Using geographic profiling to locate elusive nocturnal animals: a case study with spectral tarsiers

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<th>Journal of Zoology</th>
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<td>JZO-08-14-OM-243.R1</td>
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<tr>
<td>Manuscript Type:</td>
<td>Original Manuscript</td>
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<td>Date Submitted by the Author:</td>
<td>21-Oct-2014</td>
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<td>Keywords:</td>
<td>Geographic profiling, home range, sleep site, Tarsius tarsier</td>
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Using geographic profiling to locate elusive nocturnal animals: a case study with spectral tarsiers

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Keywords

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26 Short title

27 Geographic profiling and tarsier sleeping sites
Abstract

Estimates of biodiversity, population size, population density and habitat use have important implications for management of both species and habitats, yet are based on census data that can be extremely difficult to collect. Traditional assessment techniques are often limited by time and money, and by the difficulties of working in certain habitats, and species become more difficult to find as population size decreases. Particular difficulties arise when studying elusive species with cryptic behaviours. Here, we show how geographic profiling (GP) – a statistical tool originally developed in criminology to prioritise large lists of suspects in cases of serial crime – can be used to address these problems. We ask whether GP can be used to locate sleeping sites of spectral tarsiers (Tarsius tarsier) in Sulawesi, SE Asia, using as input the positions at which tarsier vocalisations were recorded in the field. This novel application of GP is potentially of value as tarsiers are cryptic and nocturnal and can easily be overlooked in habitat assessments (for example, in dense rainforest). Our results show that GP provides a useful tool for locating sleeping sites of this species, and indeed analysis of a preliminary data set during field work strongly suggested the presence of a sleeping tree at a previously unknown location; two sleeping trees were subsequently found within five metres of the predicted site. We believe that GP can be successfully applied to locating the nests, dens or roosts of elusive animals such as tarsiers, potentially improving estimates of population size, with important implications for management of both species and habitats.
Introduction

The ability to accurately and reliably detect and locate individuals is vital for assessing animal population density and dynamics, habitat use and ranging patterns – crucial information that underpins the development of conservation management plans for both species and their habitat (Tyre et al., 2003). Traditional census and survey techniques are often limited by time constraints, prohibitive costs and the challenging logistics of certain habitats. Particular difficulties arise when studying elusive species with cryptic behaviours (MacKenzie et al., 2005; Neilson et al., 2013), or species with declining populations, since animals become more difficult to find as population size decreases (Neilson et al., 2013; Chades et al., 2008).

Researchers attempting to census such species typically encounter two main problems. First, the overall study area is often too large to explore exhaustively and inferences must therefore be made using a smaller sampling location, for example using a probabilistic sampling method (MacKenzie et al., 2005). Second, variation arises due to detectability, and research must take into account the likelihood that many individuals will go undetected even though they may be present (Neilson et al., 2013; Chades et al., 2008). In this study, we ask whether geographic profiling, a statistical method commonly used in criminology (Rossmo, 2000) and increasingly being applied to biological data (Le Comber et al., 2006; Martin et al., 2009; Raine, Rossmo & Le Comber, 2009; Le Comber et al., 2011; Le Comber & Stevenson, 2012; Stevenson et al., 2012; Papini et al., 2013; Verity et al., 2014), can be used to improve surveys of species that are rare and/or elusive.

In criminology, geographic profiling uses the spatial locations of a series of linked crimes to calculate the probability of offender residence for each location within the study area,
producing a three-dimensional probability surface called a jeopardy surface; overlaid on a map of the study area, this is termed a geoprofile. Suspect sites are prioritised according to their height on the geoprofile (Rossmo, 2000). Geographic profiling was designed to solve the problem of information overload when dealing with cases of serial crime, since such cases typically generate too many suspects rather than too few, and resources will often preclude a detailed investigation of them all: for example, police investigating the case of the Yorkshire Ripper accrued 268,000 suspect names and 5.4 million vehicle registration numbers (Doney, 1990; Rossmo, 2000). Similar constraints – lack of time, lack of resources – will obviously also often apply in conservation.

Geographic profiling has been extremely successful in criminology, and is routinely used by organisations including the Royal Canadian Mounted Police, the Bureau of Alcohol, Tobacco, Firearms and Explosives, the Los Angeles Police Department, the National Crime Agency in the UK and the United States Marine Corps (Rossmo, 2012). This success has led to its application to biological data, notably animal foraging (where it can be used to find animal nests or roosts using the locations of foraging sites as input) (Le Comber et al., 2006; Martin et al., 2009; Raine et al., 2009; Le Comber & Stevenson, 2012), epidemiology (identifying disease sources from the addresses of infected individuals) (Le Comber et al., 2011; Le Comber & Stevenson, 2012; Verity et al., 2014) and invasive species biology (using current locations to identify source populations) (Le Comber & Stevenson, 2012; Stevenson et al., 2012) (Table 1). More recently, a version of the model based on a Dirichlet Process Mixture (DPM) model that outperforms the Criminal Geographic Targeting (CGT) algorithm used in criminology has been developed and applied to biological data (Verity et al., 2014).
Here, we apply this model to a small, cryptic nocturnal primate species, the spectral tarsier *Tarsius tarsier*. There are 10 extant species of tarsier, and eight of these are endemic to the Indonesian island of Sulawesi (Shekelle *et al*., 2008; Merker *et al*., 2009); however, there may well be many more species that have yet to be described (Shekelle, 2010). Tarsiers are nocturnal, roosting in trees and crevices during the day, but sleeping sites vary depending on forest type. In most cases tarsiers will be found sleeping in the crevices of strangler figs. They are the only extant obligatory carnivorous primates, feeding exclusively on live animals, predominantly insects. Their small size (100-150g), nocturnal lifestyle and ability to leap, almost silently, between branches in the forest make them difficult to locate in the field (MacKinnon & MacKinnon, 1980). Understanding tarsier population dynamics and home ranges is critical to understanding their likely response to habitat change and destruction. However, many tarsier species are either critically endangered or listed by the International Union for Conservation of Nature (IUCN, 2013) as data deficient, meaning that there are insufficient data for a proper IUCN assessment. Many tarsier species have been extensively studied, but much of this relates to aspects of their biology such as their phylogeny (for example, Merker *et al*., 2014 and Pozzi *et al*., 2014), and there is less information on their distribution or population size (IUCN, 2013).

Lowland forest is thought to contain the highest diversity and abundance of animal and plant species and, with the exceptionally high biodiversity in SE Asian forests, in conjunction with carbon storage within the peatlands, deforestation of this area is of global concern. Despite this, deforestation is occurring at a rapid rate within Indonesia itself (Whitten, 2000; Whitten, Mustafa & Henderson, 2002; Miettinen *et al*., 2011a). Globally, Indonesia has exhibited the largest increase in forest loss between 2000 and 2012, with a low of 10,000km$^2$ lost per year to a high of over 20,000km$^2$. Further analyses of spatial resolution land maps have revealed
an overall yearly decline of 1% of forest cover, with the main destruction occurring within
plantations and secondary vegetation. (Hansen et al., 2013; Miettinen et al., 2011a,b). These
recent studies show that deforestation is still occurring at a high rate in SE Asia, endangering
many endemic forest species, such as the tarsier, and habitat destruction leading to the loss of
suitable habitat has led to the IUCN classifying two species of tarsier, the spectral tarsier
*Tarsius tarsier* and Dian’s tarsier *T. dentatus*, as vulnerable. This vulnerable status is
primarily driven by habitat loss rather than population number (Shekelle, Merker & Salim,
2008; Shekelle et al., 2008).

One way to estimate tarsier numbers is via identification of their roost sites (Fig. 1a). In
practice, though, this is extremely difficult, and is usually carried out by tracking the animals
using their duet vocalisations – characteristic calls made prior to dawn each morning as pairs
return to their sleeping sites (MacKinnon & MacKinnon, 1980). However, the short overall
duration of the duetting period, and rapid sound attenuation in the dense rainforest typical of
this species’ habitat, mean that actually locating individuals from their duets is at best
difficult and time consuming, and at worst impossible. Other methods of estimating
population numbers, such as camera trapping, are arguably less labour intensive but perhaps
less effective (Foster & Harmsen, 2012) and in any case also present logistical difficulties
due to the dense habitat (Fig. 1b); camera trapping is also expensive.

Here, we use the DPM implementation of the geographic profiling model (Verity et al., 2014)
to identify likely sleeping sites, with locations of duet vocalisations representing ‘crime sites’
and the sleeping sites analogous to an offender’s ‘anchor point’. To test this model, we take a
retrospective approach, using data on vocalisations and sleeping trees that were collected in a
previous study. We suggest that this approach has the potential to provide a more efficient
way to identify physical locations of elusive, cryptic species such as the spectral tarsier, and to improve estimates of population size, population density and home range size for such species.

Methods

Study area

This project was conducted on Buton Island, Southeast Sulawesi, Indonesia (longitude 123º12' E-122º 33'E and latitude 5º44' S-4º 21’ S; Fig. 2). Buton has a length of 100 km and is 42 km at its widest point, and an area of approx. 4,520 km² (Priston et al., 2011). The forest where sampling took place is split into two reserves, separated only by a small road: Kakanaule Nature Reserve (810 ha) and Lambusango Wildlife reserve (28,500 ha) (Martin & Blackburn, 2010). Buton Island experiences a tropical climate, with a pronounced dry season between August and October, and a wet season between October and April; there is variable rainfall between May and July each year (Whitten 2000; Whitten et al., 2002; Gillespie et al., 2004). The traditional economy is based on subsistence farming, arising from slash and burn agriculture (Priston et al., 2011). The main anthropogenic impacts on the Buton rainforest are forest clearance for land use such as subsistence farming, illegal logging, asphalt mining and rattan collection (Priston et al., 2001).

Field data collection

Research was undertaken between May and August 2013. Surveys started before 05:00 each morning, and continued until approximately 06:00. Before dawn, between 05:00 and 06:15, mated pairs of tarsiers make shrill, sexually dimorphic vocalisations that last up to four minutes as they are returning to roost; these are repeated as the animals move closer to the
sleeping sites, covering in total a period of around 20 minutes (Faulkner, pers. obs.). Each
morning, after the first tarsier was heard, the observer remained static and noted the time of
day. GPS data on the location of the observer were recorded, and distance/compass bearing of
the vocalising animals from the observer estimated. The observer then attempted to follow
the tarsiers to the sleeping tree; where this was possible, its precise location was recorded. A
sleeping site was only classed as such if a tarsier or tarsiers were seen entering a tree, vine
tangle or rock crevice. A total of 25 sleeping trees were identified during the study, including
two located using output from a preliminary GP analysis carried out during data collection;
since these were not independent of the model they were excluded from the final analysis.

Geographic profiling

The DPM model of geographic profiling, which is fully described in Verity et al. (2014),
provides a mathematically robust method of estimating source locations from the spatial
locations of the observed crime sites. Conceptually the method can be split into two parts.
First, the crime sites are partitioned into distinct clusters, with crimes that are close to one
another being more likely to end up in the same cluster. It is assumed that all points within a
cluster originated from the same source, while points in different clusters originated from
different sources. Second, conditional on a particular partition of the data into clusters, the
posterior distribution of the unknown source locations is calculated using a method analogous
to that described by O’Leary (2010). By alternating between these two steps using standard
Markov Chain Monte Carlo (MCMC) methods it is possible to reconstruct the full posterior
distribution of the source locations, integrated over all possible partitions of the data into
groups.
In our case we were interested in using the spatial locations of tarsier vocalisations as input to the DPM model, and using the resulting geoprofile to construct a prioritised search strategy when looking for sleep sites. By carrying out this analysis retrospectively, on data in which the true sleep sites (or at least a subset of the true sleep sites) are known, we can measure the effectiveness of this search strategy compared with a number of alternative approaches.

Finally, we note that although the terminology used in geographic profiling (crime sites, offender residence, etc.) is not always appropriate for use with biological data, for consistency with the criminological literature we will here refer to tarsier sleeping tree sites as anchor points or source locations and vocalisation location sites as crime sites.

Model implementation

The DPM model was implemented in R (R Core Team, 2012) using the package Rgeoprofile as described by Verity et al. (2014); this package is available from http://evolve.sbsc.qmul.ac.uk/lecomber, or from the authors on request. Model parameters were set to default values, with the exception of sigma, the distance (in lat/long degrees) representing one standard deviation of the bivariate normal distribution centred on the source. This was set to 0.0009, corresponding to a distance of 100m at the study site location. This is equivalent to stating that 99% of the ‘crime sites’ are expected to occur within a circle of radius 300m centred on the source. This is consistent with the (admittedly sparse) literature on the dispersal distances of tarsiers, which report them as having nightly path lengths of roughly 1 km (Merker, 2006; Neri-Arboleda et al., 2002).

Model evaluation
Model output can be assessed using the hit score, the proportion of the area covering the crimes (in this case, the positions at which tarsiers were recorded, plus a ‘guard rail’ of 5% surrounding this) in which the anchor point/s (sleep tree/s) are located. The hit score is calculated by dividing the ranked score by the total search area. The smaller the hit score, the more efficient the search strategy described by the model; a hit score of 0.5 (50%) is what would be expected from a nonprioritised (i.e. random or uniform) search (Rossmo, 2000).

Results

Field study

In total, 190 tarsier call locations were recorded across 45 mornings of sampling, within both the Kakanauwe and Lambusango forest reserves. A total of 15% of the vocalisations were recorded between 05:00 and 05:30, 47% between 05:30 and 05:45, 34% between 05:45 and 06:00 and 4% after 06:00). This follows previously published data on the timing of tarsier calls (Neitsch 1999; MacKinnon & Mackinnon 1980). We identified 25 sleeping sites, mostly large strangler fig trees (Fig. 1a), but dense vine tangles and dead tree trunks were also used.

Preliminary analysis

Although the analysis here is retrospective, we ran the model on an early partial data set while field work was still in progress. This preliminary analysis strongly suggested the presence of a sleeping tree in the NW part of the study area; two sleeping trees were subsequently found within 5 m of the predicted location (Fig. 3). Since these two sleeping trees were not independent of the model, they were not used to test the model and were excluded from the full analysis reported below.
Full analysis

The mean hit score for the 23 sleeping trees identified during field work (excluding an additional two sleeping trees identified in the preliminary analysis) was 0.16 (sd = 0.154); the median hit score was 0.15. The model found 10 of the sleeping trees after searching less than 10% of the total map area of 3.4 km², and 16 after searching less than 20% (Fig. 4, Fig. 5).

Discussion

These results show that the DPM model of geographic profiling described in Verity et al. (2014) can successfully be used to prioritise the search for tarsier sleeping sites. We suggest that the DPM model could be used to help locate nests, dens or roosts of other rare and hard-to-study animals, potentially improving estimates of population size in these cases, and allowing important management decisions at both the species and habitat level to be based on better data. In fact, although the analysis here is retrospective, the DPM model of geographic profiling also proved useful in practice, with a preliminary analysis successfully predicting the locations of two sleep trees that were subsequently confirmed in the field.

While we would be cautious about inferring too much from such a limited example, we note that this is the first time that GP has been used in biology as a prelude to further investigation and at the very least demonstrates the potential of this approach.

The ability to locate tarsier roost sites quickly and efficiently is of critical importance if conservation strategies are to be put into place to help conserve this species. Although there is limited destruction occurring on Buton itself in comparison to other areas, and although many tarsier species, including the spectral tarsier, often do prefer secondary forest, possibly due to increased insect abundance arising as a consequence of disturbance, as has been suggested in
other contexts (Zhang et al., 2014) and locomotory aids from smaller trees (Merker et al., 2005), there will be a limit to how much disturbance this species can tolerate before population numbers begin to decline. The use of GP to better target behavioural studies and gain more accurate information on the species’ ecology could thus be of considerable practical use.

Large cavity-bearing trees provide important ecological functions such as nesting and denning resources for many species (Lindenmayer et al., 2012). The overall decline in cavity-bearing trees such as the strangler fig is an emerging conservation concern, due to the importance of these trees to a variety of cavity-dwelling wildlife including tarsiers, other mammals, birds and invertebrates (Struebig et al., 2013). Forests are not recruiting these trees fast enough due to the extended period required for their replacement once they are destroyed (Lindenmayer et al., 2012). A study by Cockle et al. (2010) showed that logging was reducing the basal area of primary forests by half and therefore reducing the number of trees with suitable cavities for nesting animals. However, there are limited studies on the availability of these cavity-bearing trees in Southeast Asian rainforests (Cockle et al., 2010; Struebig et al., 2013).

There are numerous advantages to using GP rather than other more simple measures of spatial tendency such as spatial mean, spatial median and centre of minimum distance. Chief among these is the fact that the DPM model can deal with multiple sources (eg, multiple roost sites in this study), as opposed to providing a single point estimate for a single source or roost site. In criminology, Rossmo & Velarde (2008) made direct comparisons between measures of spatial tendencies and the CGT (Criminal Geographic Targeting) algorithm used in geographic profiling and showed that GP is three times more effective at detecting the anchor
points of serial offenders, while in ecology, in a study looking at source populations of invasive species, Stevenson et al. (2012) found that the CGT algorithm outperformed other measures of spatial central tendency (spatial mean, spatial median, centre of minimum distance and a kernel density model) in 52 of the 53 species studied.

Although the results from this study are highly promising, geographic profiling is still in the initial stages of application to the field of biology. For example, not all species will offer a conspicuous vocalisation like the elusive tarsier; however, other measurable parameters abound. These include sightings, scat evidence or GPS data from radio collars, for example, all of which could potentially be used as ‘crime sites’ to help locate the animals’ anchor points (nests, dens or roosts). However, it is striking how well even this simple model performs: using other dispersal distributions (eg Cauchy distributions) or incorportating more complex priors based on habitat information could all add power to the model.

In conclusion, this study suggests that GP could be useful when searching for elusive and rare species such as tarsiers, increasing search efficiency, improving estimates of population numbers and range size and leading to more efficient use of scarce resources such as time, money and personnel.

Acknowledgements

We thank Operation Wallacea for supporting SF in this project, and for providing logistical support for the fieldwork, and Aidan Kelsey for invaluable assistance in the field. We thank the Indonesian Institute of Sciences (LIPI) and Kementerian Riset dan Teknologi Republik Indonesia (RISTEK) for providing permission to undertake the work (RISTEK permit no.
211/SIP/FRP/SM/VI/2013, and Balai Konservasi Sumber Daya Alam (BKSDA) for their
assistance.

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FIGURE LEGENDS

Figure 1 (a) A sleeping tree; (b) Typical habitat within the study site.

Figure 2 Buton Island. The area in the red square represents the two forested reserves (Kakanauwe and Lambusango) where the study took place.

Figure 3 Geoprofile showing the results of the preliminary analysis. Red circles show the positions of the observer when tarsier vocalisations were recorded, and blue squares the two sleeping trees whose locations were successfully predicted in this analysis. Contours show bands of 5%, with lighter colours corresponding to higher parts of the geoprofile.

Figure 4 (a) Geoprofile showing the results of the final analysis. As before, red circles show the positions of the observer when tarsier vocalisations were recorded, and blue squares the sleeping trees. Contours show 5% increments. (b) The raw probability scores (p) underlying the geoprofile in (a).

Figure 5 Histogram showing the hit scores for all 23 sleeping trees in the final analysis.
Table 1 Geographic profiling’s application in criminology, biology and epidemiology

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189x282mm (72 x 72 DPI)
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189x282mm (72 x 72 DPI)
Figure 2 Buton Island. The highlighted area represents the two forested reserves (Kakanauwe and Lambusango) where the study took place.

418x304mm (72 x 72 DPI)
Figure 3 Geoprofile showing the results of the preliminary analysis. Red circles show the positions of the observer when tarsier vocalisations were recorded, and blue squares the two sleeping trees whose locations were successfully predicted in this analysis. Contours show bands of 5%, with lighter colours corresponding to higher parts of the geoprofile.

614x451mm (72 x 72 DPI)
Figure 4 (a) Geoprofile showing the results of the final analysis. As before, red circles show the positions of the observer when tarsier vocalisations were recorded, and blue squares the sleeping trees. Contours show 5% increments. (b) The raw probability scores underlying the geoprofile in (a).

606x452mm (72 x 72 DPI)
Figure 4 (a) Geoprofile showing the results of the final analysis. As before, red circles show the positions of the observer when tarsier vocalisations were recorded, and blue squares the sleeping trees. Contours show 5% increments. (b) The raw probability scores underlying the geoprofile in (a).

287x196mm (72 x 72 DPI)