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<th>Fragmentation from hydropower: shifts in rainforest mammal communities from fragments to edges to interior forest</th>
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<tr>
<td><strong>Author(s)</strong></td>
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Fragmentation by Hydropower: Impacts of Forest Edges and Isolation on Rainforest Mammals

Luke Gibson  |  University of Hong Kong  |  lgibson@hku.hk
Tropical forests: a changing landscape

Singapore

Fires in Indonesia, October 2015
.globalforestwatch.org
Tropical forests: a changing landscape

- 83% of new croplands in tropics established on cleared forest

Rodrigo Baleia Gibbs et al. PNAS 2010
Tropical forests: a changing landscape

• 20% of humid tropics undergoing logging

Rodrigo Baleia

Tropical forests: a changing landscape

>80% of Atlantic Forest < 50 hectares

Rodrigo Baleia

Outline

Fate of biodiversity in forest fragments

Response of mammals to forest edges
Outline

Fate of biodiversity in forest fragments

Response of mammals to forest edges
Smaller habitats, fewer species

An equilibrium theory of insular zoogeography

Robert R. MacArthur and Edward O. Wilson

Received March 1, 1963

The fauna-area curve

As the area of sampling $A$ increases in an ecologically uniform area, the number of plant and animal species $s$ increases in an approximately logarithmic manner, or

$$s = a \ln A + b,$$

where $A < 1$, as shown most recently in the detailed analysis of Preston (1962). The same relationship holds for islands, where, as one of us has noted (Wilson, 1961), the parameters $a$ and $b$ vary among taxa. Thus, in the ponerine ants of Mela-
nesia and the Moluccas, $a$ (which might be called the "area coefficient") is approximately 0.5 where area is measured in square miles; in the Carabidaceae and her-
petofauna of the Greater Antilles and asso-
ciated islands, 0.3; in the land and fresh-
water birds of Indonesia, 0.4; and in the islands of the Sahul Shelf (New Guinea and environs), 0.5.

The distance effect in Pacific birds

The relation of number of land and freshwater bird species to area is very roughly in the closely grouped Sunda Is-
lands (fig. 1), but somewhat less so in the islands of Melanesia, Micronesia, and Polynesia taken together (fig. 2). The greater variance of the latter group is attributable primarily to one variable, a distance between the islands. In particular, the distance effect can be illustrated by taking the distance from the primary faunal "source area" of Melanesia and relating it to faunal number in the following manner. From fig. 2, take the line connecting New Guinea and the nearby Kei Islands as a "saturation curve" (other lines would be adequate but less suitable to the purpose), calculate the predicted range of "saturation" values among "sat-
urated" islands of varying area from the curve, then take calculated "percentage saturation" as $s/S_0$, where $S_0$ is the real number of species on any island and $S_0$ the saturation number for islands of that area. As shown in fig. 3, the percentage saturation is nicely correlated in an inverse manner with distance from New Guinea. This allows quantification of the rule expressed qualitatively by past au-
thors (see Mayr, 1940) that island faunas have become progressively "impo
erished" with distance from the nearest land mass.
Forest fragmentation and extinction debt

Biogeographic Kinetics: Estimation of Relaxation Times for Avifaunas of Southwest Pacific Islands

(immigration/extinction/birds/tropical rainforest/conservation)

JARED M. DIAMOND
Physiology Department, UCLA Medical Center, Los Angeles, California 90024
Communicated by Robert MacArthur, June 28, 1972

ABSTRACT When species diversity $S$ on an island is displaced from the equilibrium value by injection or removal of species, $S$ relaxes to equilibrium by an imbalance between immigration and extinction rates. Estimates of exponential relaxation times, $t$, for avifaunas of New Guinea satellite islands are calculated from analysis of four “experiments of nature”: recolonization of exploded volcanoes, contraction in island area due to rising sea level, severing of land bridges, and disappearance of landbridge relict species. $t$, in the range 3,000–18,000 years for avifaunas of islands of 50–3000 square miles (130–7800 km$^2$), and increases with island area. Immigration coefficients decrease and extinction coefficients increase with increasing $S$. The results may be relevant to the design of rainforest preserves.

simplification, but that never happens.

The measured relaxation is the result of two relaxation processes, whose respective rates ($K, K_s$) depend on the instantaneous state of the system. Let us assume $K_s$ (expressed in year$^{-1}$) of the island area $A$ and $K_s$ (expressed in year$^{-1}$) of the species diversity $S$. We define $E = K_s S(t)$ to be the extinction rate at time $t$, and $I = K I(t)$ to be the immigration rate at time $t$.

$$dS/dt = I - E = (K_t + K_s) S$$

Habitat destruction and the extinction debt

David Tilman*, Robert M. May†, Clarence L. Lehman* & Martin A. Nowak†

*Department of Ecology, Evolution and Behavior.
1987 Upper Buford Circle, University of Minnesota, St Paul, Minnesota 55108, USA
†Department of Zoology, Oxford University, South Parks Road, Oxford OX1 3PS, UK

Habitat destruction is the major cause of species extinctions. Dominant species often are considered to be free of this threat because they are abundant in the undisturbed fragments that remain after destruction. Here we describe a model that explains multispecies coexistence in patchy habitats and which predicts that their abundance may be fleeting. Even moderate habitat destruction is predicted to cause time-delayed but deterministic extinction of the dominant competitor in remnant patches. Further species are predicted to become extinct in order from the best to the poorest competitors, as habitat destruction increases. Moreover, the more fragmented a habitat already is, the greater is the number of extinctions caused by added destruction. Because such extinctions occur generations after fragmentation, they represent a debt—a future ecological cost of current habitat destruction.

1Diamond PNAS 1972
2Tilman et al. Nature 1994

Concepts decades old, but little research completed!
Extinction debt: How rapidly paid?

Lynam & Billick Biol. Cons. 1999
Gibson et al. Science 2013
Chiew Larn Reservoir
Chiew Larn Reservoir

- 165 km²
- Surrounded by protected areas covering >3500 km²
Chiew Larn Reservoir: Sampling sites

• 100+ islands
• Isolated in 1986-87
• Useful “dammed experiments”\(^1\) to study “ecological meltdown”\(^2\) in forest fragments

\(^1\)Diamond Science 2001
\(^2\)Terborgh et al. Science 2001
Sampling sites

16 islands, <1-56 ha
Trapping methods

1992-1994
(5-7 years isolation)

2012-2013
(25-26 years isolation)
**Trapping methods**

- 1-8 trapping transects per island
- Traps placed on ground and on lianas 1-2 meters above ground
- Baited with bananas and coconuts
- Monitored for 7 days
Trapped animals
Results: richness by transect

- Large islands ($n = 7$)
- Small islands ($n = 9$)
The survivor: *Rattus tiomanicus*

- Widespread generalist species with rapid generation time\(^1\)

- Dominates many other island systems\(^2\)

\(^1\)Tollenaere *et al.* 2010  
\(^2\)Amarasekare 1994
Measuring extinction rates

- Predicts rapid extinctions: $t_{1/2} = 13.9 \pm 3.9$ yr
- Similar rates observed in Amazonian birds

Ferraz et al. PNAS 2003
Extinction: faster on larger islands

- All islands were below some area threshold and collapsed to 1 species
How representative are these fragments?

Chiew Larn Reservoir

Brazilian Amazon
Friendly criticism

• “...theories from simple island ecosystems are still used in ways that incorrectly estimate rates of species extinction$^{21}$ and distort projections of ecological risk in human-dominated landscapes$^{2,22}$, further exhausting an environmental, apocalyptic narrative$^{23}$.”

Mendenhall et al. Nature 2014
...increasingly common in today’s world

- Tropical forests increasingly persist in small fragments
- Surrounded by inhospitable human-dominated landscapes
Similar conditions in the Atlantic Forest

- >80% of fragments <50 ha\textsuperscript{1}
- Retain on average 3.9 of 18 medium and large mammal species\textsuperscript{2}

\textsuperscript{1}Ribeiro \textit{et al.} Biol. Cons. 2009
\textsuperscript{2}Canale \textit{et al.} PLoS ONE 2012
Lessons from the islands

• Retain large forest expanses (>>100 ha!)
Can we write off fragmented forests?

- Small fragments are all that’s left in many regions
- Still hold value
- Restoration efforts must be immediate (<25 yr)

Turner & Corlett TREE 1996
Outline

Fate of biodiversity in forest fragments

Response of mammals to forest edges
Fragmentation and forest edges
Camera trapping

• 5 transects along ridges or animal trails
• 1 camera / km
• 0-6 km from forest edge
Survey statistics

- Four camera trapping surveys in 2013, 2014
- >10,000 camera trap days
- >140,000 photos
- 37 mammal species detected
Methods

Communities
• Mixed effects models: richness ~ site + survey (random effects) + distance to forest edge + distance to dam (fixed effects)
• Models with lowest AICc presented

Species
• Occupancy modeled using ML estimates
• Probability estimated across distance to forest edge
Richness: forest edges vs. interior

• Carnivores (16): 0.05 (0.04) more spp/km from edge

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• Ungulates (8): 0.05 (0.03) more spp/km from edge

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• All (31): 0.05 (0.02) more spp/km from edge

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Richness: forest edges vs. interior

• IUCN (13): 0.04 (0.04) more spp/km from edge

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• Non IUCN (18): 0.08 (0.03) more spp/km from edge

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Occupancy: sun bears

Probability of occupancy increases:

![Graph showing probability of occupancy increase with distance from edge in dry and wet seasons.](image)
Occupancy: clouded leopard

Probability of occupancy increases:

- 0.21 (1.44) per km
- 0.16 (1.10) per km

in dry season in wet season
Occupancy: golden cat

Probability of occupancy increases:

\[
\begin{align*}
\text{Probability of occupancy} & \approx 2.44 (6.98) \text{ per km} - 0.58 (0.98) \text{ per km} \\
\text{in dry season in wet season}
\end{align*}
\]
Occupancy: serow

Probability of occupancy increases:

- 0.71 (0.66) per km
- 0.21 (0.72) per km

in dry season in wet season
Occupancy: tapir

Probability of occupancy increases:

- 0.50 (0.82) per km
- 0.06 (0.74) per km

in dry season in wet season
Occupancy: gaur

Probability of occupancy increases:

- 0.23 (0.74) per km
- 1.20 (1.55) per km

in dry season

in wet season
Attraction to forest edges

- Higher diversity in forest interior
- But, higher occupancy at forest edges during wet season
Conclusion
Tropical forests: a changing landscape

Deforestation increasing by >2000 km² per year

Hansen et al. Science 2013
Fragmentation: worse than we thought

- Regional and nation-level extinction projections are underestimated

Hanski *et al.* PNAS 2013
Sodhi *et al.* TREE 2004
Fragmentation: worse than we thought

• Extinction debt can be collected rapidly, with entire native guilds lost

Gibson et al. Science 2013
Acknowledgments