Remote Forest Refugia for Fijian Wildlife

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Abstract: *On Pacific islands non-native rats and mongooses threaten many native species. In Fiji we compared visitation rates of rats and mongooses at bait stations and measured biomass of leaf-litter invertebrates to assess the relative predation pressure from these species in forest areas at different distances from the forest edge. Forest areas over 5 km from the forest edge had significantly fewer baits encountered by rats or mongooses than did natural forest areas nearer agricultural and urban habitats. Remote forest areas may function as a last refuge for island species threatened by predation from non-native rats and mongooses. The biomass of leaf-litter invertebrates in remote forest areas was higher, indicating a refuge effect for some taxa targeted by rats and mongooses. Protection of the few remaining large blocks of natural forests on Pacific islands may be the most cost-effective approach for conserving many island endemics threatened by rats and mongooses. Logging roads can compromise this refuge effect by acting as dispersal routes for rats into natural forests.*

Key Words: Fiji, invasive species, island conservation, mongoose, rats, *Rattus*, South Pacific

Refugios Forestales Remotos para Vida Silvestre de Fiji

Resumen: *Las ratas no nativas y mangostas amenazan a muchas especies nativas en islas del Pacífico. En Fiji, comparamos las tasas de visitación de ratas y mangostas en estaciones de carnada y medimos la biomasa de invertebrados de la hojarasca para evaluar la presión de depredación relativa de estas especies en áreas de bosque a diferentes distancias del borde del bosque. Las áreas de bosque a más de 5 km del borde del bosque tenían significativamente menos cebos hallados por ratas o mangostas que las áreas de bosque natural cercanas a hábitats agrícolas y urbanos. Las áreas forestales remotas pueden fungir como el último refugio para especies insulares amenazadas por la depredación de ratas no nativas y mangostas. La biomasa de los invertebrados de la hojarasca en las áreas remotas fue mayor, lo que indica un efecto de refugio para algunos taxa depredados por ratas y mangostas. La protección de los escasos bloques extensos de bosque natural en islas del Pacífico puede ser una estrategia rentable para la conservación de muchas endémicas insulares amenazadas por ratas y mangostas. Los caminos madereros pueden comprometer este efecto de refugio al actuar como rutas de dispersión de ratas hacia los bosques naturales.*

Palabras Clave: Conservación de islas, especies invasoras, Fiji, mangosta, Pacífico Sur, ratas, *Rattus*

Introduction

The voracious appetite of invasive rats has driven the decline and extinction of many Pacific island species (Atkinson 1985; Hadfield et al. 1993; Anderson 1997). Rats arrived on oceanic islands in the Pacific several centuries ago and occur in most habitats (Strecker & Jackson 1962; Sugihara 1997; Lindsey et al. 1999; Masibalavu & Dutson 2005). Conservation strategies for species that are sensitive to rat predation have focused primarily on securing populations on rat-free islets or in managed habitats with intensive rat control programs (Towns & Broome 2003; VanderWerf et al. 2003). However, islets typically have depauperate biotas relative to larger island forests and may

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lack populations of endangered species, and long-term control programs are often prohibitively expensive. For these reasons, protection of certain habitats with naturally low rat activity on larger islands may be a key strategy for the conservation of a wide range of threatened island species. We examined whether the remoteness of a site (i.e., distance from the forest edge) in Fijian rainforests on the island of Viti Levu is associated with lower rates of predation on baits and invertebrates—similar to the phenomenon documented for migratory songbirds in temperate forests of eastern North America (Robinson et al. 1995). Remote forests may act as population sources rather than sinks for threatened island species worldwide.

The Pink-billed Parrotfinch (*Erythrura kleinschmidti*), Banded Iguana (*Brachylophus fasciatus*), larger Fijian landsnails (e.g., *Placostylus* spp., *Aspastus* spp.), and Fijian *Platymantis* frogs (2 spp.) are among those vulnerable species that may have reduced probabilities of encounter and predation by rats (introduced *Rattus exulans*, *R. rattus*, *R. norvegicus*) and other invasive species, such as the Indian mongoose (*Herpestes auropunctatus*, also present on Viti Levu), in remote forests. Measuring reproduction and survivorship of rat-sensitive species in Fijian forests is challenging, so we compared the visitation rates of rats and mongooses to stations baited with roasted coconut as a proxy for predation pressure from these species. We also measured the biomass of leaf-litter invertebrates in remote and edge forest areas because invertebrates are an important food resource for rats and mongoose and offer a tractable component of the native biota with which to directly measure the impact of alien predators (Russell 1980; Sugihara 1997; Cowie & Robinson 2003).

Methods

Delineation of Natural Forest Blocks

Larger blocks of remaining natural forest on Viti Levu were delineated using Landsat thematic mapper imagery (1991–1995) classified for forest types and overlaid with maps of roads, documented logging concessions from the past decade (spatial data on many recent logging operations were not available), and mahogany and pine plantations (Fiji Department of Forestry 1996). For some areas, we made observations in the field to refine the estimated forest-edge boundaries. In general, we did not consider forest areas with more than 20% non-native habitat part of larger natural forest blocks. On the ground, the forest edge estimated from the mapping analysis varied from a sharp edge between agriculture and natural forest to a narrow mosaic band of agriculture, secondary habitats, and natural forest.

Measuring Bait Encounter Rates

Sixty-four bait stations were set at distances roughly 0.2, 1, 2, 3, 4, 5, 6, and 7 km from the forest edge (46 lowland sites <700 m in elevation and 18 montane sites >700 m in elevation, 14 transects) (Fig. 1; bait station locations and the number of baits encountered at stations are available

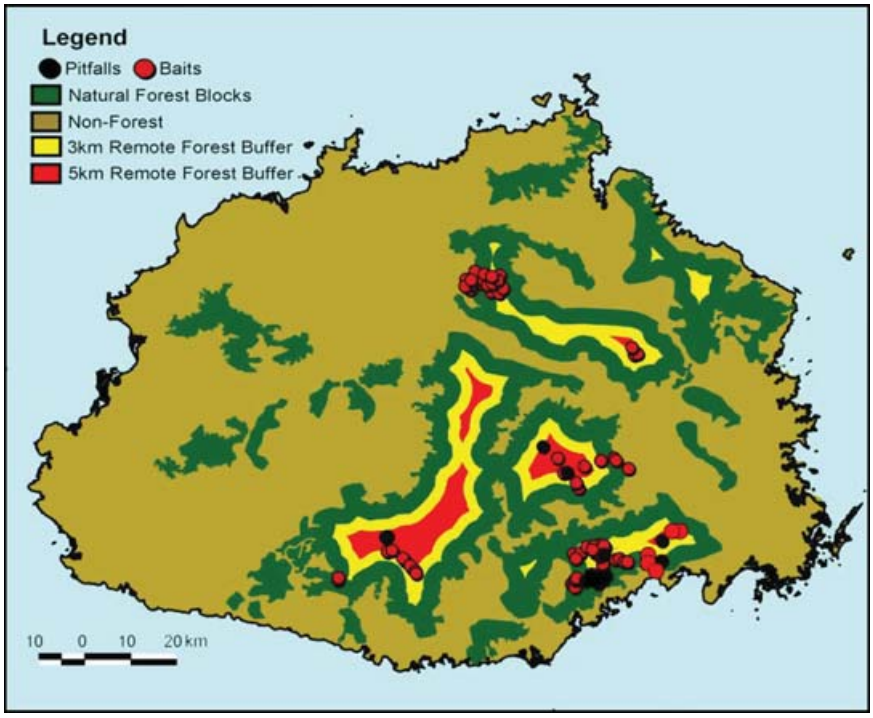

Figure 1. Remote forest areas on Viti Levu, Fiji, approximated in red (>5 km from the forest edge). Red dots represent bait station sites, and black dots represent pitfall trap sites.

from http://wcs.org/conbio_olson). At each bait station, 200 baits (triangles of roasted coconut, each about 3 cm on a side and with no husk, mounted 4 cm off the ground on flagged wires) were placed on the ground in a 20×10 grid, with 5 m between adjacent baits, and exposed for 24 hours. Baits that were chewed or missing were assumed to have been found by rats or mongoose. Rodent chew marks are easily distinguished from the granular dust associated with ant damage. We previously observed that bait stations placed on windy ridges and steep slopes and those set out during rainy evenings generally had low encounter rates, so we avoided these conditions, if possible.

We also placed paired bait stations near logging roads ($n = 5$ paired trials) and rivers (larger water courses too wide for a forest canopy, $n = 4$ paired trials), with one station 20 m from the road or river and the other 1 km from the road or river. All paired sites were >1 km into the forest from the edge.

In a third trial we measured encounter rates over 30 days (wax baits scented with coconut oil at 1–2.5 km and 5 km from the forest edge) on the ground ($n = 5$ at 1 and 5 km each from the edge) and in the trees ($n = 3$ at 5 km from the edge, 2–3 m in height on trees). We used the same grid configuration in all trials.

Comparing Leaf-Litter Invertebrate Biomass

We used pitfall traps to compare leaf-litter invertebrate biomass 1 km ($n = 10$) and 5 km ($n = 8$) from the forest edge (Fig. 1; location of pitfall traps and leaf-litter invertebrate biomass are available from http://wcs.org/conbio_olson). Linear transects of 200 pitfall traps, placed 3 m apart (600 m total length), were set out for 42 hours. We used soapy water in the cups to break the surface tension and placed fresh leaf covers 8 cm above the cup on each marker flag to deflect rain. The collected invertebrates were preserved in ethanol and weighed wet after lying for 20 minutes on filter paper.

Results

Bait Encounter Rates

Bait encounter rates were high near forest edges, with some variation among sites (in areas =1 km from forest edges 10–50% of baits were discovered after 24 hours), but rates along all transects declined with distance from the forest edge until no baits were taken beyond 5 km (hereafter referred to as remote forest areas) (data available from http://wcs.org/conbio_olson). Distance from forest edge accounted for most of the variation in bait encounter rates (analysis of variance, $r^2 = 0.653, p < 0.05$). Bait-station elevation, month, and transect had no significant influence on the variation in encounter rates. No baits (coconut oil–wax) were eaten in remote forest areas (4.5–5.5 km sites) even after 1 month on either the ground or in trees, whereas all 200 baits on the ground were encountered after 7–14 days at the 1–2 km sites. Stations 20 m from logging roads that penetrated into natural forest had significantly higher bait encounter rates than paired stations 1 km away from the road in natural forest ($W = 0, p < 0.1$, Wilcoxon matched-pairs test). Riversides also had more activity than paired sites 1 km from the river, but they had less activity than logging roads (encounter rates available from http://wcs.org/conbio_olson).

Leaf-Litter Invertebrate Biomass

Leaf-litter invertebrates sampled with pitfall traps showed significantly higher biomass in remote forest areas (5 km from the forest edge) than in forest edges (1 km from the edge) ($U = 4, p < 0.05$, Mann-Whitney U test) (data available from http://wcs.org/conbio_olson). Larger invertebrates, particularly crickets, spiders, roaches, and snails, were observed only in the remote forest area samples.

Discussion

The ecological factors associated with low rat activity in remote forest areas are unknown. Natural forests may provide poorer habitats for rat survival and reproduction than agricultural areas and secondary forests. Forest habitats near edges may have higher rat densities because of a continual influx of dispersers from nonforest habitats. The relative abundance and habits of different rat species may vary between forest edges and remote forest areas. Whatever the reasons, the implications for threatened native species is that, on average, populations in remote forest areas have better chances of successful reproduction, avoiding predation, and maintaining their natural ecological roles than do forest-edge populations. The degree to which different native species may benefit from remote forest refugia will vary according to their life histories and susceptibility to invasive predators.

Although our results suggest that rat and mongoose activity is lower in remote forest areas, even low levels of rat and mongoose predation may be sufficient over time to cause the decline of native species (Atkinson 1977; Sugihara 1997). The increased biomass and presence of larger invertebrates on the forest floor of remote forest areas, and their general absence in forest edges, suggests that some prey taxa do benefit from living in remote forest areas.

In Fiji only the islands of Viti Levu and Taveuni have sizable remote forest areas remaining (Fig. 1; remote forest areas approximated for Vanua Levu and Taveuni, Fiji, available from http://wcs.org/conbio_olson). The Ravilevu Forest of Taveuni is particularly important because it is the only remote forest area in Fiji without mongooses (Morley 2004). Samoa has a single montane remote forest area

on Savai'i (remote forest areas approximated for Samoa available from http://wcs.org/conbio_olson). Hawaii has two sizable remote forest areas, Hakalau on the island of Hawaii and Waialeale on Kauai (remote forest areas approximated for Hawai'i, Maui, and Moloka'i available from http://wcs.org/conbio_olson). Forests with remote qualities will continue to disappear in Fiji and other Pacific islands as logging roads penetrate remaining blocks of natural forest and forests are cleared and fragmented from logging, agricultural expansion, and other development.

Remote forest areas that function as refugia for threatened island species are increasingly rare and should be of the highest priority for conservation on the larger islands of the Pacific, including those of Fiji, Vanuatu, New Caledonia, the Solomon Islands, Samoa, and Hawaii, and tropical islands of the Caribbean and the Indian Ocean. Protection of larger, remote blocks of forest and their critical buffer forests (i.e., the forest areas 1–4.5 km from the forest edge) may be one of the most cost-effective strategies for achieving conservation goals set forth in the National Biodiversity Strategies (e.g., Fiji Department of Environment 2001) and other resource management plans. Island nations should also consider the ecosystem services provided by the large blocks of natural forest as they pursue forestry and development strategies. Remote forest areas, in particular, should be considered for protection, and their forest buffers given roadless-area status in forestry certification programs currently being developed in the Pacific region. Data from Fiji support the view that rats find logging roads favorable for dispersal and foraging (Forman & Alexander 1998; Delgado et al. 2001; Heske et al. 2001). Consequently, networks of logging roads built into larger forest blocks may quickly diminish their effectiveness as refugia.

Efforts to design conservation areas that incorporate remote forest refugia must take into account the openness of natural habitats and the location of natural forest buffers, roads, and larger rivers. Elevated bait-encounter rates along logging roads, rivers, and forest edges suggest that open canopy habitats may be favored by rats. Fiji's rainforests are particularly dense, and natural broken-canopy forests are rare (Mueller-Dombois & Fosberg 1998). Natural forests in the Pacific with more open canopies, such as some higher elevation *Acacia koa/Metrosideros polymorpha* forests in Hawai'i and New Caledonia *Araucaria* forests, may not be as resistant to rat invasion as Fijian remote forest areas.

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