Fragmentation by Hydropower: Impacts of Forest Edges and Isolation on Rainforest Mammals

Luke Gibson | University of Hong Kong | lgibson@hku.hk

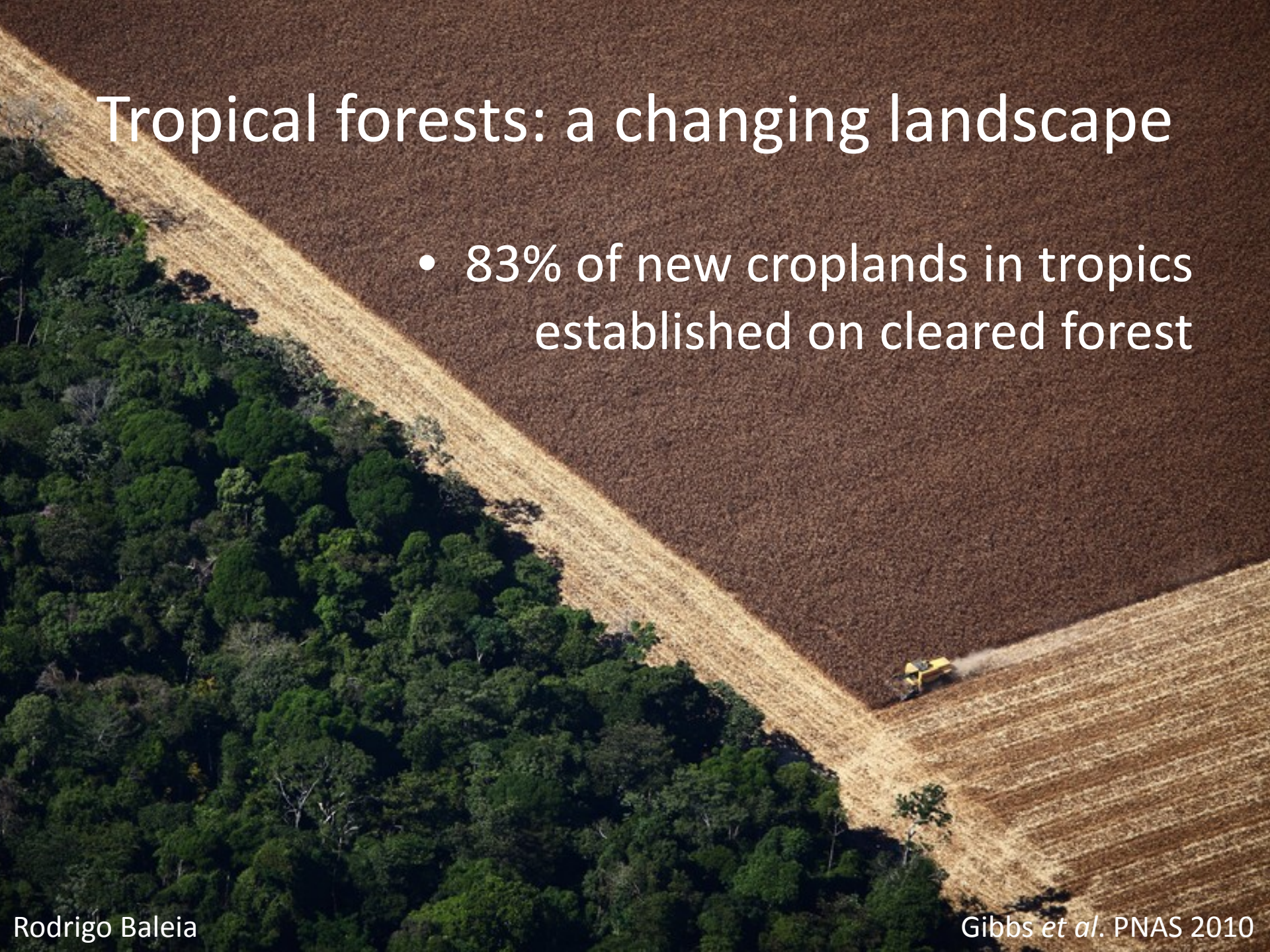
Tropical forests: a changing landscape

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

Asner *et al*. Cons. Biol. 2009

Tropical forests: a changing landscape

>80% of Atlantic Forest

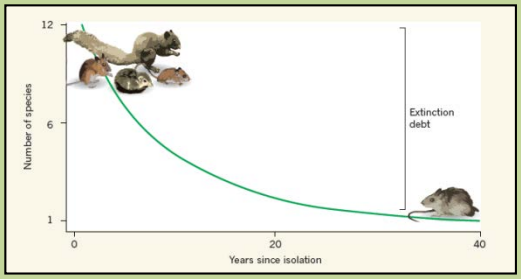
<50 hectares

Rodrigo Baleia

Ribeiro *et al.* Biol. Cons.

Outline

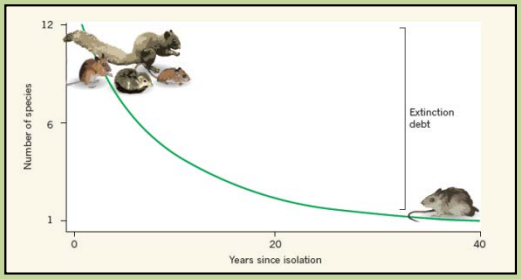
Fate of biodiversity in forest fragments



Response of mammals to forest edges

Outline

Fate of biodiversity in forest fragments



Response of mammals to forest edges

Smaller habitats, fewer species

Vol. 17 DECEMBER, 1963 No. 4

AN EQUILIBRIUM THEORY OF INSULAR ZOOGEOGRAPHY

ROBERT H. MACARTHUR[1] AND EDWARD O. WILSON[2]

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

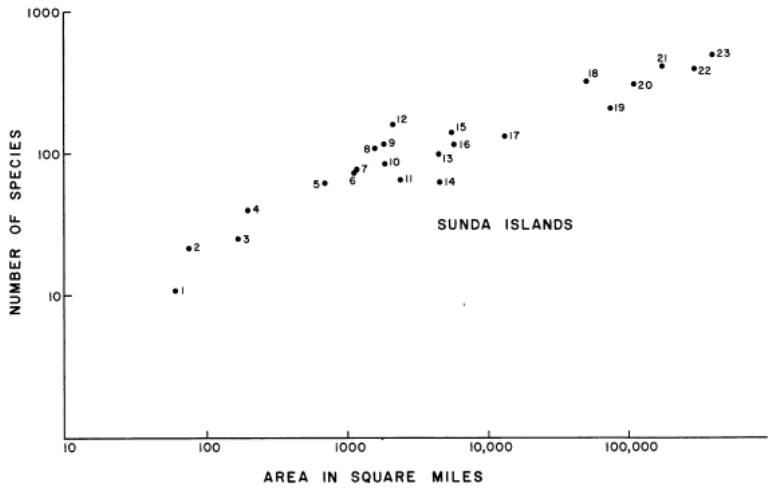
$$s = bA^k, \qquad (1)$$

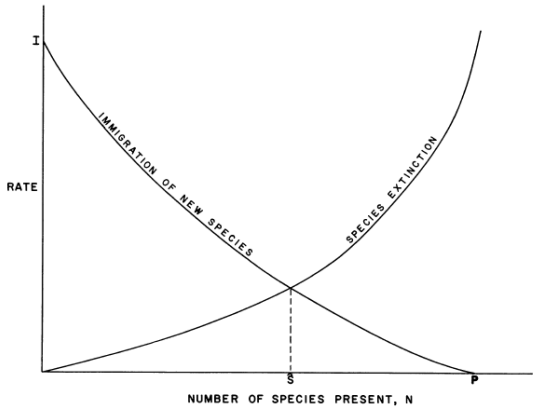
where $k < 1$, as shown most recently in in the detailed analysis of Preston (1962). The same relationship holds for islands, where, as one of us has noted (Wilson, 1961), the parameters b and k vary among taxa. Thus, in the ponerine ants of Melanesia and the Moluccas, k (which might be called the *faunal coefficient*) is approximately 0.5 where area is measured in square miles; in the Carabidae and herpetofauna of the Greater Antilles and associated islands, 0.3; in the land and freshwater 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 orderly in the closely grouped Sunda Islands (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, 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 "saturated" islands of varying area from the curve, then take calculated "percentage saturation" as $s_i \times 100/B_i$, where s_i is the real number of species on any island and B_i 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 authors (see Mayr, 1940) that island faunas become progressively "impoverished" with distance from the nearest land mass.

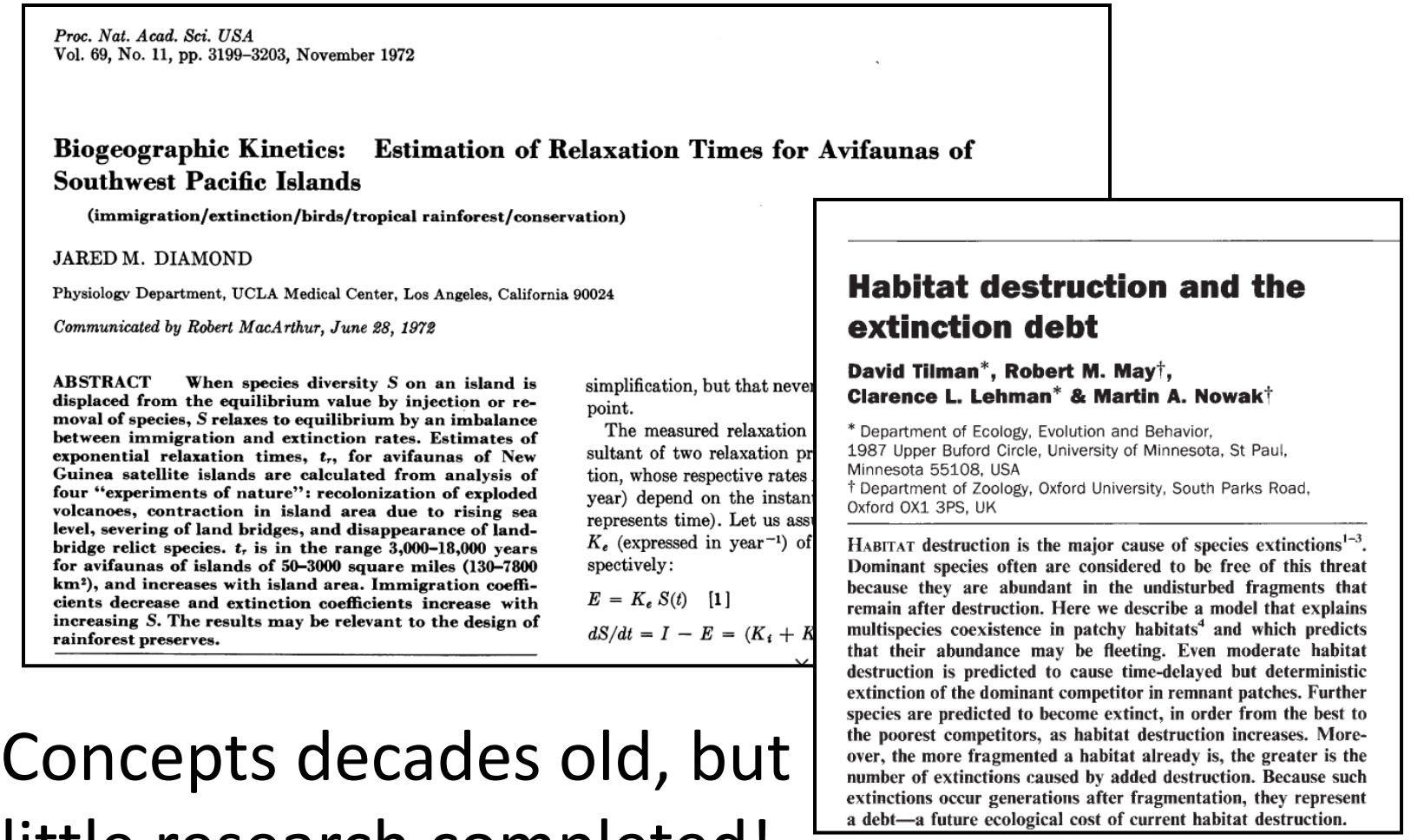
[1] Division of Biology, University of Pennsylvania, Philadelphia, Pennsylvania.
[2] Biological Laboratories, Harvard University, Cambridge, Massachusetts.





MacArthur & Wilson Evolution 1963

Forest fragmentation and extinction debt



Proc. Nat. Acad. Sci. USA
Vol. 69, No. 11, pp. 3199–3203, November 1972

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_r, 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 land-bridge relict species. t_r is in the range 3,000–18,000 years for avifaunas of islands of 50–3000 square miles (130–7800 km²), 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
point.

The measured relaxation
sultant of two relaxation pr
tion, whose respective rates
year) depend on the instan
represents time). Let us ass
K_e (expressed in year^{-1}) of
spectively:

$$E = K_e S(t) \quad [1]$$

$$dS/dt = I - E = (K_i + K$$

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[1–3]. 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[4] 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.

Concepts decades old, but little research completed!

[1]Diamond PNAS 1972
[2]Tilman *et al*. Nature 1994

Extinction debt: How rapidly paid?

Lynam & Billick Biol. Cons. 1999
Gibson *et al*. Science 2013


Chiew Larn Reservoir

Chiew Larn Reservoir

- 165 km^2
- Surrounded by protected areas covering >3500 km^2

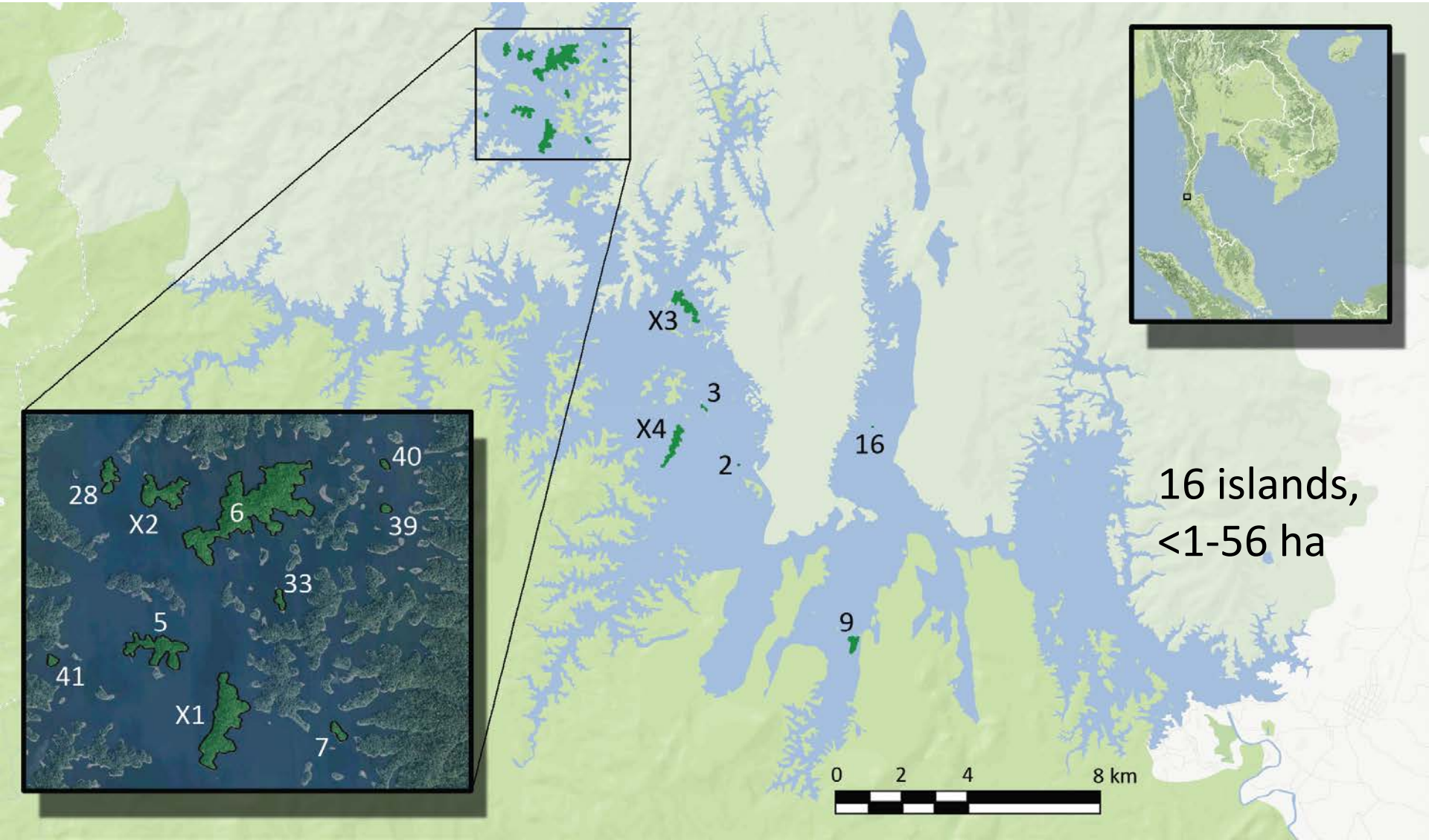
Chiew Larn Reservoir: Sampling sites

- 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



Trapping methods

1992-1994

(5-7 years isolation)

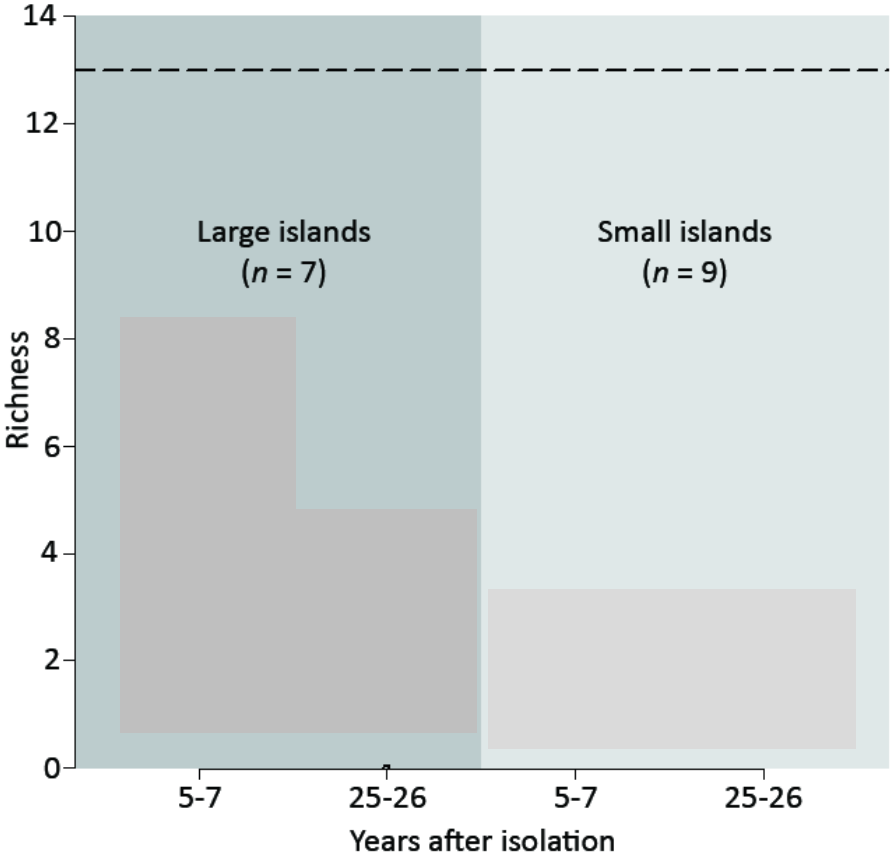
2012-2013

(25-26 years isolation)

Trapping methods

Trapped animals

Results: richness by transect



The surviver: *Rattus tiomanicus*

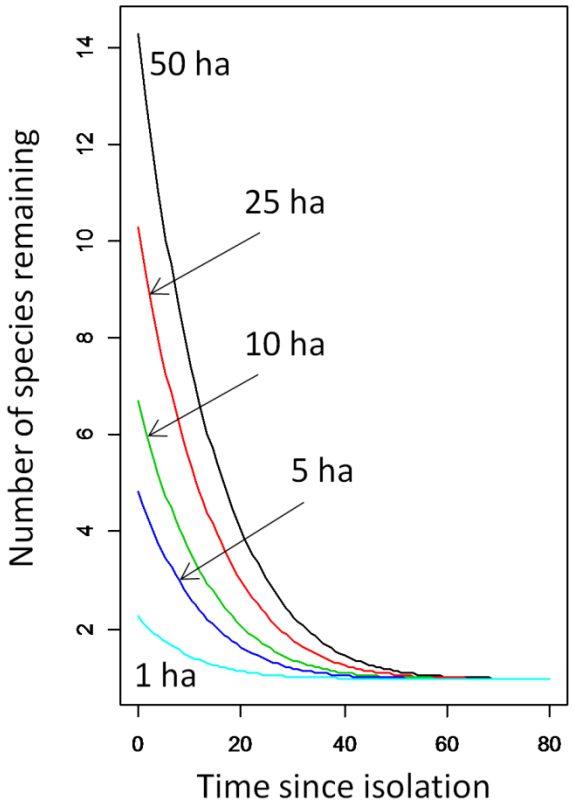
- Widespread generalist species with rapid generation time[1]

- Dominates many other island systems[2]

[1]Tollenaere *et al.* 2010

[2]Amarasekare 1994

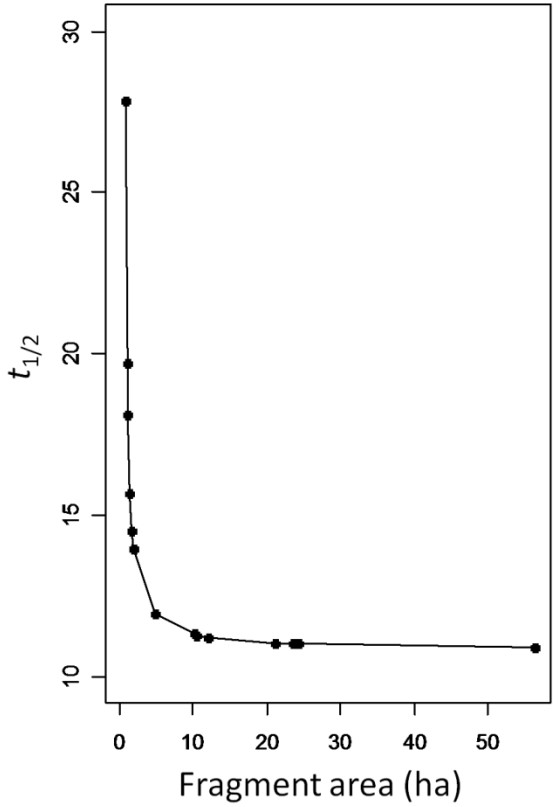
Measuring extinction rates



- Predicts rapid extinctions: $t_{1/2}$ = 13.9 ± 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]."*

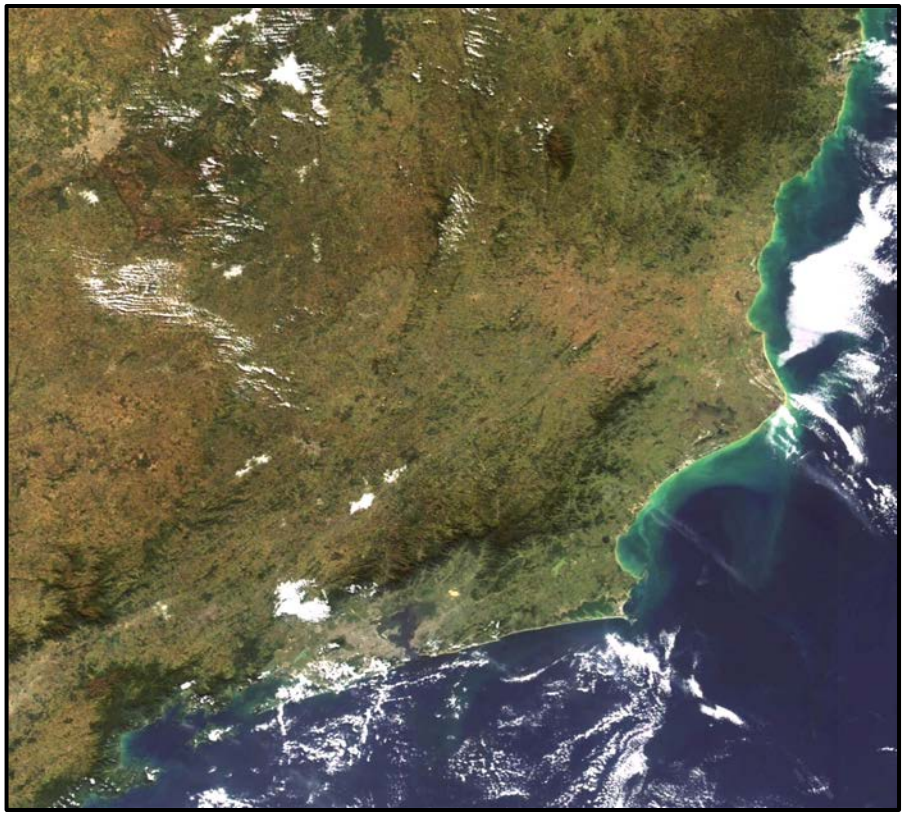
Mendenhall *et al*. Nature 2014

…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[1]
- Retain on average 3.9 of 18 medium and large mammal species[2]



[1]Ribeiro *et al.* Biol. Cons. 2009
[2]Canale *et al.* PLoS ONE 2012

Lessons from the islands

- Retain large forest expanses (>>100 ha!)

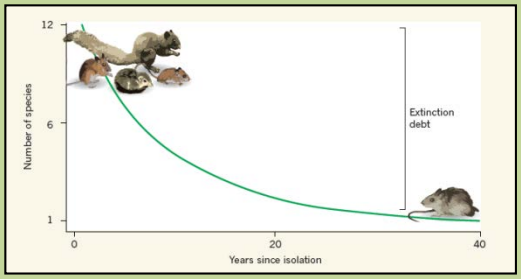
Can we write off fragmented forests?

- 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


3-11 9:56:25 AM M 1/3
HYPERFIRE


2013-02-05 2:25:18 PM M 3/3
HC500 HYPERFIRE

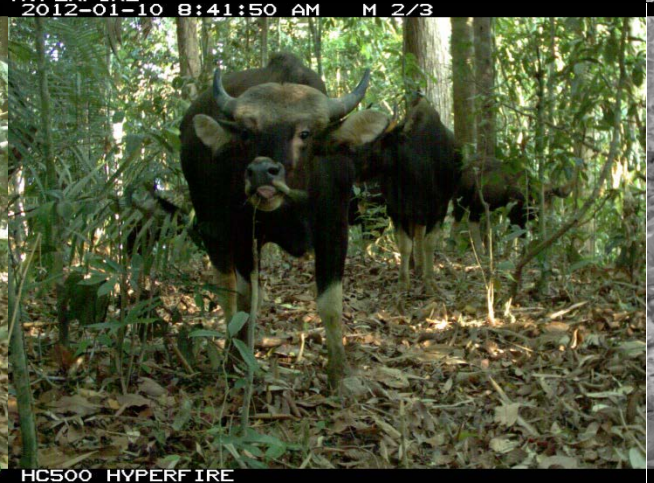

3:39 PM M 1/3
24°C
RECONYX


3-25 12:36:28 AM M 2/3
HYPERFIRE


3-30 3:38:21 AM M 2/3
HYPERFIRE


3-04-02 10:14:16 AM M 3/3
500 HYPERFIRE


0:59 PM M 2/3
32°C
RECONYX


2012-01-10 8:41:50 AM M 2/3
HC500 HYPERFIRE


2013-02-22 5:07:38 PM M 2/3
HC500 HYPERFIRE

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

mod.vec	k.vec	LL.vec	AICc.vec	dAICc.vec
rich_carn ~ distance + (1 | site) + (1 | survey)	5	-243.5022318	497.4962669	0.762623009
rich_carn ~ distance.dam + (1 | site) + (1 | survey)	5	-244.176356	498.8445154	2.110871455
rich_carn ~ distance + distance.dam + (1 | site) + (1 | survey)	6	-243.5020919	499.6983987	2.96475477
rich_carn ~ 1 + (1 | site) + (1 | survey)	4	-244.2042203	496.7336439	0

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

rich_ung ~ distance + (1 | site) + (1 | survey)	5	-300.2335643	610.9589319	0.29021663
rich_ung ~ distance.dam + (1 | site) + (1 | survey)	5	-300.99448	612.4807633	1.812048016
rich_ung ~ distance + distance.dam + (1 | site) + (1 | survey)	6	-299.8051872	612.3045893	1.635874044
rich_ung ~ 1 + (1 | site) + (1 | survey)	4	-301.171756	610.6687153	0

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

rich_all ~ distance + (1 | site) + (1 | survey)	5	-384.0556824	778.6031681	0
rich_all ~ distance.dam + (1 | site) + (1 | survey)	5	-386.5735732	783.6389498	5.03578163
rich_all ~ distance + distance.dam + (1 | site) + (1 | survey)	6	-383.9903041	780.674823	2.071654867
rich_all ~ 1 + (1 | site) + (1 | survey)	4	-386.5948828	781.5149688	2.911800673

Richness: forest edges vs. interior

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

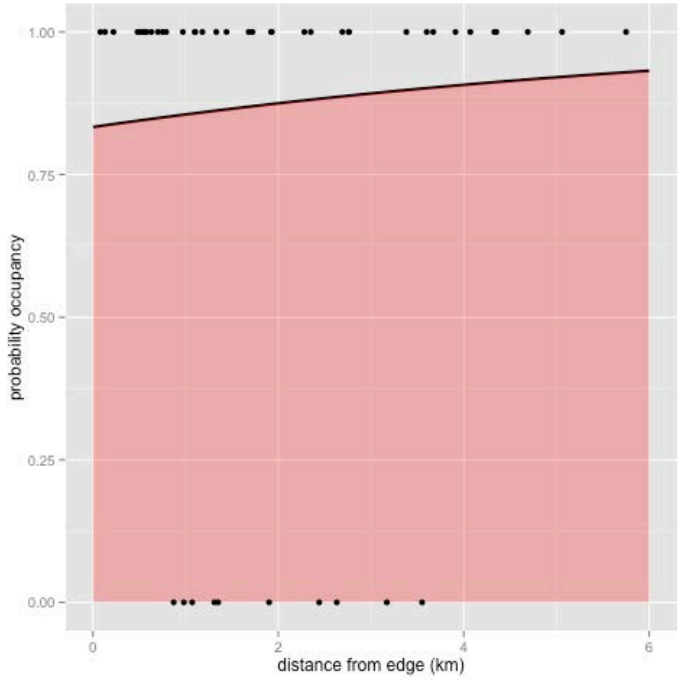
mod.vec	k.vec	LL.vec	AICc.vec	dAICc.vec
rich_iucn ~ distance + (1 | site) + (1 | survey)	5	-290.7147276	591.9212585	0.75785852
rich_iucn ~ distance.dam + (1 | site) + (1 | survey)	5	-290.9830718	592.4579469	1.294546896
rich_iucn ~ distance + distance.dam + (1 | site) + (1 | survey)	6	-290.0962077	592.8866302	1.723230236
rich_iucn ~ 1 + (1 | site) + (1 | survey)	4	-291.4190984	591.1634	0

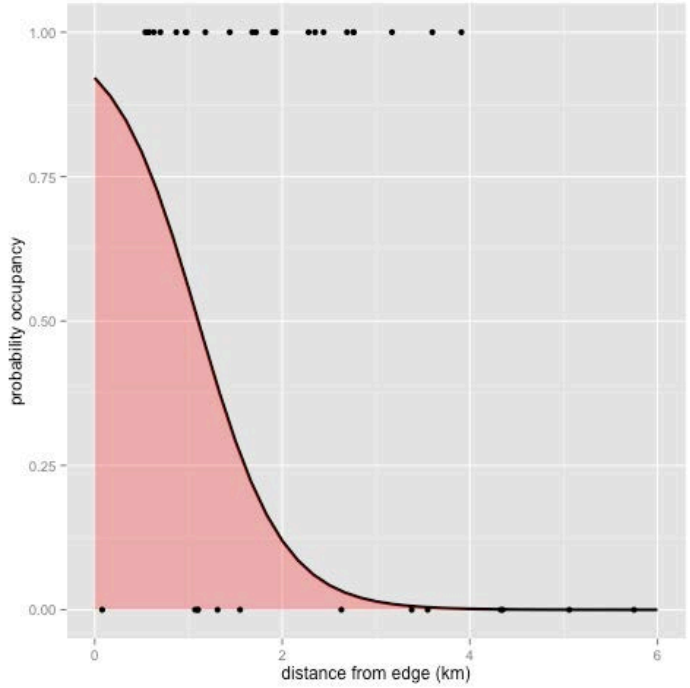
- Non IUCN (18): 0.08 (0.03) more spp/km from edge

rich_notiucn ~ distance + (1 | site) + (1 | survey)	5	-298.0502298	606.5922629	0
rich_notiucn ~ distance.dam + (1 | site) + (1 | survey)	5	-300.4886702	611.4691437	4.876880843
rich_notiucn ~ distance + distance.dam + (1 | site) + (1 | survey)	6	-297.9963989	608.6870126	2.094749786
rich_notiucn ~ 1 + (1 | site) + (1 | survey)	4	-300.7648951	609.8549935	3.262730638

Occupancy: sun bears

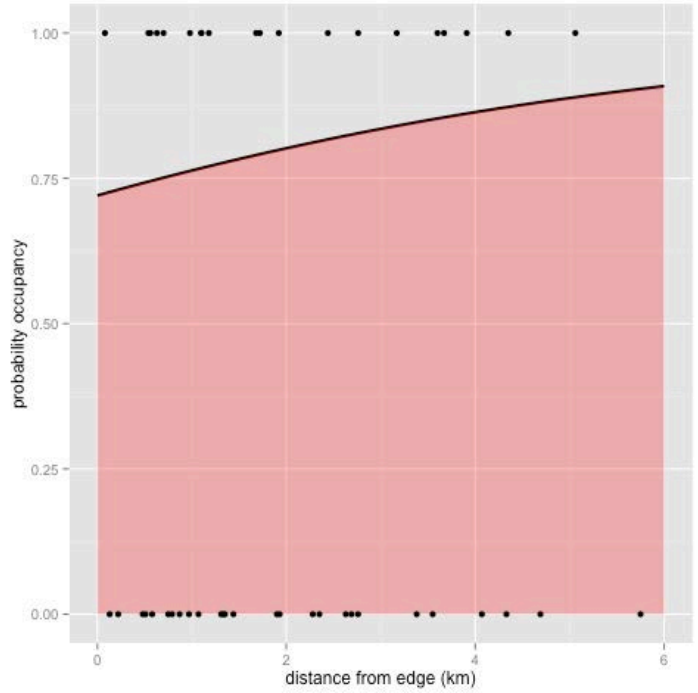
Probability of occupancy increases:

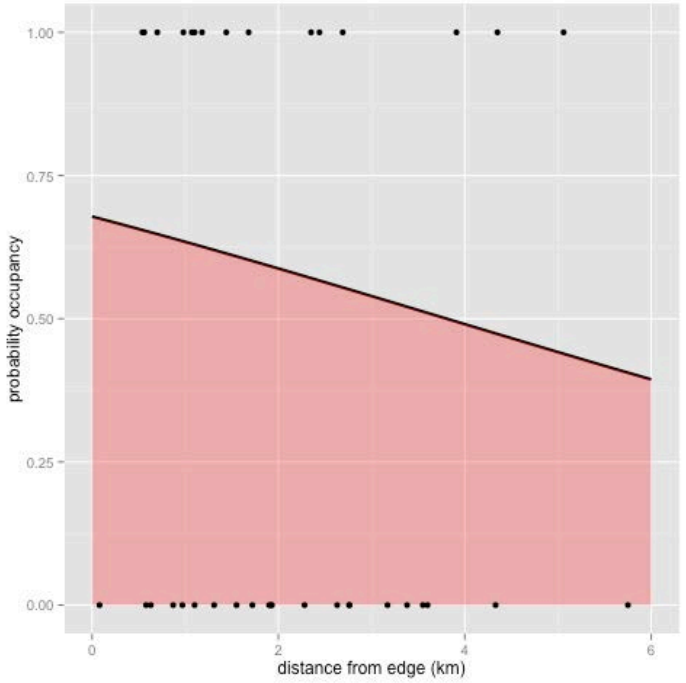




Occupancy: clouded leopard

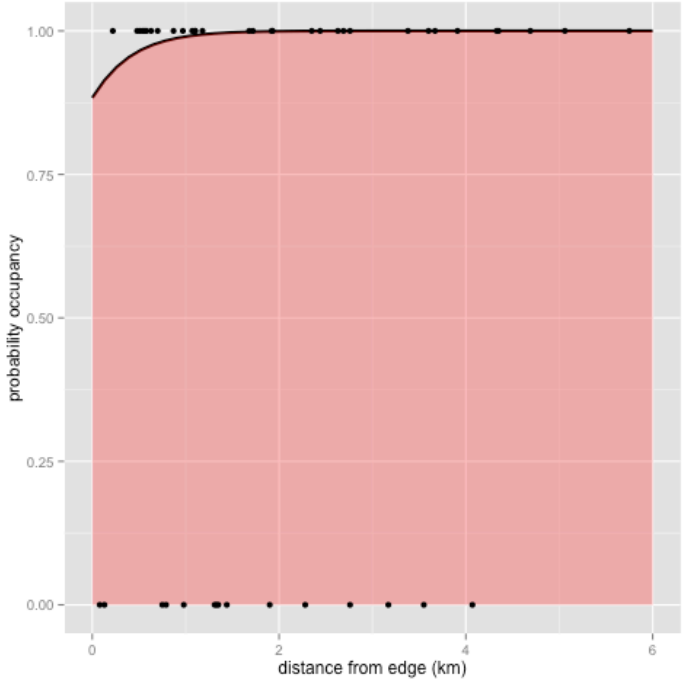
Probability of occupancy increases:

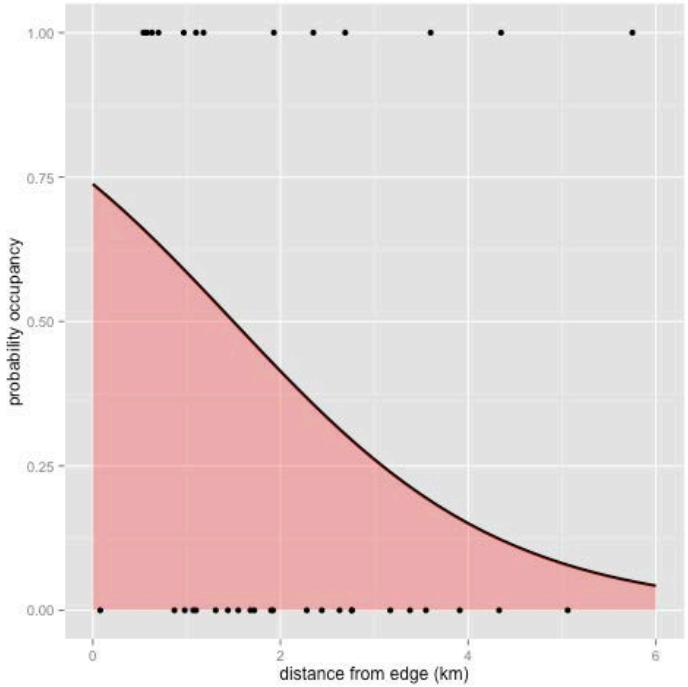




Occupancy: golden cat

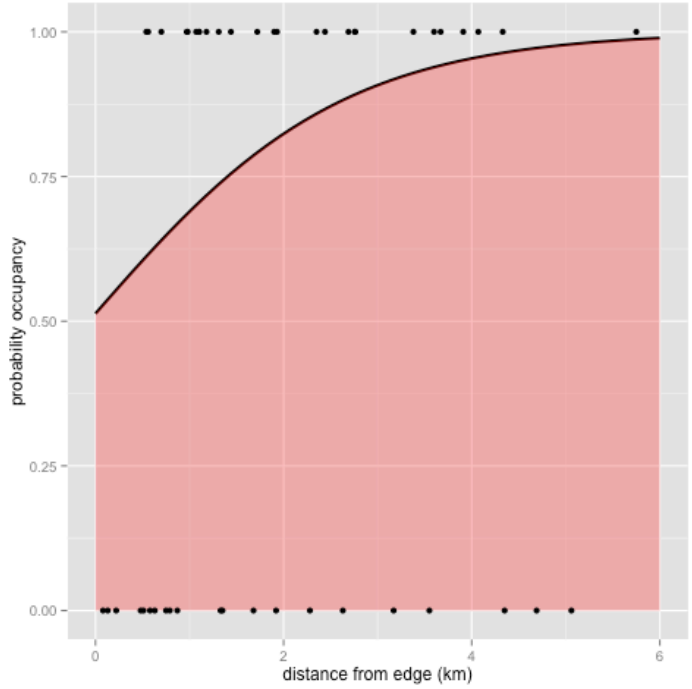
Probability of occupancy increases:

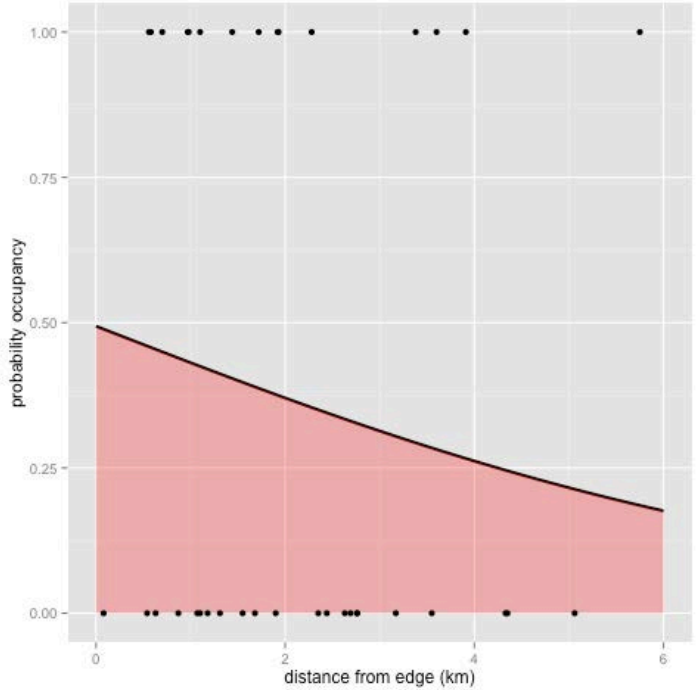




Occupancy: serow

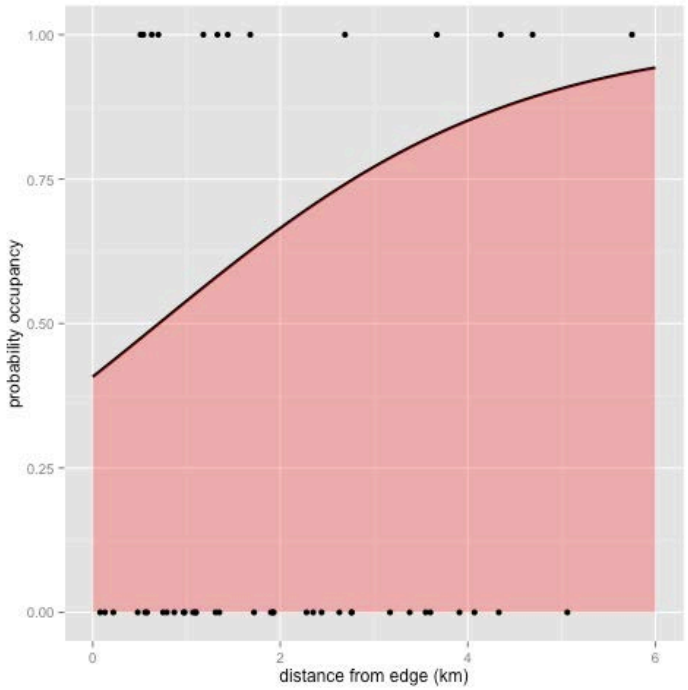
Probability of occupancy increases:

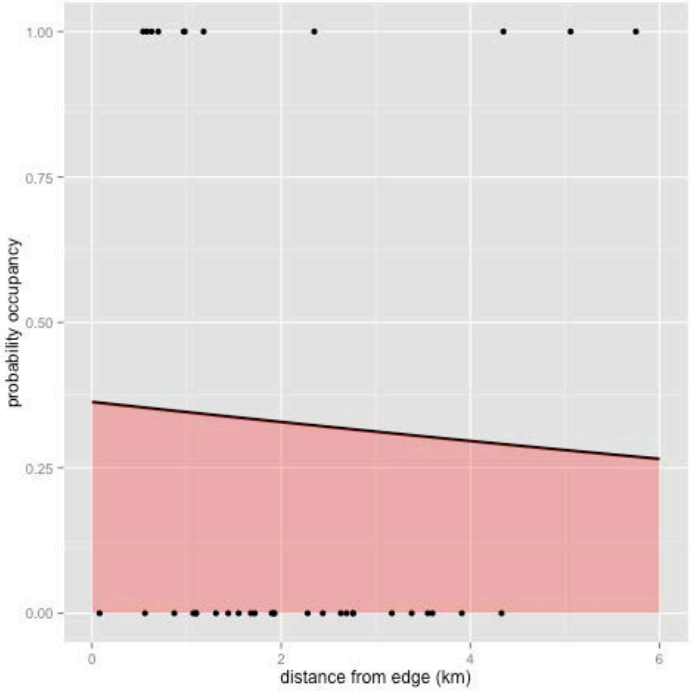




Occupancy: tapir

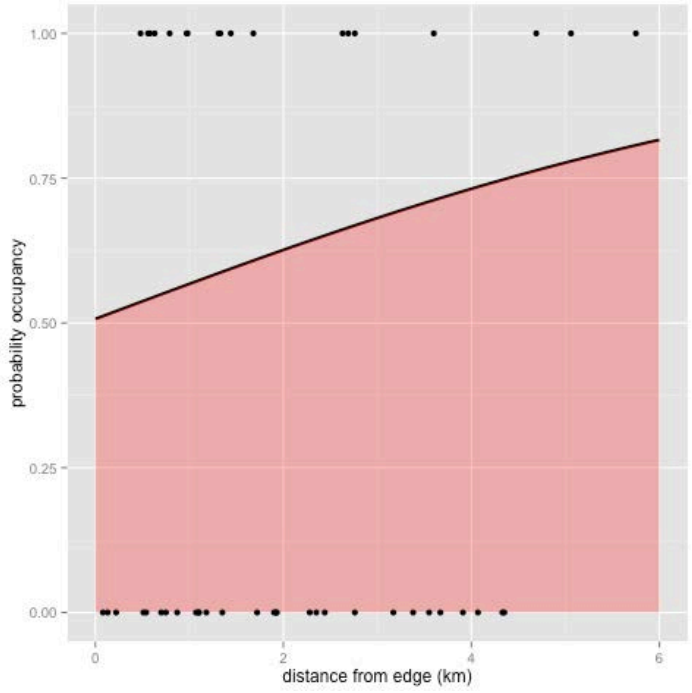
Probability of occupancy increases:

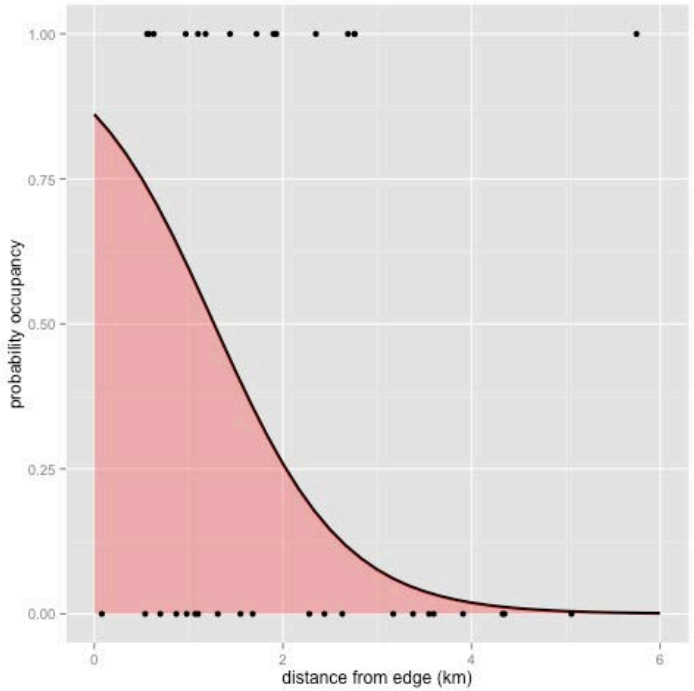




Occupancy: gaur

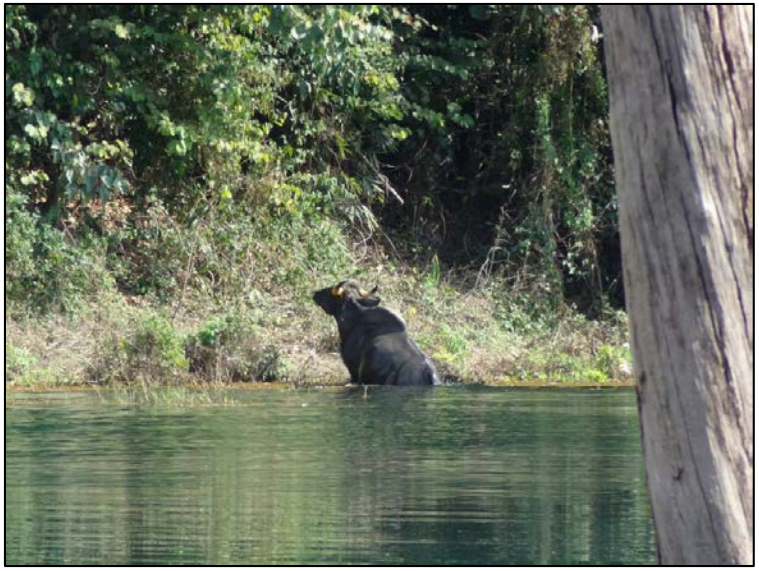
Probability of occupancy increases:





Attraction to forest edges

- Higher diversity in forest interior
- But, higher occupancy at forest edges during wet season



Conclusion

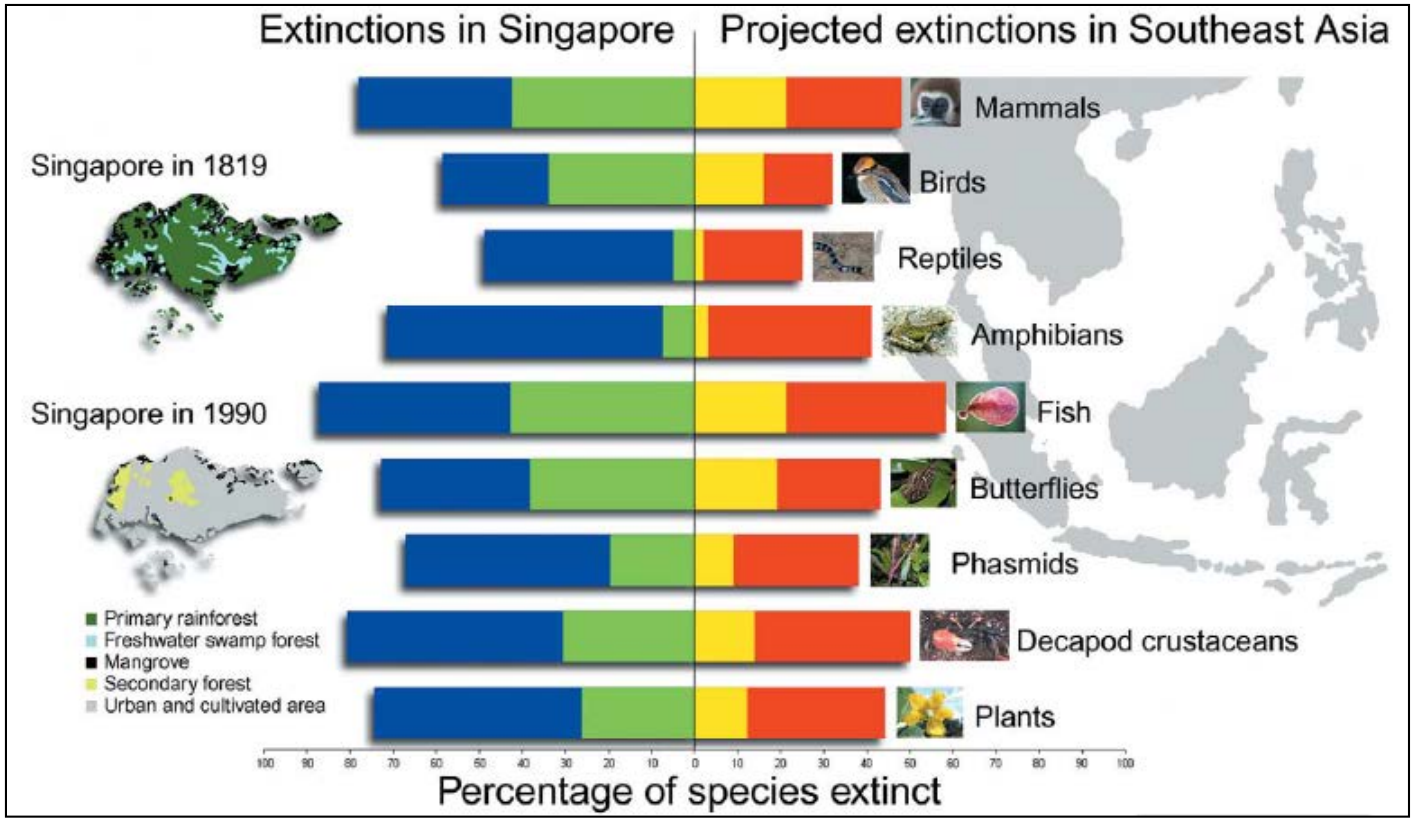
rapidly

Tropical forests: a changing landscape

Deforestation increasing by >2000 km^2 per year

Hansen *et al*. Science 2013

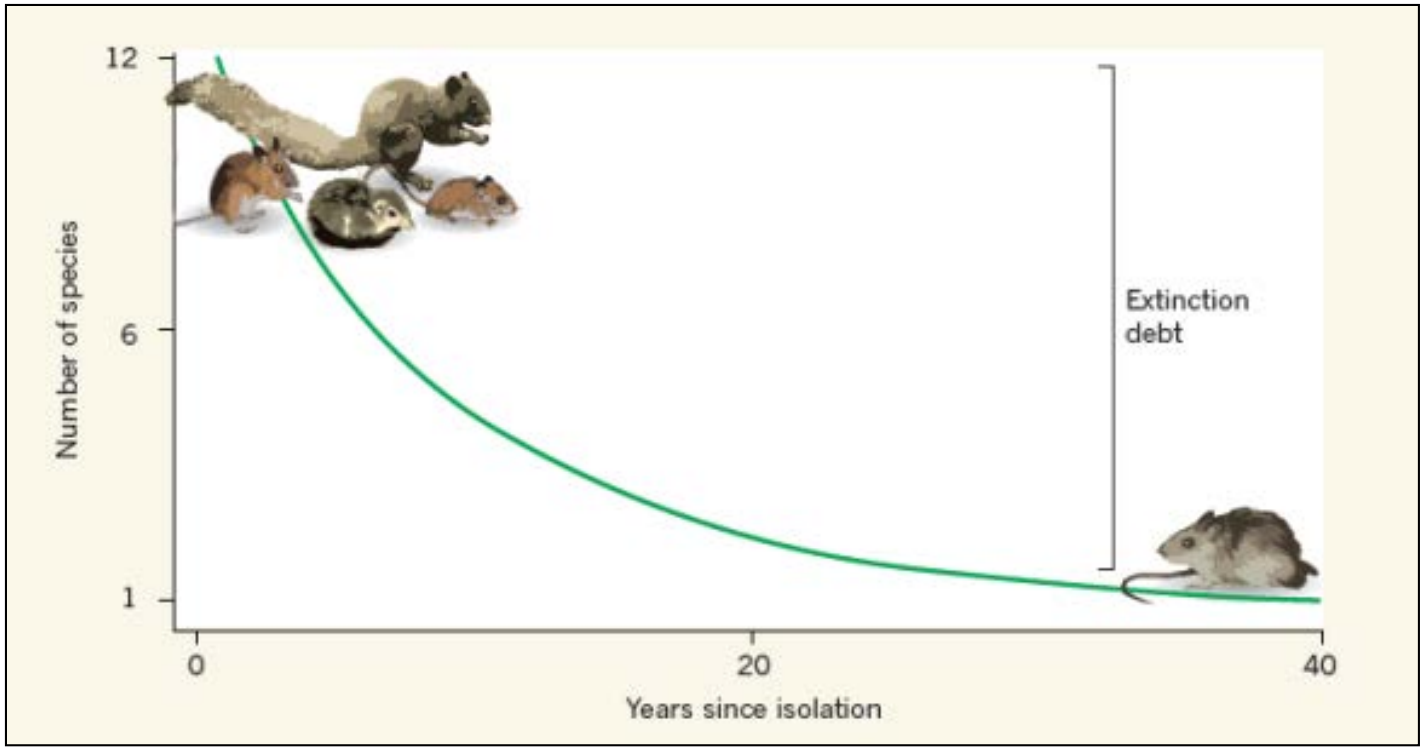
Fragmentation: worse than we thought



- Regional and nation-level extinction projections are underestimated

Hanski *et al*. PNAS 2013
Sodhi *et al*. TREE 2004

Fragmentation: worse than we thought



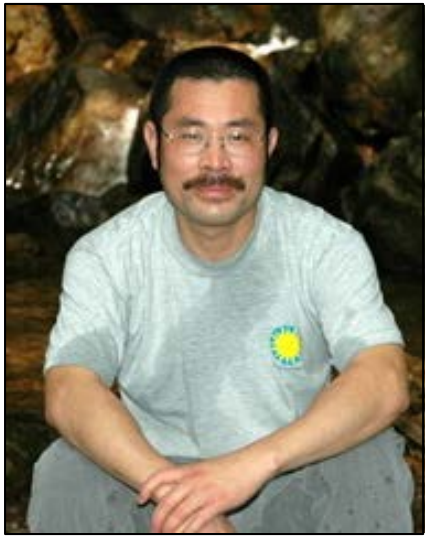
- Extinction debt can be collected rapidly, with entire native guilds lost

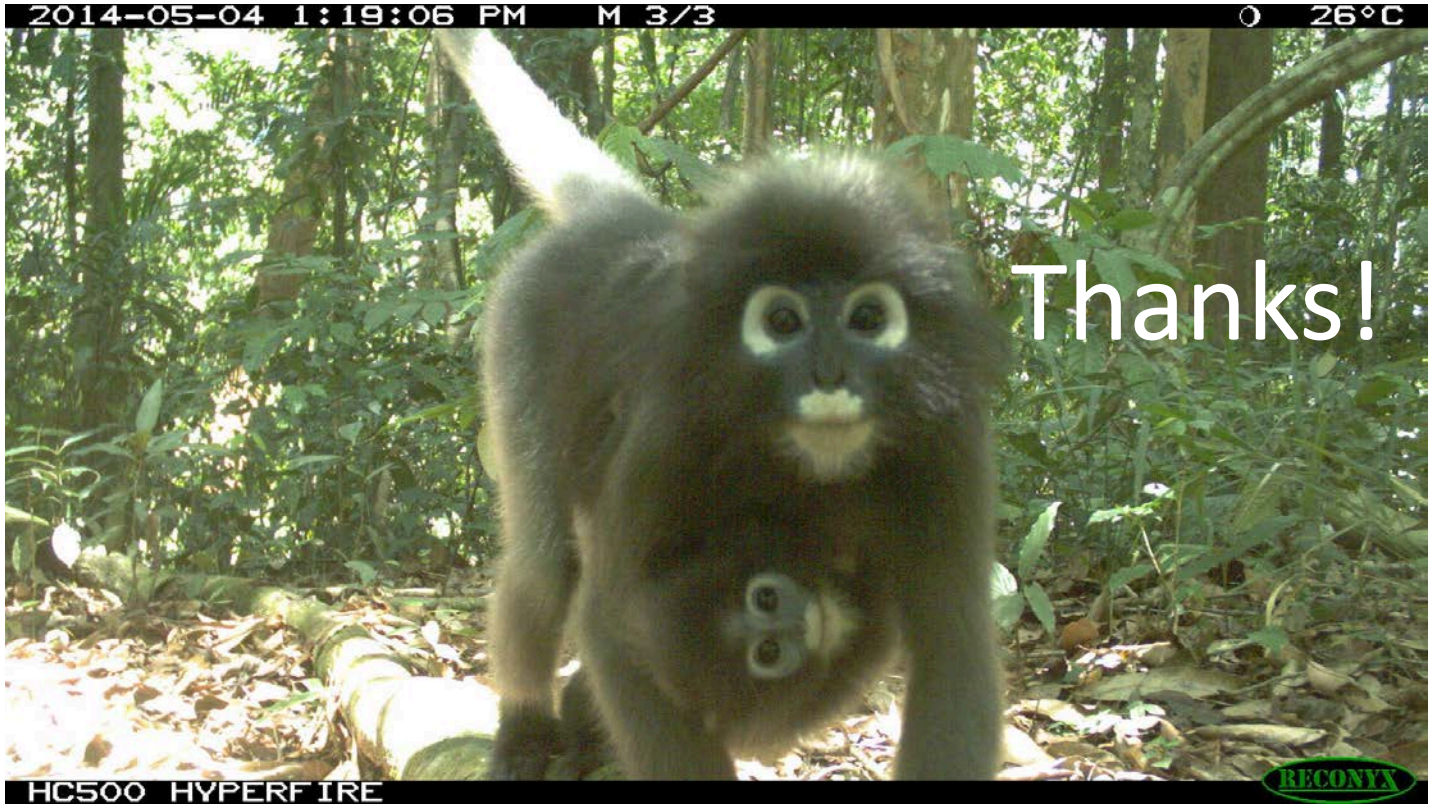
Gibson *et al*. Science 2013

Acknowledgments

NUS
National University
of Singapore

Agency for
Science, Technology
and Research
SINGAPORE




2014-05-04 1:19:06 PM M 3/3 26°C
Thanks!
HC500 HYPERFIRE
RECONYX