

# Habitat, microdistribution and conservation status of the enigmatic Bruijn's Brush-turkey *Aepypodius bruijnii*

IWEIN MAURO

## Summary

The endemic brush-turkey of Waigeo Island in eastern Indonesia, *Aepypodius bruijnii*, is revealed to nest only on the island's previously ornithologically unexplored highest summits, along an ecological gradient above 620 m elevation where a structurally distinctive, wind-sheared and possibly locally edaphically controlled, stunted cloud-forest thrives on infertile substrates. The species is confirmed to breed at two locations only, and the known population totals 47 mound-owning males or 84 mature individuals. Its global population is estimated at 349 mound-owning males or 977 mature individuals, primarily confined to 60 km<sup>2</sup> of cloud-forest habitat spread over six locations, with 98% of the population restricted to just three locations in the eastern part of the island. Details are provided on the bird's altitudinal distribution, habitat preferences, spatio-temporal use of incubation sites, population densities, locations and incidental lowland records. Threats that impinge on the species are discussed in depth, and it is concluded that its current precautionary treatment as Vulnerable warrants upgrading to Endangered in accordance with the revised IUCN Red List categories and criteria. Habitat destruction as a consequence of wild fires and a recent logging epidemic is identified as the major factor threatening this unique brush-turkey's long-term survival.

## Introduction

In spite of 22 historical ornithological expeditions and modern reconnaissance visits (Mauro 2004, 2005) and two rediscoveries (De Schauensee 1940; Heij and Post 2001), Bruijn's Brush-turkey *Aepypodius bruijnii* remained entirely unknown in the living world for more than 120 years between its formal description and its recent field discovery reported in detail by Mauro (2002, 2004, 2005). At one time it was even doubted whether the large Pleistocene island fragment of Waigeo (c. 3,100 km<sup>2</sup>; 0°12'S, 130°45'E; Figure 1) at the northern extremity of the Raja Ampat archipelago in Indonesian New Guinea genuinely was its *terra typica* (Peters 1934; De Schauensee 1940). Any comment on the species' conservation status remained tentative in the absence of biological information. It was initially classified as Endangered (Dekker and McGowan 1995; Stattersfield *et al.* 1998) chiefly on the principle of reasonable precaution, although was recently downgraded to Vulnerable (Dekker *et al.* 2000; BirdLife International 2001) as a result of more stringent evaluation criteria.

Bruijn's Brush-turkey belongs to the megapodes (Megapodiidae), a family renowned for its exceptional incubation strategy, exploiting environmental heat sources and exhibiting no parental care (overview in Jones *et al.* 1995). I previously

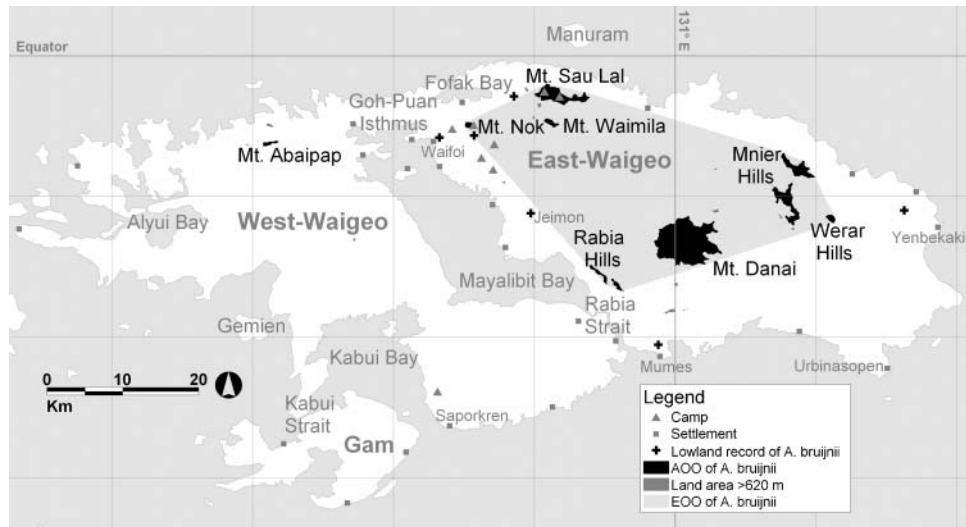


Figure 1. Locations of Bruijn's Brush-turkey *Aepyodius bruijnii* on Waigeo, with the distribution of land above 620 m elevation and the position of incidental lowland records.

confirmed that the species builds heaps of leaf litter and other organic material (henceforth called 'mounds'), in which the heat produced by microbial decomposition incubates the eggs (Mauro 2002, 2004, 2005). I also provided circumstantial evidence for its presumed male resource-defence polygyny and polyandry mating system (Mauro 2004, 2005), uniquely among the megapodes rooted within the closely allied New Guinean and Australian brush-turkey genera *Aepyodius* and *Alectura*. In the brush-turkeys, adult male territoriality is assumed to centre on the mound and vocal advertisement is restricted entirely to the mating season proper and may primarily be associated with sexual display on, or in the immediate vicinity of, the mound (Jones *et al.* 1995; Sinclair 2002; I. M. unpublished data). The number of reproductively mature males capable of permanently defending a mound is the single most relevant population unit for conservation assessment in a male resource-defending promiscuous megapode, given that exactly these males secure virtually all copulations, and monopolize the chance of successful progeny (see Jones 1990a, b).

Here, I assess this critical population parameter, and explore the conservation status and needs of this truly enigmatic taxon, founded on insights gained during multiple and prolonged field surveys of Waigeo's previously ornithologically unexplored summits.

## Methods

During pilot surveys in April–May 2002 (Table 1, Figure 1) I discovered Bruijn's Brush-turkey in the field on Mount Nok and gained insight into its vertical breeding distribution (Anonymous 2002a, b, Mauro 2002, 2004, 2005). This prompted follow-up fieldwork in October–December 2002 and May–June 2003 (Table 1, Figure 1). I timed new fieldwork based on: (1) Information that Waigeo receives an annual rainfall of 1,500–2,000 mm (van Royen 1960), most of which falls in a

Table 1. Survey effort at key study sites on Waigeo.

Study site	Camp altitude (m)	Camp coordinates (WGS '84)	Study period	No. of field days	Person-hour search effort	Altitude covered (m)
<i>Saporkren area</i>	140	S 0°26'16" E 130°43'46"	09–21.04.02	10	160	0–235
<i>Waifo coastal forest</i>	0	S 0°05'59" E 130°42'51"	31.05–02.06 / 17–18.11.02	5	200	0–100
<i>Cempedak Camp</i>	345	S 0°05'13" E 130°44'12"	29.04–12.05.02	14	560	280–665
<i>Mount Nok Base Camp</i>	730	S 0°04'57" E 130°45'43"	14–28.05 / 05–16.11.02	27	944	465–880
<i>Mangkawan Hills Camp</i>	140	S 0°06'18" E 130°47'11"	21–26.10.02	7	280	140–340
<i>Waremag River Camp</i>	30	S 0°07'16" E 130°46'16"	27–28.10 / 04.11.02	3	120	30–60
<i>Mobit Hills Camp</i>	285	S 0°08'05" E 130°47'06"	29.10–03.11.02	6	240	285–560
<i>Mount Sau Lal Camp</i>	780	S 0°02'34" E 130°50'45"	20.11–16.12.02 / 14–21.05.03	35	1,336	500–970
<i>Wekabau Ridge Camp</i>	780	S 0°02'55" E 130°51'49"	22.05.03–13.06.03	23	736	500–930

distinctive wet season from December through to May (local information). (2) The finding that elsewhere in seasonally humid environments the onset of breeding for mound-building megapodes is defined by local precipitation regimes (Jones *et al.* 1995). (3) My own observation that incubation was in progress on Mount Nok in mid-May 2002 (Mauro 2002, 2004, 2005). Severe drought conditions, exacerbated by the El Niño warm episode of an ENSO weather disturbance, however, afflicted the region during 14 consecutive months spanning June 2002 to July 2003. The vegetation of the entire Raja Ampat district showed signs of drought stress by November–December 2002 (Takeuchi 2003), and I noted rainfall only on seven out of 87 field days during this period.

Reproductive and vocal activity in Bruijn's Brush-turkey was not forthcoming, hence I relied exclusively on qualitative mapping of its mounds to assess population status. Assisted by a team of local hunters, I performed a systematic and exhaustive search in the Mobit and Mangkawan Hills, on Mounts Nok and Sau Lal (Table 1, Figure 1). Except for the western slopes of Mount Sau Lal, where post-fire successional low-stature scrub and pioneering woodland occurred up to an elevation of 820 m locally, the predominant vegetation everywhere was multi-storied, closed-canopy primary forest, details of which will appear elsewhere. In total, inclusive of the pilot surveys, I searched for 4,576 person-hours; initially within every altitudinal belt, later confined mainly to the increasingly tested and confirmed altitudinal breeding distribution. I spot-mapped each mound using GPS and a barometric altimeter, and assigned it to one of four distinctive phases through which the mounds of this species normally pass: construction phase, active phase, collapsed phase and spread-out phase (Mauro 2004, 2005). By repeating this procedure over disjunct survey periods, I obtained snapshots that provide insight into spatio-temporal distribution and utilization of incubation sites. I also described the main physical characteristics of mound sites, with special reference to distances from ridge tops and suspected

permanent and temporary water sources, gradient, and aspect of the site. Given that Bruijn's Brush-turkey and the only other megapode on the island, Dusky Scrubfowl *Megapodius freycinet*, breed in complete vertical parapatry (Mauro 2004; see below), the issue of assigning mounds to species is not under discussion here. I restrict the term 'active' mound to the period of thermal stability of the mound, recognizable on account of its characteristic plateau shape (cf. maintenance phase in Jones 1988b; active phase in Mauro 2004, 2005), during which incubation of eggs may take place. I further considered mounds to be 'tended' whenever there was evidence of them being manipulated, from the spreading out of the compacting material of a cooled mound onward.

The lowest altitude at which I recorded a mound of Bruijn's Brush-turkey was 620 m. Adopting this as an altitudinal cut-off, I delineated in a study area (henceforth SA) for Mounts Nok and Sau Lal, the external boundary of breeding habitat realistically suitable to the species through exclusion of geomorphologically unsuited terrain by means of combining GPS-waypoints, sketch-mapping and panoramic photography. Within the Mount Sau Lal SA I also mapped broad habitat types. I applied nearest neighbour and Delaunay/Dirichlet tessellation connection schemes to describe and analyse spatio-temporal distribution of incubation sites within the Mount Sau Lal SA. Quoted distances are spherical (geodesic) not considering slope.

I used the unedited NGA-NASA SRTM-3 three arc-second resolution digital elevation model to assess distribution and extent of land above 620 m elevation on Waigeo, and estimate the species' breeding range and total world population. However, SRTM-3-derived 620 m contour surfaces for Mounts Nok and Sau Lal exceeded their corresponding manually delineated SAs by factors of 2.05 and 1.47 respectively, and application of SA densities to SRTM-3 surfaces would thus return grotesque population overestimates. Therefore, I applied correction factors  $C_{<2 \text{ km}^2} = 0.49$  to small relicts  $<2 \text{ km}^2$  and  $C_{>2 \text{ km}^2} = 0.68$  for SRTM-3 surfaces  $>2 \text{ km}^2$  based on the proportional SA/SRTM-3 discrepancy for the relict Mount Nok and the sizeable Mount Sau Lal, respectively. I calculated a single most parsimonious population estimate applying the observed mound-territory/ $\text{km}^2$  density for Mount Nok  $D_{<2 \text{ km}^2} = 4.01$  to SRTM-3 relicts  $<2 \text{ km}^2$ , and the mean for primary forest on Mount Sau Lal  $D_{>2 \text{ km}^2} = 9.19$  to surfaces  $>2 \text{ km}^2$ . I removed from further analysis 20 SRTM-3 620 m relicts averaging  $0.09 \text{ km}^2$  ( $\pm 0.1$ ;  $0.003\text{--}0.39 \text{ km}^2$ ;  $n = 20$ ) and totalling  $1.78 \text{ km}^2$  that were too tiny to hold a single territory at the applicable  $D_{<2 \text{ km}^2}$  density. Based on the mean impact of the most serious threatening process (see below), I further considered separate 620 m contours  $<3.5 \text{ km}$  apart and interconnected through a ridge not descending below 450 m as a single 'location' in the sense of the IUCN Red List categories and criteria (IUCN 2001), and throughout use the term only in this specific sense. Finally, I estimated extent of occurrence (EOO) by minimum convex polygon (MCP) around locations, and area of occupancy (AOO) by  $4 \text{ km}^2$ -cell grid-mapping of known records excluding cases of vagrancy (IUCN 2001, 2003).

## Results

### *Altitudinal distribution and habitat preferences*

I found incubation sites of Bruijn's Brush-turkey only on Mounts Nok ( $n = 3$ ) and Sau Lal ( $n = 75$ ) at an average altitude of 769 m ( $\pm 92.8$ ; 620–930 m;  $n = 78$ ), along an

ecological gradient above 620 m elevation, where a structurally distinctive, wind-sheared and possibly locally edaphically controlled, stunted cloud-forest grows on infertile ultramafic rocks. Such 'Kruppelholz' formations typically were thin-stemmed, rarely exceeding 20 cm diameter at breast height, grew c. 7–12 m tall, with occasional emergents in sheltered valleys up to c. 18 m (*contra* Moeliker and Heij 2002, who reported trees c. 40 m in height from the summit area of Mount Nok), and featured gnarled trunks and branches heavily draped in epiphytic moss and ferns, and a dense understorey of seedlings, saplings and palms (particularly *Pandanus*). On the relict Mount Nok (Table 2) all three incubation sites were located at 705–730 m within a very restricted area around the summit that is shrouded in clouds during parts of most days. I did not record the species below 620 m in spite of having devoted in excess of 1,940 person-hours or 42.4% of search effort there. Moreover, I noted merely three credible testimonies of brush-turkeys, each involving solitary, apparently female types, having been hunted within recent living memory from low-lying sectors of Mounts Nok and Sau Lal exploited by humans on a regular basis. One was snared close to the village grounds of Waifofo near sea level c. 1986, another captured by dogs along the Apiap River at c. 30 m near 0°02'56"S, 130°48'34"E in the early 1990s, and the last individual, also taken by dogs in the mid-1990s, was along a small tributary of the Wai Paley River near 0°5'43"S, 130°45'44"E at c. 110 m in the general area locally known as Katotara (Figure 1).

Dusky Scrubfowl was found to occur principally in flat alluvial lowland forests along the broader river valleys between sea level and c. 100 m. Here its huge mounds

Table 2. Locations of Bruijn's Brush-turkey *Aepyodius bruijnii* on Waigeo ranked in declining order of importance.

Location <i>sensu</i> IUCN (2001)		Summit altitude (m)	Summit coordinates (WGS '84)	SRTM-3 620 m contour area (km <sup>2</sup> )	Inferred no. of mound-owning males <sup>a</sup>
Mount Danai		950	S 00°12'08" E 131°00'53"	36.19	226.4
Mnier–Werar Hills	<i>Mnier Hills</i>	870	S 00°10'04" E 131°07'54"	10.717	67
	Werar Hills	760	S 00°11'31" E 131°11'07"	0.823	1.6
	Subtotal			11.539	68.6
Mounts Sau Lal–Waimila	<i>Mount Sau Lal</i>	970	S 00°02'29" E 130°51'05"	8.038	45 <sup>b</sup>
	<i>Mount Waimila</i>	710	S 00°02'29" E 130°51'05"	0.974	1.9
	Subtotal			9.012	46.9
Rabia Hills		720	S 00°15'45" E 130°55'04"	1.852	3.6
Mount Nok		880	S 00°04'54" E 130°45'17"	0.864	2 <sup>b</sup>
Mount Abaipap		700	S 00°06'13" E 130°30'55"	0.676	1.3
Total				60.135	348.8

<sup>a</sup>Correction factor  $C_{<2 \text{ km}^2} = 0.488$  and density factor  $D_{<2 \text{ km}^2} = 4.01$  for small relicts  $<2 \text{ km}^2$ ;  $C_{>2 \text{ km}^2} = 0.681$  and  $D_{>2 \text{ km}^2} = 9.19$  for SRTM-3 620 m surfaces  $>2 \text{ km}^2$  (see Methods).

<sup>b</sup>For Mounts Sau Lal and Nok observed values are presented.

typically were being maintained communally. Once beyond the foothill boundary proper, *Megapodius* incubation sites were confined to patchily distributed relatively extensive expanses of flat or only slightly undulating terrain, and were being tended by solitary territorial pairs (Mauro 2004, 2005). I found such isolated incubation sites locally at 230 m in limestone karst country in the Saporkren area, at 260 m in hill forest on ultrabasics along the western spine of Mount Nok and at a maximum elevation of 285 m in limestone karst country in the Mobit Hills (Table 1, Figure 1). In November 2002 I observed silent, solitary individuals at 465 m, 625 m and 730 m on Mount Nok.

I conclude that the two species breed in complete vertical parapatry, separated by an altitudinal gap exceeding 300 m, set against a maximum elevation of 970 m available for the island.

Adult male brush-turkeys selected relatively steep slopes, sloping on average 24.3% ( $\pm 13.6$ ; 0–60%;  $n = 70$ ), to establish incubation sites. The spatial distribution of incubation sites was overwhelmingly concentrated along the main crests and buttressed ridgetops, harbouring 89% of cases ( $n = 69$ ) within the immediate vicinity of the apices and supporting flanks. The remaining nine were located within valleys near permanent water-holes in dry stream beds. Of 71 mounds, 45 (63%) were on east- to south-facing slopes (18 faced E, 16 faced S, 11 faced SE, 8 faced N, 7 faced NE, 6 faced SW and 5 faced W). Of 78 mounds, 61 (78%) were located in multi-layered primary forest with a closed canopy generally comprised of multiple dense, broadleaf crowns *c.* 10–18 m in height. Eleven (14%) were within multi-storied, closed-canopy forest but directly below individual, often emergent conifers *c.* 9–15 m tall, featuring a comparatively open crown. Four (5%) were in what appeared to be genuinely edaphically controlled dwarfish primary formations, typically virtually unlayered and densely stocked with *c.* 5–7 m thin-stemmed, dead-straight tree-poles. Finally, the remaining two (3%) stood in low-stature <5 m tall, generally open, completely unlayered secondary, pioneering woodland, recovering from wild fires in 1982–1983. In each of the latter three distinctive environmental circumstances, totalling 22% of cases ( $n = 17$ ), solar radiation on the mounds in question was high. Whereas secondary, pioneering woodland comprised 18% of the Mount Sau Lal SA, only two mounds (3%), were located within such woodland.

#### *Spatio-temporal use of incubation sites and population densities*

Average nearest neighbour distance for mounds synchronically tended on Mount Sau Lal was 204 m ( $\pm 47.3$ ; 141.7–346.7 m;  $n = 44$ ). The two concurrently active mounds on Mount Nok were 399 m distant. Average population density at the Mount Sau Lal SA was estimated to be 8.2 mound-territories/km<sup>2</sup>. However, density varied considerably across broad habitat types: from 2 mound-territories/km<sup>2</sup> in post-fire successional woodland, over 8 in edaphically controlled, pole-stemmed primary tracts, finally to 10.4 in multi-layered, closed-canopy primary forest. Mean density for primary formations thus was 9.2 mound-territories/km<sup>2</sup> ( $= D_{>2 \text{ km}^2}$ ; see Methods, Table 2). Tentative delineation of mound-territories for the Mount Sau Lal SA applying Delaunay/Dirichlet tessellation of points representing simultaneously tended mounds (Figure 2) yields a mean mound-territory area of 0.08 km<sup>2</sup> ( $\pm 0.04$ ; 0.04–0.22 km<sup>2</sup>;  $n = 14$ ) for interlocked points and 0.14 km<sup>2</sup> ( $\pm 0.1$ ; 0.04–0.53 km<sup>2</sup>;  $n = 31$ ) for outlying spots. For the relict Mount Nok SA mean territory was 0.25 km<sup>2</sup>

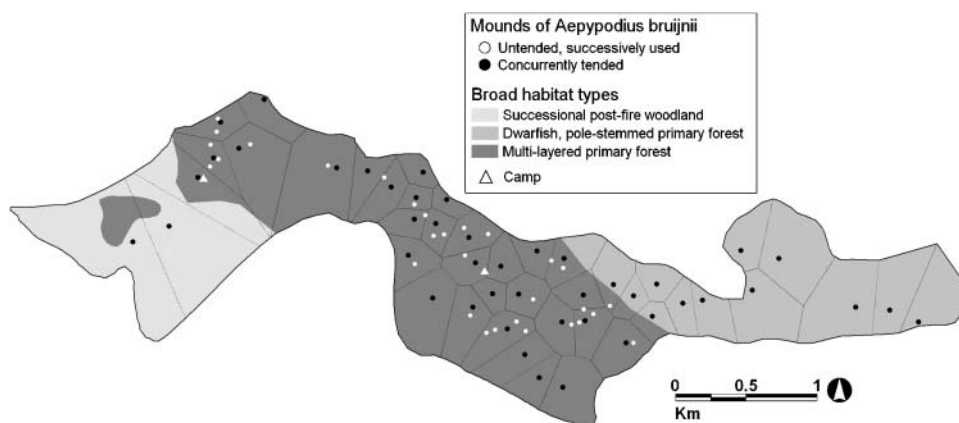


Figure 2. Spatio-temporal distribution of mounds of Bruijn's Brush-turkey *Aepyodius bruijnii* at the Mount Sau Lal study area: black dots represent concurrently tended mounds constituting the centroid of the Delaunay/Dirichlet tessellation arbitrarily defining each territory; white dots are locations of successively used, untended mounds.

( $n = 2$ ), i.e. a population density of 4 mound-territories/km<sup>2</sup> ( $= D_{<2 \text{ km}^2}$ ; see Methods, Table 2).

In 57.8% ( $n = 26$ ) of the 45 delineated mound-territories above, only a single incubation site was found, i.e. the mound constituting the centroid of the tessellation delineating each territory. Respectively two, three, four and five successively used incubation sites were found in 27% ( $n = 12$ ), 9% ( $n = 4$ ), 4% ( $n = 2$ ) and 2% ( $n = 1$ ) of cases. Mean distances between up to four disused incubation sites within a territory and the centroid tended mound that defines it, comprised 82.5 m ( $\pm 30.1$ ; 31.8–153.2 m;  $n = 30$ ). Comparison of the status of 28 incubation sites that could be followed over both survey periods yields the following: (1) Of 24 that were tended in late 2002, 15 or 63% showed evidence of an intermittent abortive start of renovation and of ongoing manipulation in mid-2003. (2) Nine mounds or 38% showed no further evidence of manipulation. (3) Only one of these had been abandoned in favour of a novel half-finished construction 36 m away.

#### Core breeding zones and global population

Cloud-forest covers 61.9 km<sup>2</sup> or 2% of Waigeo's land area. Excluding the 1.78 km<sup>2</sup> scattered over 20 relicts too tiny to support even a single territory (see Methods), it is estimated that the breeding habitat of Bruijn's Brush-turkey comprises just 60.1 km<sup>2</sup> or 1.9% of the island's area. Based on habitat extent and observed mound-territory densities a global population of 349 sexually mature mound-owning males is estimated (Table 2).

Three mountain systems in the eastern sector of Waigeo together contain 94% of breeding habitat and 98% of the total inferred world population of Bruijn's Brush-turkey (Table 2, Figure 1). Mount Danai alone contains 60% of the breeding habitat and 65% of the total population. The Mnier–Werar Hills contain 19% of the habitat and 20% of the population, and Mounts Sau Lal–Waimila 15% of habitat and 13% of the population. The remaining 5.6% of the breeding habitat and 2% of the inferred

global population are contained within three locations ranging between 0.68 and 1.85 km<sup>2</sup>.

## Discussion

### *Altitudinal distribution and habitat preferences*

The rarity of Bruijn's Brush-turkey has been linked to potential competitive exclusion by the ecologically similar Dusky Scrubfowl (Dekker and Argeloo 1993, BirdLife International 2001), considered a more recent arrival on Waigeo. However, my work reveals that the two breed in complete vertical parapatry, and a relatively wide phylogenetic gap within Dusky Scrubfowl (Birks and Edwards 2002) suggests that *Megapodius* also has an ancient history on the island and that the disjunct breeding zones the two species maintain are the result of a long-term and stable evolutionary *status quo*.

I did not record Bruijn's Brush-turkey below 620 m in spite of having invested in excess of 1,940 person-hours there. Moreover, a conservative estimate of previous scientific ornithological field effort below 500 m on Waigeo easily arrives at 23,300 person-hours (Mauro 2004) with only a single specimen record for the species (De Schauensee 1940). However, two permanent records now exist for the true lowlands of Waigeo, in addition to three credible local testimonies I report on above. The preserved head and gnawed bones acquired by the Natuurmuseum Rotterdam (NMR # 9989-01605) belonged to a female taken in late November 2000 by local hunters within ultrabasic scrub and woodland at 150 m along a tributary of the Werar River c. 4 km inland from Yenbekaki (Heij and Post 2001; Figure 1). The first live specimen (NMR # 9989-01606) was also a female, with well-developed ovary; it was snared in mid-July 2002 within internally degraded mature foothill forest at c. 80 m in limestone country c. 3 km due east of Mumes (Moeliker *et al.* 2003; Figure 1). In addition, the 1938 female (ANSP # 140581) from Jeimon (De Schauensee 1940) certainly originated from outside the species' breeding habitat and was definitely collected below 640 m (Mauro 2004; Figure 1).

Four respondents who had hunted the species, associated its occurrence with prolonged periods of drought, and the circumstances of the specimen from Mumes are consistent with a presumed drought etiology. My work revealed that adult mound-tending males endured extreme drought conditions on territory, whereas female types appeared to have completely vacated optimum cloud-forest habitat (Mauro 2004, 2005), and all lowland records to date involve female-type individuals. However, the species ranks as technically undetectable when dispersed in small numbers across vast lowlands, hence the possibility looms that such apparent altitudinal shifting of female types extends far beyond the casual disturbance-response, and obscures juvenile dispersal and/or genetically strategic interchange of adults between isolated breeding habitats. As a matter of reasonable precaution, any *in situ* conservation initiative for the species should therefore soundly consider this potential temporal dependency upon lowlands of at least a subset of the population.

I conclude that the best available evidence suggests lowland occurrences are incidental (*contra* Moeliker 2002a, b), and recommend these be treated as cases of vagrancy with regard to applying criterion B of the IUCN Red List criteria (IUCN 2001; see below). All traceable positions of lowland records were on average only



5.9 km ( $\pm 3.88$ ; 1.1–10.3 km;  $n = 6$ ) distant from the nearest known or inferred breeding habitat and lie east of Mayalibit Bay.

With 89% of cases concentrated along the main crests and buttressed ridgetops, it seems plausible that Bruijn's Brush-turkey primarily selects incubation sites on the basis of an optimal projection along declivities of male advertising calls (see also Sinclair 2002). That east- to south-facing slopes appeared to be favoured, may further be related to the fact that these receive sunlight during presumed morning sexual display, though the amount of suitable land on west- and north-facing slopes was also disproportionately restricted. Characteristics related to provisioning of organic material and protection of the mound from desiccation, as advanced in other megapode studies (Jones 1988a, Sinclair 2002), probably determined 78% of disclosed incubation sites that promoted a stable microhabitat. The likelihood that a combination of solar and microbial heat nurtures incubation in the remaining 22% of cases (cf. Palmer *et al.* 2000), constitutes a confounding factor with respect to site selection. Finally, more than 20 years after the last fire event on Mount Sau Lal, the species' population density in areas of post-fire succession there was still 4.5 times lower than in adjacent primary tracts.

#### *Spatio-temporal use of incubation sites and population densities*

Sinclair (2001) demonstrated disadvantages of mound renovation over novel construction in terms of thermal conductivity. However, I consider it impossible that additional disused mounds could have been systematically overlooked in 58% of delineated mound-territories at the Mount Sau Lal SA that held only a single incubation site. Therefore, I advance recurrent utilization of these sites over successive breeding seasons as the most parsimonious explanation. A comparison of the status of 28 incubation sites that could be followed over both survey periods is consistent with such recurrent use over consecutive years. However, out of 24 mounds tended in late 2002, there were only 10 cases where successful incubation during the previous breeding season could be positively inferred either from the collapsed state of a mound or the fact that it constituted the centroid of the territory it defines. Conversely, occurrence of up to five successively used incubation sites in the remaining 42% of mound-territories is in agreement with rotational usage of incubation sites over successive breeding seasons as described by Jones (1988a, b, 1990a, b) for *Alectura*.

On present evidence territorial adult males ordinarily tend a single mound only during a breeding season. However, since construction of a second mound may be expected to commence only after the first reaches thermal stability (Jones 1988b), and this particular condition was evidently being impeded by ongoing drought conditions during this study (see Methods), synchronous attendance of two mounds by the same territorial male may have gone largely unnoticed. Nevertheless, whilst for 42% of territories the possibility of concurrent utilization cannot be ruled out, such an occurrence due to the extreme density of the favoured breeding habitat was likely in only three cases where presumed doublets were separated by 32, 36 and 42 m respectively, and showed evidence of recent manipulation.

Little comparable published information exists on population densities in megapodes derived from qualitative mapping of mounds. However, with an observed 4–8 mound-territories/km<sup>2</sup>, Bruijn's Brush-turkey probably ranks as a low-density species. In

comparison, *Alectura* in the wild occurs at densities of 22.2 mound-territories/km<sup>2</sup> (Marchant and Higgins 1993), an order of magnitude 2.4–5.5 times greater.

### *Core breeding zones and global population*

The lack of information on sex-ratio and turnover rate of breeding individuals in the species dictates that numerical quantification of its total reproductively mature population (IUCN 2001) can only be achieved through inference by analogy with closely allied taxa. In three studies of *Alectura* (Jones 1990b; D. N. Jones *in litt.*, August 2004), soliciting sexually mature females outnumbered mound-owning males by a factor of 1.8 on average ( $\pm 0.05$ ; 1.75–1.85;  $n = 3$ ). If this figure is applied to the estimated number of mound-owning males in Bruijn's Brush-turkey (Table 2), a global population of 977 mature individuals is estimated. This score does not include an unestimatable pool of non-breeders, thought to be mostly males (Jones 1987).

Of six locations identified (Table 2, Figure 1), Bruijn's Brush-turkey is currently confirmed to breed on Mounts Sau Lal and Nok only, and the known population totals 47 mound-owning males or 84 mature individuals. A recent botanical survey that reached elevations up to 700 m on Mount Danai, established that forests remain in pristine condition there (C. Webb *in litt.*, June 2005). In contrast, sizeable tracts in the Mnier Hills appeared to be covered with low-stature scrub and anthropogenic grasslands (Mauro 2004), and hence the population estimate for the Mnier–Werar Hills is almost certainly too high. Additional work may well bring to light that a number of the selected relicts do not support a breeding population after all. This possibility seems particularly plausible for Mount Abaipap west of Mayalibit Bay, given its comparatively higher degree of isolation from viable recruitment sources and the complete lack of reliable records for the species this side of the bay (but see Diamond 1986). The critically low population ceilings of all relicts moreover suggest an imminent risk of at least temporary extirpation.

I conclude that only the three principal locations, together containing 98% of the world population, are meaningful for the long-term survival of Bruijn's Brush-turkey, and until a population is proven extant west of Mayalibit Bay, recommend querying its occurrence there. This reduces the species' EOO to 1,734 km<sup>2</sup> if the entire eastern part of the island up to the Goh-Puan bottleneck is considered. An MCP around the five locations that side of the bay yields an EOO of 751 km<sup>2</sup>. Present AOO tallies six 4 km<sup>2</sup> cells or 24 km<sup>2</sup>. Moreover, even if future fieldwork should prove all locations within its EOO to be fully saturated at the IUCN 4 km<sup>2</sup> grid cell reference scale, AOO still could not exceed 192 km<sup>2</sup>. Finally, I recommend that Bruijn's Brush-turkey, pending further field investigation on neighbouring Batanta Island where there is a tentative report (Diamond 1986), continues to be treated as endemic to Waigeo, as has been done by practically all recent authors (see e.g. Jones *et al.* 1995, Dekker *et al.* 2000, BirdLife International 2001).

### *Conservation and the future of Bruijn's Brush-turkey*

Waigeo consists predominantly of limestone and ultrabasics, infertile substrates that are known to delay recovery of vegetation following environmental perturbation (overview in Proctor 2003). I identified habitat destruction as a result of wild fires as the most serious threatening process for Bruijn's Brush-turkey. Four traceable fire

paths from the past 25 years averaged  $64.8 \text{ km}^2$  ( $\pm 46.4$ ; 2.5–200  $\text{km}^2$ ;  $n = 4$ ), together affecting *c.* 259  $\text{km}^2$  or 8.4% of the island's area (Mauro 2004). These known fire events acted over disproportionately large surfaces when compared with the size of individual locations of the species (Table 2). Fires are directly responsible for severe internal degradation and partial obliteration of 18% of cloud-forest on Mount Sau Lal together with a presently unquantifiable yet significant portion of the Mnier Hills, and probably irretrievably degraded hundreds of square kilometres of low-lying forested areas, including corridors between locations. The impact of fire must also be assessed against the backdrop that the predominant scrub vegetation over ultramafic outcrops on Waigeo, long interpreted as an edaphic climax, is now considered to represent an early stage in a successional sequence induced by fire (Takeuchi 2003, see also Proctor 2003). Finally, three out of four wild fires occurred during the El Niño-induced drought event of 1982–1983, but interviews indicated that most fires on the island are started deliberately, and the use of fire has certainly increased significantly in the wake of logging operations.

In the accessible lowlands of Waigeo, forest is being lost at an extremely alarming pace due to recent illegal logging. About 14% of the West Waigeo Nature Reserve was already affected in 2000 (Anonymous 2000), and evidence is mounting that most of the accessible tracts within the reserve have by now been severely degraded by the usual interplay of logging, road building, and the widespread subsequent use of fire as a cover-up. While timber extraction proper will probably only affect low-lying areas in the short term, the preservation of lowland forest corridors linking breeding habitats of Bruijn's Brush-turkey is imperative in view of a potential temporal dependency upon lowlands of at least a subset of the population.

My work suggests that human predation, contrary to previous speculations (e.g. Dekker and McGowan 1995, Moeliker 2002a, b), is currently a negligible threat to the population, and that introduced mammalian predators may be a more serious cause for concern. Runaway dogs are certainly a problem locally (Mauro 2002, 2004) and constitute a hazard to Bruijn's Brush-turkey in view of its reluctance to flush (Mauro 2004, 2005). In addition, the prehistorically introduced wild boar *Sus scrofa* and the native monitor lizard *Varanus indicus* are suspected nest predators (Mauro 2004).

I propose that the species, currently treated as Vulnerable (BirdLife International 2001), be upgraded to Endangered (EN) based on criteria B<sub>1</sub>+2ab(ii, iii, v) (IUCN 2001). Bruijn's Brush-turkey is almost certainly confined to an area of 1,734  $\text{km}^2$  in the eastern half of Waigeo and its EOO as delineated by MCP comprising all locations there amounts to 751  $\text{km}^2$  (<5,000  $\text{km}^2$ ; criterion B<sub>1</sub>). The species' AOO now stands at 24  $\text{km}^2$  and even if all locations within its EOO eventually should prove to be fully saturated at the IUCN 4  $\text{km}^2$  grid cell reference scale, still could not exceed 192  $\text{km}^2$  (<500  $\text{km}^2$ ; criterion B<sub>2</sub>). Viable populations that are safe from genetic stochasticity exist at only three locations (< 5 locations; qualifier a). Fires severely degraded and partially obliterated 18% of the Mount Sau Lal SA together with a significant portion of the Mnier Hills, and quite possibly irretrievably degraded hundreds of square kilometres of low-lying forested areas including corridors between disjunct breeding zones (qualifier b(ii, iii)). A continuing decline in number of mature individuals is inferred from the species' observed constrained population density in post-fire successional regrowth on Mount Sau Lal (qualifier b(v)).

The entire world population of Bruijn's Brush-turkey is believed to occur east of Mayalibit Bay and this has far-reaching implications for conservation planning and

prioritization on Waigeo. The East Waigeo Nature Reserve covers 1,195 km<sup>2</sup> or 69% of the island's eastern half (Mauro 2004). However, almost a decade since its formal establishment, precise boundaries still need to be defined and it is unknown at present how well the reserve maps onto the 751 km<sup>2</sup> MCP delineating the species' EOO (Figure 1, Table 2). An effort to harmonize borders is especially relevant at this time as a development master plan for the Raja Ampat regency is currently being drawn up. More generally, based on the principle of representation, in terms of both species diversity and habitats, the region east of Mayalibit Bay must now immediately be upgraded as the key area for terrestrial conservation on Waigeo. In addition, I recommend that: (1) an island-wide awareness campaign is set up to prevent future wild fires; (2) 'parforce' pig-hunting and snaring be restricted to designated sectors near habitation and subsistence areas; and (3) the species' core locations be declared strictly 'no hunting areas' and accessed for scientific monitoring only (Mauro 2004).

Finally, from a conservation point of view five research priorities emerge: (1) Establish with absolute certainty that populations of Bruijn's Brush-turkey indeed are present at both inferred principal locations (Mount Danai and the Mnier–Werar Hills) and the remaining hitherto unsurveyed ridges and peaks identified in this study. (2) Establish beyond reasonable doubt whether the species is genuinely absent from Batanta. (3) Study nesting-site philopatry and the extent of gene flow across locations, preferably using a non-invasive molecular technique. (4) Investigate the impact of ENSO-induced drought events on the species' reproductive success. (5) Study the impact of alien mammalian predators on the island.

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IWEIN MAURO

P. O. Box 289, Sorong 98401, Indonesia. E-mail: iweinmauro@gmail.com

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