Human impacts on two endemic cassowary species in Indonesian New Guinea

Jedediah F. Brodie and Margaretha Pangau-Adam

Abstract Cassowaries are important seed dispersers in tropical rainforests of New Guinea, but little is known about their population ecology or their responses to human disturbance. We used camera traps to measure the occurrence, local abundance, and activity patterns of northern cassowaries *Casuarius unappendiculatus* in lowland forests near Nimbokrang, Papua, and dwarf cassowaries *Casuarius bennetti* in the Arfak Mountains, West Papua. Our goals were to assess human impacts on cassowaries at multiple spatial scales and to measure their activity patterns over an elevational divide. At fine spatial scales local abundance of cassowaries was strongly reduced in areas frequented by humans. At larger spatial scales the distance to the nearest village or drivable road did not affect local abundance but altered the stage structure of the individuals detected, with a higher proportion of juveniles relative to adults. Local abundance of cassowaries was unrelated to site usage by introduced pigs. Both populations studied were strongly diurnal and their activity patterns were not significantly different. Efforts to control hunting remain critical to sustaining cassowaries and the seed dispersal services they provide.

Keywords Activity patterns, bird conservation, climate change, exploitation, hunting, introduced species, Papua, ratite

Introduction

Cassowaries *Casuarius* spp. are the largest avian frugivores and the largest-bodied seed dispersing animals in the tropical forests of New Guinea and Australia. Dispersal of seeds by cassowaries is known to be important for many plant species (Mack, 1995; Westcott et al., 2005; Bradford & Westcott, 2010, 2011; Pangau-Adam & Muehlenberg, 2014) and even for the evolution of reproductive traits in some plant taxa (Pannell, 1997; Hall & Walter, 2014), and cassowaries were estimated to be the most important vertebrate disperser of plant seeds at a floristically diverse site in New Guinea (Mack & Wright, 2005).

Of the three cassowary species the southern cassowary *C. casuarius* (height 1.3–1.7 m) is native to New Guinea and Australia, and the northern *C. unappendiculatus* (1.2–1.5 m) and dwarf cassowaries *C. bennetti* (1.0–1.1 m) are endemic to New Guinea (heights from Pratt & Beehler, 2015). Australian populations of the southern cassowary have been studied using sign surveys (Westcott, 1999), transects (Moore, 2007), radio telemetry (Westcott et al., 2005) and global positioning system telemetry (Campbell et al., 2012). However, other than a preliminary study on the impacts of logging on northern cassowaries (Pangau-Adam et al., 2015) almost nothing is known about the population ecology of the species in New Guinea.

The northern and southern species are categorized as Vulnerable, and the dwarf as Near Threatened on the IUCN Red List (BirdLife International, 2012a,b, 2013), and all three are thought to have declining populations (IUCN, 2015). This threat is largely attributable to their susceptibility to over-hunting (Johnson et al., 2004; Sales, 2009) and, in some areas, habitat loss (Crome & Moore, 1990; Campbell et al., 2012; Pangau-Adam et al., 2015).

We studied a population of *C. unappendiculatus* in lowland forests and a population of *C. bennetti* in submontane forests of Indonesian New Guinea using motion-triggered camera traps. Substantial habitat remains available in both areas (Miettinen et al., 2012; Fig. 1) but hunting pressure was thought to be high, based on proximity to human settlements and conversations with local hunters (Pangau-Adam & Noske, 2010). We sought to assess how both species responded to potential hunting pressure, using accessibility (e.g. the distance to the nearest village or road) as a proxy. We also tried to ascertain whether accessibility influenced cassowary population structure. In heavily hunted populations it can become increasingly difficult for juveniles to reach adulthood or for adults to survive, and thus the age structure can shift to a higher proportion of juveniles (Mills, 2007; Brodie et al., 2011).

Other than hunting, mammal introductions in New Guinea are of conservation concern because the region lacks most placental mammal lineages. Exotic primates near Jayapura, Papua, for example, could have significant effects on native birds not adapted to these nest predators (Corlett & Primack, 2011). There were no ungulates in

Jedediah F. Brodie* (Corresponding author) Departments of Zoology and Botany, University of British Columbia, Vancouver, Canada
E-mail brodie@biodiversity.ubc.ca

Margaretha Pangau-Adam† Biology Department, Faculty of Natural Sciences and Mathematics, Cenderawasih University, Papua, Indonesia

*Also at: Biodiversity Research Centre, University of British Columbia, Vancouver, Canada
†Also at: Department of Conservation Biology, University of Göttingen, Germany

Received 17 June 2015. Revision requested 20 July 2015.
Accepted 31 July 2015. First published online 10 November 2015.

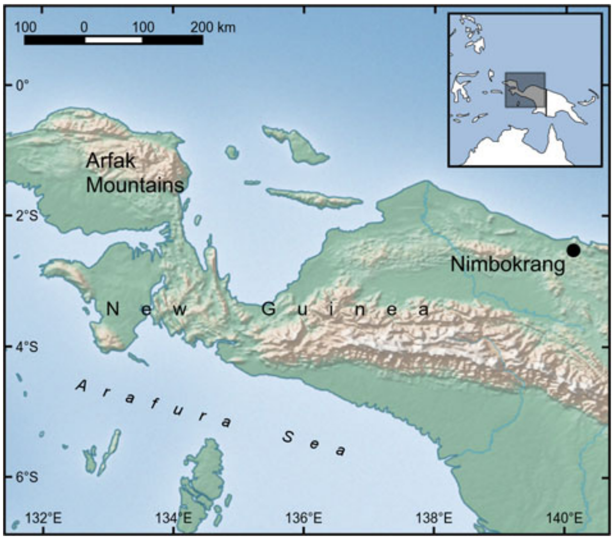

FIG. 1 The study sites in the Arfak Mountains and Nimbokrang, in Indonesian New Guinea.

New Guinea prior to the introduction of pigs (*Sus scrofa* × *S. celebensis*) by humans sometime in the last few thousand years (Flannery, 1995). Pigs breed quickly and are omnivorous, suggesting that they could possibly compete with cassowaries for fruit. We conducted a preliminary assessment of possible interference competition between these species by examining at fine spatial scales whether cassowaries avoided areas frequented by pigs.

Climate change is another potential threat. Many tropical animals are thought to be near their thermal maxima (Tewksbury et al., 2008), implying that any near-future rises in temperature could force them to migrate to higher elevations, possibly leading to biodiversity loss in the lowlands (Colwell et al., 2008). For many tropical bird species, ambient temperatures are already thought to exceed the upper critical temperature beyond which they must expend energy to stay cool (Khaliq et al., 2014). We conducted a preliminary assessment of whether *C. unappendiculatus* in the lowlands were near their thermal maximum by examining whether they constrained their daily activity to mornings and evenings (i.e. avoiding the heat of the day) relative to the activity patterns of *C. bennetti* at higher elevations.

Specifically, we predicted that (1) local abundance of cassowaries would be higher at sites further from human access and at sites with low usage by humans (predators) and pigs (introduced potential competitors), (2) the age structure of cassowary populations would be related to potential hunting pressure, with a lower proportion of mature adults at sites closer to human access, and (3) northern cassowaries in the lowlands would be less active during the hottest portion of the day than dwarf cassowaries in the mountains.

Methods

Study system and field sampling

In June 2014 we deployed 40 Reconyx HC500 camera-trap units (Reconyx, Inc., Holmen, USA) at two humid tropical forest sites: in the lowlands near Nimbokrang, Papua Province, and in the Arfak Mountains, West Papua Province (Fig. 1). The cameras were retrieved 5–7 months later. The Nimbokrang area has flat, alluvial forest, much of which was flooded to a depth of a few centimetres at the time of camera deployment; the area we worked in was at 15–660 m elevation. The forests have not been commercially logged, although illegal selective logging of merbau *Intsia bijuga* (Fabaceae) is widespread. The northern cassowary is the only cassowary in this area. In the Arfak Mountains we worked near the village of Syoubri, at elevations of 1,030–2,280 m in lower montane forests (Flannery, 1995). The topography is steep; for example, one camera transect spanned 560 vertical metres over 1,260 linear metres (a mean slope of 44%). The forests have a lower canopy than in Nimbokrang, and denser understorey vegetation. There has been no commercial logging, and forest clearance for small-scale subsistence agriculture is limited to areas near villages. The dwarf cassowary is the only cassowary there. Subsistence hunting is common in both areas, and cassowaries are preferred prey species (MP-A & JB, pers. obs.).

The cameras were arranged along transects radiating from two villages and the nearby Korea Road in the Nimbokrang area, and two villages in the Arfak Mountains. Cameras were set c. 1 km apart along each transect, usually on small game trails, stream beds, ridge tops, or in other areas that animals might use for movement or foraging. The distance from the cameras to human habitation or roads was 0.2–6 km, with various distance categories approximately equally represented. Cameras were attached to the bases of trees, housed within protective metal cases. They operated 24 hours per day, recording colour images during the day and black-and-white at night. Although cassowaries may be active at any time, foraging is thought to be strictly diurnal (Moore, 2007). Upon being triggered by motion in front of the receptor, a camera recorded a sequence of three images and then did not record again for at least 30 s.

Data analysis

To test prediction (1) we used *N*-mixture models (Royle, 2004) to estimate whether the local abundance of cassowaries at specific sites (i.e. camera trap stations) was related to the distance from the site to the nearest drivable road or village (a metric of potential hunting pressure), and the usage of the site by pigs and humans. We conducted these analyses separately for each species and also pooled data on the two species, to increase our limited sample size. We accounted

TABLE 1 *N*-mixture model selection results for all models with ΔAIC < 2 for the northern cassowary *Casuarius unappendiculatus*.

	Top model	2nd model	3rd model	4th model	Mean model
ΔAIC	0.00	1.56	1.80	1.96	
Akaike weight	0.45	0.21	0.18	0.17	
R^2	0.39	0.41	0.40	0.39	
Local abundance function[1]					
Intercept	0.93 ± 0.42	0.96 ± 0.43	0.95 ± 0.43	0.93 ± 0.43	0.95 ± 0.43
Distance[2]			0.11 ± 0.24		0.02 ± 0.04
Pig relative abundance index[3]				−0.04 ± 0.24	−0.01 ± 0.04
Human relative abundance index[3]		0.14 ± 0.20			0.03 ± 0.04
Detection function[1]					
Intercept	−4.01 ± 3.02	−4.24 ± 5.15	−4.19 ± 4.55	−4.26 ± 5.94	−4.17 ± 4.27
Camera hours	5.89 ± 16.06	6.96 ± 27.52	6.70 ± 24.27	7.24 ± 31.78	6.55 ± 22.78

[1] Coefficients ± SE from standardized variables
[2] The linear distance from each camera trap site to the nearest village or drivable road
[3] The number of independent detections per 100 trap-days

for the large number of zero detections in the data, typical for camera-trapping studies, by pooling data into 5-day sampling intervals and using zero-inflated Poisson distributions in the *N*-mixture models. These models are robust to variation in sampling effort across sites. We ran models representing all possible combinations of the three local abundance covariates in combination with no detection covariates, a time detection covariate (to account for trends in detectability), and a camera hours detection covariate (the total number of hours during which a camera operated at each site during each 5-day sampling interval). All continuous variables were standardized prior to analysis. We used multi-model inference by averaging parameter coefficients across all models with ΔAIC < 2.0. To assess site usage by humans and pigs we measured a relative abundance index for each species at each camera station as the number of independent detections per 100 camera days. Two detections were considered independent if they were non-consecutive (i.e. another species was detected at the camera station in between) or if they were > 30 minutes apart; these are increasingly standard criteria for analysis of camera trap data (e.g. O'Brien et al., 2003; Brodie & Giordano, 2012; Carter et al., 2012).

We tested prediction (2) using logistic regression of distance from road or village (predictor variable) vs cassowary life stage (1 for mature adults, 0 for juveniles), again conducting analyses for the two species separately and pooled. As such, these were tests of the influence of human access on cassowary stage structure, conditional upon detection. The life stages are easily distinguished, with adults having black body feathers with blue and red skin on the neck, whereas juveniles are uniformly brown. We did not assess chicks (light coloured with black stripes) in this analysis. We analysed independent detections for both species, where independence was determined by the same criteria used to calculate relative abundance indices for humans and pigs.

To test prediction (3) we compared the activity patterns of the two cassowary species using Watson's two-sample test of homogeneity (Jammalamadaka & Sengupta, 2001). This is a non-parametric test analogous to a Kolmogorov–Smirnov test but for use with circular (e.g. hours in a day, months in a year, compass bearings) rather than linear variables.

Results

We detected northern cassowaries on 71 of a total of 2,433 camera-days at Nimbokrang, and dwarf cassowaries on 46 of 2,211 camera-days in the Arfak Mountains. The top *N*-mixture model for *C. unappendiculatus* did not have any abundance covariates (Table 1). The top models for *C. bennetti* and the two species pooled both had negative human site usage terms, as did five of the seven models with ΔAIC < 2 for *C. bennetti* (Table 2) and all four of the models with ΔAIC < 2 for the species pooled (Table 3). Relative usage of each camera site by pigs, and the distance from each station to the nearest road or village were not related to local abundance of either cassowary species individually or the two species pooled (Tables 1–3). Camera hours was an important detection covariate for *C. unappendiculatus* and the two species pooled but not for *C. bennetti* (Tables 1–3).

We obtained 76 independent detections of *C. unappendiculatus* and 50 of *C. bennetti*; 82% of *C. unappendiculatus* detections and 14% of *C. bennetti* detections were of mature adults. Chicks were detected only once, when two northern cassowary chicks were photographed with an adult in Nimbokrang. The proportion of independent detections that were adults was not significantly related to distance from the nearest road or village for *C. unappendiculatus* (logistic regression, P = 0.12) or *C. bennetti* (P = 0.73) alone (possibly because of limited sample size), but for the two

TABLE 2 *N*-mixture model selection results for all models with ΔAIC < 2 for the dwarf cassowary *Casuarius bennetti*. R^2 values are calculated relative to the intercept-only model, and therefore that model does not have an R^2.

	Top model	2nd model	3rd model	4th model	5th model	6th model	7th model	Mean model
ΔAIC	0.00	0.92	1.34	1.39	1.52	1.92	1.95	
Akaike weight	0.26	0.16	0.13	0.13	0.12	0.10	0.10	
R^2	0.17		0.20	0.20	0.19	0.17	0.05	
Local abundance function[1]								
Intercept	−0.07 ± 1.12	0.23 ± 0.77	−1.05 ± 0.92	−0.69 ± 1.12	−0.70 ± 1.12	−0.59 ± 1.16	−0.46 ± 0.44	−0.56 ± 0.97
Distance[2]						−0.16 ± 0.51		−0.02 ± 0.05
Pig relative abundance index[3]			0.28 ± 0.25				0.37 ± 0.26	0.07 ± 0.06
Human relative abundance index[3]	−3.01 ± 2.94		−2.42 ± 2.58	−3.06 ± 2.97	−3.08 ± 2.98	−3.22 ± 3.17		−2.19 ± 2.16
Detection function[1]								
Intercept	−2.22 ± 0.46	−2.17 ± 0.42	−2.08 ± 0.30	−2.22 ± 0.46	−2.07 ± 0.50	−2.31 ± 0.58	−2.03 ± 0.29	−2.17 ± 0.43
Camera hours				0.30 ± 0.48				0.04 ± 0.06

[1] Coefficients ± SE from standardized variables

[2] The linear distance from each camera trap site to the nearest village or drivable road

[3] The number of independent detections per 100 trap-days

TABLE 3 *N*-mixture model selection results for all models with ΔAIC < 2 for the northern and dwarf cassowaries pooled.

	Top model	2nd model	3rd model	4th model	Mean model
ΔAIC	0.00	1.80	1.97	1.97	
Akaike weight	0.47	0.19	0.17	0.17	
R^2	0.26	0.27	0.15	0.26	
Local abundance function[1]					
Intercept	0.09 ± 0.67	−0.06 ± 0.75	0.09 ± 0.67	0.00 ± 0.83	0.04 ± 0.71
Distance[2]		0.11 ± 0.25			0.02 ± 0.05
Pig relative abundance index[3]				0.05 ± 0.28	0.01 ± 0.09
Human relative abundance index[3]	−2.08 ± 1.58	−1.95 ± 1.57	−2.08 ± 1.58	−2.05 ± 1.59	−2.05 ± 1.58
Detection function[1]					
Intercept	−2.67 ± 0.39	−2.59 ± 0.40	−2.61 ± 0.38	−2.63 ± 0.45	−2.64 ± 0.40
Camera hours	0.64 ± 0.52	0.64 ± 0.52		0.64 ± 0.52	0.53 ± 0.43

[1] Coefficients ± SE from standardized variables

[2] The linear distance from each camera trap site to the nearest village or drivable road

[3] The number of independent detections per 100 trap-days

species pooled this relationship was significant (slope = 0.31, $P < 0.01$; Fig. 2).

Both species were strictly diurnal in activity patterns (Fig. 3) and the activity patterns did not differ significantly between the two species (Watson's two-sample test statistic = 0.15, critical value = 0.19, $P > 0.05$).

Discussion

The impacts of unreported and unregulated hunting on cryptic animals can be difficult to assess (Brodie et al., 2015). We assembled multiple lines of evidence related to large- and small-scale distribution, local abundance, and population stage structure of cassowaries rather than relying on any single measure. Despite heavy hunting pressure (Pangau-Adam & Noske, 2010) human accessibility was not strongly related to the local abundance of cassowaries. This may be because we did not sample sufficiently remote areas; all of the locations in which we worked could potentially be heavily hunted. Human accessibility was related to cassowary population stage structure, with mature adults comprising a significantly larger proportion of detections at locations far from villages or drivable roads. It could be

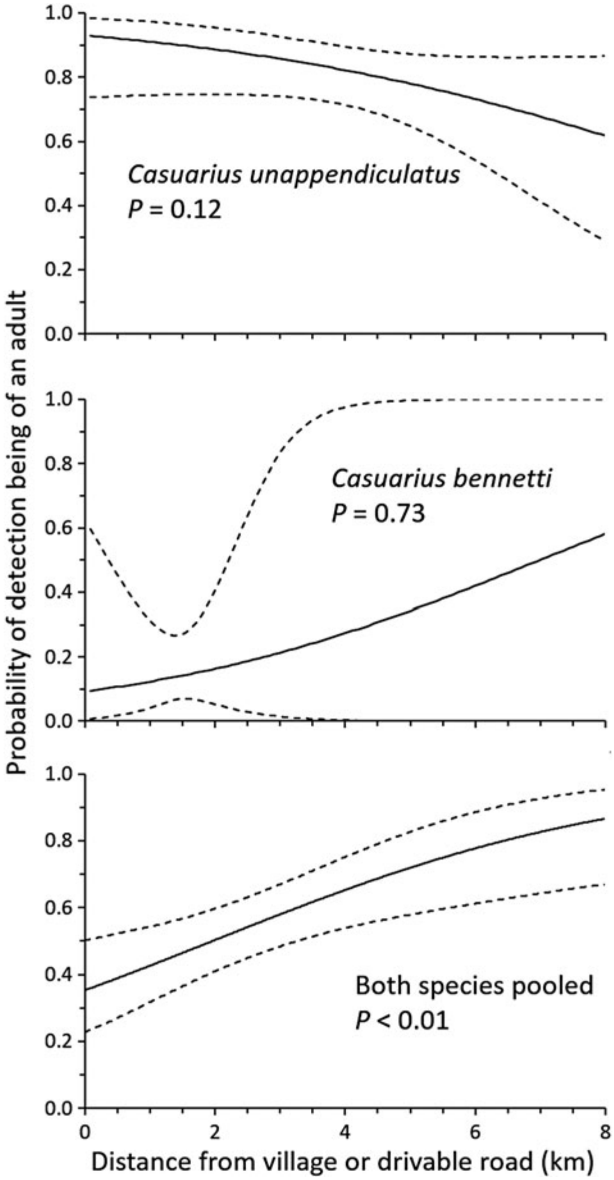

FIG. 2 Logistic trendlines for the life-stage structure of the northern *Casuarius unappendiculatus* and dwarf cassowaries *Casuarius bennetti* as a function of human accessibility; dashed lines represent 95% confidence intervals.

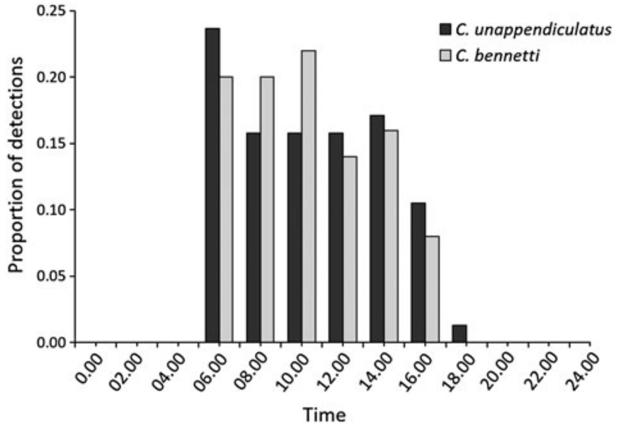

FIG. 3 Activity patterns of the northern and dwarf cassowaries. The patterns for the two species are not significantly different according to Watson's two-sample test of homogeneity for circular predictor variables.

that mature adults remain in the deep forest and exclude juveniles from their territories, forcing the latter to live closer to roads, where they are more vulnerable to hunting. On their own, stage ratios are impossible to interpret in terms of the dynamics of the population (Caughley, 1974; Mills, 2007). However, given that local abundance does not change in more inaccessible areas, where more of the individuals are immature, this could be a signal of exploitation. It also appears that, at fine spatial scales (i.e. $< c.\ 1\ km^2$), cassowaries avoid areas frequented by humans, which could be evidence of an impact of hunting on cassowary distribution. Previous work has suggested that logging activities are a prime threat to northern cassowary populations (Pangau-Adam et al., 2015); our results expand upon this by identifying hunting as another potentially critical threat.

We did not detect a strong influence of pigs on the distribution of cassowaries at fine spatial scales. This could indicate that introduced pigs are not competing strongly with cassowaries, at least via interference competition. However, we note that absence of evidence does not constitute evidence of absence; it remains possible that pigs affect cassowary populations by depressing the availability of fruit (i.e. exploitative competition) or attracting humans, a shared predator (i.e. apparent competition; sensu Holt, 1977).

The two cassowary populations did not differ significantly in their activity patterns, suggesting that lowland northern cassowaries do not avoid being active during the hottest parts of the day any more than higher elevation dwarf cassowaries. There is therefore no evidence that lowland cassowaries are thermally stressed. Lowland populations also retain the ability to adjust behaviourally to rising temperatures (by shifting their activity patterns) and may not be highly susceptible to modest near-term regional warming. However, we caution that more information is needed on this topic. Cassowaries and other lowland species may have abrupt thresholds in their physiological responses to temperature, below which they display no adverse effects but above which they cannot cope (Colwell et al., 2008).

Some cassowary populations are known to migrate altitudinally, perhaps in response to shifting patterns of fruit availability (Wright, 2005). This could potentially violate our *N*-mixture model's assumption that local abundance was closed during the sampling periods (Royle, 2004), especially given our long sampling intervals (up to 7 months at a few camera stations). However, none of our top models included time as a detection covariate, suggesting that detectability did not change significantly over the sampling period as would have been the case if a substantial portion of the population migrated into or out of the study areas during this period.

Cassowaries are functionally important as dispersers of plant seeds (Mack, 1995; Wright, 2005; Bradford & Westcott, 2010, 2011). Their loss through overexploitation could therefore have important consequences for forest regeneration (McConkey et al., 2012) and ecosystem functioning (Brodie & Gibbs, 2009). Efforts to control hunting and ensure its sustainability remain critical across New Guinea. To this end, in August 2006 and November 2013 we organized interactive educational workshops for researchers, university staff and local communities in Nimbokrang on the importance of cassowaries for forest ecosystems and the sustainability of community-based wildlife hunting. We also employed hunters as local guides during our fieldwork, hoping to raise awareness about sustainable hunting. Finally, we prepared a list of recommendations concerning sustainable wildlife hunting, which has been disseminated to local governments in Papua, Indonesia.

Acknowledgements

JB was supported by the Natural Sciences and Engineering Research Council of Canada and the Canadian Foundation for Innovation. MP-A was supported by the Dorothea Schlözer Fellowship Programme, University of Göttingen, Germany. We thank the local communities for permission to conduct this work. We are grateful to Om Dance, Om Augustinus and Om Zeth for assistance with field work.

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Biographical sketches

Jedediah Brodie studies the ecology and conservation of large vertebrates, particularly in tropical rainforests. He has focused on how anthropogenic stressors such as bushmeat hunting, logging and climate change affect populations directly, and how they disrupt animal–plant interactions such as seed dispersal. Margaretha Pangau-Adam is an ecologist with a particular interest in frugivory, seed dispersal and forest regeneration, community-based wildlife management, and biodiversity conservation.