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Is the Papuan Harrier *Circus spilonotus spilothorax* a globally threatened species? Ecology, climate change threats and first population estimates from Papua New Guinea

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Summary

We undertook a 3-week expedition to Papua New Guinea in April-May 2007 to assess the breeding, threats and population densities of the Papuan Harrier *Circus spilonotus spilothorax* and to determine a first global population estimate for this almost entirely unknown species. Two of the first nests known were discovered in April 2007 with three chicks each, in the eastern lowlands, in rank grass and reeds. The melanistic form of this subspecies was more common in the lowlands (< 1,500 m a.s.l) than in the highlands, but interbreeding of this and the typical form occurred in the lowlands. Movements of identifiable individuals through two highland grasslands indicated up to eight birds per day on passage, corroborating local knowledge that other raptors move into the highlands at the start of the dry season (April). Linear road counts indicated no harriers in the wooded highlands but up to 2.9 harriers 10 km^{-1} in lowland grasslands. Area counts gave an average of 6.5 harriers 100 km^{-2} in the grasslands and a breeding density of 1.21 nests 100 km^{-2}. Given that preferred grassland and swamp habitat comprises *c.* 7% of the forest-dominated island of New Guinea, the global Papuan Harrier population can be no more than *c.* 3,600 birds and *c.* 740 breeding pairs. Wildfires peaked at 38 per month in the study area, occur throughout the dry season, and led to the loss of both nests. This suggests that many nests and prey may be lost at critical times and burning may be ultimately detrimental for the species. Grassland fires throughout Indonesia and Papua New Guinea are increasing with climatic warming and ENSO events, so we suggest that the Papuan Harrier may warrant a 'Vulnerable' conservation ranking due to small total population size and an accelerated reduction in habitat quality due to ongoing climate change.

Introduction

The endemic-rich island of New Guinea (Heads 2002) holds 31 species of diurnal raptor including seven species of Accipitrine hawks (Diamond 1985, Beehler *et al.* 1986) and the large but elusive New Guinea Harpy Eagle *Harpyopsis novaeguineae* (Legra 2005). Almost all are unstudied. The paucity of knowledge has led to some confusion regarding the only resident harrier there – the Papuan Harrier *Circus spilonotus spilothorax*. Despite being a resident on an island full of endemic vertebrates (Beehler *et al.* 1986, Coates 1985, Flannery 1995), it is currently treated by most authorities (Ferguson-Lees and Christie 2001, BirdLife International 2004) as a subspecies of Eastern Marsh Harrier *Circus spilonotus*, a bird that currently never visits the island. It is said to vary from rare to locally common in grasslands and swampy areas with two colour morphs (dark brown and typical: Coates and Peckover 2001) making it easily confused with the

Australasian Swamp Harrier *Circus approximans* which occasionally visits the island (Beehler *et al.* 1986, Coates and Peckover 2001).

Some authors have suggested that the Papuan Harrier be treated as a full species based on plumage differences with the Eastern Marsh Harrier, the lack of immigration of this species from the north, and its resident status in New Guinea (Simmons 2000, Coates and Peckover 2001). This proposal has been rejected by BirdLife International whose policy is to require published evidence from DNA or morphological data to change accepted wisdom (http://www.birdlife.org/datazone/species/taxonomy.html 2008). For these reasons we undertook an expedition to Papua New Guinea in April–May 2007, where we visited sites in both the central highlands (> 1,500 m) and lowlands in the east of the country to study breeding activity, movements, and habitat preferences of breeding birds, and estimate overall densities of all harriers. To resolve the subspecies debate we additionally collected tissue (feathers and blood) samples for DNA analysis. The first genetic results are still pending (M. Wink and R. Simmons in Unpubl. data), but we assume full species status (based on the previous arguments) in order to take a precautionary principle approach to give this bird a first-order global conservation ranking. Our results represent the first systematic efforts to understand the ecology of Papuan Harriers, a species for which only one nest has previously been found (Campbell pers. comm. in Coates 1985) and whose lack of current conservation ranking (BirdLife International 2008) may jeopardize its future welfare.

Methods and Study Area

New Guinea is a wooded tropical island some 2,00 km long, lying 5–6° south of the equator just north of Australia, with high annual rainfall varying from 1.2 to 10 m year^{-1} (McAlpine *et al.* 1983, Beehler *et al.* 1986). Politically, the island comprises Irian Jaya (or West Papua) in the western half and Papua New Guinea (PNG) in the east. About 93% of the island is wooded with the remainder comprising lowland swamp, highland grassland and cool alpine areas (Beehler *et al.* 1986, S. Haberle *in litt.*). Highlands, defined as land above 1,500 m (Whitmore 1984), account for about 14% of the surface area (Beehler *et al.* 1986). Rainfall is variable from region to region but the highlands here receive about 1.85–6.4 m of rain in the wetter months of November through March (McAlpine *et al.* 1983, Symes and Marsden 2005).

During a three-week study period (24 April – 17 May 2007) three study areas in the eastern part of PNG were searched intensively for foraging and breeding birds; two in the highlands (Goroka 6° 05′ S, 145° 25′ E; 1,500 m; and Mt Hagen 5° 46′ S, 144° 17′E; 1800 – 2,800 m), and one in the lowlands – the Markham and Ramu Valleys (Figure 1) at 400–500 m. These were initially chosen based on reports of one nest from Mt Hagen and multiple sightings from the lowland valleys (Coates 1985). We have used harrier densities gathered here to extrapolate to other parts of the island with appropriate habitat to give a preliminary population estimate. Intervening areas were searched by car but most effort was expended on following harriers at the two large airstrips in the highlands – areas of grassland and low bush, 2.1–2.3 km long and undisturbed by the otherwise dense populations of people in the surrounding towns. Intervening highlands were characterized by dense woodland with some areas cleared for small subsistence gardens (Marsden *et al.* 2006), or by annual fires and dominated by open grassland. During the dry season of highland PNG (April–September), anthropogenic grassland burning is very common in both the highlands and the lowland Markham and Ramu Valleys (pers obs.). Such fires are not new, and occur most commonly during drought associated with ENSO (El Niño-Southern Oscillation) climatic events (Johns 1989, Haberle *et al.* 2001).

The fertile Markham and Ramu valleys lie either side of Watarais (5°57′S, 145° 54′E), with the Markham River flowing north-east from here, and the Ramu River flowing north-west. The Ramu Valley supports extensive sugar-cane plantation, emerging oil palm plantations and some fallow fields (Figure 1). The Markham valley is dominated by *Imperata cylindrical* grassland interspersed with subsistence gardens, and some trees such as Coconut Palms *Cocos nucifera*. Rainfall is 1,954 mm per annum and soil fertility high but declining (Hartemink 2003). Human

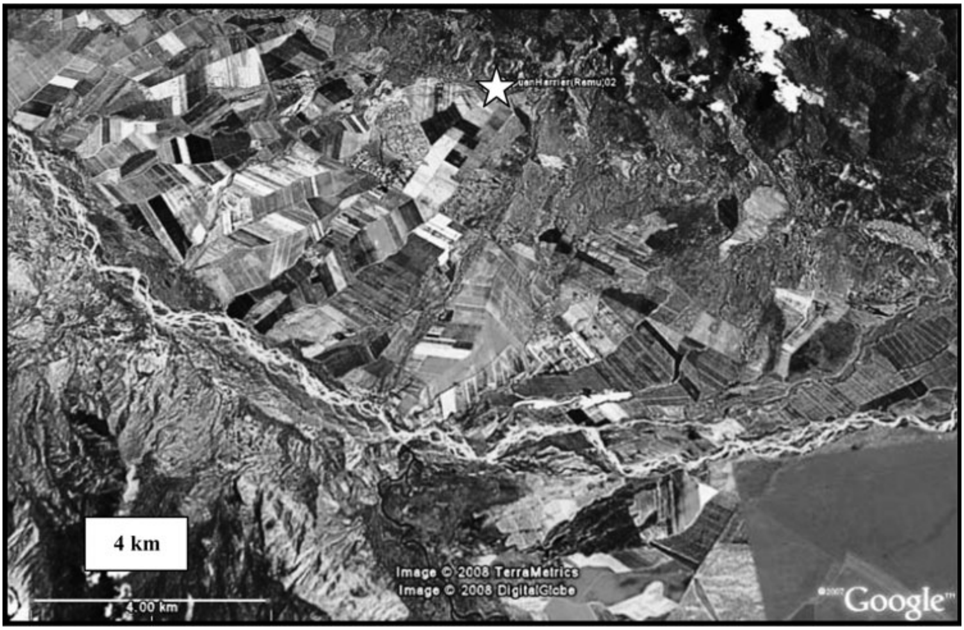

Figure 1. A Google Earth™ image of the Papuan Harrier nest site No. 2 (star) in the Ramu Valley Papua New Guinea. The image shows the intensive sugar-cane farming in the Ramu Valley (S5° 57.045′, E145° 54.330′), the Ramu River to the south and already burned cane field. Further dry-season burning reduced the grassland area available and this nest was lost to fire.

population density in both valleys is low but widespread and concentrated around traditional villages (Fig. 1).

A combination of raptor road counts and fixed-point observations were employed to determine the density and movements of individual harriers through grassland areas where they occurred. For estimates of harrier breeding density a transect width of 2 x 1.5 km was chosen in the grassland valleys. This area was conservatively chosen based on the discovery of a breeding male observed at slightly greater distance of 1.9 km that led to the second nest. A total transect length of 50 km traversed slowly by vehicle over three days in this valley gave a transect area of 150 km^2. Densities of harriers and their nests were calculated from this. Other road surveys are given as linear densities of birds per 10 km. Typical road counts (Young *et al.* 2003) covering over 600 km were undertaken with two observers travelling $\leq$ 80 km h^{-1} along major routes within the highlands (comprising grasslands and woodland habitat with numerous small subsistence farms), between the highlands and lowlands (comprising hill forest habitat), and over shorter routes within the two valleys (unburned open grasslands with little agriculture).

Individual birds were identified using a combination of digital photographs, video clips and pencil sketches. The diversity provided by melanism, pale subadult plumage, yellow- vs brown-eyed birds and marked differences between adult males (black, grey and white plumage) and adult females (brown streaked plumage: Coates and Peckover 2001) allowed us to identify individual birds as resident or on passage.

All observations were undertaken with 8.5x binoculars and nest positions were marked using a Garmin II Global Positioning System accurate to about 10 m. Digital photographs and video clips were captured with a Canon Powershot S3 with 12x optical magnification and bird images were downloaded onto a laptop computer for scrutiny of colours and distinguishing marks.

Nests were found by following prey-carrying males from a moving vehicle or an elevated hillside position. Prey delivered via a food pass to breeding females and taken to the nest revealed their position (Simmons 2000). Other areas over which male and female harriers were performing aerial displays were also observed until food was delivered or no further breeding activity occurred.

To quantify the scale of burning, NASA images on the Modis website, supplied by University of Maryland (http://maps.geog.umd.edu/firms/maps.asp) were consulted. Images of fire scars during the initial surveys (April–May 2007) and throughout the dry season (April–September) were downloaded.

Results

More melanistic (dark brown) adults than typically-plumaged harriers occurred in the lowlands than above 1,500 m a.s.l. In total, six of 21 adult and subadult birds (29%) were classed as melanistic in the lowlands, while only one of 15 individually identified birds (7%) was classified as such in the highlands. Thus, while melanism accounted for 19.4% of 36 individually recognized Papuan Harriers, the typical adult grey (male) and streaked brown (female) were the commonest plumage types.

Movements and harrier densities

No harriers were seen in grassland valleys around Goroka but birds were present at the less disturbed airports supporting grasses and few bushes (Table 1). At Goroka airstrip, where a maximum of three different harriers occurred at any time, no individuals appeared to stay for more than two days. In five days of observation, covering 11 h 20 min at Goroka airstrip, three birds declined to no birds, then one immature bird was recorded on the last day. At Mt Hagen airport, five days observation (2–7 May) covering 27 h 50 min, a maximum of 2–9 harriers per day passed through and foraged over the wet grassland surrounds (Table 1). As far as we could tell only one of these birds stayed for more than two days – a dark adult female displaying and exhibiting typical harrier pre-breeding behaviour. A small roost of 4–5 birds was apparent in the 1 m high grass adjacent to the second airstrip; birds entered this area about 20 min before sunset (17h40) and had left before we arrived the following morning shortly after sunrise.

No harriers were observed in 441 km of wooded hill forest areas of the highlands, but other raptors were common including Brahminy Kite *Haliastur indus*, Whistling Kite *H. sphenurus*, Black Kite *Milvus migrans*, Variable Goshawk *Accipiter novaehollandiae*, Collared Sparrowhawk *A. cirrhocephalus*, Brown Falcon *Falco berigora*, Black-winged Kite *Elanus caeruleus* and White-bellied Sea Eagle *Haliaeetus leucogaster* (Table 2). Papuan Harriers were encountered again in the lowland grasslands in the Ramu and Markham Valleys below 500 m. Linear densities of

Table 1. Number of individually recognized Papuan Harriers seen passing through Mt Hagen Airport, Eastern Highlands, 2–7 May 2007.

DATE (h observed)	Adult Male	Adult Female	Sub-adult male	Sub-adult female	Juv	Total number of birds
2 May (6.5)	2	1	3–5	–	1	7–9
3 May (9.3)	–	2	1	–	1	4*
4 May (7.0)	–	2	4	1	1	8
6 May (3.0)	–		1	–	–	2
7 May (2.0)	–	2	1	–	–	3

*excludes small roost of 4–5 birds active at airport in which sexes difficult to distinguish

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Table 2. Harriers and other raptor species encountered in highland and lowland areas of Eastern Papua New Guinea during road surveys between 26 April and 13 May 2007. Papuan Harriers densities are given as birds 10 km^{-1} traversed and the lowland sites are the last 4 rows.

Location	Habitat	Harriers seen	Km driven	Harriers 10 km^{-1}	Other raptors seen
Bena Valley	mixed grass/ woodland/gardens	0	24	0.0	Black Kite 14
Aseroka Valley	mixed grass/ woodland/gardens	0	15	0.0	Black Kite 1
Goroka to Mt Hagen	Hill forest	2*	183	0.1	Black Kite 18 Whistling Kite 2 Brahminy Kite 2 Sparrowhawk sp 2
Mt Hagen to Kumul Lodge	Hill forest	0	66	0.0	Black Kite 5 Brahminy Kite 1
Kumul Lodge to Mt Hagen	Hill forest	0	42	0.0	Black Kite 14 Variable Goshawk 2
Goroka to Kassam Pass	Hill forest	0	150	0.0	Black Kite 25
Ramu Valley	Lowland grassland/ Sugar cane	3	34	0.88	Sparrowhawk sp. 1 Black Kite 40 Brown Falcon 2
Ramu Valley	Lowland grassland/ Sugar cane	5	29	1.72	Black Kite 18 Whistling Kite 1 Brown Falcon 3
Markham Valley	Lowland grassland/ Sugar cane	4	14	2.86	Black Kite 4 Black-winged Kite 1
Ramu + Markham Valley	Lowland grassland/ Sugar cane	11	50	2.20	Black Kite 115 White-bellied Sea Eagle 1 Collared Sparrowhawk 1

*2 harriers observed only in the last 10 km of valley grassland

harriers there varied between 0.9 and 2.9 birds 10 km^{-1} (Table 2). Birds foraged over semi-burned grassland and were attracted to the burning areas, alongside numerous Black Kites. Within an estimated area of 150 km^2 a maximum of 11 harriers were seen from the road per day. The average density of birds seen over 3 days was 6.5 harriers 100 km^{-2} with a range from 4.6–7.3 harriers 100 km^{-2}.

Breeding density and first estimate of harrier population size

Given that two active harrier nests (35 km apart) occurred within the same area, the minimum estimated nesting density was one nest 82.5 km^{-2} (or 1.33 active nests 100 km^{-2}). The *potential* nest density, given that 4 nests were suspected (pairs calling and intense aerial displaying by two males) within the same area, gives an extrapolated nest density of 1 nest 41.25 km^{-2} (or 2.67 nests 100 km^{-2}).

We can use the Papuan Harrier densities to provide a first estimate of the world population size of this species. About 7% of the island of New Guinea (792,500 km^2; National Geographic 1990) is potential harrier habitat of grassland and swamp (Beehler *et al.* 1986, S. Haberle *in litt.*). Given that the harriers do not occur on any of the surrounding archipelagos of New Britain, New Ireland or Bougainville (Coates and Peckover 2001), and forage but are unlikely to breed in intense agricultural areas because of disturbance, there is about 55,475 km^2 of suitable habitat for Papuan Harriers. At a mean density of 6.5 birds 100 km^{-2} (range 4.6 – 7.3 birds 100 km^{-2}), we estimate a total population across the island of New Guinea to be 3,606 birds. Given the range in field densities, the population size varies from 2,552 to 4,050 birds.

Using the known nesting density, estimated at 1.33 nests 100 km^{-2} and the same assumptions regarding suitable habitat available to Papuan Harriers, the maximum estimate of breeders on the island of New Guinea is about 738 nests. Using *potential* nests (2.67 nests 100 km^{-2}) the estimated number of pairs on New Guinea is 1,481. Both are upper estimates given that the densities were derived from grassland valley habitat considered ideal for breeding birds.

Breeding activity

Two nests, both in the lowland valley (404 and 510 m), were found following male to female prey transfers. Nest 1 was in a dense and extensive stand of rank grass and reeds, on damp ground without standing water, *c* 180 m off a tar road at the west end of the Markham Valley. Villagers within 1 km of the nest were unaware of the birds' presence. Nest 2 in the Ramu Valley was built in a river flood plain adjacent to sugar cane fields, on damp ground (Figure 1). Both nests were built adjacent to reed clumps, about 1 m high, that stood slightly above the surrounding grasses. This offered complete shade to the nest contents, in an area that regularly experienced day-time temperatures exceeding 30°C.

Both nests had three small downy white chicks. Given a mean incubation period of about 31 days for harriers (Simmons 2000), the first egg in Nest 1 was estimated to have appeared on 6 April, and Nest 2 is estimated to have started on 2 April, the start of the dry season.

Breeding success and grassland burning

Both nests were revisited in mid June, four weeks after discovery, to check for success. Nest 1, in a subsistence agriculture area, was destroyed by a fire that also burned the surrounding area (P. Limu pers. obs.). Nest 2 in the Markham River floodplain was likewise destroyed by fire that swept the area (L. L. pers. obs.). Thus neither nest was successful nor could growth of the nestling harriers be monitored. The distance between the two nests was 35.1 km.

The lowland areas where the nests were found were dominated by grassland and sugar cane. Both sides of the valley were steep-sided grassy hills topped by montane rainforest. All of these grasslands were burned or in the process of burning as we left the area in mid May. Local knowledge indicates that all grasslands and old sugar cane fields in this valley are burned before the end of the dry season (P. Limu pers. comm.).

To quantify the scale of burning, fire scars captured in Modis-NASA images from April–May 2007 and throughout the dry season (April–September) were magnified and counted. This indicated that the Ramu and Markham valleys were particular hotspots of fire activity beginning in April ($n = 1$), increasing in May (21 fires), reaching a peak in June (38 fires), and declining to 24 fires in August. By September there were no fires (Figure 2). The total number of individual scars in this 6-month period was 108 in the 150 km^2 area, an average of 18 per month.

Discussion

These data represent the first systematic investigation of the Papuan Harrier of New Guinea and the first detailed evidence of breeding. Our most important results indicate that Papuan Harriers (i) occur commonly in two plumage forms – a rarer dark brown one and the more typical grey and white (male) birds which interbreed; (ii) the bird is confirmed as breeding in the dry season in damp grasslands and floodplains; and (iii) the first estimated world population size of this island endemic gives a small population of about 3,600 birds and 740 breeding pairs. We suggest below that the small population size and the timing and extent of grassland burning in its strongholds

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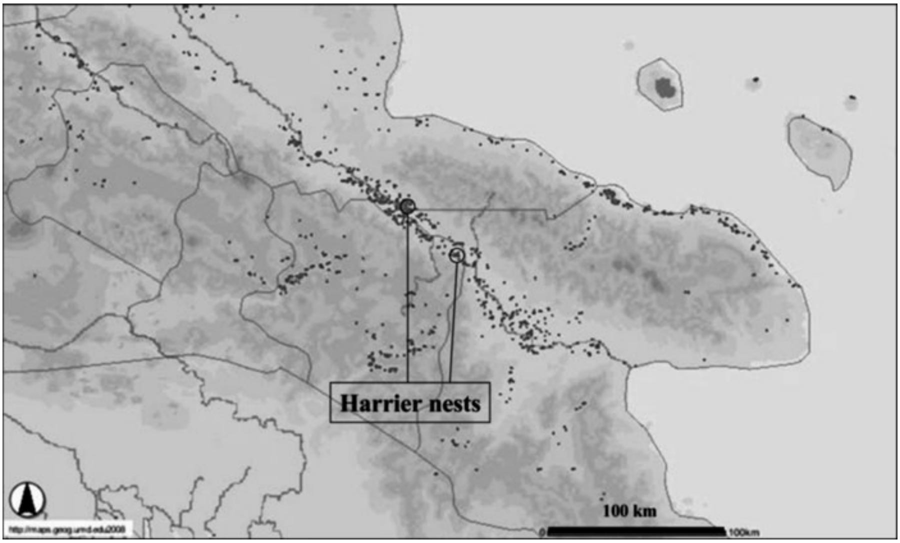

Figure 2. Fire scars in north-eastern Papua New Guinea, recorded from space from April–December 2007. The position of the two Papuan Harrier nests is indicated. The frequency of fires in the 150 km² study area of the Ramu and Markham valleys in this period was 17 per month reaching a peak of 38 fires in June. (Modis and NASA images, downloaded from http://maps.geog.umd.edu/website/Activefire_html for South East Asia)

are large enough threats for this species to warrant a 'Vulnerable' conservation ranking. A global conservation ranking is, however, only possible once the status of this species has been verified (M. Wink, R.E. Simmons unpubl. data) and a suspected rate of decline is quantified or suspected. We quantify the (increasing) frequency of fire as the most likely threat to breeding success in both present day and future PNG.

Movements in relation to rainy seasons

The rapid turnover of individual Papuan Harriers through both highland airports suggested that birds were on passage to other areas. We were unable to follow individuals away from the airports but discussions with knowledgeable residents in highland villages near the town of Goroka indicated that raptors entered habitat around their villages during April–September, the dry season (K Yombu pers. obs.). This is corroborated by observations from swamp areas in the southern lowlands around Kurik (Figure 3) where Hoogerwerf (1964) observed that Papuan Harriers were absent from May–September (dry season) but present in all other months over four years. It is also notable that breeding seasons of other birds of prey in PNG coincide with the dry season (Bell 1982). This is understandable given the amount of rain (2–10 m per annum in the highlands: McAlpine *et al.* 1983, Symes and Marsden 2005) which may prevent raptors from breeding or foraging for prey in heavy to torrential rain. The observation that breeding of most insectivores, frugivores and mixed feeders in the Eastern highlands occurs in the dry or early-wet season (Symes and Marsden 2005), means that harriers may also have an additional prey source of young birds, given that avian prey remains were relatively common in the diet (unpubl. data). Our observations of Black Kite, Black-winged Kite and Brown Falcon copulating and nest building in early May in the Markham Valley corroborate this. Breeding of the Madagascar Harrier *Circus macrosceles* in the dry season is similarly observed in the high rainfall

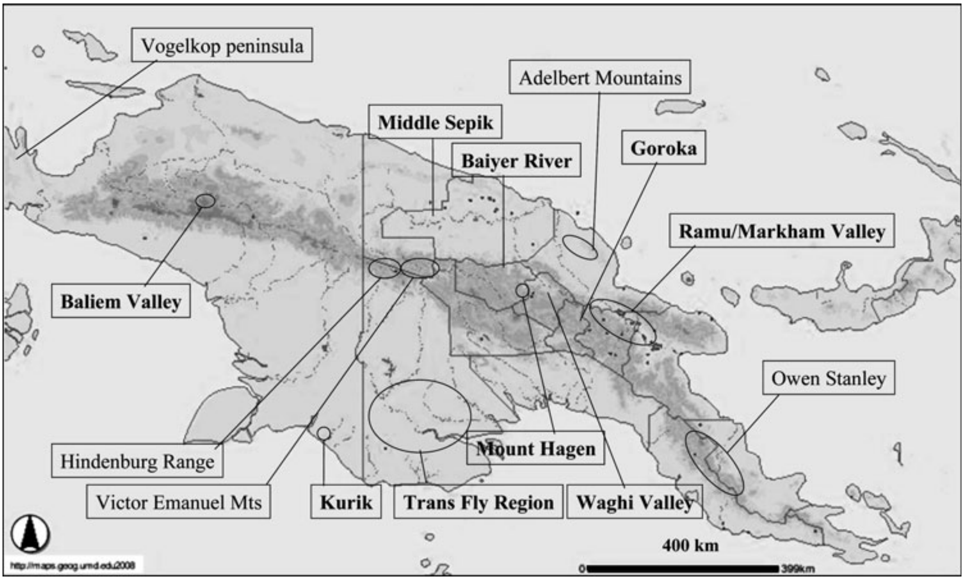

Figure 3. The island of New Guinea indicating places mentioned in the text including the two main study sites (Ramu/Markham Valley and Mount Hagen-Goroka highlands) and other regions where Papuan Harriers have been found (in bold) or assessed and not found.

regions of Madagascar (Rene de Roland *et al.* 2004) and wildfires also occur at these times (Rene de Roland *et al.* unpubl. data). Thus we assume that at least some raptors are moving from low ground into the highlands in order to breed. While we did not find any breeding of harriers in the highlands, a displaying and calling female Papuan Harrier that remained for over two days at Mt Hagen airstrip suggested breeding was imminent at the end of April. Brown Falcon and Brahminy Kite moving through Yabiufa Village (2,000 m) near Goroka suggest that the movement is not confined to harriers.

Population size, wildfire and global conservation status

The Papuan Harrier was found to be locally common but transient in two highland grasslands above 1,500 m. As expected, the first road counts for PNG recorded no harriers but several other woodland raptors in the hill forest habitats. Thus reduced visibility in dense woodland cannot account for the lack of harriers. They were frequently recorded in the lowland grasslands of the Markham Valley. While nesting densities of 1.33 nest 100 km^{-2} are the first recorded for the Papuan Harrier they require confirmation with larger samples. Densities averaging 6.5 harriers 100 km^{-2} allow us a first opportunity to estimate the global population given that birds have been reported from other suitable lowland habitats such as the Trans Fly region and Gali Ephata marsh (near Kurik) in southern Papua New Guinea (Figure 3), the Middle Sepik of northern New Guinea and the Baiyer River region (Hoogerwerf 1964, Coates 1985, B. Coates pers. comm., P. Gregory pers. comm.). A few highland grasslands also hold harriers around the Baliem Valley (at 3,000 m), the Tari Gap and Wahgi Valley (Mayr and Gilliard 1954, Coates 1985, Hornbuckle 1997, P. Gregory pers. comm.) but no density estimates have been reported. Our own observations at high altitude suggest lower densities and few resident birds, possibly because of the low diversity of small mammals apparent in such grasslands (K. Aplin *in litt.*). This corroborates previous ornithological expeditions to highlands such as the Adelberts, Owen Stanley, Victor Emanuel, Hindenburg Mountains and the far western Vogelkop peninsula (Figure 3) where no harriers were reported by past and present ornithological expeditions (Gilliard and Lecroy 1961, 1967, Coates 1985, P. Gregory pers. comm., B. Beehler pers. comm). Therefore, the world population figure of 3,606 birds (range 2,552–4,050 birds) is probably an upper estimate. A second reason for believing this is close to maximum comes from the fact that density estimates were derived from the Markham and Ramu Valleys, which yielded more long-term sightings prior to this study than anywhere else in Papua New Guinea (Coates 1985). Density estimates from other parts of New Guinea, particularly lowland swamps (B Coates pers. comm.), are required to corroborate this first estimate. Dividing the island into suitable habitat blocks and completely or randomly searching such habitat are two proven methods for surveying difficult species such as harriers (Bretagnolle *et al.* 2000, Curtis *et al.* 2004).

Given these caveats and assuming the population estimate is accurate to within a thousand birds, what does this mean for the Papuan Harrier global conservation ranking? Species numbering $< 10{,}000$ mature individuals that also show declines inferred or known to be at least 10% over 10 years or two generations (whichever is longer), are classified as 'Vulnerable' (Birdlife International 2008). We suggest that this species may warrant a 'Vulnerable' ranking given the low number of birds estimated for New Guinea, and the direct threat posed by grassland wildfire to these ground-nesting birds and their prey.

Widespread grassland burning in the Ramu and Markham valleys resulted in both nests being lost to fires. Given that the entire valley and the grassy hillsides are completely burned by the end of the season (P. Limu pers. comm.), other nests also have a high likelihood of failure. Villagers frequently start fires to isolate terrestrial mammals such as Ground Cuscus (or Possum) *Phalanger gymnotis* in the unburned patches, which are subsequently killed and eaten. Thus, these fires are an annual event, starting in the dry season and are anthropogenically driven. Moreover, increasing fire frequency may have already made the grasslands inhospitable for small mammals because they are reported to be of low diversity in the grasslands (K Aplin *in litt.* 2007). Satellite images not only corroborate the extent of fires but their frequency throughout the dry season (Figure 2). Assessed month by month, fire scars revealed a peak in June just after the harriers started breeding and at least 108 separate fires in the 150 km^2 study area. Cloud cover often obscures fires in Papua New Guinea so this is a minimum estimate of frequency. So both early and late nests are equally likely to be destroyed by fires in any remaining dense vegetation, which breeding harriers prefer (Baker-Gabb 1986, Rene de Roland *et al.* 2004, Simmons 2005). Despite the potentially increased area of grasslands generated from widespread fire use in the last 5,000 years (Haberle *et al.* 2001), the timing and extent of burning are both detrimental to ground-nesting harriers. Fires have been detected for at least 32,500 yr BP (before present) in charcoal deposits in lake sediments (Haberle 1998, Haberle *et al.* 2001). Grasslands favoured by harriers were promoted by a 5°C cooler climate in PNG prior to 17,000 BP but were reduced as wetter weather promoted increased forest cover over PNG between 17,000 and 9,000 yr BP (Haberle *et al.* 2001). A greater frequency of fire in forested areas from *c.* 7,000 yr BP to present is associated with increased climatic instability and increased agricultural activity (Haberle *et al.* 2001). Both have increased the amount of relatively low diversity grassland in highland PNG (Hope and Tulip 1994, Haberle *et al.* 2001, Haberle 2007), and may have benefited at least some bird species through range expansions (Diamond 1972). These studies point to a waxing and waning of open areas favoured by harriers, dependent upon climate and modern man. That man is responsible for many present-day fires is apparent from palynological studies around Mt Wilhelm, Papua New Guinea's highest peak, indicating that forest clearance through fire started 700 years ago and the main period of clearance was about 300 years ago (Corlett 1984, 1987). That reforestation can occur in as quickly as 20 years in the absence of fire (Corlett 1987) means that grasslands must be frequently burned to remain as such (Corlett 1987, Haberle *et al.* 2001). If harriers consistently time their breeding to the start of the dry season, their ground nests will always be susceptible to grass fires. We predict, but cannot quantify, that over

10 years the population may decrease at 10% per year; a decrease promoted by increasing human populations and accelerated by climate warming.

The evidence that the New Guinea climate is becoming more fire-prone comes from regional research and local knowledge. Fires are becoming more frequent and destructive in the lowland rainforest of Indonesia; in 1997 extensive fires (50,000 km^2) swept through Irian Jaya (west Papua), and Sumatra causing widespread ecological damage to rainforest there (Kinnaird and O'Brien 1998). More importantly, recent research has shown that the frequency of wildfires is positively correlated with El Niño events that bring dry conditions to southern hemisphere countries (Haberle *et al.* 2001, Westerling *et al.* 2006, Kinnaird *et al.* 2007). Because El Niño events are becoming more frequent with climate change (Timmerman *et al.* 1999), logically fire frequency will also increase. This is also reflected locally in changing agricultural coffee crops in the Eastern New Guinea highlands that are now possible twice per year because they require dry conditions for the picking and drying of coffee beans. Less than a decade ago this was not possible because of higher rainfall (K. Yombu pers. comm.). Both results point towards an expected greater frequency and magnitude of wildfires throughout New Guinea because of global warming. Any Papuan Harriers breeding in the dry season will almost certainly experience reduced success, as will many other grassland species.

Legra *et al.* (2008) have also shown a secondary consequence of global warming on Papua New Guinea - sea level rise inundating low-lying regions. They report that with a 1 m rise in sea level, 21% of the Trans Fly region in southwestern Papua New Guinea will be inundated, flooding grasslands and fresh water swamps. This will decrease further the area available to breeding and foraging Papuan Harriers in PNG.

Of other threats, direct human persecution appears to be negligible based on the lack of fear shown by foraging birds around gardens and traditional villages in the highlands, and airports and modern buildings elsewhere in the highlands. The lack of animosity or recognition of the Papuan Harrier by local villagers suggests that there is no direct human persecution of this species. Poison baiting for Rats (*Rattus* spp.) within oil palm plantations in the Ramu Valley (P. Limu pers. comm.) is localized and harriers were not seen foraging within these habitats.

Further study is required of this and other raptors and grassland species in New Guinea in a landscape where the forest birds of paradise have always taken research precedence (Mack and Wright 1996). Research should focus on understanding the dynamic between the double-edged effects of fire opening up forested landscapes for grassland species, and the costs to biodiversity caused by burning too frequently at the start of many species' breeding season.

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