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Camera trap as a non-invasive tool in research on rare and elusive mammals

Ph.D. Thesis extended summary

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Supervisor

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The Ph.D. Thesis **Camera trap as a non-invasive tool in research on rare and elusive mammals** was created during doctoral studies at the Faculty of Environmental Sciences, Czech University of Life Sciences Prague.

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The Ph.D. Thesis is available for public at the Department for Science and Research, Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 1176, Prague.

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Introduction

Knowledge of the richness of species that inhabit a particular area is an essential metric for both conservationists and practitioners (O'Connell, Nichols & Karanth 2010; Rondinini *et al.* 2011). Changes and trends in biodiversity and population sizes in time, for example under human disturbance or habitat loss, are subjects studied worldwide for decades and serve as important indications for future strategies (Henschel *et al.* 2010; Visconti *et al.* 2011). Usual high costs, organizational difficulties, invasiveness and questionable reliability of survey methods, as direct observation, aerial counting surveys or line transects sampling, make their outputs often incompatible (Jachmann 2002; Redfern *et al.* 2002). Also, many taxa or individuals remained undetected because of their nocturnal or crepuscular activity pattern or secretive habits, some species can be confused with others of similar size, shape or colour.

Presence and performance of an observer during his data collecting process, especially in case of recording natural and unaffected animal behaviour, has been analysed (Altmann 1974; Marsh & Hanlon 2007). The negative *seeing what we want to see* effect is known and bias naturally increases with the number of observers. The majority of animal species cannot be sampled directly by human's eye because of their habitat requirements (e.g. aquatic species), but a variety of remote detectors were invented and offers new possibilities (Austin *et al.* 2007; Owen-Smith, Fryxell & Merrill 2010; Rovero *et al.* 2013; Dumond, Boulanger & Paetkau 2015).

Relatively cost-efficient and easily standardized solution has occurred in last the decades with the digitalization of photography and massive production of the device known as the camera trap (Rovero *et al.* 2013). Such an independent detector is bias-free in the probability of recording objects passing by and in most cases does not disturb animals. Recent discoveries of new mammal species are proof of this (Surridge *et al.* 1999; Robichaud & Timmins 2004; Cheyne, Husson & Macdonald 2010). Moreover, camera traps allow for insight into the otherwise hidden behaviour of even the most timid animals and this feature fulfils curiosity and datasheets of a wide range of scientists. The skyrocketing number of published field studies based on camera-trapping speaks for itself (Rovero *et al.* 2013).

My interest in photography, endangered animal species and nature conservation worldwide has led me to the decision to employ a novel camera trapping method in practice. This Ph.D. Thesis aims on applications the camera trapping method on a variety of different topical occasions to investigate previously unexplored endangered areas and species, and to evaluate the potential of the approach. I strived to enlarge the pool of knowledge both for conservational and methodological purposes.

The Ph.D. Thesis is compiled out of three scientific articles, which describe surveys on species inventory, temporal activity pattern and density and abundance estimates.

Objectives

Species inventory

The objectives of our camera-trapping study in the Niokolo-Koba National Park (NKNP), Senegal, were to (1) produce the general mammalian species inventory of the core area of the park, (2) evaluate sampling effort and estimate species' richness, (3) estimate species' occupancy (Ψ), and (4) determine the best ecological and environmental predictors (body mass, trophic guild, distance from rivers, distance from park's border) of Ψ and detection probability (p) as a species' response patterns to these predictors.

Temporal activity pattern

We conducted a camera-trap field survey on Bohol Island, Philippines, in an attempt to uncover the tempo-spatial co-occurrences of terrestrial vertebrate species on regularly used trails with the confirmed presence of cats in the protected primary rainforest (Zone I), a transition zone along the border of the primary rainforest with the agricultural landscape (Zone II), and inside the rural landscape in the proximity of human settlements (Zone III). Our objectives were to (1) create a general inventory of camera-trapped taxa, (2) model the species accumulation curve using previous knowledge of the possible number of mammalian, avian and reptile species detectable by camera-traps, and (3) compare the diel activity levels of cats with those of potential prey and competitors.

Density and abundance estimates

Our survey in the Fathala Reserve, Senegal, was designed to empirically determine the most appropriate model, which will enable reliable estimates of the abundance of the Western Derby eland based on the proposed detector array, duration of sampling and density of cameras. For the first time we applied a nonspatial and spatial capture-recapture models on a closed population of marked antelope. We estimated the Derby eland's abundance using the programs CAPTURE (models M_h and M_0) and R, package *secr* (basic *Null* and *Finite mixture* models), in two different densities of camera traps in the line and grid placement derived from the x-matrix covering the entire reserve of Fathala. The results, which change with the variable duration of the trapping period, were compared with the known real abundance. We also tested the pooling of trapping occasions and its impact on results and compliance with the closed model assumptions.

Methods

Species inventory

We designed a regular grid of 41 camera trap locations with 5-km span (density of one camera per 25 km^2) covering an area of 1,025 km^2 of the Niokolo-Koba National Park, Senegal. Data from two 70-day-long sampling periods were analysed: January 12 - April 22 and May 1 - July 9, 2015. We considered two records with a 1-hour gap to be an independent event (Rovero & Marshall 2009). As standard descriptors of the animal community (Tobler *et al.* 2008), the relative abundance index (RAI), the naïve occupancy, and the species accumulation curve with 1,000 random iterations in EstimateS Version 9.1.0 (Colwell 2013), were calculated. To estimate species richness, occupancy, and detectability, we fitted Bayesian hierarchical models (Royle & Dorazio 2008): multiple-species (i.e. community) single-season models, one based on direct occupancy and a species-level detectability estimation, and the second being a multiple-species generalization of the Royle-Nichols model based on abundance and an individual-level detectability estimation (Yamaura *et al.* 2011). In both cases, we fitted models with/without occupancy covariates, and with/without data augmentation, which resulted in eight different models. We considered distance to the nearest river ("river"), distance to the nearest passable road ("road"), and distance to the NKNP border ("border") as possible occupancy covariates for each species. We checked the convergence of all our models using the Gelman-Rubin $\hat{R}$ statistic (Gelman & Rubin 1992), multiple $\hat{R}$ statistic (Brooks & Gelman 1998) and the goodness of fit of the models using Pearson χ^2 residuals. For all data computation, we used R statistical software (R Core Team 2017). For fitting the models, we used the OpenBUGS program (Lunn *et al.* 2009) via the *R2OpenBUGS* package (Sturtz, Ligges & Gelman 2005). For model diagnostics and summaries, we used the *coda* package (Plummer *et al.* 2006) together with our own functions written in R. All statistical plots were created using the *ggplot2* package (Wickham 2009). We used ArcGIS 10.5 for computation of environmental covariates as well as creation of predicted occupancy maps.

Temporal activity pattern

The study was conducted between July 2nd and December 4th, 2014 in the surroundings of the town of Bilar, Bohol Island, Philippines. Our 41 camera traps set on the most frequented trails monitored three types of landscape typical of tropical regions: Zone I – protected primary rainforest including; Zone II – transition zone between the primary rainforest and rice fields and farms; Zone III – mixture of brush and degraded forest and plantations on the edge of villages. We made a list of terrestrial mammalian and avian ground-dwelling species known or expected to occur on Bohol. We pooled both native carnivore species into a group called 'civets'. Group of prey species consisted 'rodents' (mice, rats and squirrels) and ground-dwelling birds. Photographs were defined as events (or activity records) when the delay between two consecutive images of an individual exceeded 10 min. We used a species accumulation curve based on the cumulative number of camera-trapping days, computed in EstimateS Version 9.1.0 (Colwell 2013), to find out if our survey lasted a sufficient number of days to capture the 22 selected terrestrial vertebrate species known from Bohol. We followed Tobler *et al.* (2008) and calculated well-performing estimators of species richness: the non-parametric abundance-based estimator ACE, and the non-parametric incidence-based estimators ICE and Jackknife 1. An abundance-based rarefaction approach with 95% confidence intervals and 1,000 random iterations of sample order was used. The pair-wise temporal overlap of selected activity patterns was analysed using the R statistical environment package '*overlap*' (Meredith & Ridout 2014). We applied kernel density estimation on circular data pooled within all study sites (Ridout & Linkie 2009). The coefficients of overlap (Δ) were calculated with a smoothing parameter of 1.0. We used a smoothed bootstrap of 10,000 resamples to determine standard errors and 95% confidence intervals. We only analysed combinations of pairs of species, which scored at least 30 independent events in the activity record (Ridout, pers. comm.) in a given environment.

Density and abundance estimates

Our study took place from May to September 2013 at a fenced 10.6-km^2 section of the Fathala reserve in Senegal. We used 30 camera traps placed in a grid with a 500-m span throughout the entire reserve. The placement pattern was designed to generate data from a) the entire grid, b) reduced grid of 14 cameras, c) a single line of eight cameras and, d) a reduced line of four camera traps crossing every habitat transversely. Altogether, 16 Derby elands (real density = 1.51 animals/1 km^2) inhabited the area during the study. Each animal was identified by comparing images with the pattern depicted in Brandlová *et al.* (2014). We were finally able to utilize the data from 26 camera traps for computation in CAPTURE. Each day was considered a trapping occasion. In secr, we processed the data from all 30 cameras with the application of the *usage* function treating the varying detector-specific effort. For estimation of abundance via nonspatial CR analyses, we used the program CAPTURE (Rexstad & Burnham 1991). For each recognized eland we generated a capture history of a row of 66 numbers, marked 1 if the animal was photographed within the occasion, or 0 if it was not. In every processed test the models M_h (capture probability differs among animals, usually considered realistic), which use the jackknife estimator, as well as M_0 (assuming constant capture probability) were determined to be appropriate by CAPTURE's goodness-of-fit test. The closure test was processed by CAPTURE and by direct observation. We computed the estimations of Derby eland abundance ($\widehat{N}$) using spatially explicit analyses of density estimates in the R language (version 3.1.2, R Development Core Team, 2014) in the package *secr* (version 2.9.3, (Efford & Fewster 2013)). We employed two models - the *Null* model, where detection is affected only by the use of space, and the 2-class *Finite mixture* model (*h2*), which allows for the modelling of variation in detection probability among individuals. We compared both models with the use of the Akaike Information Criterion (AIC). We defined habitat mask, which spans within the borders of the reserve and was composed of the number of detectors corresponding with the analysed density of camera traps (i.e. 30 or 14) with the buffer width of 100 m. For the line arrays, only eight, respectively four cameras were marked as "1" in the secr *usage* argument, remaining 22, reps. 10 had the zero value. The detector type for analysis was set as 'proximity', which allows multiple detections of individuals on the same occasion. We estimated population size ($\widehat{N}$) using expected *E (N)* as the volume under a fitted density surface. The value is then equal to the density ($\widehat{D}$) multiplied by the area of the region (Efford & Fewster 2013).

Results of conducted studies

Species inventory

We registered altogether 1,876 trap days out of 2,590 possible (72.4%). We recorded and identified 35 species of mammals. Only one species, Guinea baboon (*Papio papio*), was captured in >200 events. The species accumulation curve showed a steep increase in the number of species detected in the first 200 trap days (59.4%, e.g. 20.8 species); 1,000 trap days resulted in 87.6%, or 30.7 recorded species with an on-going slow progression of the curve. Only the model MSA-N, i.e. the abundance-detectability model with a known number of species, fitted the data well (Bayesian *p* value being 0.6). This model has thus been used for occupancy and individual-based detectability estimation. The mean detectability and occupancy were 0.058 (0.0279, 0.0877) and 0.364 (0.2093, 0.5637), respectively (95% CI are shown in parentheses), with highest occupancy values for the common warthog, Western bushbuck, and crowned duiker. Only six species showed significant response in occupancy to environmental covariates: common crested porcupine exhibited an increasing probability of occurrence with increasing distance from the nearest road and river; Egyptian mongoose was found to have higher occupancy probability closer to the NKNP border as well as farther from the nearest road; Northern lesser galago tended to occupy sites more distant from rivers; by contrast, spotted hyena occupied sites closer to rivers, but farther from roads; Western oribi had higher occupation probability closer to the roads, but farther from the NKNP border (although, as mentioned, it had a relatively poor fit); and finally, Western reedbuck preferred sites more distant from roads. The only model that could be used for estimation of the number of species present in the study area was the multi-species occupancy-detectability (MSO) model. The posterior mean was 42.6 and 95% CI was (29, 73). The distribution of the proportion of present species (parameter Ω) was concentrated around 0.25 (see Fig. 8), which indicates the data augmentation up to the total number of 150 species in the virtual super-community was sufficient for an unbiased estimate of species richness.

Temporal activity pattern

Altogether, over 2,885 trap days we captured 30 species of vertebrates – 10 mammals (including *Sus philippensis*), 19 birds and one reptile, *Varanus cumingi*. We did not record four expected bird species: *Megapodius cumingii, Coturnix chinensis,* *Turnix sylvaticus* and *Gallinago megala*. We trapped 81.8% of expected vertebrates. The mean estimated species richness computed in EstimateS was 19.7 species (ACE = 19.6, ICE = 19.5 and Jackknife 1 = 20.0). We recorded 15.89 species (72.2% of expected species) in 1,000 trap days. Based on the number of events, the most frequent native species was the barred rail (*Gallirallus torquatus*). We found that feral cats most often occurred in the Zone II and III, and were absent inside the primary forest. A similar trend was found for ground-dwelling birds. Most rats and other small mammals were recorded in the transition Zone II between the RSPL forest and agricultural land. Cats showed a decrease in late-afternoon activity near villages, whereas activity in the transition area peaked right before noon. Generally, the activity of cats by daylight was higher in transition zones; in Zone III cats were recorded mainly at night. The highest overlap in diel activity between cats and potential prey was recorded with rodents in rural areas (Δ = 0.62); the lowest was in the same habitat with ground-dwelling birds (Δ = 0.40). The cats' activity declined in daylight in the proximity of humans, while it peaked at the transition zone between rainforest and fields. Both rodents and ground-dwelling birds exhibited a shift in activity levels between sites where cats were present or absent. Rodents tend to become strictly nocturnal in cat-free habitats. No cats' temporal response to co-occurrences of civets (*Paradoxurus hermaphroditus* and *Viverra tangalunga*) was found but cats in diel activity avoided domestic dogs (*Canis lupus familiaris*). Cats showed the second lowest overlap among all groups with dogs in Zone III (Δ = 0.45) where dogs were dominant and active during the day. In Zone II these two animals appeared to peak in their activity at different times: dogs were most active in the morning and late afternoon, whereas cats peaked before noon.

Density and abundance estimates

We accumulated data from a total of 1,716 trap-days and recognized 192 events of camera trap encounters with non-identified Derby elands. We were able to identify 108 independent captures of 16 Derby eland individuals, scoring a 56.3 % success rate in recognition. We needed 962 trap-days to capture and recognize all 16 Derby elands inhabiting the reserve. CAPTURE's model M_h was selected as the most appropriate for every pattern, as it scored 1.00 in the selection criterion, followed by M_0. In the grid, all three models produced the estimated the size of Derby eland population identically 16 animals at 66 occasions with a lowest value of SE = 0.15 in

M_h Chao. In the line pattern for the same trapping period, only M_h Chao scored 16 individuals (SE = 2.3). The shorter trapping period lasted, the more variable results CAPTURE's models produced. The sparse data of the shortest periods of both line patterns resulted in higher estimates in M_0 and noticeably lower in M_h. All closed models finally underestimated real size in the reduced line pattern—M_0 ($\widehat{N}$ = 14, SE = 2.7), M_h ($\widehat{N}$ = 12, SE = 3.0), M_h Chao ($\widehat{N}$ = 13, SE = 2.2). We undertook a trial computation of the line pattern data pooled out of 2, 3, 6 and 11 days (33, 22, 11 and 6 occasions), resulting in an increase of the probability of capture ($\hat{p}$) from 0.034 to 0.304. We did not recognize major differences between chosen SECR models outputs. As tested using AIC, the *h2* mixture model was never preferred in each computation. Both models along with rising sampling period consistently decreased their initially overestimated abundances to the nearly real size value. The models in the grid at 66 occasions scored equally $\widehat{N}$ = 16.1, SE = 4.1, in the reduced line the *h2* model was slightly more precise ($\widehat{N}$ = 15.4, SE = 5.4) than the *Null* model ($\widehat{N}$ = 15. 1, SE = 5.3). Generally, the *h2* model performed similarly better when data appeared sparse. With the increasing duration of sampling, standard errors decreased with narrowing confidence intervals in all models and arrays. Our test specified 66 days (1,716 trap-days) as the sufficient period for appropriate abundance estimation in the grid and line pattern regardless of the detector/animal ratio.

Conclusions

My Ph.D. Thesis strived to examine the widely used methodology of camera-trapping in its gaps of knowledge (such as empirical evaluation of abundance and density estimates) and in habitats and animal populations overlooked by researchers. For these, I endeavoured to investigate and suggest a user-friendly methodology and to offer the first scientific outputs, as a basic building block for future comparative studies. As the main breakthrough of our studies I consider the capability of listing and analyzing small-bodied vigilant species (e.g. mongoose, wildcat, rodents), as well as ground-welling birds and medium-sized mammals with significant ecological and eco-tourism importance, such as aardvark, honey badger, West African wild dog, serval, caracal, African civet, or Philippine warty pig. Our findings revealed the first tempo-spatial co-occurrences between feral cats and their potential prey and competitors in a typical mixture of Philippine landscapes. Feral cat diet is paradoxically the least researched in tropical habitats with the richest terrestrial biodiversity. This most damaging invasive carnivore species should be investigated throughout its range, especially on islands.

To my knowledge, no comparative data from standardized camera-trapping are available both from the archipelago of the Philippines and from the ecosystem of the savannah. Due to the on-going and unprecedented existential distress of animal populations in the African iconic landscape, I feel an urgent need to act. Our study in the Niokolo-Koba National Park was descriptive rather than theoretical. It aimed at setting up a sound long-term survey methodology for the national park, with the possibility of repeatedly updating the knowledge base concerning the status of species in the area. This perfectly suits the ability of Bayesian methods to use such updates via specification of informative prior distributions for model parameters in future analyses. I encourage researchers to employ and also to further investigate this approach. The issue is of paramount importance because results emerging from camera traps may show a grave asymmetry with recent alarming Living Planet Index reports (WWF 2014, 2016). I hope that our call for further systematic investigation of trends in biodiversity will be heard throughout the community of scientists and practitioners.

Závěry

Má disertační práce byla zaměřena na metodu získávání zoologických a ekologických vědeckých poznatků pomocí relativně nového zařízení – fotopasti. Cílil jsem na empirické ověření již používaných postupů (odhady početnosti nebo denzity) a na zvířecí populace nebo prostředí, které prozatím vědci přehlížejí. Nové postupy při výzkumu pomocí fotopastí sebou přinášejí rozvíjející se analytické nástroje, jejichž sofistikovanost může komplikovat použití metody, a tím bránit v získávání potenciálně srovnatelných dat. Zaměřil jsem se proto ve svých vědeckých článcích i na ověření vhodnosti jejich použití a doporučil další kroky.

Za hlavní přínos prezentovaných studií, vzešlých z intenzivní týmové práce, považuji opakované potvrzení účelnosti fotopastí při monitoringu malých a skrytě žijících druhů nejen savců, ale i na zemi se vyskytujících ptáků. Přinesli jsme první poznatky o časoprostorových aktivitách kočky domácí na Filipínách, jednom z center světové biodiverzity. Kromě analýzy výskytu tohoto invazního druhu predátora v typické krajině Filipín jsme ukázali, jak se jeho denní aktivity překrývají s možnou kořistí a kompetitory. V senegalském národním parku Niokolo Koba, v ohrožené savaně západní Afriky, jsme získali a zpracovali první data o výskytu pozemních savců a nastavili metodiku jejich sběru a vyhodnocení. Zvolený bayesovský přístup nám dále umožní doplňovat nové proměnné. Současně doufáme, že povzbudíme výzkumníky v podobném systematickém monitoringu biodiverzity v savanách. Tento ekosystém a jeho fauna s velkým ekoturistickým potenciálem čelí bezprecedentnímu negativnímu tlaku a spolehlivý zdroj dat je proto urgentní nezbytností. Fotopasti taková data poskytnout mohou.

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Curriculum Vitae

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Education

- since 2012 doctoral study – Czech University of Life Sciences Prague, Department of Ecology
- 1999 – 2006 magister study – Charles University in Prague, Department of Ecology-Ethology
- 1992 – 1996 Forestry High School Žlutice (Střední lesnická škola Žlutice)

Occupation

- since 02/2013 Czech University of Life Sciences Prague, *technician*
- 01/2012 – 01/2013 Czech News Agency (ČTK), *reporter*
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- 2013 IGA 2013 FŽP ČZU - The impact of climatic factors on the behavior of the European badger (*Meles meles*) in the Czech Republic, No. 20134220
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- 2003 Fond mobility UK
  Nadace Český literární fond
  Nadace Nadání Josefa, Marie a Zdeňky Hlávkových
  Nadační fond SLŠ Žlutice
- 2002 American Society of Primatologists, ASP General Small Grant 2002

Projects

- since 2015 monitoring of biodiversity in the Niokolo-Koba National Park, Senegal
- since 2014 monitoring of biodiversity and invasive carnivores in the Philippines
- 2010 – 2017 cooperation on conservation program of the Western Derby eland
- since 2008 cooperation on monitoring of the Cross River Gorilla, Cameroon
- since 2008 cooperation on research of the European beaver
- 1999 – 2006 research on ecology of the aye-aye in Madagascar, MSc. Thesis

Publications

Scientific articles

- Bogdan, V., Jůnek, T., & Vymyslická, P. J. (2016). Temporal overlaps of feral cats with prey and competitors in primary and human-altered habitats on Bohol Island, Philippines. *PeerJ*, *4*, e2288.
- Jůnek, T., Vymyslická, P. J., Hozdecká, K., & Hejcmanová, P. (2015). Application of Spatial and Closed Capture-Recapture Models on Known Population of the Western Derby Eland (Taurotragus derbianus derbianus) in Senegal. *PloS one*, *10*(9), e0136525.
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Conferences

- Jůnek T., Jůnková Vymyslická P., Hozdecká K., Hejcmanová P. Estimation of Derby eland seasonal activity from camera-trapping data: a novel insight into the ecology of ungulates. 10th International Conference on Behaviour, Physiology and Genetics of Wildlife, Sep. 28 - Oct. 1, 2015, Berlin, Germany.
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