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Prioritising the protection of habitat utilised by southern cassowaries *Casuarius casuarius johnsonii*

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ABSTRACT: The southern cassowary *Casuarius casuarius johnsonii* L. is an endangered flightless bird from northern Australia. The cassowaries' rainforest habitat has been extensively cleared, and the population primarily exists within discrete protected areas. They do, however, venture outside the reserves into modified landscapes, and it is here they are exposed to threatening processes. We used GPS-based telemetry and the adaptive local convex hull (*a*-LoCoH) non-parametric kernel method to define the relationship between cassowary home range (HR) and a protection-area network. The study showed that: (1) females had a larger HR than males; (2) overlapping HR occurred between but not within the sexes; (3) HRs of the same sex partitioned along defined boundaries; and (4) the current protected areas only encompassed core HR for the inhabiting cassowaries. This information was incorporated within a spatial-conservation-prioritisation analysis to define the relative cost:benefit relationship for protecting the currently non-protected land utilised by the cassowaries. The results showed that the current reserve system may accommodate up to 24 adult cassowaries, only offering HR protection at the 40 to 60% *a*-LoCoH. This could be raised, relatively cheaply (1.2-fold the current costs), to 70% *a*-LoCoH for all birds by protecting adjacent forested areas on private land. Protection beyond the 70% *a*-LoCoH, however, required protection of large expanses of agricultural land, resulting in an exponential increase in monetary cost (5.1-fold). We argue that total HR protection for the cassowaries was an unfeasible conservation option, but protection of core habitat was achieved relatively cheaply. Combining core HS protection with target incentives to landowners of adjacent cleared land may be the most cost-effective conservation strategy for *C.c. johnsonii*.

KEY WORDS: LoCoH · GPS · Telemetry · Spatial conservation prioritisation · Ratite

INTRODUCTION

Habitat fragmentation is at the crux of the global decline in biodiversity (Butchart et al. 2010). Animal extinctions are escalating as land clearing and vegetation conversion divides preferred habitats into units of ever decreasing size. The creation of protected areas is a common strategy to mitigate species loss, effectively generating habitat islands in human-dominated landscapes. Historically, defining the location and boundaries of a reserve has been decided by economics (Prendergast et al. 1999), and a vast majority of protected areas are situated on land unsuitable for commercial development rather than in areas of conservation significance (Fuller et al. 2010). More recently, however, there has been a drive to protect ar-

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eas with high biodiversity value, and even converting degraded habitat (Plieninger & Gaertner 2011). Areas proposed for wildlife protection must be funded from a limited budget, and inevitably not all potential areas can be afforded. A relatively novel technique gaining considerable support for resolving the trade-offs that must inevitably be made is spatial conservation planning (Ando et al. 1998, Moilanen et al. 2009). This approach uses optimization algorithms to balance the cost of purchasing, rehabilitating and protecting land against the number of species that action will conserve; in essence, maximising the number of protected species for the available funds (Watts et al. 2009). In the conservation of threatened species, spatial prioritisation analyses to set the monetary cost of habitat protection are typically based upon species presence/absence or abundance data, and often rely on expert opinion to define the relative importance of habitat (Joseph et al. 2006, 2009, Donlan et al. 2010). This approach is often undertaken due to the lack of consistent and credible spatial data and the challenges associated with understanding the processes and identifying the spatial data to represent them (Possingham et al. 2005, Klein et al. 2009). We argue that the adequacy, comprehensiveness and efficiency of a conservation plan for a threatened species would be improved if density estimates of land occupation were to be incorporated into the prioritisation analysis.

The southern cassowary *Casuarius casuarius johnsonii L.* is the world's largest avian frugivore. It is a highly mobile, large, flightless bird which inhabits the wet tropical rainforests of Queensland, Australia. The species' role as seed dispersal agent corresponds to that performed by guilds of birds and mammals in other tropical rainforests (Forget et al. 2007). The spatial movements of cassowaries are the only routine method by which seeds from large-seeded fruiting rainforest plants are transported away from the parent tree and to higher elevations (Westcott et al. 2005), and therefore the ecology of cassowaries is considered salient to the rainforest ecosystem in general. The landscape inhabited by cassowaries has undergone extensive land-clearing and vegetation conversion. Pockets of remnant rainforest have been protected, but beyond the reserve boundaries the contemporary landscape is a mosaic of degraded regrowth forest, agricultural and pastoral land, road networks, and residential and commercial developments (Stewart et al. 2001). Cassowaries are frequently sighted traversing though the human-modified landscapes and are known to feed at remnant trees, orchards and residential gardens (Crome & Moore 1990, Bentrupperbäumer 1998, Moore 2007). It is here that they interact with human-derived processes, all too often to the detriment of the cassowary. Exacerbating these issues is the isolation of sub-populations, and localised extinctions have been documented within these population pockets (Crome & Moore 1990, Latch 2007). The species currently exist in 2 disjunct populations, with the Wet Tropics population listed as 'Endangered' and the Cape York population listed as 'Vulnerable' (Latch 2007).

In the present study, we examined a discrete population of cassowaries inhabiting a protected-area network (Moresby Range National Park and Etty Bay Conservation Area). The study objective was to determine how adult cassowaries move between protected areas and surrounding human-modified landscapes, and to assess the relative costs of improving protection for the inhabiting cassowaries.

MATERIALS AND METHODS

Study location

The study was conducted at Moresby Range National Park (279 ha), Queensland, Australia (17.559° N, 146.087° E), during April 2009 (Fig. 1). The area is typical of much of the cassowary's habitat

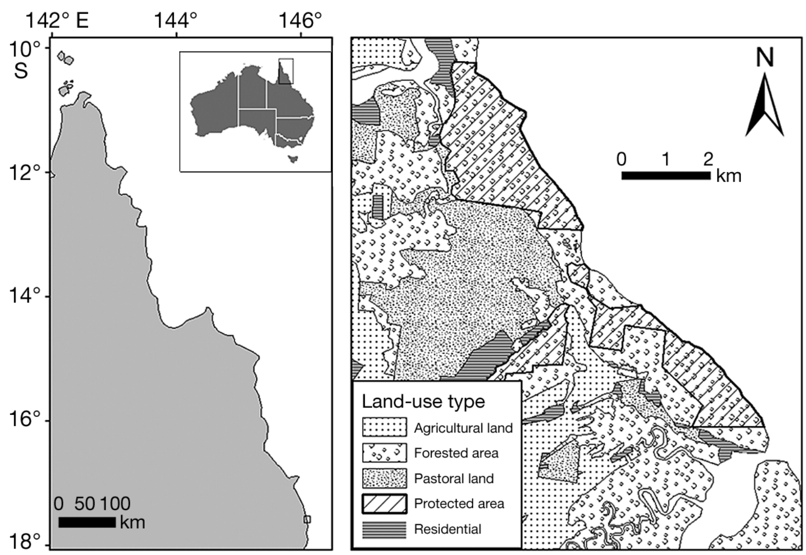

Fig. 1. Protection-area network of Etty Bay, and Moresby Range, Queensland, Australia, with surrounding modified landscape

throughout Queensland, where birds are concentrated within a patch of rainforest surrounded by a human-modified landscape.

Experimental protocol

The southern cassowary *Casuarius casuarius johnsonii* monitored in the present study were all adult birds (2 males and 3 females), inferred from their size and morphological features (Fig. 2). The mean (±SE) length of the metatarsus was 350 ± 2 mm for males and 388 ± 3 mm for females. Extrapolation of body mass from metatarsus length from archival post mortem data (G. Lauridsen unpubl. data), estimated female and male body masses of 60 and 40 kg, respectively.

It was not logistically possible to capture cassowaries from within the rainforest, and birds were located by opportunistic searches along the fringes of the reserve. Once spotted, the birds were sedated by a mixture of tiletamine and zolazepam (Zoletil 100, Virbac), administered at a dose of ~7.5 mg kg^{-1} by blow dart (Wildlife and Animal Capture, Warwick, Queensland). Once sedated, the bird was moved to a shaded area and given an intra-muscular injection of 10 mg of diazepam (Parnell Laboratories). Heart rate, body temperature and ventilation rate were monitored throughout the procedure.

A unit incorporating a GPS-based tracking device and VHF transmitter was attached to the left tarsus of each bird with a neoprene-lined canvas cuff (Fig. 2). The cuff was tailored to fit the leg of each individual bird and positioned to allow full flexion of the leg. The GPS-tracking units were positioned on the outside of the leg to improve GPS satellite reception, and to ensure the unit did not hinder leg movement. The total weight of the GPS-tracking unit plus attachment cuff was 380 g, and was <1% of the estimated body mass of the smallest study bird. Following transmitter attachment (5 to 10 min), the birds were allowed to recover in a quiet shaded area, until they regained mobility and moved off on their own volition. This generally occurred from 2 to 3 h after the initial sedation. All procedures were carried out with the appropriate animal ethics clearance and permits (EPA/2008/12/34).

The GPS-tracking units were purpose-built for the study (Sirtrack, Hamilton, New Zealand, n = 4; Titley Electronics, Brisbane, Australia, n = 1) and took a location fix every 30 min. If a location fix was not recorded within 3 min, the logger powered down to conserve battery life. After a 48 h recovery period, the GPS-based devices powered on and recorded the location of each bird over the following 21 d. Each unit also contained a VHF radio transmitter which transmitted continually during the tracking period. In order to remove the GPS-tracking units, each bird was located by the VHF radio transmitter, sedated, and the device removed. Each bird was given a thorough health inspection by a veterinary surgeon before release.

Fig. 2. *Casuarius casuarius johnsonii*. An adult female with the GPS-based telemetry device, VHF transmitter and canvas attachment cuff

Data analyses

For each of the GPS-based relocations the associated satellite dilution of precision (SDOP) value was used to assess positional resolution and precision. The average degree of error for positional fixes with a specific SDOP value was pre-determined for each GPS unit prior to the study from stationary logging tests (21 d). Location fixes with SDOP values of 4.0 had a mean accuracy of error of 12.1 ± 0.6 m (Sirtrack) and 9.8 ± 1.1 m (Titley). Only fixes with an SDOP value <4 were used within the home-range analysis. The adehabitat library of functions (Calenge 2006) in the R programming language (R Development Core Team 2010) was used to standardise location data to only 1 fix every hour. There was no significant relationship between landscape type and the SDOP value when tested for all fixes obtained (MANOVA, $p < 0.05$).

Home ranges were estimated using the minimum convex polygon (MCP) and the adaptive local convex hull (*a*-LoCoH) nonparametric kernel method. The *a*-LoCoH was chosen over the MCP to define habitat usage, because it provides clearly defined regions where data are more abundant (for details see Getz et al. 2007). The *a*-LoCoH isopleths were overlaid on land-use imagery maps, and the area of each habitat type within each of the isopleths was extracted using ArcView GIS 9.3.1 (ESRI). The proportion of each habitat type within each of the probability density isopleths was calculated for each bird.

Setting of priority habitat

To determine the relative cost of land protection for the cassowary the systematic conservation planning software MARXAN with zones was used (Ball et al. 2009). MARXAN is used to solve a range of spatial prioritisation problems, selecting planning units that represent the conservation of various targets for a minimum total cost (Ball et al. 2009). In the present study, we used the different probability density estimators (*a*-LoCoH) for home range as the target conservation feature. Firstly, the study area was divided into square planning units (50 m^2; n = 4945) in ARCView, and each planning unit was assigned the relative land-use type contained within it. If multiple land-use types existed within the planning unit, the land use composing greatest coverage was assigned. The land acquisition costs for each landscape categorisation within the planning unit were derived from the Queensland Value General (Carwardine et al. 2010). In addition to the acquisition costs, we added current management costs for the reserve, and restoration costs of \$9100 and \$25 600 ha^{-1} yr^{-1} for degraded (i.e. fragmented forest) and cleared land (i.e. agricultural land), respectively. These values were calculated from recent rainforest restoration projects undertaken in the Queensland Wet Tropics area (Catterall & Harrison 2009). A planning unit was assigned usage by the cassowary if >50% of the planning unit occurred within the density estimation *a*-LoCoH isopleth. The importance of a planning unit to the tagged cassowaries was determined through the application of the home range at the various *a*-LoCoH density estimators from 50 to 100%. Land designated as residential was not included within the analyses.

RESULTS

All 5 tagged *Casuarius casuarius johnsonii* were observed foraging the day after tag attachment and showed no signs of irritation from the GPS-tracking device. Birds which had previously shown a degree of habituation to humans had not lost this trait after the tagging procedure. Upon tag removal, there were no signs of rubbing or abrasion in the area of device attachment.

Behavioural ecology

The female cassowaries had a significantly greater (3- to 6-fold) total home range (MCP) than the males (Fig. 3, Table 1). The level of home-range overlap between cassowaries of the same sex was very low, but almost the entire home range of the males fell inside the home range of a female. (Fig. 3, Table 2).

The *a*-LoCoH non-parametric kernel method was preferred over the MCP for determining the relationship between the home range and land use because it allowed for non-use areas within the home-range boundaries (Fig. 4). This resulted in a smaller total home-range estimate for *a*-LoCoH compared to MCP (Table 1). Overlaying the *a*-LoCoH over land-use type showed that the core home range (50% *a*-LoCoH) of the females was almost exclusively within closed canopy rainforest, whilst that of the males was primarily within residential areas (Fig. 5). Outside their core home ranges the females began to move outside the reserve boundaries and to incorporate cleared pastoral and agricultural land into their range, while the outer margins of the males' home ranges occupied the protected area. This difference in the use of landscape resulted in a disproportionate exposure to roads between males and females (Table 3).

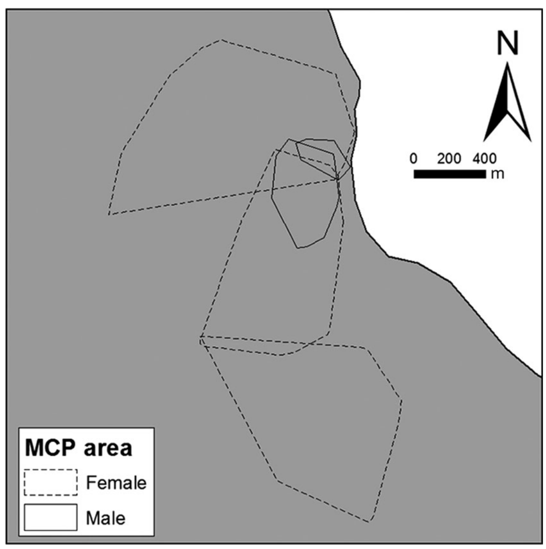

Fig. 3. *Casuarius casuarius johnsonii*. Home ranges of cassowaries determined by minimum convex polygon (MCP; n = 5)

Setting of priority habitat

The monetary cost of areas utilised by the tagged cassowaries and that are currently under protection was calculated at $392 000 for all 5 birds. This is an arbitrary value likely to change over time, but its magnitude should remain stable relative to the land values outside the reserve. The cost to purchase, rehabilitate and protect all the land utilised by the tagged cassowaries (100% *a*-LoCoH) outside the reserve was 5.1-fold the monetary cost of the current protection area (Fig. 6). The cost of protecting the home ranges at the 40% density estimate for *a*-LoCoH was only 1.04-fold the current monetary cost, and protection of the home range at the 70% *a*-LoCoH level could be achieved for only 1.22-fold the current costs of the protection area. This was the case because the bulk of land between 40 and 70% *a*-LoCoH was composed of forest areas

Table 1. *Casuarius casuarius johnsonii.* Home-range (HR) parameters (ha) calculated by the minimum convex polygon (MCP), and the adaptive local convex hull (*a*-LoCoH) non-parametric kernel method for each cassowary (2 males, 3 females)

HR	Male		Female		
	M1	M2	F1	F2	F3
MCP	16.06	4.01	59.49	68.11	85.48
100% *a*-LoCoH	9.11	2.20	30.21	51.59	58.82
95% *a*-LoCoH	6.55	1.61	24.78	43.91	39.31
50% *a*-LoCoH	1.44	0.18	4.08	13.73	13.76

Table 2. *Casuarius casuarius johnsonii.* Proportion of the home range (*a*-LoCoH) of cassowaries (2 males, 3 females) which is overlapped with other tagged individuals

HR	Male		Female		
	M1	M2	F1	F2	F3
100% *a*-LoCoH					
Same sex	0.04	0.16	0.02	0.02	0.02
Opposite sex	0.9	0.85	0	0.07	0.11
95% *a*-LoCoH					
Same sex	0	0	0	0	0
Opposite sex	0.66	0.1	0	0	0.11

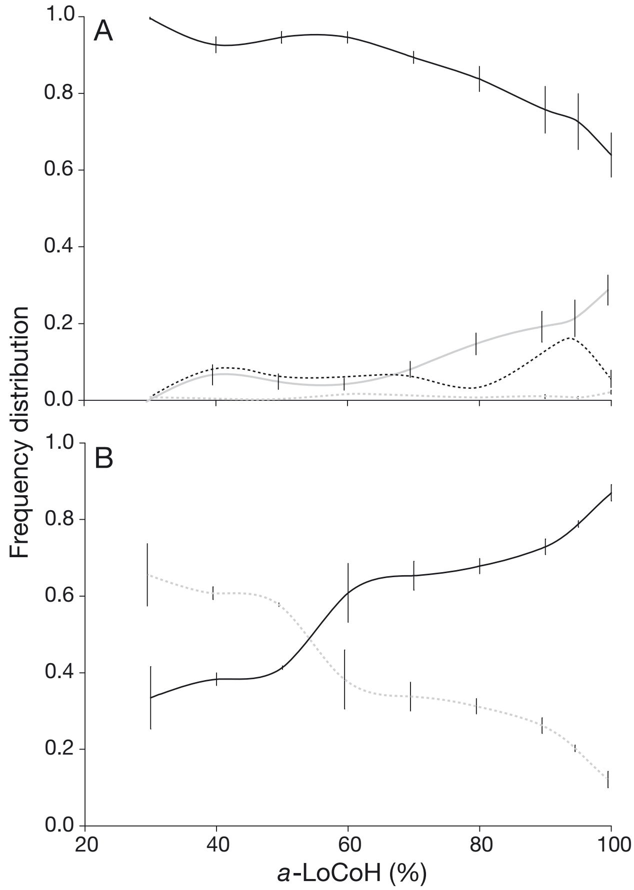

Fig. 5. *Casuarius casuarius johnsonii.* Distribution of land-use type incorporated within the home range of (A) female and (B) male cassowaries between 30 and 100% *a*-LoCoH. Solid black line: protection area; grey dashed line: residential; solid grey line: farmland; black dashed line: unprotected forest. Data are means ±SE

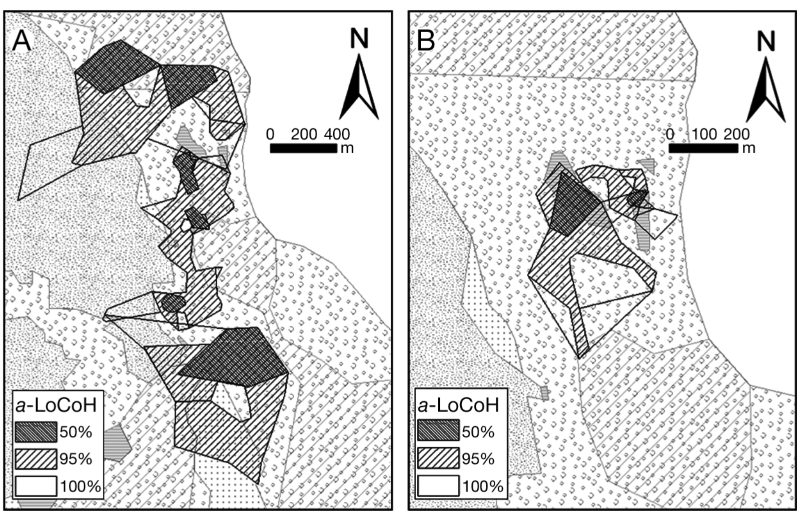

Fig. 4. *Casuarius casuarius johnsonii.* Land-use type (see Fig. 1 key) falling inside the different home-range levels (adaptive local convex hull, *a*-LoCoH) of (A) female and (B) male cassowaries

Table 3. *Casuarius casuarius johnsonii.* Length of road (m) which is located within each cassowary's home range (2 males, 3 females)

HR	Male		Female		
	M1	M2	F1	F2	F3
100% a-LoCoH	620	154	492	625	503
50% a-LoCoH	148	28	0	0	0

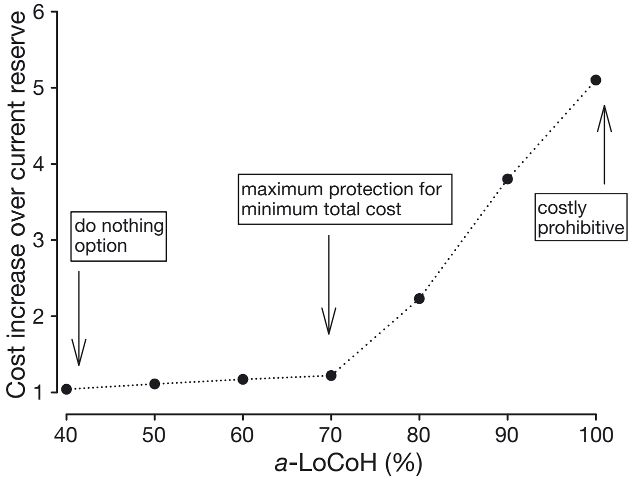

Fig. 6. *Casuarius casuarius johnsonii.* Cost in fold-increase over the current conservation costs for protecting the habitat of cassowaries at the various levels of the home-range density estimator (*a*-LoCoH). Various management scenarios are proposed with their relative cost values

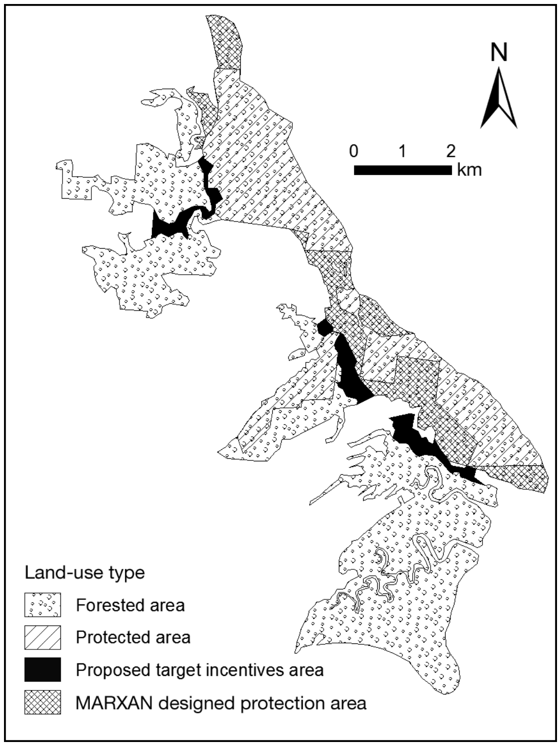

Fig. 7. *Casuarius casuarius johnsonii.* Current protection-area network (1062 ha) and the adjacent forested areas which are currently unprotected (2279 ha). Areas adjacent to the protected areas which MARXAN prioritised for protection are hatched (478 ha); the cleared areas of farmland where target incentives should be directed due to infrequent traversing by the cassowaries are black (171 ha)

(Fig. 5), which have a low purchase and restoration cost. Protection of the home range at 70% *a*-LoCoH would maximise the amount of home range that could be protected for the minimum total cost. Protection of the home range beyond 70% *a*-LoCoH resulted in an exponential increase in costs. This occurred because the birds incorporated large areas of agricultural land at the upper margins of their home range (Fig. 5), and this land had a high purchase and restoration value.

The home-range density estimator (70% *a*-LoCoH) for the minimum total cost was used to set the conservation target for redefining the boundaries of the protection-area network (Fig. 7). The results showed that only forested, and not cleared, areas should be prioritised for protection. This was the case because of the high costs associated with purchasing and rehabilitating these land-use types and because large expanses of land only occupied the outer margins (70 and 100% *a*-LoCoH) of the home range.

DISCUSSION

The present study illustrated 3 key points: (1) modern GPS-telemetry devices are valuable tools which provide detailed information on home-range placement and habitat usage for the southern cassowary *Casuarius casuarius johnsonii*; (2) home-range information enables reasonably accurate estimations of population abundance (Schwarz & Seber 1999); and (3) the integration of these biological data into spatial prioritisation analyses with land-value information may improve the design of protected areas by prioritising the best match between the most significant habitat for the limited conservation funds available.

Behavioural ecology

The creation of MCPs from the female GPS-tagged *Casuarius casuarius johnsonii* produced home-range estimates that were very similar to the MCP home-range estimates derived from a multi-year focal study of adult female cassowaries inhabiting a different, yet equally sized, cassowary protection area (Bentrupperbäumer 1998). Importantly for management, our home-range estimates were considerably smaller than the 208 ha home range reported from a study conducted in the greater Mission Beach area (Crome & Moore 1990, Moore 2007). Because HR size between individuals will exert a powerful influence on population abundance (Schwarz & Seber 1999), this 4-fold variation in the size of the home range between locations/habitat types is, at first glance, of considerable significance. Unfortunately, it was not possible to make any noteworthy conclusions, because Moore's (2007) home-range estimates relied upon only a small number of relocations provided by visual sightings, and, primarily, individual identification was made using footprints, a method of dubious and untested reliability (Westcott 1999, Buckland et al. 2008). We argue, therefore, that these estimations of HR for southern cassowaries are methodologically biased. Given the reasonable concordance between our results and those of Bentrupperbäumer (1998), we suggest that our results, even though they were only collected for a short period of time, were reasonably accurate for the home range of an adult cassowary living in a similar landscape.

Cassowaries are generally considered to be territorial birds that actively exclude conspecifics (Bentrupperbäumer 1998). In this study, the adult female GPS-tagged cassowaries held territories which fitted closely together along defined boundaries; therefore, home-range size is likely to be a good estimator of population abundance for female *Casuarius casuarius johnsonii* (Schwarz & Seber 1999). If we propose that all the land within the protection-area network (1062 ha) is occupied by female cassowaries, whose movements are entirely contained within the reserve boundaries, then the current protected area may encompass the home ranges of 17 adult females. The GPS-based telemetry data, however, showed that the tagged adult female cassowaries did not limit the boundaries of their home range to the protected area. This does not seem to be restricted to the tagged cassowaries, as other females were sighted moving through pastoral and residential areas outside the park boundaries (H. A. Campbell pers. obs.). If all females occupying the protection-area network encompassed only their core home range within the reserve boundaries, and the habitat resources were similar, then the current protection-area network may support many more adult female birds.

The number of male cassowaries occupying the protection-area network may be estimated from their spatial relationship with the females. Nearly the entire home range of tagged males was situated within the home range of a female; this has been recorded at other locations as well, with some female ranges containing 1 or 2 males (Crome 1976, Crome & Moore 1990, Bentrupperbäumer 1998, Moore 2007). If we propose that each female has at least 1 male occupying their home range, then the reserve could potentially contain more than 34 adult cassowaries. This is assuming that all land throughout the conservation area contains habitat of similar quality for cassowaries. The relationship between cassowary home-range size and habitat/resource suitability remains an objective of future studies.

The preferred habitats of the tagged cassowaries showed both a commonality within the sexes and a disparity between the sexes. The females maintained core home ranges within remnant rainforests but visited fragmented forest stands outside reserve boundaries. This suggested that, whilst the protection-area network and closed forest was the preferred habitat, resources were available outside the protected area and these were utilised by the birds. Surveys of these fragmented forest stands revealed high densities of the invasive shrub pond apple *Annona glabra*, whose fruit cassowaries are known to eat (Westcott et al. 2008). Pond apple only fruits during a few months of the year, and further studies are required to assess how seasonal fruiting cycles may alter the proportion of the home range that female cassowaries maintain outside protected areas. In contrast to females, the core home ranges of tagged males were primarily within residential areas. Presumably, the males frequented residential areas to receive food either directly or indirectly from humans. Female cassowaries are larger than males and could certainly exclude males from a resource. The females in our study, however, chose to maintain their core home ranges within the rainforest and only occasionally visited the residential areas which formed core habitat for the tagged males. There are a number of potential explanations for this disparity in habitat use: (1) other resources than food define the home range, (2) segregation of habitat by the sexes due to inter-gender asynchrony (Wearmouth & Sims 2008); (3) sex-specific dietary selection from different nutritional requirements arising from different reproductive roles (Lewis et al. 2002, Xavier & Croxall 2005); (4) the rainforest is a better source of food resources and the females are actually excluding males; (5) our sample sizes are small and our sampling was biased towards cleared areas by access to the birds and, as a consequence, it is possible that such sampling of males will result in a greater bias towards use of urban areas simply because of their smaller home ranges. Whilst at this time we can only speculate as to the causes of this apparent disparity, sex-based differences in movement and habitat use will have major ramifications for defining protected areas and minimising threatening processes for cassowaries. For example, out of the 119 cassowaries killed by vehicle strike over the last 18 yr, 59% of the adult birds were female, compared to only 38% of the sub-adults (Queensland, Department of Resource Management, unpubl. data). Under the assumption that there is a direct relationship between exposure to motor vehicles and the scale of spatial movement, these data suggest that home range, habitat utilisation and range of spatial movement differs between sexes and age classes. Elucidation of such a relationship may aid in the implementation of procedures to reduce cassowary vehicle strike.

Setting conservation targets

The present study demonstrated that protection of the home range at the 70% *a*-LoCoH density estimate could be achieved for only a relatively small increase over the current cost of the reserve. This was achieved by purchase and protection of forested areas adjacent to the protected areas which were currently unprotected. The results also showed that protection of cleared areas was an inefficient conservation option, protecting relatively poor cassowary habitat for a high cost. The problem, however, is that the cassowaries traverse through these pastoral and agricultural areas whilst moving from their core habitat to resources within the outer margins of their home range. It is here that they are exposed to threatening processes (traffic, dogs, entanglement), and we argue that an alternative management strategy for these areas may be to offer target incentives to land owners to reduce these threatening processes (Fig. 7). Using the home-range information, it would be possible to identify these threats, show which landowners should be courted, and how large the incentives offered might be. For example, it may provide spatial information as to the best location for cassowary crossing points, road fencing, or where access with dogs should be restricted. In this manner, the land most critical to cassowary conservation could be prioritised over land that is simply made available by the owners but which has a lower relative cassowary conservation value.

CONCLUSIONS

The technique of using highly accurate home-range density-estimator information within a spatial prioritisation analysis certainly has great value at a spatial scale which encompasses the home ranges of a small population of tagged individuals. In the present study, we extrapolated the priority settings to the surrounding protection-area network, offering a simplified example of how these methodologies could be used to inform management decisions over a broader area. This type of individual-based modelling would be useful for prioritising land for cassowary conservation at the population level, although larger sample sizes over longer time periods would be required. This represents a significant improvement in efficiency over the use of presence data because it recognises that different habitats have different relative values, and, therefore, will differ in their contribution to the conservation goal. Methodologies used in the present study may provide a framework for threatened species research world-wide, particularly in locations where preferred habitat is being subjected to fragmentation.

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