Thesis Working Plan: Objective 2

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Title: Assessing population ecology of fossa (*Cryptoprocta ferox*) and species richness of terrestrial vertebrates, as detected by remote camera traps and lemur transects, in Makira Natural Park, northeastern Madagascar.

Goal: My goal is to further the conservation of Madagascar's apex predator, the fossa, and overall rainforest biodiversity by providing the first estimate of fossa density in northeastern Madagascar and examining the effects habitat fragmentation, human activity and exotic species have on fossa density and overall species richness and composition, as detected by camera traps and lemur transects.

Objectives:

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1. Compute density estimates for fossa in Makira and determine what factors—habitat fragmentation, habitat characteristics, prey (lemur) and interspecific (fanaloka; *Fossa fossana*) densities, human activity, native and exotic carnivore and small mammal occupancy—influence fossa density.
2. Examine relationships between the characteristics of the terrestrial vertebrate community that can be detected by camera traps and lemur transects—i.e., species richness and community structure—at intact and fragmented sites, to fossa density, habitat fragmentation, human activity and exotic species presence.

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OBJECTIVE 2: Examine relationships between the characteristics of the terrestrial vertebrate community that can be detected by camera traps and lemur transects—i.e., species richness and community structure—at intact and fragmented sites, to fossa density, habitat fragmentation, human activity and exotic species presence.

a) Estimate species richness, native and exotic species occupancy and determine community structure for terrestrial mammals, terrestrial birds and lemurs as detected using camera trap and lemur transect data for all surveys.
b) Examine relationships between species richness and native species occupancy and fossa density, habitat fragmentation, human activity and exotic species occupancy.
c) Examine temporal trends in species richness and native and exotic species occupancy at FRK and MGB; estimate community parameters (i.e., local extinction and species turnover) at AJB.

Caveat

Due to the methods that have been used, we will not be able to examine the entire ecological community present at any of the sites surveyed. Our methods—camera traps and lemur transects—are best used for detecting terrestrial vertebrates and lemurs; thus, whenever "community" or "species richness" or any other community measurement is mentioned, it is meant to apply to the terrestrial vertebrates and lemurs that can be detected by camera trap or lemur transect.

Justification

Irwin et al. (2010) found that disturbance in Madagascar tends to reduce species diversity (especially that of native or endemic species) and creates a species turnover in communities that favors the replacement of specialist or native species with generalists/introduced species. Measuring community characteristics like species richness is especially important in areas such as Madagascar's rainforests that are highly threatened or little explored (Giman et al. 2007, Gotelli and Colwell 2011). Determining the richness of species in an area can help inform conservation and management decisions (Brose and

Martinez 2004). Examining relationships of species richness to factors like habitat fragmentation and human activity can give us insight into how humans and human influence on the landscape can affect the overall biodiversity of an area and can quickly prioritize areas in need of management intervention. Information on the trends of ecological communities, especially in tropical forests, is seldom available, despite species in tropical areas often being naturally rare and highly threatened (Ahumada et al. 2011).

As detailed earlier, my colleague Zach Farris has collected camera trap data from seven sites (for 11 surveys) on one of the most species-rich areas in Madagascar. Although the target group for the camera trap surveys was carnivores, one of camera trapping's benefits is that researchers often obtain large datasets with data on non-target species (O'Brien 2008). Camera trap surveys that are used to estimate the density of a carnivore often produce a reliable inventory of other similarly sized mammals that could then be used to examine the greater ecological community (Tobler et al. 2008). As I mentioned in Objective 1*c*, although the camera traps were set for carnivores, we have collected enough captures of other terrestrial species (ground-dwelling birds and small mammals) to make an analysis of Makira's communities feasible. I intend to do just that in this portion of my study. I will use the data already collected by Farris and collaborators as well as new data collected by me in additional surveys as described earlier.

Community Characteristics as a Snapshot in Time: Estimating "True" Species Richness

Species richness—the number of species found in an area—is an important community characteristic, both in determining what and how many species are in a certain area alone and for comparing among sites. In many studies that look at the greater ecological community using camera traps, species richness is given as a list of species that were caught on camera (O'Brien 2008, Abi-Said and Amr 2012, Samejima et al. 2012). This is despite the fact that there has been an increase in the awareness that detection probability is usually not equal to one (meaning that there may be species which are not being detected; Brose and Martinez 2004). The heterogeneity inherent in individual *and* species detectability is often quite obvious in the camera trap data, with certain species being caught more often due to body size, camera placement, differences in actual abundance, survey effort and design (Alzan and Lading 2006, Harmsen et al. 2010, Silveira et al. 2008, Tobler et al. 2008, Burton et al. 2012, Foster and Harmsen 2012). In the end, absence of evidence does not always mean evidence of absence.

Recently, there has been a surge in the use of community analogs of CMR models to account for these undetected species (Tobler et al. 2008, Kéry 2010). While modeling species in a CMR framework, researchers can estimate detection probabilities of species, model different types of detection (e.g., M_h—detection is affected by individual [or in this case, species] heterogeneity) and estimate species richness. Taking species detection probability into account is essential, as there can be discrepancies between the number of species observed and the number of species actually present at a site (Dorazio and Royle 2005). In CMR species richness modeling, one simply scales up: individuals become species, creating a species capture history of 0s and 1s through the survey occasions. Abundance (N) becomes estimated species richness (S), essentially the "abundance of species" (Boulinier et al. 1998). Modeling for heterogeneity becomes especially important in species richness estimation, because individual and species heterogeneity affect overall detection probability (Brose and Martinez 2004, Kéry 2010). Using a modeling framework where you assume there are groups (or mixtures) of species that have different detection probabilities that are constant within their group (e.g. a high detection probability group versus a low detection probability group) can help address the effects of heterogeneous detection probability (Kéry 2010).

Knowing the number of species that should be in an area will not give clues as to what they are and due to the often positive relationship between species detection probability and the number of individuals available in that species, estimates of species richness may end up being positively biased (Nichols et al. 1998). However, there is still the added benefit of including detection probability and the effects of individual/species heterogeneity into the estimation of species richness. In comparative studies, CMR tends to perform better than other types of species richness estimators (Walther and Moore 2005).

Community Characteristics: Examining Community Dynamics over Time

Estimating parameters such as extinction probability, species persistence and the rate of change in species richness over time can inform researchers on temporal changes in ecological community composition, structure and vital rates. As we could look at a closed "population" of species with closed CMR models, we can examine dynamic communities using Pollock's robust design and estimate informative rates such as species persistence, colonization and extinction (Pollock 1982, Nichols et al. 1998, Brose and Martinez 2004, Kéry 2010). The robust design, when implemented in Program MARK, can model all types of detection probability (i.e., M_h or detection probability influenced by heterogeneity), make use of finite mixtures and estimate seven parameters (Johnson et al. 2009):

- Species richness: number of species corrected for detection probability
- Local species persistence: probability that a species is present from time i to time j
- Temporary emigration: probability that a species is present at time i but absent at time j
- Immigration: probability that a species is absent at time i and remains absent at time j
- Mixture: proportion of the community with a high detection probability
- High detection: probability of detection for the high detection group
- Low detection: probability of detection for the low detection group

Using equations from Nichols et al. (1998), we can then derive point estimates of four other parameters:

- Local extinction: probability of local extinction of a species from time i to time j
- Local turnover: probability that a new species is present at time j but not time i.
- Number of colonizers: number of new colonizing species present at time j but not time i
- Rate of change: finite rate of change in species richness between time i to time j

One must estimate the variances of these four derived point estimates, which one can do by parametric bootstrapping (Nichols et al. 1998, Johnson et al. 2009).

Due to the heterogeneity of species detectability, there have been thoughts that derived estimates such as local extinction probability will be positively biased. Detection probability is positively related to the abundance of a species, and the abundance of a species if often negatively related to its extinction probability. However, studies have shown that, despite a positive bias, the bias is minimal (Alpizar-Jara et al. 2004, Jenourvrier and Boulinier 2006).

Using Hierarchical Multi-Species Models to Estimate Species-Specific and Community Parameters

In many cases, estimating parameters for uncommon or rare species can be difficult due to few detections (Mackenzie et al. 2005, Zipkin et al. 2009). Recently, hierarchical multi-species occupancy models have begun to be widely used to estimate species richness, occupancy, detection probability and to examine the effects of habitat, site characteristics, or management treatments on both entire communities and individual species simultaneously (Dorazio and Royle 2005, Kéry and Royle 2009, Zipkin et al. 2009, Burton et al. 2011, Burton et al. 2012). Hierarchical models are essentially models with multiple levels; in the case of hierarchical multi-species occupancy models, observed data on a species is conditional on the true occupancy and detection probabilities of that species, which is in turn conditional upon whether that species was actually present within the sampled community (Burton et al. 2011). Each species' occupancy and detection probability is a variation of a mean community occupancy and detection probability, which allows for more precise estimation of occupancy and detection probabilities of species for which researchers have very little data, although these estimates do tend to be biased towards the community mean ('Bayesian shrinkage'; Dorazio and Royle 2005, Royle and Dorazio 2006, Burton et al. 2012). Because carnivore and lemur detections have seemingly lessened in more recent surveys in Makira (e.g., MGBII and AJBIV), I will be exploring the use a hierarchical, multi-species occupancy models to estimate species richness, occupancy and detection probabilities and how they change through time.

Analyses:

Objective 2a: Estimate species richness, native and exotic species occupancy, and determine community structure for terrestrial mammals, terrestrial birds, and lemurs using camera trap and lemur transect data for all surveys.

Camera Trap Data: I will estimate species richness for all surveys by identifying all animals captured and using closed population, single-season CMR models in Program MARK. For small mammals, all species will be identified at minimum to the genus. Due to morphological similarities in some Malagasy small mammal species, correctly identifying to species could be difficult. We will collaborate with Dr. Steve Goodman (Field Museum of Natural History, Chicago) to ascertain the reliability of our identifications. I will note if species identified is native or exotic and test for closure as in Objective 1*b*. Demographic/geographic closure in this case means that no species colonized or went extinct or immigrated/emigrated in the study area during the survey period.

I will estimate single species occupancy for all species observed and overall native and exotic small mammal, bird, and carnivore species occupancy for each survey using Program PRESENCE (Mackenzie et al. 2006). The structure of an ecological community, and changes to the structure through the years, or differences in structure across sites can provide researchers with information about the types of species present, their role in the community, and their commonness. I will determine community structure as per Ahumada et al. (2011) by categorizing each species into a feeding guild (insectivore, herbivore, carnivore, and omnivore), determining their occupancy and graphing this descriptive summary data for visual examination. I will do this for all potential 14 surveys.

Lemur Transect Data: I will estimate lemur species richness for all surveys by identifying all lemurs captured, testing for closure as in Objective 1*b* and then estimating species richness using closed population CMR models in Program MARK. Lemur species occupancy (single species) will be estimated using Program PRESENCE for each survey (Mackenzie et al. 2006). I will determine community structure as per Ahumada et al. (2011) by categorizing each species into a body size (small, medium and large) and activity (diurnal and nocturnal) guild and graphing this descriptive summary data for visual examination. I will do this for all potential 14 surveys for a sample size of n = 14.

Survey Comparisons: I am currently exploring appropriate analytical methods to compare species richness (lemur and terrestrial), lemur species occupancy, and native and exotic small mammal, bird, and carnivore species occupancy among intact and fragmented sites.

Expected Results:

- Species richness, lemur species occupancy, and native small mammal, bird, and carnivore species occupancy will be significantly higher at intact sites.
- Exotic small mammal and exotic carnivore species occupancy will be significantly higher at fragmented sites.
- Intact sites will have more complex community structure, with more native species in the guilds and species occupancy will be higher.

Objective 2b: Examine relationships between species richness and native species occupancy and fossa density, habitat fragmentation, human activity, and exotic species occupancy.

I will use linear regression and mean fossa density as estimated in Objective 1 to determine if fossa density is positively correlated with high species richness and native species occupancy and whether they can be useful biodiversity indicators. I will also use linear regression to examine the relationships between species richness and native species occupancy and habitat fragmentation (e.g., % edge, patch area and distance to nearest patch), human trapping success, and exotic species occupancy.

Expected Results:

- Fossa density will be positively correlated to high species richness and native species occupancy, making it a useful biodiversity indicator.

- Species richness and native species occupancy will be negatively related to habitat fragmentation, human activity and exotic species occupancy.

Objective 2c: Examine temporal trends in species richness and native and exotic species occupancy at FRK and MGB; estimate community parameters (i.e., local extinction and species turnover) at AJB.

Examining community dynamics such as species turnover, colonization and extinction rates is essential when examining the effects of external forces on ecological communities over time. Due to the lack of data for MGB (two surveys) and FRK (one with a possible second survey to be done depending on funding), I will plot the species richness and estimates of individual species occupancy (native and exotic) for each survey to examine temporal trends. Significant differences will be determined using 95% confidence intervals. Because AJB has four (potentially five) surveys, I will estimate species richness, local species persistence, temporary emigration, immigration and the proportion and detection probabilities of two mixtures or groups within the community—high detection probability and low detection probability—using robust design CMR models in Program MARK. I will derive local extinction, local turnover, the number of colonizers and the rate of change using equations from Nichols et al. (1998) and estimate the variances using bootstrapping methods (Nichols et al. 1998, Johnson et al. 2009).

<u>Expected Results:</u>

- Species richness and native species occupancy at FRK, MGB, and AJB will decrease over the years.
- Exotic species occupancy will increase at MGB and AJB and stay constant or decline at FRK.
- Local species persistence and turnover, temporary emigration, immigration, and the number of colonizers will decrease over the years at AJB.
- Local extinction rates will increase at AJB over the years and the species richness rate of change will be negative, and will increase in value over the years.

- Detection probabilities of both high-detection probability and low-detection probability mixtures will decrease as years go by due to the relationship between species abundance and species detectability at AJB.

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