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1 Short communication

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

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9 Mark Bowler^{1,2,3*}, Daniel Couceiro⁴, Rocio Martinez⁴, Gabriella Orehuela^{4,5}, Juan Diego
10 Shoobridge^{4,6}, Eduardo Nycander⁴, Everton B. P. de Miranda⁷, Mathias W. Tobler²

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8 ¹School of Engineering, Arts, Science and Technology Science, University of Suffolk,
9 Waterfront Building, Neptune Quay, Ipswich, IP4 1QJ, UK; ²Institute for Conservation

10 Research, San Diego Zoo Global, Escondido, California, CA 92027-9614, USA; ³Suffolk
11 Sustainability Institute, Waterfront Building, Neptune Quay, Ipswich, IP4 1QJ, UK;

12 ⁴Rainforest Expeditions S.A.C. Av Aeropuerto, La Joya Km 6, Puerto Maldonado, Madre de
13 Dios, Peru; ⁵Facultad de Ciencias Forestales - Universidad Nacional Agraria La Molina,

14 Peru. ⁶Laboratorio de Botánica Aplicada, Laboratorios de Investigación y Desarrollo (LID),
15 Universidad Peruana Cayetano Heredia, Lima, Perú; ⁷Centre for Functional Biodiversity,

16 School of Life Sciences, University of KwaZulu-Natal. Pietermaritzburg, 3209, South Africa

17 *Corresponding Author: m.bowler@uos.ac.uk

18 **Abstract**

19 The harpy eagle (*Harpia harpyja*) is one of the main predators of arboreal mammals in the
20 neotropics, affecting the ecology and behaviour these species. Knowledge of harpy eagle
21 diets across their geographical range is patchy, the ability of harpy eagles to adapt to
22 changing habitats is still open to question. The three main species in the diet of harpy eagles
23 nesting at Tambopata were porcupines (*Coendou* sp.) (n=7) howler monkeys (*Alouatta sara*)
24 (n=6) and two-toed sloths (*Choloepus didactylus*) (n=4), all species that do well in disturbed
25 forests. We conclude that harpy eagles can reproduce in secondary forests, feeding on
26 abundant disturbance-tolerant species, if they themselves are not hunted and their nesting

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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.

ARTICLE

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

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52 ultimately distribution, and the breadth and flexibility in the diet of harpy eagles will affect
53 their density and breeding success in impacted forests (Miranda, 2015). The first step in
54 assessing harpy eagle feeding ecology is to determine which species are preyed upon. We
55 examined the diet of harpy eagles nesting at Refugio Amazonas, a site where emergent
56 trees are still abundant and eagles and their prey are protected by tourism activities, but
57 where historical hunting and habitat degradation have created an impacted forest structure
58 and mammalian community.

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

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

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

90 Table 1. Harpy Eagle nest monitoring period.

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

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 93 We recorded the diet of the eagles on a total of 143 days (Table 1.). A total of 53 kills were
 94 recorded. In 36 events, the sex of the bird bringing the prey could be determined due to the
 95 larger size of the female (Figure 2.); the female was identified bringing prey 15 times, and
 96 the male 21 times. When prey delivery was observed well enough to inspect the item
 97 brought, on 24 of 34 of occasions (71%) the prey was partially consumed by the time it was
 98 brought to the nest.

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

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

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

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 110 Parent birds brought prey to the eaglet until early 2019. Around March 2019, the parent birds
 111 removed all the sticks from the nest, while the young bird persisted in the vicinity. The young
 112 bird continued to bring prey to the branching point where the nest had been at least until

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2 113 August 2019. It is not clear if the young bird was catching its own prey or being provisioned
3 since no hunts or exchanges were observed.
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5 115 Rarefaction curves show that at least 25 samples are needed to identify the four main prey
6 species of harpy eagles at a site (Miranda, 2015). In our case three species tied for fourth
7 place, so we are confident in ranking the three main prey species at Refugio Amazonas. At
8 116 other sites, harpy eagles ate larger proportions of primates and sloths (Miranda, 2015).
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10 117 Although most harpy eagles at other sites consumed porcupines, they were only a main prey
11 item in one other study, which was also in the Tambopata National Reserve's 'Buffer Zone'
12 (Piana, 2007). In common with most studies of harpy eagles to date (see Miranda, 2018),
13 118 the Refugio Amazonas nest was in a human-modified landscape, dominated by old regrowth
14 forest. Porcupines are abundant in secondary forest (Chiarello, 1999), and are not hunted by
15 humans due to their strong odour (Emmons and Feer, 1997). Both the two-toed sloth and
16 119 the red howler monkey probably also benefit where forest disturbance occurs and hunting is
17 low (Lopes and Ferrari, 2000). Furthermore, the two-toed sloth is protected from hunting by
18 its cryptic and largely nocturnal habits (Superina et al., 2010) and their low muscle to body
19 mass ratio (Beebe, 1926; Endo et al., 2010; Peres, 2000).
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38 129 We concur with Miranda (2015) that the harpy eagle's apparently opportunistic and
39 adaptable diet enables them to live in impacted forests, feeding on abundant disturbance-
40 130 tolerant prey items. If harpy eagles are indeed scarce outside expansive pristine areas, this
41 may have more to do with a lack of nest sites or direct persecution than with changes to
42 131 mammal communities (Muñiz-López et al., 2012; Vargas-González et al., 2006). Refugio
43 Amazonas has persisting emergent *Dipteryx micrantha* and *Ceiba pentandra* nesting trees,
44 132 but these are increasingly rare in accessible parts of the Amazon (Asner et al., 2006; Putzel,
45 2010). Harpy eagles are probably rarely persecuted in the local area around Refugio
46 133 Amazonas, due to their value to tourism. Elsewhere, harpy eagles are killed to protect
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138 livestock (e.g. Brazil, Trinca et al., 2008) or for food (Freitas et al., 2014; Rio Napo, Peru, M.
139 Bowler *unpublished data*).

140 Harpy eagles preyed mostly on canopy folivores, as shown in previous studies (Aguiar-Silva
141 et al., 2014). Those are probably the species of greatest abundance in the canopy (Alho,
142 2011). Four nocturnal species made up 34% of the diet of the harpy eagles, which may
143 suggest nocturnal hunting. On the other hand, harpy eagles may prey on sleeping animals
144 during the day. Although porcupines often sleep in tree cavities, porcupines and two-toed
145 sloths can be found sleeping in the forks of branches during the day (Emmons and Feer,
146 1997), where they are at risk from diurnal predation by harpy eagles. Nocturnal, cavity
147 sleeping night monkeys (*Aotus nigriceps*), one of the most common primate species in
148 Amazonian forests and abundant at Refugio Amazonas (M. Bowler *unpublished data*), were
149 not recorded as prey. However, the presence of strictly nocturnal kinkajou (*Potos flavus*) and
150 olingo (*Bassaricyon alleni*) in the diet, which sleep only in tree cavities, does suggest that
151 harpy eagles are able to hunt in very low light in the early mornings or late evenings, and on
152 bright full moon nights (Miranda *in press*).

153 The adult harpy eagles taking sticks from their nest after their chick had fledged is a
154 behaviour that has been seen previously at other sites in the region (E. Nycander
155 *unpublished data*). It is possible the parent birds were stimulating chick dispersal, removing
156 the platform used to eat. Harpy eagles are known to have alternative nests (Vargas-
157 González and Vargas, 2011), and have been recorded killing offspring unable or unwilling to
158 disperse (Muñiz-López, 2017). We speculate that the birds may have used an alternative
159 nest site, rather than push their offspring out of the nest (Muñiz-López, 2017; Urios et al.,
160 2017).

161 Our study left 52.8% of prey unidentified. compared to 16% with bone collection (Izor, 1985)
162 and 0% with direct observation (Touchton et al., 2002) However, our camera was 30 m from
163 the nest and level with it, so prey items often quickly disappeared into the bowl of the nest

164 before identification could be confirmed. We recommend that monitoring cameras are
165 positioned more closely and looking down into the nest in future studies, following Aguiar-
166 Silva et al. (2017). Furthermore, our methods produced data not usually obtained through
167 using bone collection exclusively, such as the parent individual delivering the prey item. A
168 combination of both methods may be useful in future studies.

169 Harpy eagles can survive and thrive in secondary forests if not hunted and their nesting
170 trees are conserved. Harpy eagle nests in Tambopata have a high value for tourism, leading
171 to the protection of them and their nesting trees (Hill and Hill, 2011). Strategies that further
172 allow landowners to benefit from harpy eagles nesting on their property through revenues
173 from tourism, as described by (Miranda et al., 2019), may be instrumental in incentivising the
174 conservation and regeneration of forests in anthropogenic landscapes.

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261 **Declaration of competing interest**

262 None.

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280
281 **Permits**

282 This research was conducted with the necessary permits from The Peruvian Ministry for
283 Protected Areas (SERNANP).

284
285 **Figure Legends**

286 Figure 1. Location of the harpy eagle nest under study near Refugio Amazonas on the edge
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2 287 of the Tambopata National Reserve, Peru.
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8 289 Figure 2. Harpy Eagles with prey at the nest near Refugio Amazonas Lodge on the edge of
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10 290 the Tambopata National Reserve, Peru. A. Female harpy eagle with red howler monkey
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12 291 *Alouatta sara*. B. Male (left) harpy eagle bringing Bolivian black-capped squirrel monkey
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14 292 *Saimiri boliviensis* to female. C. Female (left) harpy eagle with two-toed sloth *Choloepus*
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16 293 *didactylus* and juvenile harpy eagle (right).
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