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SHORT COMMUNICATION

How forest marsupials are affected by habitat degradation and fragmentation? A meta-analysis

Francisco E. Fontúrbel · Alina B. Candia · Daniela A. Salazar · Javiera Malebrán · Catalina González-Browne · Carezza Botto-Mahan

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Abstract Habitat fragmentation and degradation are important biodiversity change drivers worldwide. Their effects have been described for many animal groups, but little is known about marsupials. We conducted a meta-analysis aiming to evaluate the actual effects of habitat fragmentation and degradation on forest marsupials. From a literature survey, we obtained 85 case studies reporting disturbance comparisons. We found a negative overall effect, as well as a negative effect for habitat fragmentation, but not for habitat degradation. Marsupials from Oceania were negatively affected by habitat disturbance, whereas there was no effect for those from South America. Arboreal marsupials were negatively affected, whereas terrestrial marsupials did not. Species from the families Dasyuridae (*Antechinus* spp.) and Microbiotheriidae (*Dromiciops gliroides*) showed to be sensitive to habitat disturbance.

Keywords Arboreal marsupials · Australia · Conservation priority · South America

Introduction

Habitat fragmentation and degradation constitute major biodiversity change drivers worldwide (Chapin et al. 2000). Habitat fragmentation has been studied in detail during the last two decades (Didham et al. 2012; Ewers and Didham 2006; Lancaster et al. 2011), but the effects of habitat degradation are less evident since they are not directly related to the amount of habitat or its spatial configuration. Recently, small mammals have been subject of many studies on habitat fragmentation and—on a less degree—degradation, with a strong emphasis on rodents (Pardini 2004; Umetsu and Pardini 2007). Nevertheless, marsupials are a largely understudied group usually taken into account as part of the small mammalian community, but it is not frequent for studies on habitat disturbance to focus only on them. To our best knowledge, no study has formally addressed the effects of habitat fragmentation and degradation on forest marsupials. To fulfill this gap, we examined the effects of habitat disturbance on marsupials through a meta-analysis. We hypothesized that habitat fragmentation has a more negative effect than habitat degradation; furthermore, we expect that this will have a stronger effect on the arboreal marsupials than on the terrestrial ones, as previously described for rodents (Mortelliti et al. 2010).

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F. E. Fontúrbel (✉) · A. B. Candia · D. A. Salazar · J. Malebrán · C. González-Browne · C. Botto-Mahan
Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago, Chile
e-mail: fonturbel@gmail.com

Methods

Literature survey and data inclusion criteria

We searched the available literature using the ISI Web of Science database (January 1988–April 2014), using the following keywords: “marsupial* AND habitat fragm*”, “marsupial* AND habitat degrad*”, and “marsupial* AND habitat disturbance”. The survey yielded 129 articles. Then, we examined those articles looking for those studies that met four criteria as follows: (1) describing a type of habitat disturbance, namely habitat fragmentation (defined as those studies focused on habitat remnants where the observed effects could be mainly attributed to area, edge, or isolation effects) or habitat degradation (defined as those studies focused on habitats exposed to fire or clearing, where area, edge, or isolation effects were negligible). (2) Having at least two contrasting situations, a control (undisturbed) and a disturbed (fragmented or degraded) treatment. For habitat fragmentation studies, we considered as fragments those remnants <120 ha, and as continuous forest those stands >600 ha (Markl et al. 2012) or at least one order of magnitude larger than the largest fragment. (3) Reporting mean, sample size, and a dispersion measure (standard error or standard deviation). (4) Reporting the effect of habitat disturbance on marsupial abundance, species richness, body condition (including body mass or any standard body condition index), home range, parasite load, or road crossing probabilities. Exotic species were not considered.

After inspecting the literature, 22 articles fulfilled our inclusion criteria, from which we gathered 85 case studies that included data for 32 species. Since some articles presented more than one study case, we considered as independent cases those reporting different species or different locations (Aguilar et al. 2006; Morales and Traveset 2009). When more than one fragment size was evaluated at a study case, we contrasted the smallest fragment with the largest continuous stand; likewise, we compared those situations reporting the most and the least degraded habitats (Markl et al. 2012). When data was presented only in graphics, we used GraphClick 3.0 (Arizona Software, Switzerland) to extract mean and dispersion values.

Effect size calculation and moderators

To measure the effect size of each case study, we used the Hedges unbiased standardized mean difference (Hedges and Olkin 1985), which is calculated with the following equation:

$$d = \frac{X_E - X_C}{S_{EC}} J$$

where X_E is the mean value of the disturbed measure, X_C is the mean value of the control measure, S_{EC} is the pooled standard deviation of both treatments, and J is a term that corrects effect size for low sample sizes. This measurement has been largely used in ecological meta-analysis when the main goal is to estimate the magnitude of the effect of a particular treatment by comparing the results of the control and experimental group (Gurevitch et al. 2001). Negative values indicate that abundance, richness, or body condition became reduced at the disturbed habitats.

We first conducted a global analysis to describe overall habitat disturbance effects on marsupials. Then, we defined five moderator variables as follows: (1) disturbance type (habitat fragmentation or degradation), (2) habit (terrestrial or arboreal), (3) metric used (abundance, richness, body condition, parasite load, road crossing, or home range), (4) taxonomic distinctiveness (at family level), and (5) geographic region (South America or Oceania). We excluded those moderator levels with less than four cases because we consider them less informative. Aiming to examine the degree of heterogeneity among moderator levels, we calculated the between-group homogeneity Q_{between} statistics, which is a χ^2 distributed statistic that compares the variation between and within moderator levels (Markl et al. 2012).

Effect model and publication bias

Since we included studies measuring different response variables at a variety of species and geographic locations, we chose a random-effect model that was more appropriate to analyze our data (Borenstein et al. 2009). We also used mixed effect model for the analysis of the moderator variables (Gurevitch and Hedges 1999).

To quantify potential publication bias due to data correlation, we calculated the Kendall's tau correlation with continuity correction to determine whether effect and sample size were correlated. Since studies reporting null effects are unlikely to be published and hence omitted from literature surveys (potentially overestimating positive or negative effects), we estimated the Rosenthal's fail-safe number that indicates the number of unpublished case studies with null effects needed to reverse the actual effects calculated (Hillebrand 2008). This calculation indicates a robust result when fail-safe number is equal or greater than five times the sample size plus ten more articles (5 N+10; Rosenthal 1979). Aiming to account for potential asymmetries in the distribution of positive and negative effects, we conducted a "trim and fill" procedure to verify the robustness of our results by correcting bias and recalculating mean effect and confidence intervals (Jennions and Møller 2002). All analyses were conducted using Comprehensive Meta-Analysis software (Borenstein et al. 2005).

Results

We identified 85 case studies from 22 different articles, comparing disturbed and non-disturbed habitats (see Table S1 in Electronic supplementary material for detailed information). Overall, habitat disturbance had a negative effect on marsupials (Fig. 1a). Specifically, habitat fragmentation had a negative effect on marsupial, whereas degradation had no effect (Fig. 1b). Regarding marsupial habits, we found a negative effect for arboreal marsupial species, whereas terrestrial marsupials had no effect (Fig. 1c). Regarding the metrics examined, abundance and body condition had no effect, whereas parasite load and road crossing presented negative effects (Fig. 1d). Examining data by taxonomical distinctiveness (at family level), we found negative effects for Dasyuridae and

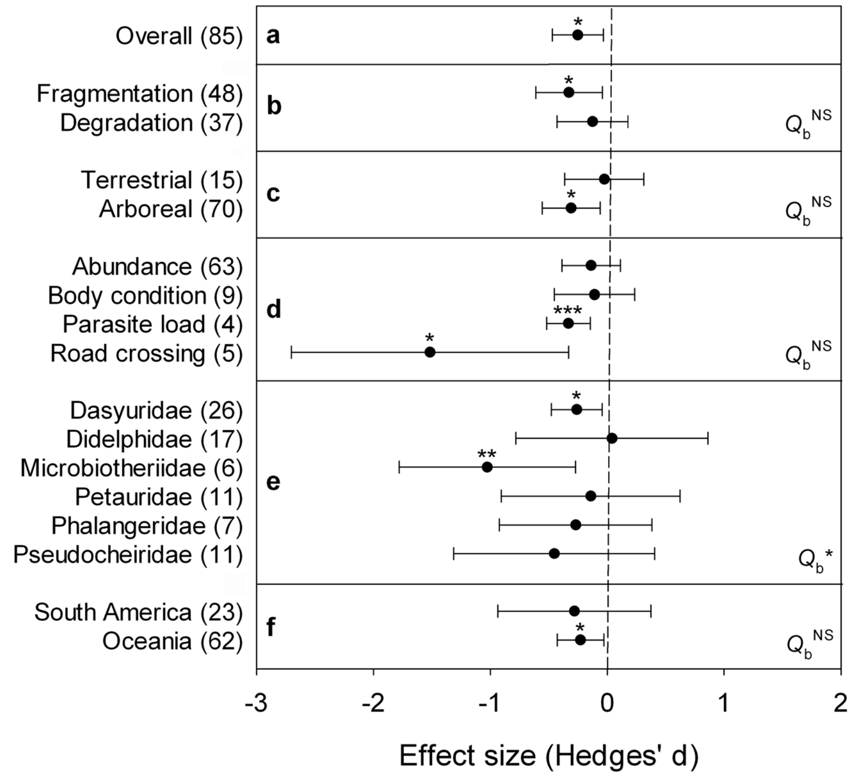

Fig. 1 Habitat disturbance effects on marsupials. Mean and 95 % confidence intervals are shown for **a** overall effects, **b** disturbance type, **c** habits, **d** metric used, **e** taxonomy (family level), and **f** geographic region. Number of case studies is presented in *parentheses*. *Asterisks* over confidence intervals indicate that they are significantly different from zero. Q_b represents the $Q_{between}$ statistics that tests between-group homogeneity. Significance levels $^{NS}P \geq 0.05$, $*P<0.05$, $**P<0.01$, $***P<0.001$

Microbiotheriidae families and no effect for the remaining families (Fig. 1e). Finally, South American marsupials were not affected, whereas those from Oceania were negatively affected (Fig. 1f).

We found no correlation on our data (Kendall's tau= −0.077, P=0.297), indicating that effect sizes are not depending on sample sizes. Regarding the fail-safe number, we would need to add 474 unpublished case studies with null effect to reverse our results, indicating that our results are robust since this figure is larger than the 5 N+10 threshold of 435 case studies. Further, our results did not change in significance after performing the "trim and fill' procedure, indicating that our results are robust.

Discussion

Habitat fragmentation had a negative effect on marsupials, but habitat degradation did not. Such apparent resilience to habitat degradation might be derived from a large variability in responses to forest clearing or fire, which may emerge from changes on competition interactions among marsupial species (Youngentob et al. 2012), and the reduction of natural cavities (Lindenmayer et al. 2009). The effects of habitat fragmentation could be confidently attributed to variations in area, edge, and isolation (Didham et al. 2012), but interpreting the effects of habitat degradation is a more challenging task. Many scenarios could emerge at degraded habitats, ranging from adverse situations (e.g., loss of nesting sites; Lindenmayer et al. 2009) to beneficial ones (e.g., antagonist reduction; Youngentob et al. 2012), which might explain at least in part the lack of effect detected on abundances and body condition.

We found a negative effect on arboreal marsupials, which may result obvious for forest marsupials, but this evidence is relevant for managing forest fragments and degraded stands, especially when species from Microbiotheriidae and Dasyuridae families are involved. Arboreal marsupials depend on three-dimensional habitat structures in some degree, experiencing a "fence effect" on remnant edges, especially when non-forested matrices preclude dispersal among fragments even at short distances (Lindenmayer et al. 1999; Fontúrbel et al. 2010).

Many studies that present data on marsupials also dealt with rodents, examining the small mammalian community as a whole. However, given that rodents are mostly terrestrial or scansorial, with a few arboreal species, they respond to habitat disturbance differentially (e.g., Pardini 2004; Umetsu and Pardini 2007), and the specific effects on marsupials might be confounded when they are analyzed together with rodent species. This is particularly critical for those arboreal species that, despite their apparent resilience (in terms of abundance) to habitat fragmentation, might be losing genetic variation due to limited landscape connectivity (Lancaster et al. 2011).

The finding that habitat fragmentation had a negative effect on marsupials, particularly concerning arboreal species, should be considered of conservation concern, and appropriate actions should be taken to guarantee their long-term persistence. Similar to what has been conducted for habitat fragmentation, we urge scientists to conduct more research on marsupials thriving on degraded habitats to develop a robust understanding of the ecological phenomena occurring under this type of habitat disturbance.

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