INTRODUCTION

Surviving in fragmented landscapes: Identifying variables that influence primate population viability and persistence in forest fragments and a summary of the included papers

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Research Highlights

- The papers included in this special issue examine interspecific responses to habitat fragmentation by primate populations
- We identify intra and interspecific variables that can help predict primate population viability and potential persistence in fragmented landscapes

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Introduction to the special issue "Surviving in fragmented landscapes: Identifying variables that influence primate population viability and persistence in forest fragments" and a summary of the included papers

As primatologists in the 21st century, we are well aware that many of the world's primate populations now live in increasingly fragmented habitats. Entire volumes (Marsh, 2003; Marsh and Chapman, 2013) as well as a vast number of journal articles since the late 1980s have been devoted to examining a wealth of topics related to responses of primate species living in fragmented conditions (e.g. changes in feeding and ranging ecology, behavior, matrix use, genetic health and more). **Because** so many primate populations are now faced with the challenge of surviving in severely fragmented habitats, interspecific variation in responses to such habitats is to be expected. This special issue of American Journal of Primatology emerged from a symposium that took place at the 27th International Primatological Society Congress in Nairobi Kenya in August, 2018, entitled "Surviving in fragmented landscapes: Identifying variables that influence primate population persistence in forest fragments". The goal of the symposium, and of this special issue, is to examine interspecific responses to habitat fragmentation by primate populations and to identify specific variables that can help predict population viability and potential persistence in fragmented ~~forests~~ **landscapes**. The authors of the papers included here have taken varied approaches in addressing this question, and the questions and methods described in these contributions can potentially prove useful for future studies relating to how primate populations adapt or fail to adapt to ongoing forest fragmentation. Geographically, this collection of twelve papers ranges from studies of a variety of lemur species in diverse habitat types and regions of Madagascar, to Bale monkeys in Ethiopia

and chimpanzees in Uganda, Javan slow lorises as well as a pan-specific consideration of Asian primates, and howler monkeys throughout the **N**eotropics.

From one variable to many when assessing population viability and persistence in fragments

In this special issue, Birot et al. demonstrate how the addition of just one anthropogenic variable, the installation of artificial canopy bridges to connect forest patches, helped Javan slow lorises **(*Nycticebus javanicus*)** increase their home ranges, include new feeding trees into these expanded ranges, while reducing their terrestrial use, thereby offsetting predation of these small primates. Additionally, the waterline bridges that were installed assisted local farmers with crop irrigation, and resulted in these farmers helping to maintain the bridges. This initiative increased local human awareness of the value of slow lorises in this region, and the bridges served as connective routes for other endemic mammals. Conversely, Boonratna discusses a wealth of inter-related variables that can assist in influencing the persistence of Asian primates confined to forest fragments, and he describes how the use of the IUCN-CMP Unified Classifications of Direct Threats can help identify specific variables that relate to the causes and consequences of fragmentation throughout Asia.

Ecological flexibility eclipsed by fragment isolation

While some primate species tend of cope with fragmentation better than others, isolation of primate populations, however ecologically flexible, has been demonstrated as **one of the strongest** negative consequence of fragmentation (Oklander et al, 2010; Holmes et al., 2013; Knapp, 2013). Here, Bicca Marques et al. caution that while individual populations of howler monkeys throughout the **N**eotropics may cope well in fragmented forests **in the short-term**, we should not consider them immune to the effects of anthropogenic habitat alteration, particularly as such populations can become significantly isolated over time. Gould and Cowen evaluated the

potential for overall population viability and juvenile recruitment in ring-tailed lemurs inhabiting nine widely-scattered forest fragments of varying sizes in south-central Madagascar. While fragment size and certain specific key food resources emerged as important predictors of ~~variables related to~~ population occurrence and juvenile recruitment of these ecologically flexible lemurs, Gould and Cowen caution, in a similar manner to Bicca Marques and colleagues, that geographic isolation and lack of dispersal opportunities in many of these fragments could eventually affect overall population viability.

Matrix use as a promoter of population persistence in fragments

Use of the surrounding matrix, particularly in terms of helping to meet nutritional needs, has proven to be an important survival strategy for primates ~~confined to fragments~~ **coping with fragmented habitats** (Marsh, 2003; Anderson et al., 2007; Pozo-Montuy et al., 2011). Here, Mekonnen et al. compared matrix use in Bale monkeys **(*Chlorocebus djamdjamensis*)** at two sites in Ethiopia with diverse forest habitat and degrees of anthropogenic land use, and found that one population spent significantly more of their time in the matrix rather than in the forest, while the opposite pattern was the case with the second population. Accompanying these results, the authors note that humans living near the first population expressed more negative attitudes towards these monkeys compared with the perceptions of local people towards the Bale monkey group that spent more time in the fragment. The authors emphasize that long-term coexistence between humans and Bale monkeys can only be achieved if the importance of matrix habitats are recognized and incorporated into management plans. McLennan and colleagues also found that following a dramatic anthropogenic reduction in ~~fragment size~~ **the size of forest** fragments over seven years, a chimpanzee **(*Pan troglodytes*)** population in Bulindi, Uganda came to rely heavily on the matrix: particularly agricultural fruit crops. They note that while frugivory inside the

fragments decreased over time, corresponding to fragment degradation, reliance on cultivated fruit increased markedly, providing chimpanzees with certain nutritional benefits. **Like some other semi-terrestrial primates, chimpanzees can be highly mobile in fragmented landscapes. This, along with behavioral flexibility, enables some primates to exploit matrix habitats efficiently, thus aiding their persistence in fragments.** However, **the authors** caution that longer-term data are needed to determine whether **potential** benefits of consuming crop foods for these chimpanzees will be overshadowed by anthropogenic mortality risk.

Long-term data were, in fact, the basis for the paper by Donati and colleagues, and they emphasize the value of such longitudinal research on primate populations in fragments--an approach that can be helpful in understanding the survival strategies employed by animals restricted to fragmented forest patches. These authors present information from an 18-year study of ~~a group~~ **several groups** of translocated collared brown lemurs (*Eulemur collaris*), and they describe how these lemurs adapted their feeding behavior over time in the new fragment. **Donati et al. point out the ability of these lemurs to maintain a stable, frugivorous diet in the new area**, **and that the** ~~importance~~ **availability** of exotic **and** pioneer **plant species** ~~in the new habitat, and that the availability of exotic species~~ can be of great importance for population survival and persistence in degraded and fragmented habitats. **Since translocated primates must cope with unfamiliar areas, studying them offers the opportunity to understand the factors contributing to the successful recolonization of unoccupied fragments.**

Landscape approaches to assessing primate population viability and persistence in fragments

Kling and colleagues examined an appreciable sample of previously reported fragmentation studies in Madagascar to attempt to detect trends in responses by lemurs to fragmented

landscapes. While finding some commonalities in specific, comparable metrics, they determined that larger, landscape-scale analyses were rarely employed, thus making it difficult to see the 'bigger picture' in relation to forest fragmentation. However, both Eppley et al., and Steffens et al., in this issue, apply landscape-scale evaluations in order to assess population viability in fragmented habitats. Eppley and colleagues used Generalized Linear Models to examine how a number of habitat fragmentation characteristics and species' functional traits can affect the probability of population presence in 32 larger-bodied lemur species ~~over a large geographic range in Madagascar~~. While habitat area and protected status positively influenced lemur distribution, fragmentation negatively affected lemur populations of all dietary guilds. **Folivore-frugivores appear to show greater variability in response to variations in habitat size and landscape complexity compared to nearly exclusive folivores and frugivores.**

Steffens et al. also considered a landscape-scale approach, and examined how the scale of habitat loss affects three species of nocturnal lemurs in northwestern Madagascar: the fat-tailed dwarf lemur **(*Cheirogaleus medius*),** the grey mouse lemur (*Microcebus murinus*), and the golden-brown mouse lemur ***(M. ravelobensis).*** Incorporating logistic regression models of primate occurrence against habitat amount using 11 different landscape scales, the authors found that the dwarf lemur was more sensitive to habitat amount compared with the mouse lemurs, neither of which showed any response to the habitat loss on any of the scales used. They suggest that fat-tailed dwarf lemurs respond to habit loss via hibernation for part of the year, while the mouse lemurs' strategy for coping with such loss is mitigated by small habitat requirements, omnivorous diet, and a high reproductive rate.

Also focusing on nocturnal species, Andriatsitohaina and colleagues looked at variation in small bodied mammalian responses to fragmented habitat in northern Madagascar, examining

distribution and abundance of the golden-brown mouse-lemur (***M.*** *ravelobensis)* and the gray mouse lemur *(M. murinus)*, as well as the endemic western tuft-tailed rat (*Eliurus myoxinus)* and invasive black rat (*Rattus rattus*). The authors found that while *M. ravelobensis and E.* ***myoxinus*** were negatively affected by habitat fragmentation, *M. murinus* and *R. rattus* were not. The authors suggest that the response to fragmentation effects by small mammals should be examined at a species-specific levels to truly understand inter-specific variability and to avoid generalizations.

Finally, Mercado Malabet et al. examined the influence that ecological and anthropogenic factors have on the distribution patterns of crowned lemurs (*Eulemur coronatus)* in a spatially heterogeneous forest fragment. They found that lemur distribution was primarily explained by variation in forest quality and proximity to freshwater, but not by anthropogenic activities – perhaps because the human footprint was relatively ubiquitous throughout the fragment. Despite this finding, the authors caution that further study is needed to assess how human activities might influence lemur viability in the fragment in the long-term through impacts on the structure and quality of forest for crowned lemurs.

Conclusion

This collection of papers illustrates a diversity of responses by various primate species around the globe to the process of habitat fragmentation. While some common denominators ~~identified as important, such as~~ **(e.g.** the negative effect of fragment size and isolation), are in line with previous studies, it is clear that there is no homogenous response overall. Species-specific and site-related variation is often present and it is likely to be mediated by species functional traits and landscape-level variables. A multi-scale approach, in general, and a finer-scale landscape-level approach, in particular, emerge as crucial steps ~~in addition to population genetics' studies to~~

in interpreting **species-specific trends, and such approaches can assist with the development of** ~~**orientate**~~ **management strategies.**

Increased **use** of **both** multi-scale and longitudinal **approaches** will also help to shed light on the unclear distinction between what is really 'fragmented' and what is **considered** 'continuous' forest. ~~, that also depends on a variety of factors and not only the primate species, habitat and matrix.~~ Small fragments have long been considered less important for species conservation, while in fact they may not be that small for certain species and/or they may serve as essential points to maintain connectivity. Our special issue illustrates that medium-term persistence in small fragments is not only a reality for species traditionally considered resilient to fragmentation, ~~like~~ **such as** howler monkeys, but also for frugivorous and/or relatively large species, although only long-term monitoring can ~~unveil~~ **reveal** if overall population viability will be affected by a possible lack of dispersal opportunities and other phenomena predicted by the island biogeography theory.

It is also imperative to better understand ~~better~~ and more effectively manage ~~more effectively~~ the dynamic interactions between the primates and the non-native flora and fauna that surround them, **and how these are**, ~~that are~~ in turn, affected by complex anthropogenic landscape changes. Some of the papers in this special issue ~~we could see~~ **emphasize the importance of exotic and pioneer plant species for lemur survival** ~~or re-establishment in degraded/small fragments or~~ **as well as** the use of nutrient-rich crops by chimpanzees in a landscape vastly dominated by human activities. As native habitats are being destroyed but surrogate habitats are being created, or anthropogenically modified habitats are being protected effectively by local communities, the role of non-native species will become increasingly important to primate conservation. ~~It is essential to think outside of the box.~~

Our hope is that the papers included in this special issue will provide insight and ideas regarding how we can help assess and promote the success of primate population survival in forest fragments, and facilitate sustainable human–primate coexistence in fragmented landscapes.

Lisa Gould, Giuseppe Donati, and Matthew McLennan, guest editors.