We speculate that the birds may have used an alternative nest site, rather than push their offspring out of the nest (Muñiz-López, 2017; Urios et al., 2017).

Our study left 52.8% of prey unidentified compared to 16% with bone collection (Izor, 1985) and 0% with direct observation (Touchton et al., 2002). However, our camera was 30 m from the nest and level with it, so prey items often quickly disappeared into the bowl of the nest before identification could be confirmed. We recommend that monitoring cameras are positioned more closely and looking down into the nest in future studies, following Aguiar-Silva et al. (2017). Furthermore, our methods produced data not usually obtained through using bone collection exclusively, such as the parent individual delivering the prey item. A combination of both methods may be useful in future studies.

Harpy eagles can survive and thrive in secondary forests if not hunted and their nesting trees are conserved. Harpy eagle nests in Tambopata have a high value for tourism, leading to the protection of them and their nesting trees (Hill and Hill, 2011). Strategies that further allow landowners to benefit from harpy eagles nesting on their property through revenues from tourism, as described by (Miranda et al., 2020), may be instrumental in incentivising the conservation and regeneration of forests in anthropogenic landscapes.

Declaration of competing interest

None.

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Permits

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