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Responses of tropical forest herpetofauna to moderate anthropogenic disturbance and effects of natural habitat variation in Sulawesi, Indonesia

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A B S T R A C T

Tropical forest destruction is a major contributor to global biodiversity loss, with much of remaining forests subject to extensive subsistence use. Compared to forest clear-felling and conversion, the impacts of these less intense but complex disturbance regimes on biodiversity remain poorly understood. Given the challenges of protecting pristine tropical forests for conservation in developing regions, there is a strong imperative to understand the role of altered forests with a range of low to moderate disturbance regimes in long term biodiversity conservation. We sampled tropical rainforest reptile and amphibian diversity over a nine year period along a gradient of moderate anthropogenic disturbance to intact primary rainforest in Sulawesi, Indonesia. We evaluated the relative influences of anthropogenic disturbance proxies and natural habitat variability on species richness and assemblage composition. Reptile and amphibian species richness were affected by natural variability in a range of habitat characteristics, but not by moderate anthropogenic disturbance. In contrast, species composition varied with both natural and anthropogenic disturbance metrics. Our results indicate that even low to moderate levels of anthropogenic disturbance have measurable, pervasive, impacts on tropical herpetofaunal diversity. However, moderately disturbed and altered forests that retain relatively high canopy cover and habitat complexity still retained most species associated with primary forest, indicating that they provide a significant contribution to herpetofaunal biodiversity conservation. Management implications from these findings complement those for birds and large mammals in tropical Asia, in that sustainable biodiversity conservation is likely to be best achieved by maintaining larger forest areas of variable disturbance and usage regimes around more remote, minimally disturbed core areas.

1. Introduction

Tropical forest destruction is a major contributor to global biodiversity loss (Sodhi et al., 2010). Southeast Asia is currently experiencing some of the world's highest rates of deforestation (Miettinen et al., 2011). Additionally, much remaining forest is affected by secondary disturbances and habitat alteration from harvesting of forest resources (McMorrow and Talip, 2001; Fitzherbert et al., 2008). Historically, equatorial tropical forests have been subjected to extensive subsistence use, including slash and burn agriculture, selective logging, firewood collection and rattan harvesting (Freeman, 1955; Fretes, 1992; Fox, 1995; Hoang et al. 2011), resulting in ecosystems experiencing multiple disturbance regimes. Whilst many of these disturbance processes are arguably less severe than clear-felling, their impacts on biodiversity remain poorly understood (Sodhi et al., 2010; Burivalova et al. 2014).

Some have argued that maximizing tropical biodiversity conservation depends mainly on retention of primary forest (Giam et al., 2011a; Giam et al., 2011b; Gibson et al., 2011). However, remaining tracts of primary tropical forest continue to be eroded and altered, including those within protected areas (Miettinen et al., 2011). Due to the limited extent and effectiveness of protected areas and the poor prospects for long-term conservation of remaining large tracts of primary forest (De Fries et al., 2005), degraded or altered forests need to be incorporated into conservation planning (Giam et al., 2011a;

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Giam et al., 2011b; Fisher et al. 2011). As biodiversity conservation in Southeast Asia becomes increasing dependent on management of habitats with varying levels of anthropogenic disturbance, a greater understanding is needed of the relationships between forest structure, disturbance processes, and the biota (Gillespie et al. 2005).

Until recently, the conservation value of disturbed or secondary tropical forests has been largely ignored (Giam et al., 2011a; Giam et al., 2011b). Management strategies that attempt to balance sustainable multiple-use forest management with biodiversity may lead to more sustained conservation outcomes in developing countries, where population pressures and resource demands on forests are large and resources to protect them are small (De Fries et al., 2005; Wright, 2010). Reptiles and amphibians are important components of the vertebrate diversity of tropical forests. Collectively they exhibit high species richness (e.g. Zug et al., 2001); may attain very high densities (Rodda et al., 2001; Zug et al., 2001); and play important roles in food webs (Heatwole and Taylor, 1987; Wells, 2007). Due to high diversity of life history strategies, trophic levels and microhabitat niches, the sensitivities of different taxa or guilds to varying disturbance regimes are expected to be complex (Gardner et al. 2007a).

Major alterations to forests, such as clear-felling and conversion to agro-forestry, have severe effects on tropical herpetofaunal diversity (e.g. Gillespie et al. 2005; Gardner et al. 2007b; Burivalova et al. 2014). Recent studies have begun to examine the conservation value of altered forests for herpetofaunal species with disturbance regimes less severe than clear-felling (e.g. Wanger et al., 2009, 2010; Hilje and Aide, 2011; Gillespie et al., 2012). However, entire communities have rarely been examined, and studies have typically focused on relatively major disturbance processes, such as agricultural conversion or commercial forestry (see Wanger et al. 2010; Burivalova et al. 2014).

To assess the conservation value of forests subjected to less intense anthropogenic disturbance we need to better understand how low to moderate anthropogenic disturbances affect different taxa and guilds, and how such disturbances might differ from natural disturbances and habitat heterogeneity. We explored these questions by examining patterns of herpetofauna diversity along a forest disturbance gradient in Sulawesi, Indonesia. We expected that structural habitat characteristics influencing herpetofaunal species richness and/or composition would correspond to the level of anthropogenic disturbance, proxies of which would be the distance to the nearest road and/or distance to the nearest village. We also expected the responses to such structural habitat differences to vary amongst guilds.

2. Methods

2.1. Study site

This study was undertaken within and adjacent to the Lambusango and Kakenauwe Forest Reserves (Fig. 1) on Buton Island, the largest (approx. 4400 km^2) offshore island, approximately 6 km from southeast Sulawesi, Indonesia. Kakenauwe and the production forest zone north of Lambusango are close to villages and are bisected by a narrow road. Contemporary and historic disturbances are evident near the road and villages, including selective logging, evidenced by the presence of cut stumps, felled tree trunks, and absence of large trees of commercial value; numerous well-used human trails through the forest; trapping snares (typically targeting Red Jungle Fowl, *Gallus gallus*, and Anoa, *Bubalus* sp.); firewood collection; and removal of rattan, a climbing palm used to make furniture (Fretes, 1992). Further south into the Lambusango reserve, signs of these disturbances diminish. No visible signs of selective logging are evident more than approximately 3 km south of the road; large trees of high commercial value are more prevalent; forest trails are few and less established, and snares are rarely encountered. However, rattan harvesting has occurred extensively well beyond this area, throughout all but the most remote parts of the island (B. Carlisle unpublished data) and local villagers have indicated that hunting occurs over a similarly wide area.

2.2. Sampling design

We established 75 sampling sites spread across a gradient of anthropogenic disturbance from primary rainforest through to moderately disturbed forest that, although never clear-felled or replaced with other land uses, had a long history of subsistence use. The study area was bisected by one vehicle road, with sampling sites spanning ~1 km north-west into the Kakenauwe Reserve, and 5 km south into the Lambusango Reserve (Fig. 1). With the exception of the road, sites were within continuous forest, thus avoiding potential confounding effects of edges and fragmentation (see Fischer et al. 2006). Throughout this anthropogenic-disturbance gradient, sites were selected by on-ground inspection; on ridges, mid-slopes with varying aspects, gullies and riparian terraces, ranging from 118 to 337 m above sea level. Site locations were recorded using a GPS (Garmin Map62s). Distance between sites varied but maintained a minimum of 200 m and undulating terrain ensured that no adjacent sites had similar landscape habitat attributes. Sampling was undertaken from June to September from 2001 to 2010, except 2003, coinciding with the transition from wet to dry season (Gillespie et al., 2005). Undertaking repeated sampling over multiple years minimized biases in site-based measures of community composition potentially resulting from annual fluxes in species populations or imperfect detection.

We used three methods to sample herpetofauna:

1. Pitfall traps consisted of five plastic buckets, embedded in the ground 4-5 m apart, connected with a plastic fence, 50 cm high and 30 m long, passing across each bucket, with the bottom edge embedded in the ground. Due to local availability, each site used three 60-l (57 cm deep) and two 70-l (65 cm deep) buckets. Traps were checked every morning. Traps were closed during periods of heavy rain. Between 25 and 48 sites were sampled each year. The combination of sites sampled each year varied in order to minimize temporal confounding sampling effects. Each site was sampled three to six of the nine sampling seasons, resulting overall in 14,094 trapsite day/nights, comprising of 70,470 individual trap nights.
2. Nocturnal censuses, 20-minutes duration, were undertaken by four authors (GG, SH, JS and AUH) using head torches within a 20 m radius of each pitfall trap. Searches were undertaken between 1830 and 2200 h. Nocturnal censuses were undertaken at least once during each year that each site was sampled except 2005, totalling 404 nocturnal censuses.
3. During 2001 and 2002, diurnal surveys of 60 minutes duration, were undertaken by GG and SH within a 20 m radius of each pitfall trap. Visual scans and active searches under rocks, logs, and within litter and debris were undertaken; however, this method was unproductive (see Gillespie et al. 2005). Subsequently visual scans were undertaken daily within 20 m of the pitfall site, on approaching and leaving during daily checking (GG, SH, JS and AUH).

2.3. Anthropogenic disturbance and habitat structure

We used distance from the road and distance to the nearest village from our sampling sites as proxies for human disturbance. Previous studies have demonstrated that anthropogenic disturbance levels in tropical forests are strongly related to distance from roads (Trombulak and Frissell, 1999; Laurance et al. 2009; Hoang et al. 2011) and distance from villages (Karanth et al. 2006; Bhat et al. 2011; Allnutt et al. 2013; Kodandapani et al. 2014). We also observed at our study sites that local people accessed the forest for harvesting of various forest resources via walking trails originating from the road or nearby villages. Hence greater levels of disturbance were expected at locations proximal to the road or nearby villages. The four villages in proximity to sample