Habitat Fragmentation & Biodiversity

Discuss the various effects of habitat fragmentation as a force driving the loss of biodiversity

What impact does fragmentation have on biodiversity in the tropics?

Fragmentation occurs with forests are cleared in varying-sized parcels, creating a patchwork of forest

Results in loss of area and isolation of habitat and increases edge effects

Knowledge of how species and communities respond to fragments is necessary for effective conservation

Fragmentation

In fragmentation ecology, we study the effects of reduced area, isolation and modes of connectivity among fragments in a larger landscape matrix – much growth in the field has been from island biogeography and landscape ecology.

Agricultural fields, separated by hedgerows with abutting areas of forest give an example of a landscape mosaic

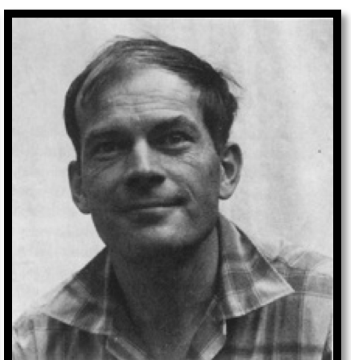
Recall: principles of Island Biogeography

Island biogeography predicts that islands attain a dynamic equilibrium of species richness, where immigration of new species is offset by extinction of resident species

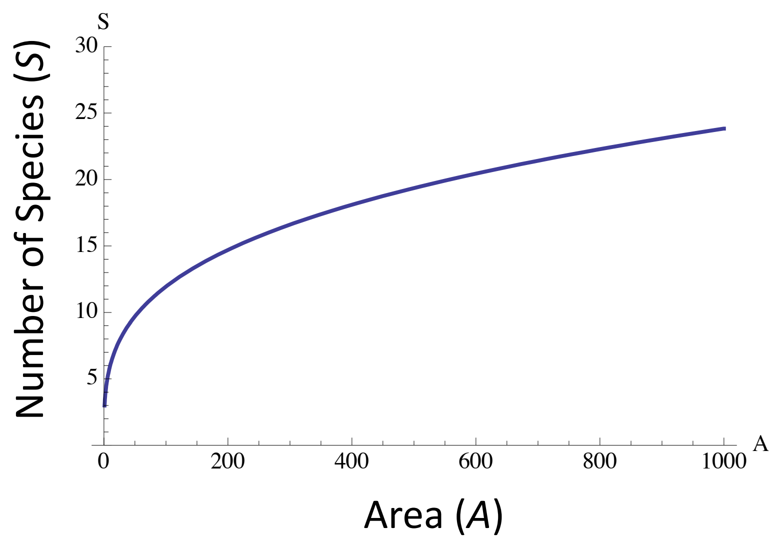
Species-Area effect - larger islands hold more species than smaller ones

E.O. Wilson

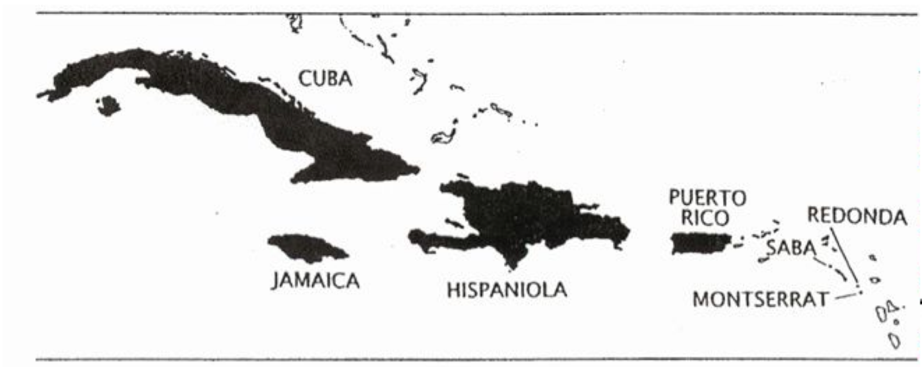
Robert MacArthur



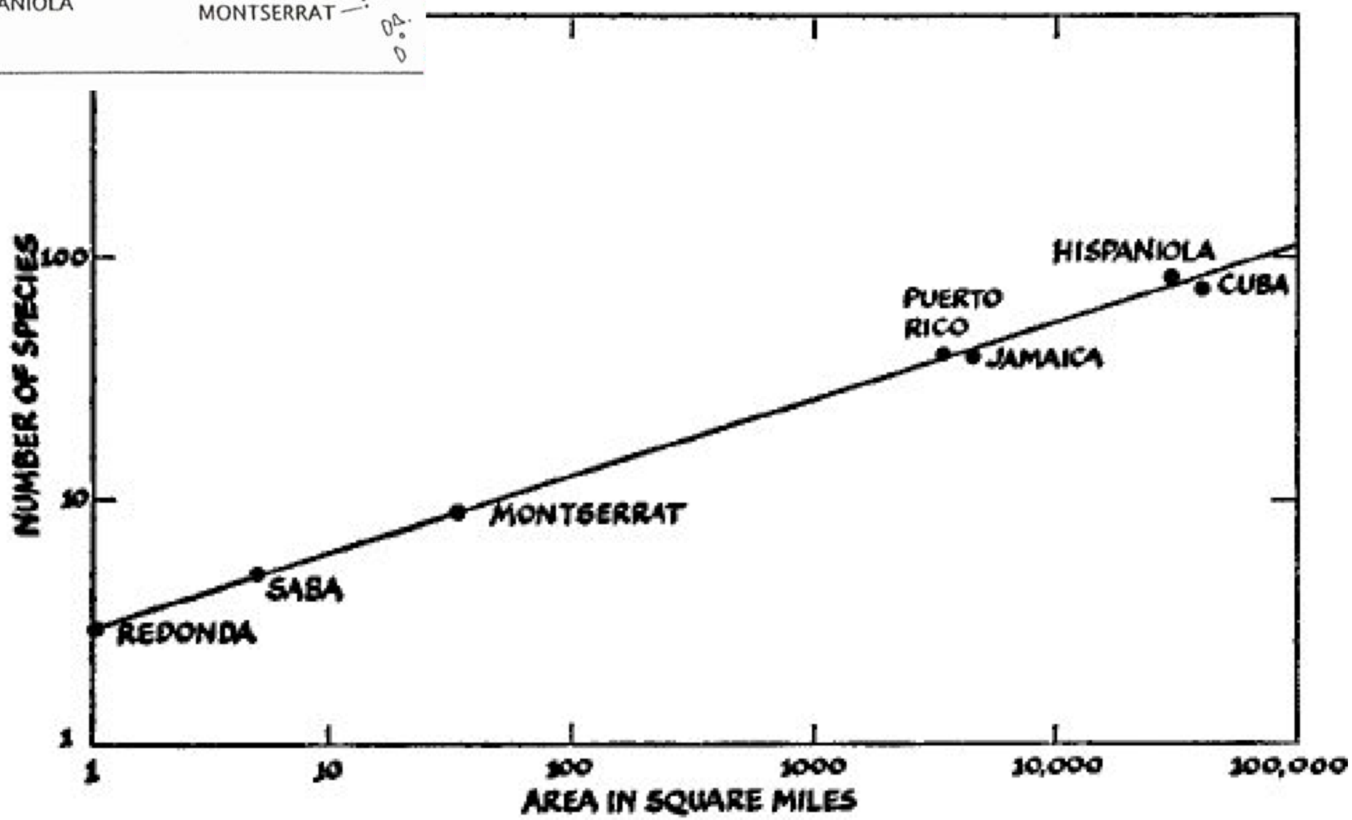
$S = cA^z$ approximates the species - area relationship:



Recall: principles of Island Biogeography

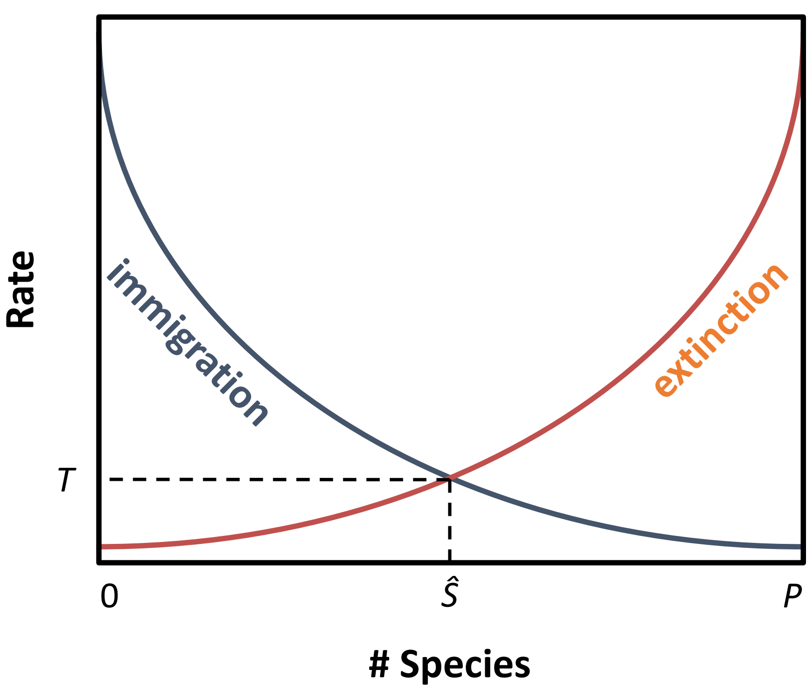


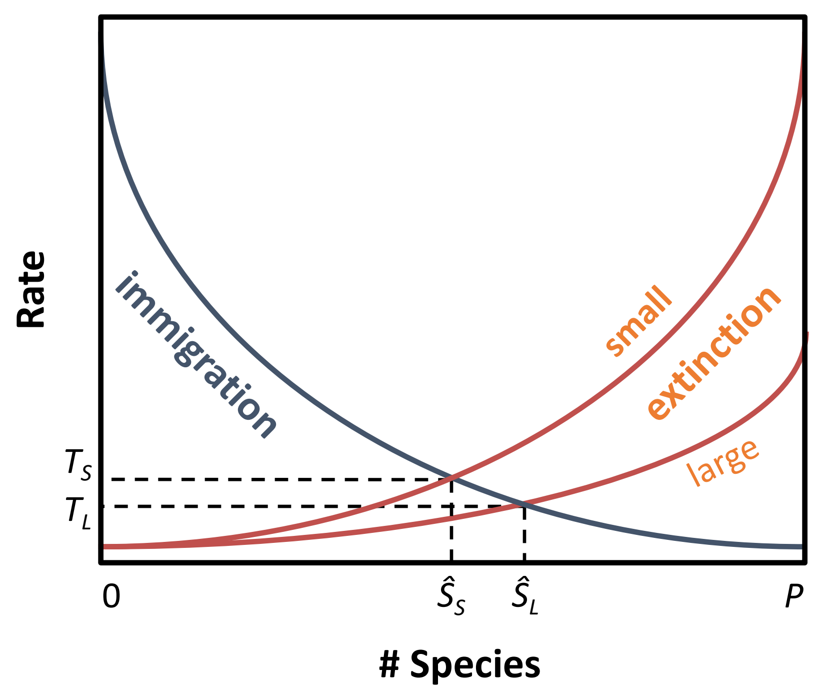
The area-species curve of the West Indian amphibians and reptiles (from MacArthur and Wilson 1967).



Recall: principles of Island Biogeography

Should area increase, theory predicts more species will be accommodated, and the equilibrium species richness shifts upward; if island area decreases, species richness will decline until reaching a lower equilibrium point





Fragmentation is a form of area loss

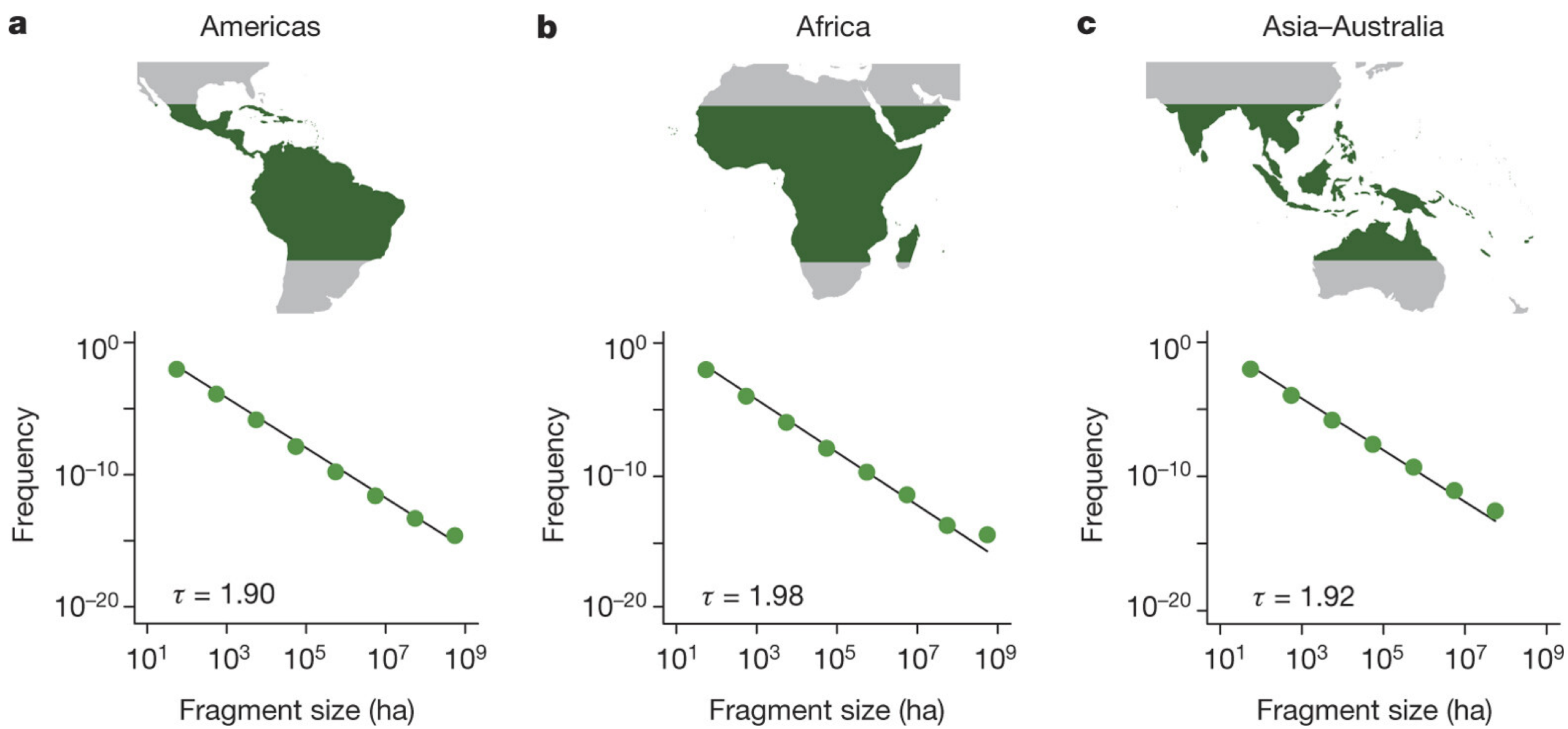
Millions of hectares of tropical forest habitats are cleared annually to be converted to pasture or agriculture – many times fragments are left, creating remnant *islands*

View of a totally deforested area in Alta Floresta, Brazil. Forest remnants are barely visible; the haze is smoke from fires to burn the slash

Cross-continental similarities in tropical forest fragmentation?

A global assessment of fragmentation of tropical forests showed remarkable similarities: Across continents, despite widely different land use practices, fragments had similar sizes

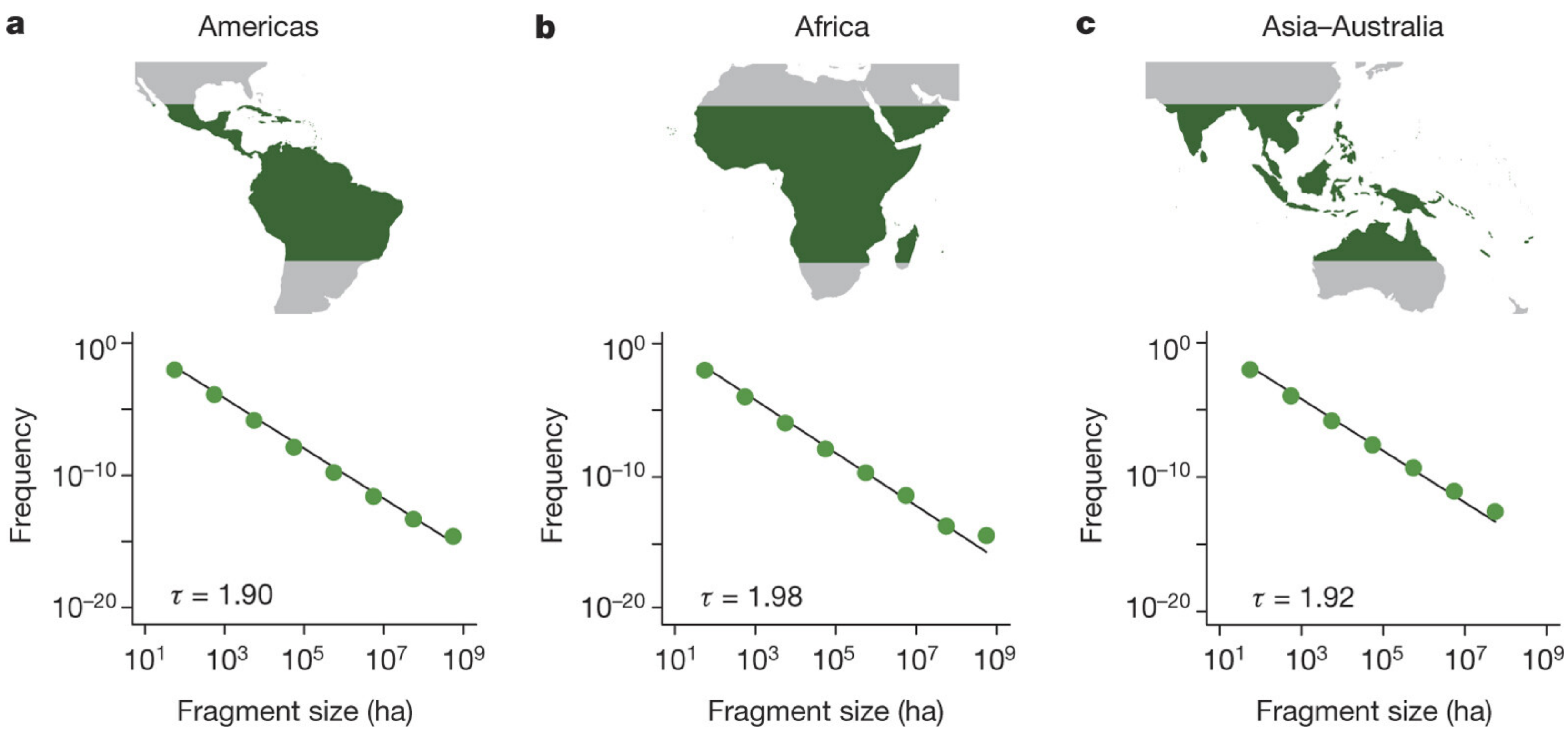
In Central & South America, 11.2 % of forest fragments are smaller than 10,000 ha (Africa = 9.9 %; southeast Asia = 9.2 %)



Continental-scale fragment size distribution of tropical and subtropical forests; Taubert et al. 2018 *Nature*

Cross-continental similarities in tropical forest fragmentation?

Taubert et al. 2018 study concluded that forest fragmentation is close to a “critical point of percolation” in each region – a point at which the rate of fragmentation will increase dramatically; a 33-fold in the number of fragments in Central and South America by 2050, and the average size will drop from 17 hectares to 0.25 ha.



Continental-scale fragment size distribution of tropical and subtropical forests; Taubert et al. 2018 *Nature*

Biological Dynamics of Forest Fragments Project (BDFFP)

North of Manaus, Brazil, there is an ongoing study established specifically to evaluate the effects of forest fragmentation on biodiversity

Established in 1979 with support from the Brazil National Institute for Research in Amazonia and the World Wildlife Fund, later managed by the Smithsonian Institute

Scientists involved have worked with woody plants, birds, primates, bats, nonflying mammals, ants, butterflies, Euglossine bees, and beetles.

Biological Dynamics of Forest Fragments Project (BDFFP)

Researchers worked with cattle ranchers to design the project, in accordance with a recent Brazilian law that landowners must leave 50% of their land forested

Ranchers created forest to create fragments of different sizes and distances from an undisturbed, protected 1000ha area, serving as a control -- like "mainland source"

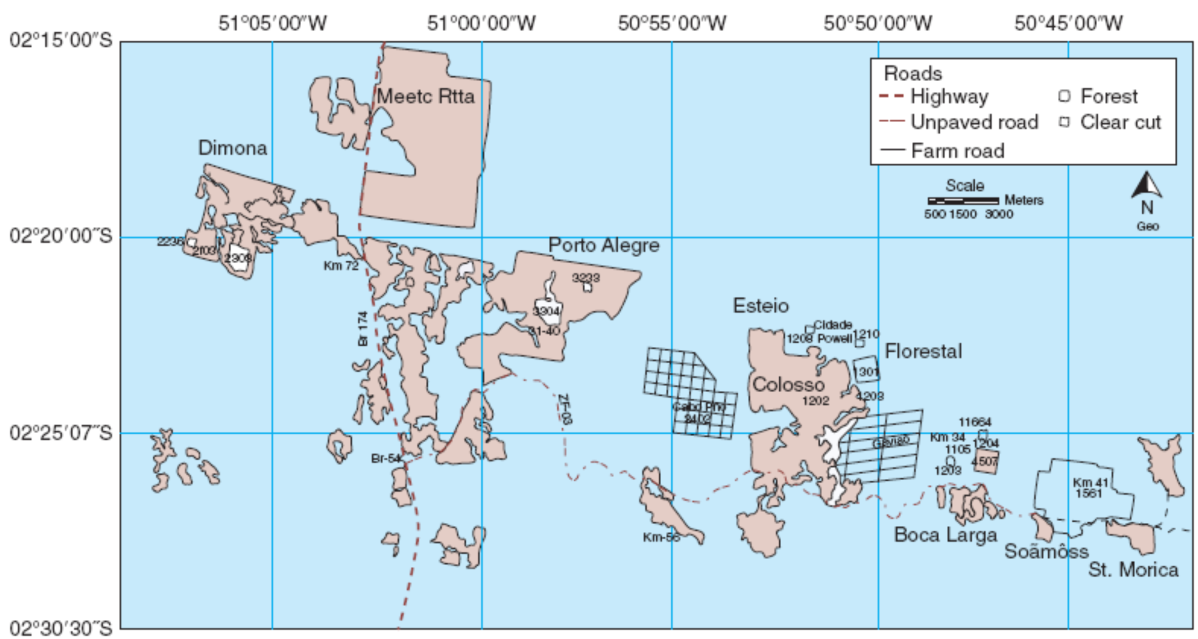
Sizes of fragments were 1, 10, 100 and 200 ha and varied in distance from mainland source from 100 to 900 m

Biological Dynamics of Forest Fragments Project (BDFFP)

Many opportunities for addressing questions on species composition and change:

- How do different sized plots (1 ha vs 10 ha) that are equidistant to a source differ in species composition?
- Does the tree composition change in fragment? How?

- Are understory birds more sensitive to area effects than canopy species?
- Which species of monkeys are most sensitive to area and isolation?



Location of the study area of the BDFFP north of Manaus

Biological Dynamics of Forest Fragments Project (BDFFP)

The upshot: Virtually all taxonomic groups studied are sensitive in varying ways to both area and distance effects – some species decline, others increase

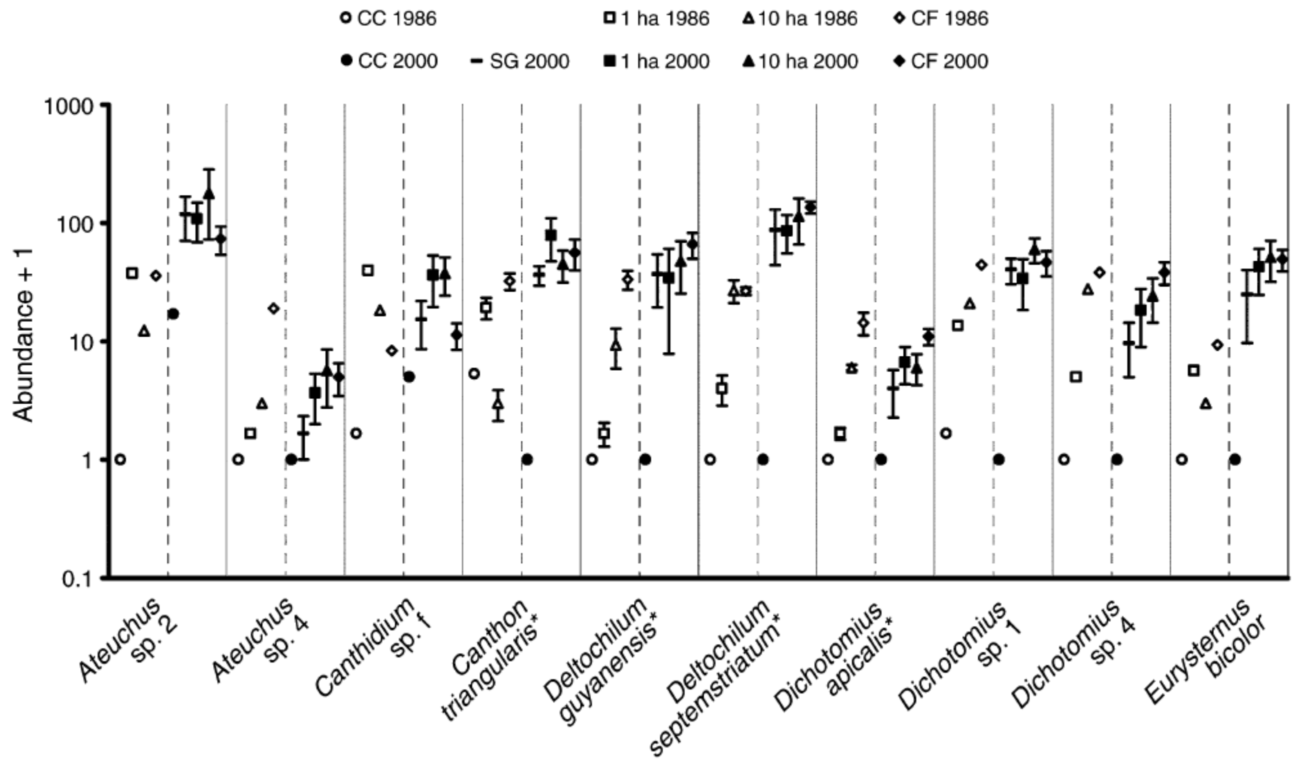
- Isolated fragments experienced an influx of understory birds, but numbers dropped within 200 days to levels below the sustained diversity prior to fragmentation
- Army-ant followers largely disappeared from fragments, similar to patterns elsewhere
- Euglossine bees were detected much less in fragments isolated by >80 m, apparently reluctant to cross large open habitats
- Primate richness in four 10-ha fragments combined was less than the number of species in a 100-ha fragment
- Three species of *Phyllomedusa* frogs were lost from small fragments – presumably because they rely on peccary wallows for breeding pools

Phyllomedusa frog species

Biological Dynamics of Forest Fragments Project (BDFFP)

Fragmentation produces ecological domino effects, but these can be dynamic

E.g., Dung beetles made a recovery within ten years, attributed to the regrowth of secondary vegetation between fragments that facilitated movement across the landscape matrix – differences were no longer apparent across different size fragments in 2000

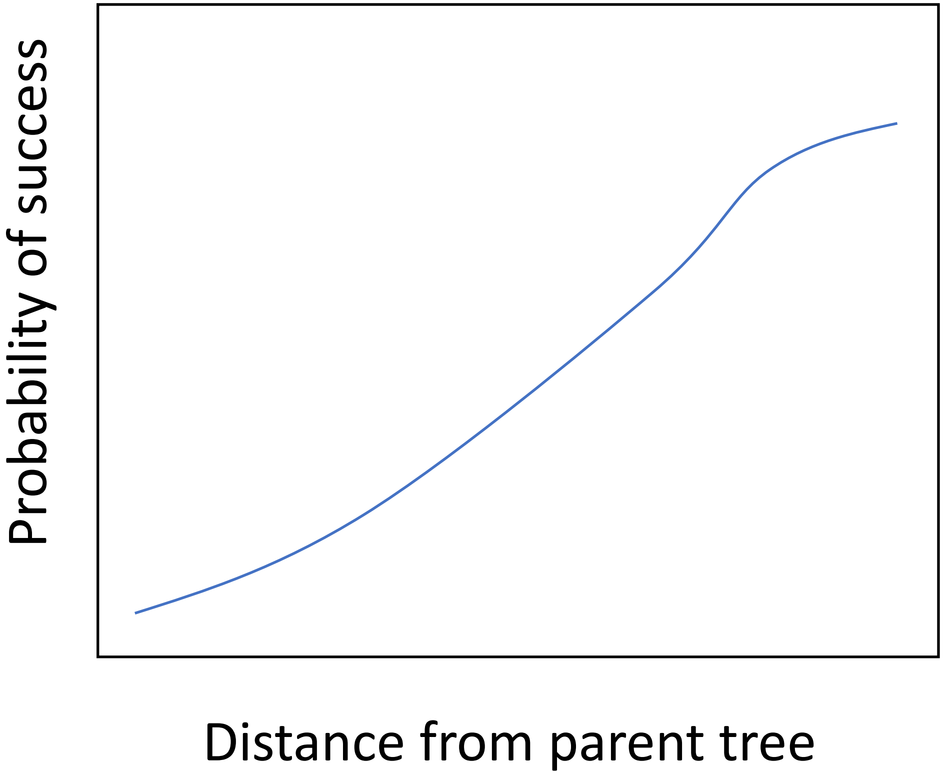


Deltochilum dung beetle

Quintero & Roslin 2005

Biological Dynamics of Forest Fragments Project (BDFFP)

Fragmentation can reduce seed dispersal by disrupting mutualisms



Recall: Negative density dependence model –
Based on the idea that the parent tree is the strongest competitor against its own seedlings

Likelihood of germination increases with distance from the parent tree

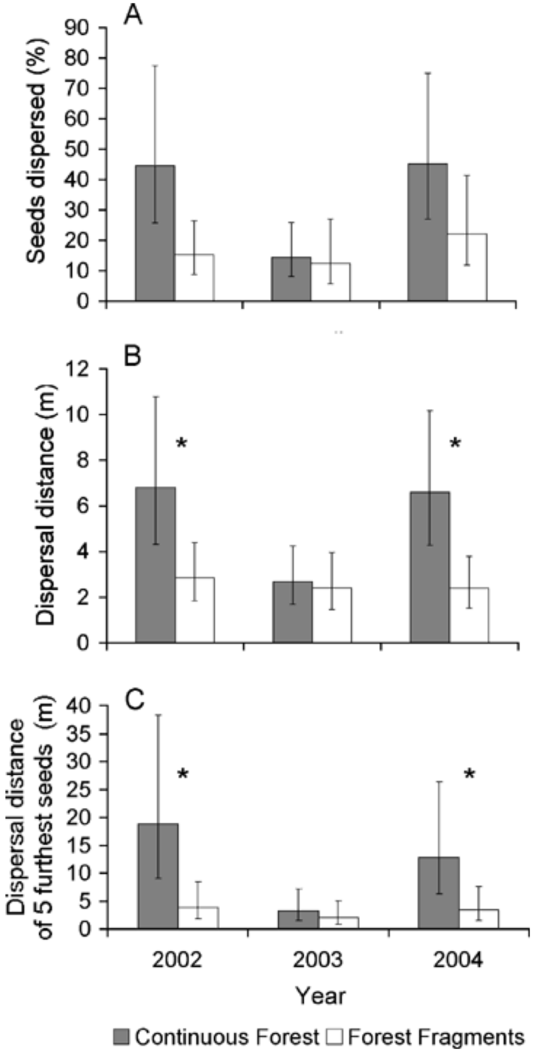
Biological Dynamics of Forest Fragments Project (BDFFP)

Fragmentation can reduce seed dispersal by disrupting mutualisms

A study of a canopy emergent tree *Duckeodendron cestroides* in BDFFP showed that trees in continuous forest had greater seed dispersal distances than did those in fragments

Large fruits are consumed and dispersed by agoutis, pacas, peccaries and primates, which are less abundant in fragments – future recruitment will be higher in continuous forests

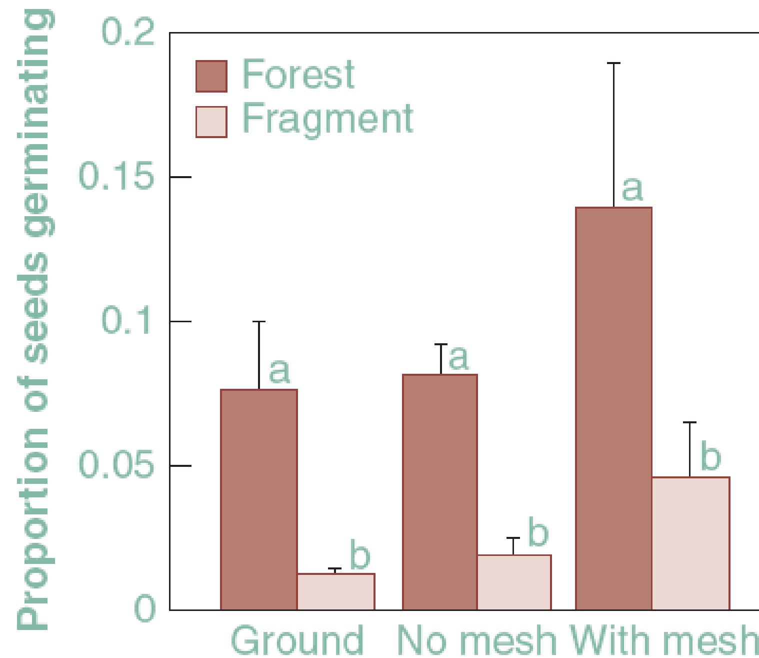
It may take many years to detect how such a disruption of mutualisms for canopy trees can result in population declines



Cramer et al. 2007

Tropical Fragmentation: Heliconia

This common understory plant across Amazonia has been investigated to determine fragmentation effect on pollination and the plant's overall ecology



Seeds of *Heliconia acuminata* planted in forest fragments were less likely to germinate than those planted in continuous forest – Seeds in small fragments were more subject to edge effects and experienced hotter drier conditions

Further study found that high dispersal from continuous forest could offset loss in fragments – proximity to continuous forest is essential in mitigating biodiversity loss

Tropical Fragmentation: Birds

Fragmentation is known to exert significant effect on bird species, but these are variable

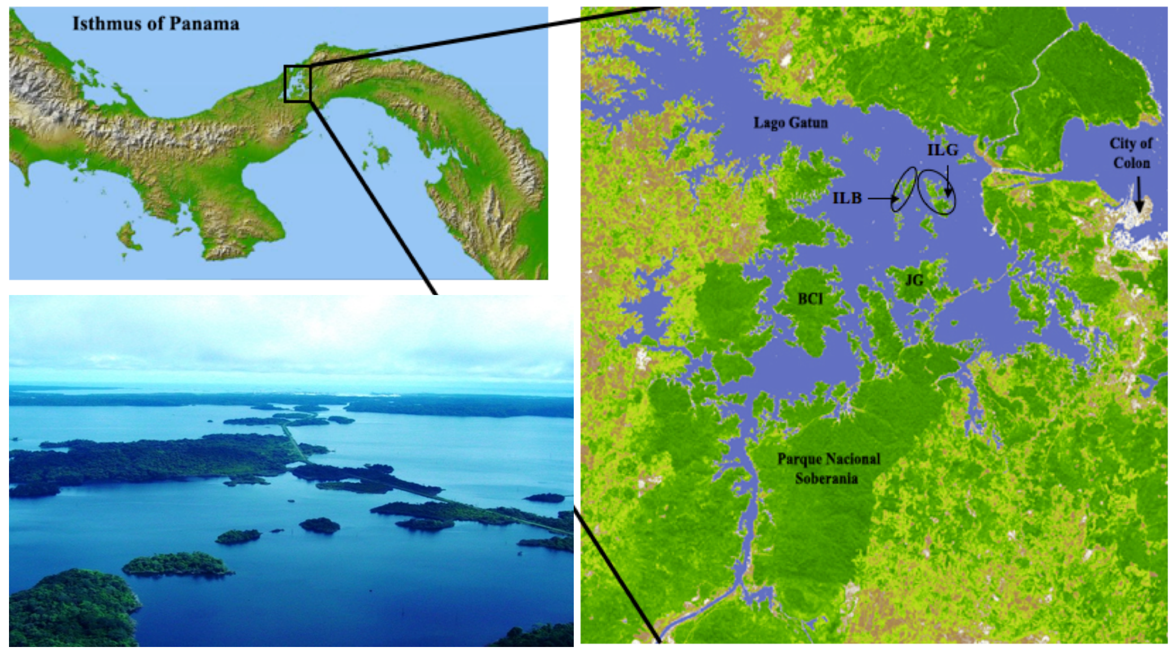
Tropical bird species have larger territories than temperate species, which makes them more susceptible to fragmentation when fragments are small

Many species, like those in mixed flocks, are reluctant to cross roads 30 m wide!

The black-throated antshrike (top) is an obligate forest interior species, but the barred antshrike (bottom) thrives in successional areas and forest edges

Tropical Fragmentation: Birds

Evidence for extreme dispersal limitation in tropical birds

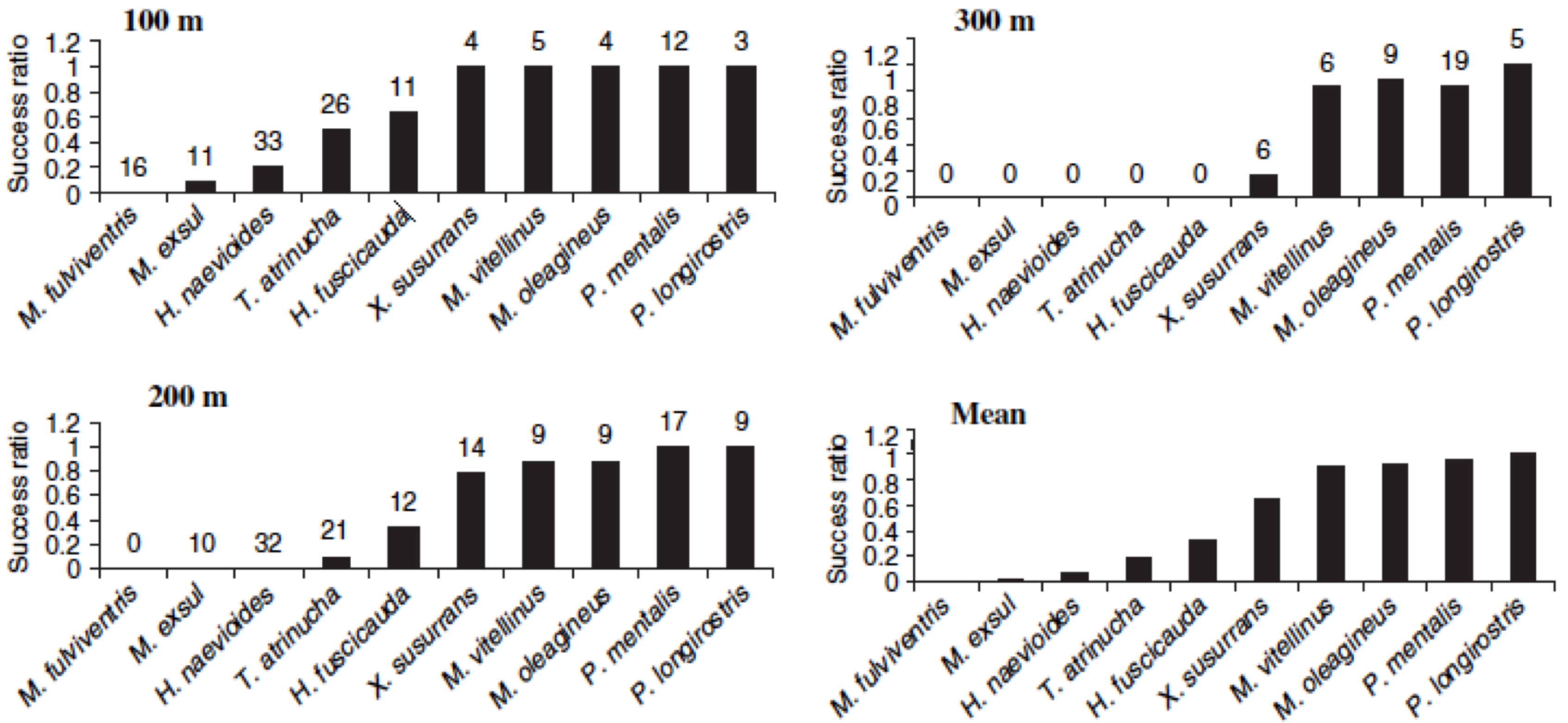


This study captured forest birds and conducted experimental releases where birds were required to fly 100, 200 and 300 m over water -- asked whether individuals were capable of flying across large gaps in extreme circumstances

Moore et al. 2008

Tropical Fragmentation: Birds

Found high variation in flight capacity among species



Poor performers

Good performers

Tropical Fragmentation: Birds

Table 3 Experimental performance of focal species listed in ascending order of mean success ratio

Species	Mean distance flown in metres (SD) when released from				Maximum distance flown in metres when released from‡		
	100	200	300	Mean†	100	200	300
Myrmotherula fulviventris	24 (19.2)	–	–	24	70	–	–
Myrmeciza exsul	48 (29)	34 (28)	–	41	90	90	–
Hylophylax naevioides	57 (40)	47 (37)	–	52	160	150	–
Thamnophilus atrinucha	86 (33)	118 (60)	–	102	160	240	–
Habia fuscicauda	104 (46)	216 (177)	–	160	180	750	–
Xiphorynchus susurrans	128 (25)*	211 (24)	200 (52)	179	150	260	300
Manacus vitellinus	106 (13)*	211 (21)	273 (66)	196	130	240	330
Mionectes oleagineus	100 (0)*	249 (153)	317 (91)	222	100	700	475
Pipra mentalis	113 (27)*	224* (43)	342 (154)	226	190	350	700
Phaethornis longirostris	108 (14)*	211* (24)	626* (267)	315	125	270	1000

Moore et al. 2008

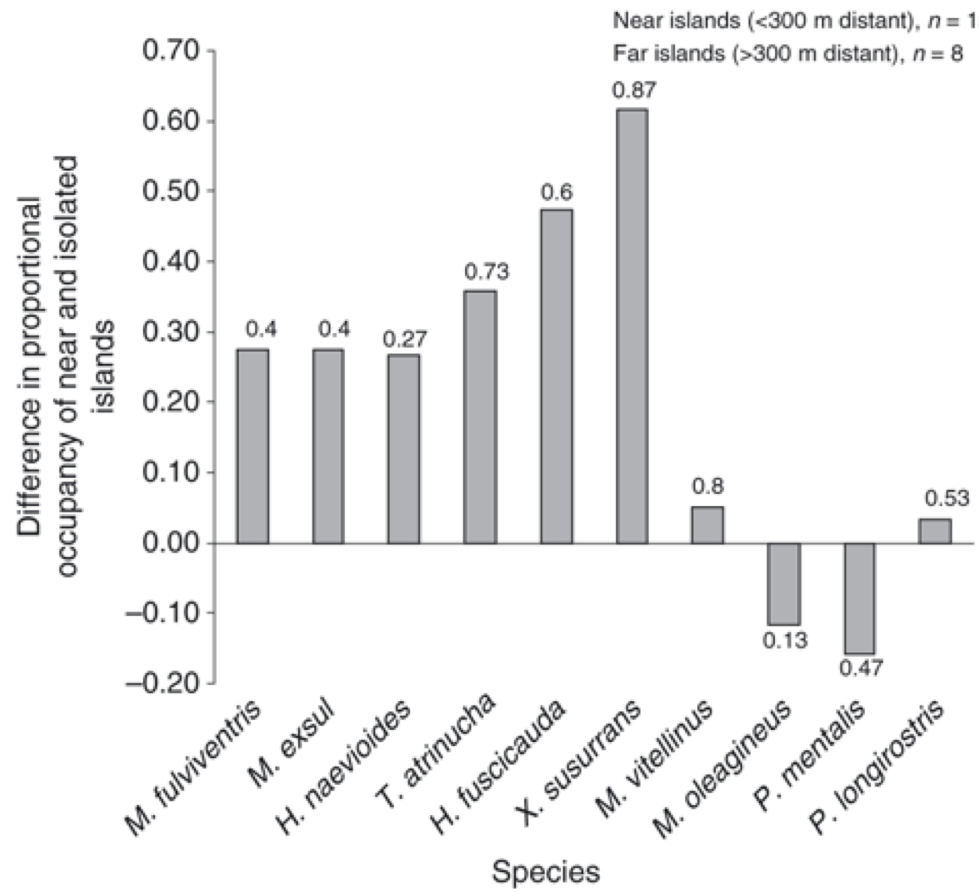
Poor performers

Good performers

Tropical Fragmentation: Birds

Experimental dispersal abilities across species were concordant with patterns of current distribution – poor performers showed occupation of islands nearer to mainland sources

Species with a difference near zero occupy near and far islands nearly equally.



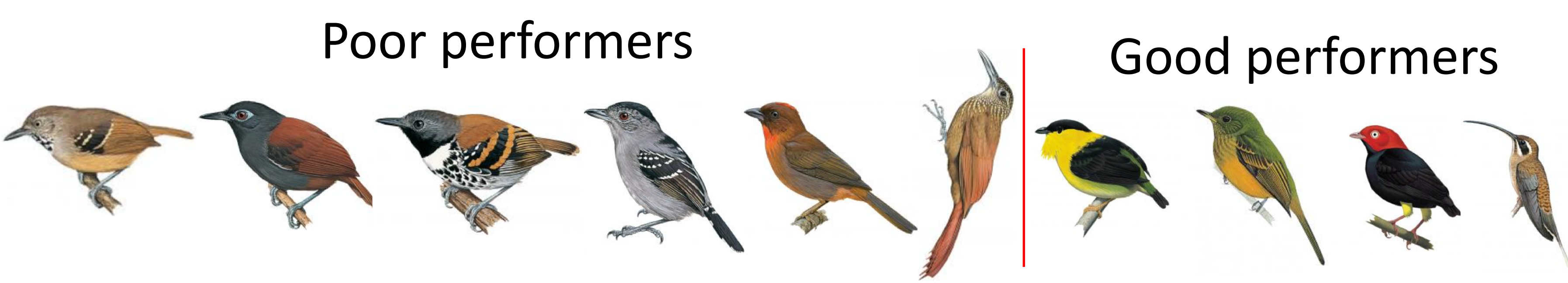
Poor performers

Good performers

Tropical Fragmentation: Birds

Experimental dispersal abilities were also concordant with patterns of historical extinctions

Species that performed poorly suffered significantly higher extinction rates



Ecological meltdown: Lago Guri

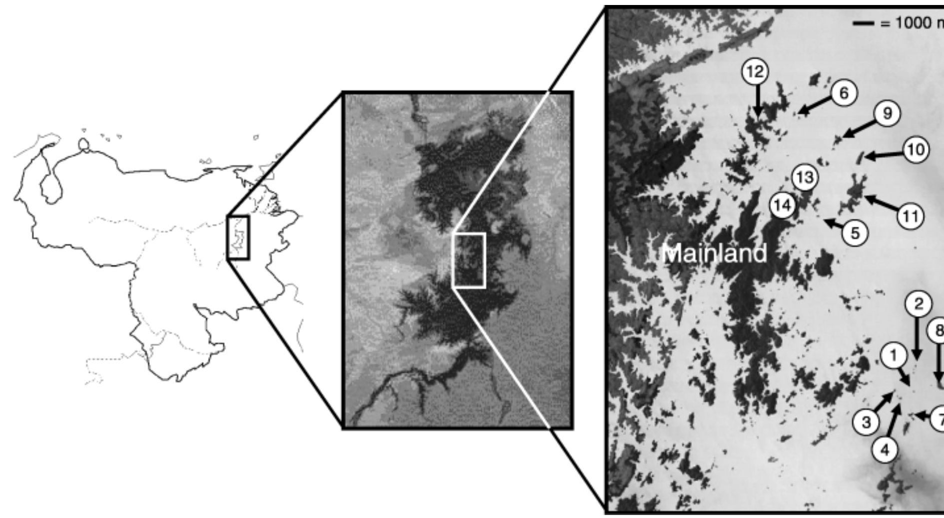
Recall: Case study of the Lago Guri Islands, Venezuela

Lago Guri was formed in 1986 by the creation of a large hydroelectric reservoir in eastern-central Venezuela (near confluence of Caroni and Orinoco Rivers)

Caused inundation of 4300 km2 of hilly terrain, permanently flooding contiguous lowland forest and leaving hilltop islands

This trapped many animals on newly formed islands, including Red howler monkeys, by up to 10 km of open water

Red howler density has increased up to 30 times that in mainland forest



Ecological meltdown: Lago Guri

In 1993, an inventory of the fauna on select islands was done to show how changes compared to control sites on the mainland – found an ecological meltdown of species loss on smaller islands

Small and medium islands lacked ~75% of vertebrate species found on the mainland and two large islands

Animals persisting on the small islands were small predators (spiders, frogs, lizards), seed predators and herbivores

Ecological meltdown: Lago Guri

In 1993, an inventory of the fauna on select islands was done to show how changes compared to control sites on the mainland – found an ecological meltdown of species loss on smaller islands

Animals that persisted on the small islands became hyperabundant - Red howler density has increased up to 30 times that in mainland forest

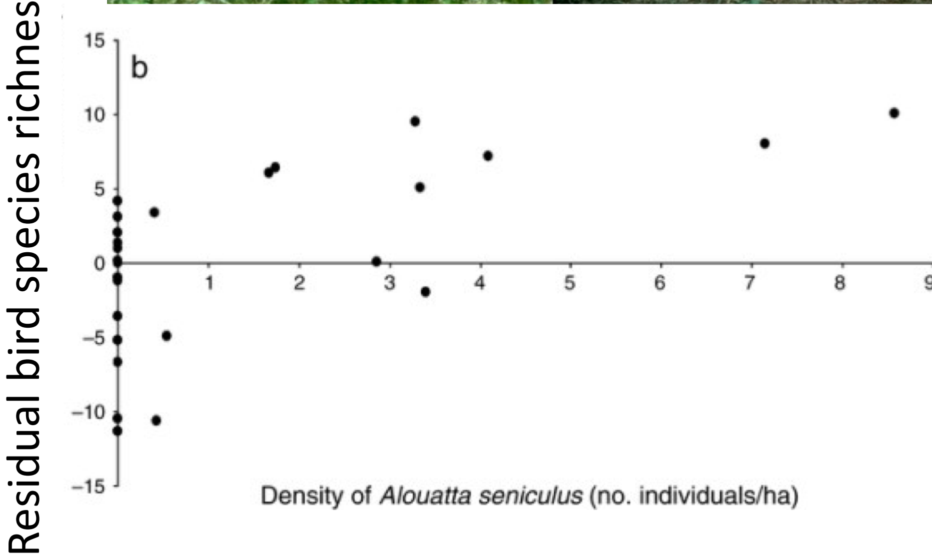
Vegetation changed dramatically – plants <1m tall became rare, more than half were lianas, lower recruitment of canopy trees

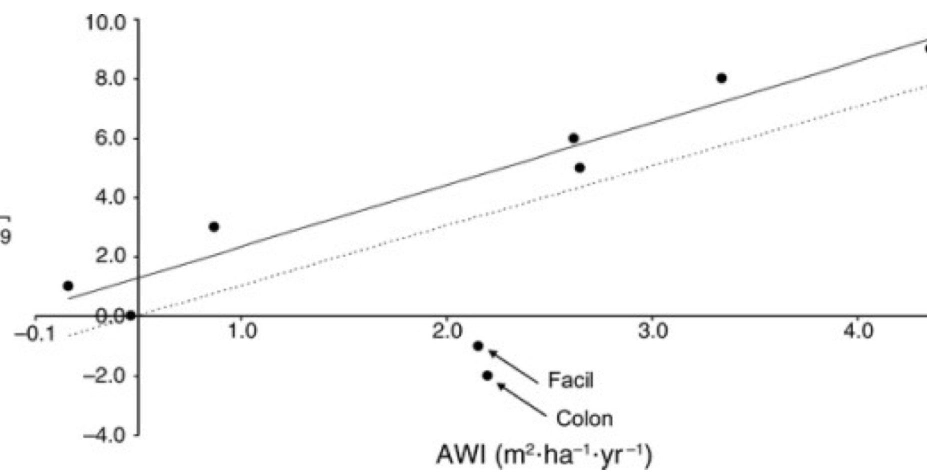
Ecological meltdown: Lago Guri

Ecological cascade on smaller islands initiated by loss of predators and subsequent hyper-diversity of herbivores. Indirect effects observed for other communities (positive effects on bird richness with increasing annual woody increment (AWI)

Islands are clearly not in equilibrium – as nutrient availability declines, diversity will decrease

Understory of an herbivore-impacted island compared to normal dry forest

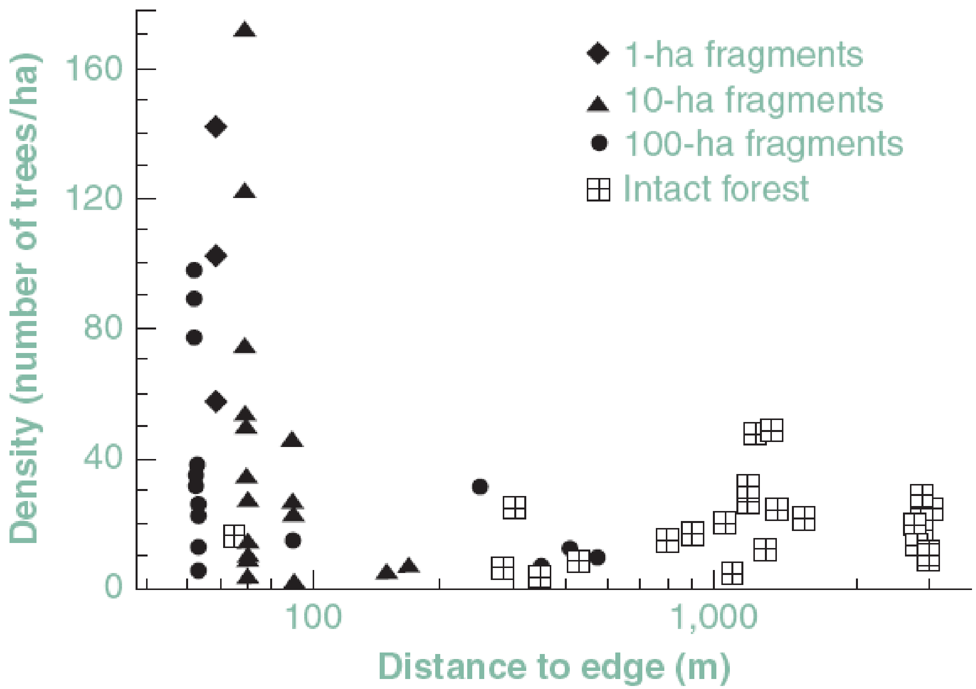




Feeley & Terborgh 2006, *Ecology*

Edge effects and matrix suitability

Edge effects occur at borders of forest fragments; microclimate differs from forest interior and favors other groups of species

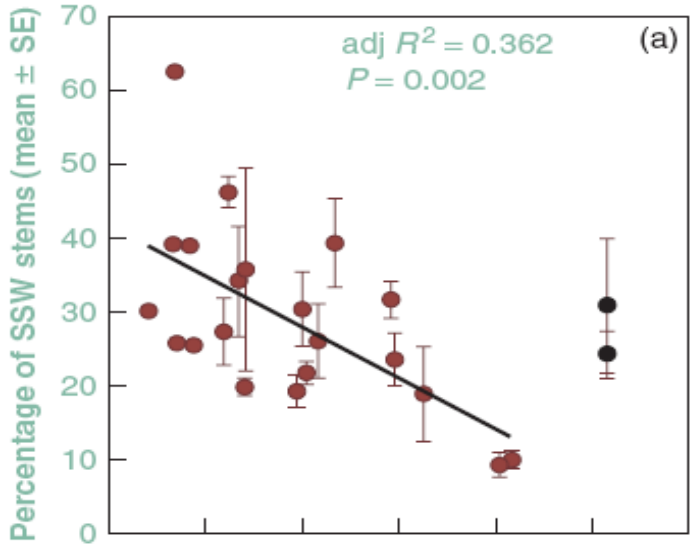


Cecropia are aggressive colonizers along edges

In the BDFFP sites, early successional species were uncommon prior to fragmentation, but successional species tripled along edges following fragmentation, representing 25% of species on some plots

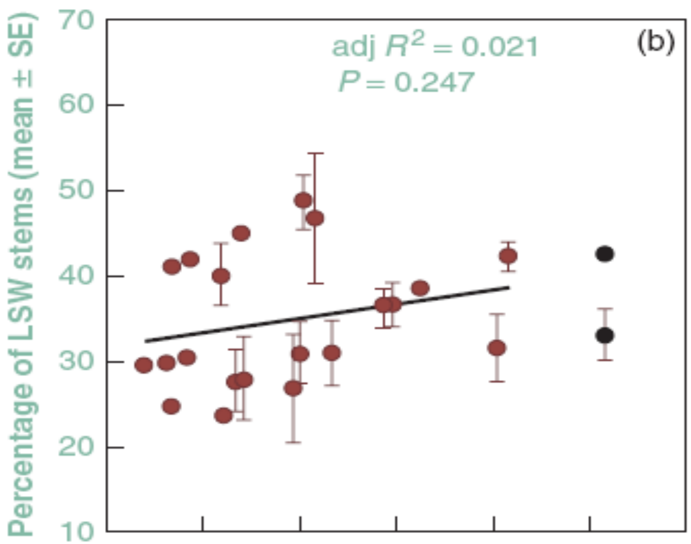
Laurance et al. 2006

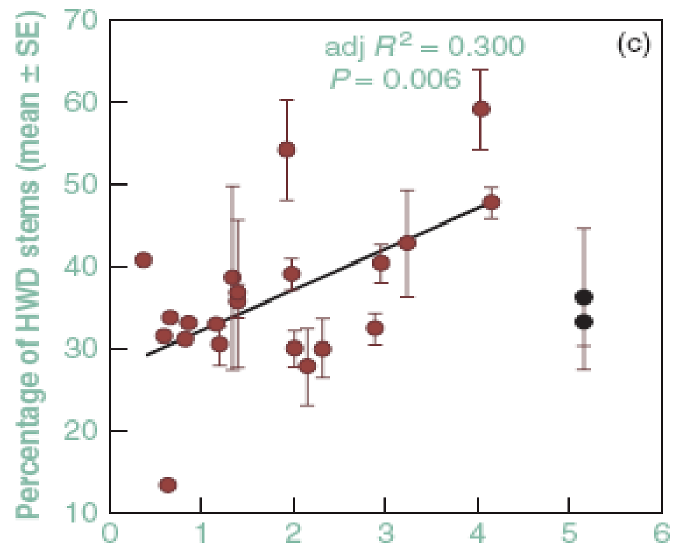
Edge effects and matrix suitability



In a study in Mato Grosso Brazil, small fragments had higher concentrations of small-seeded softwood trees (SSW), typical successional species

Large-seeded softwood (LSW) and hardwood stems (HWD) had higher concentrations in larger forest patches



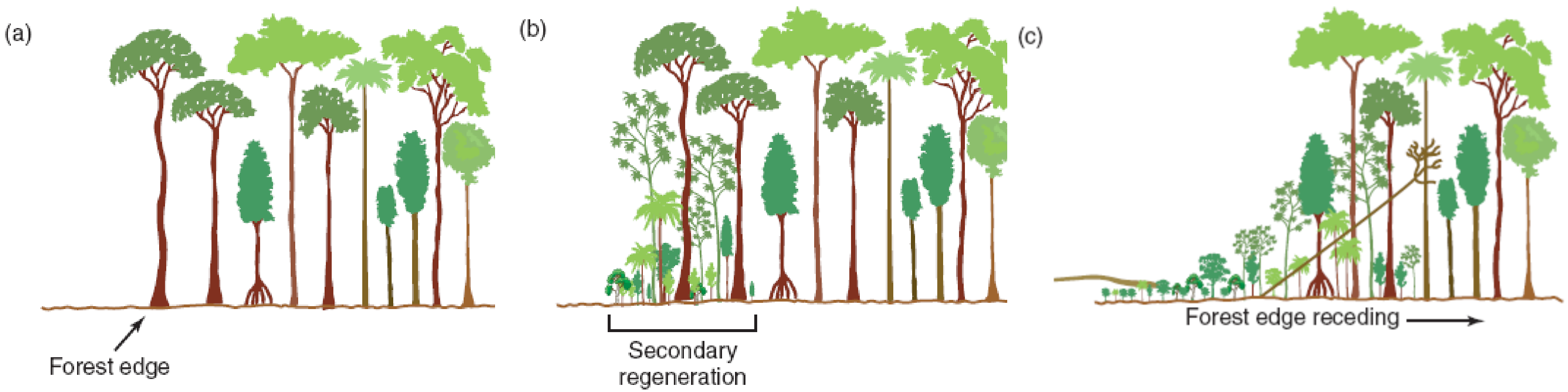


Log forest patch area (ha)

Edge effects and matrix suitability

Why do successional tree species increase along edges and in small and medium fragments?

- Mortality of non-successional species is higher along fragment edges, opening up the edge to colonization by successional species
- Seed rain from species inhabiting edges allows successional species to penetrate the forest
- Variability in edge effects can be attributed to surrounding plant communities in the *matrix* – frequent disturbances (*high-matrix harshness*) allow greater penetration of edge effects



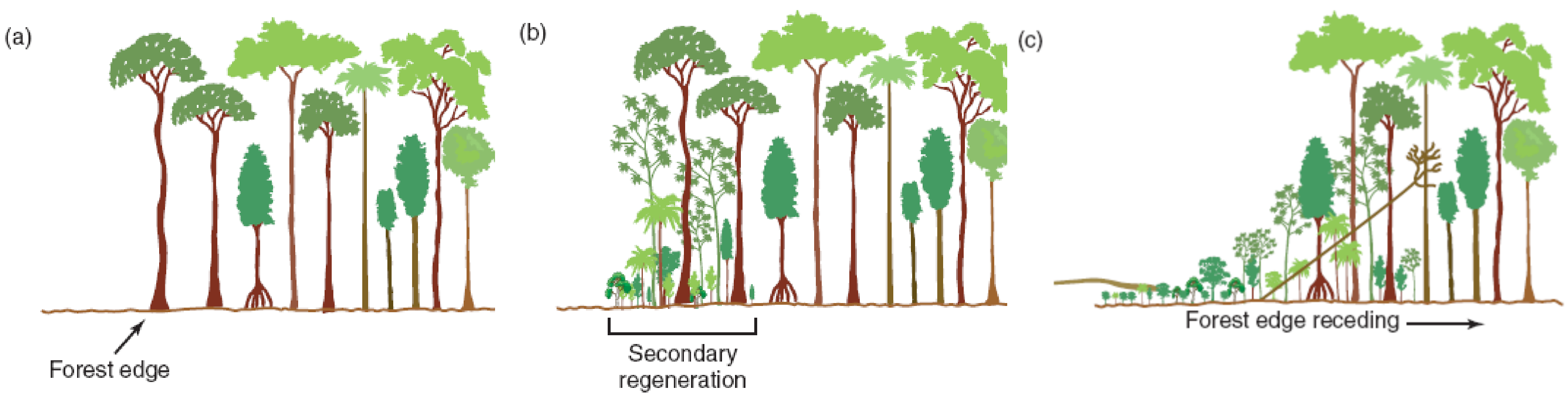
Edge effects and matrix suitability

To minimize ecological deterioration of fragmented areas:

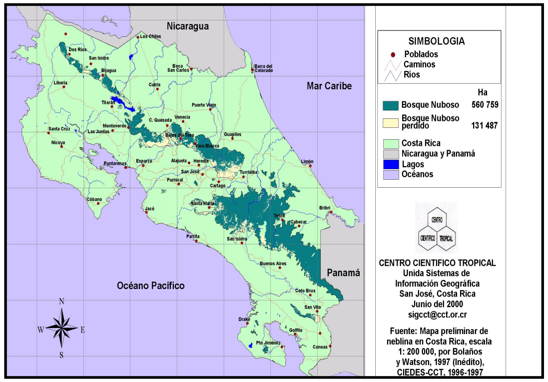
- Protect large forest remnants rather than smaller ones (maximize area/perimeter relationship)

- Protect forest edge from structural damage such as effects from fires

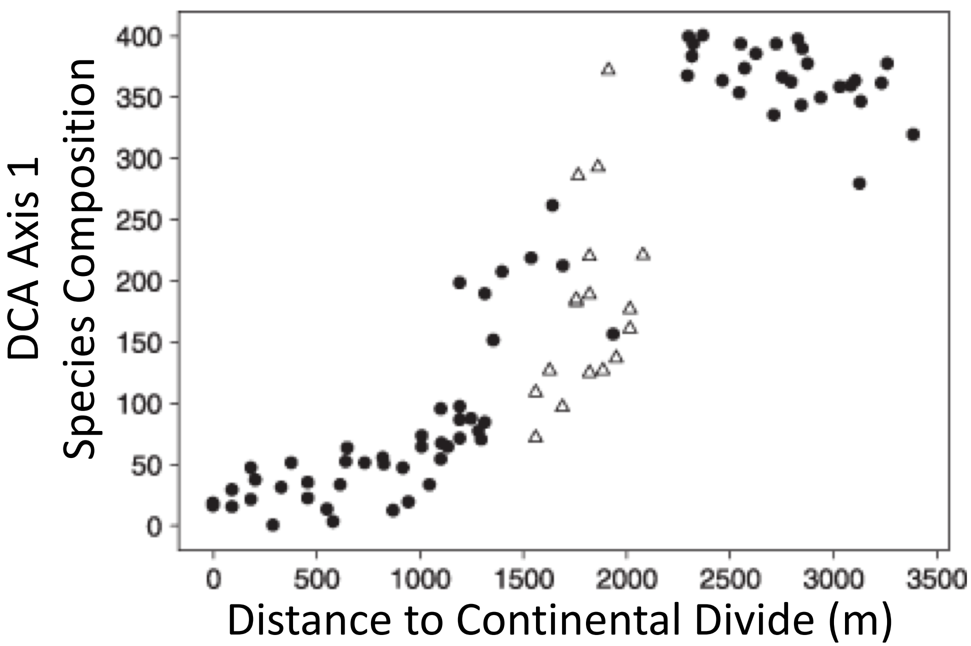
- Minimize matrix harshness through careful land use: less intensive types of land use, less road building, restriction of hunting

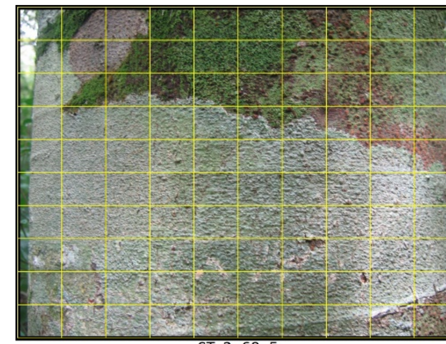


Edge effects and climate change in cloud forests



In Monteverde, Costa Rica, change in bird species composition on the mountainside reflects shifts in moisture with consequent effects on forest structure and epiphytes

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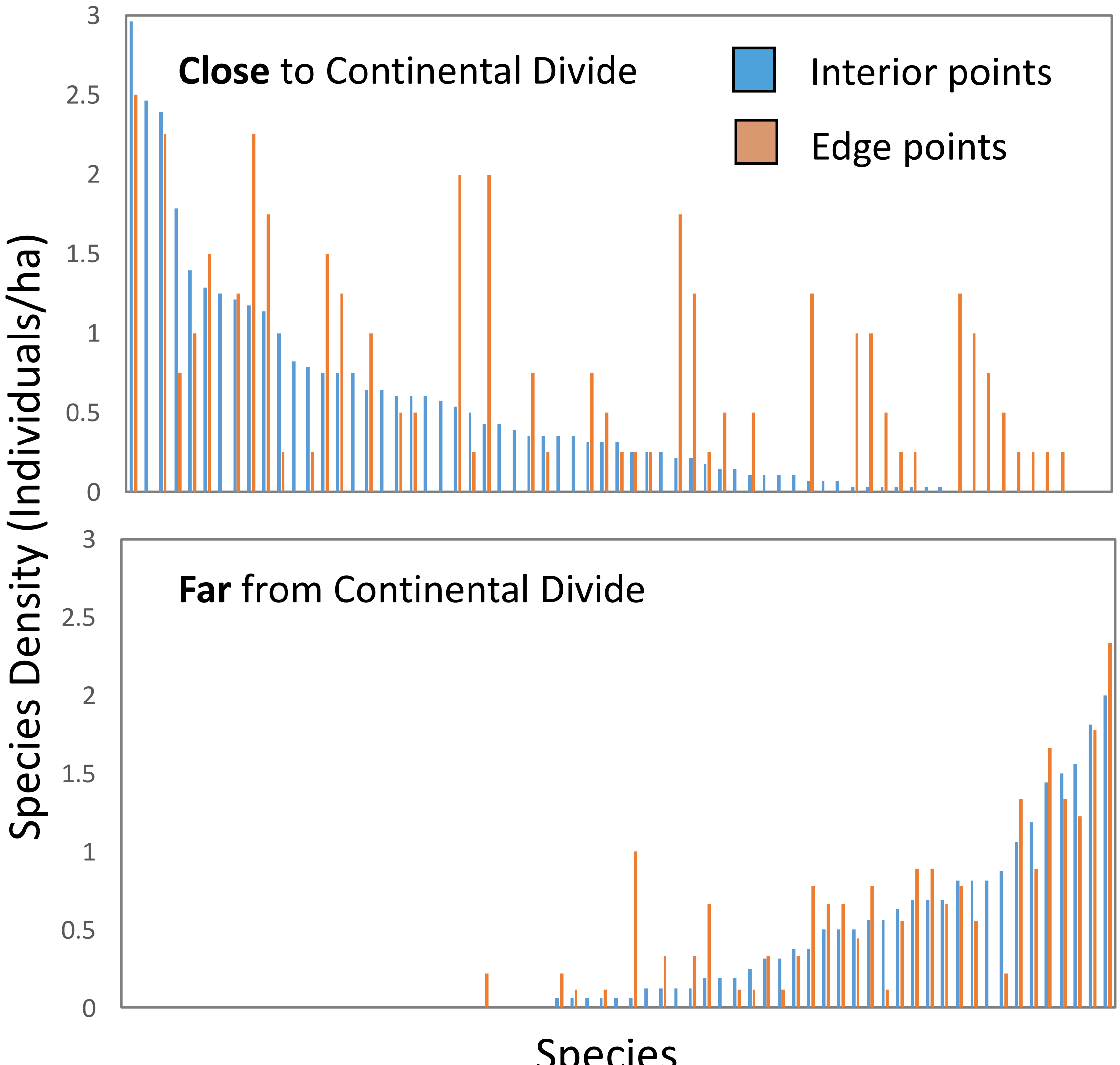
Edge effects and climate change in cloud forests

In cloud forest edge communities differ much more from interior forest communities; in lower elevation dry forest, edge and interior communities are similar



Cloud forest interior differs greatly from edge habitat

Similarity = 0.53

Dry forest communities differ little between edge and interior

Similarity = 0.81

Kyle et al. *in revision*

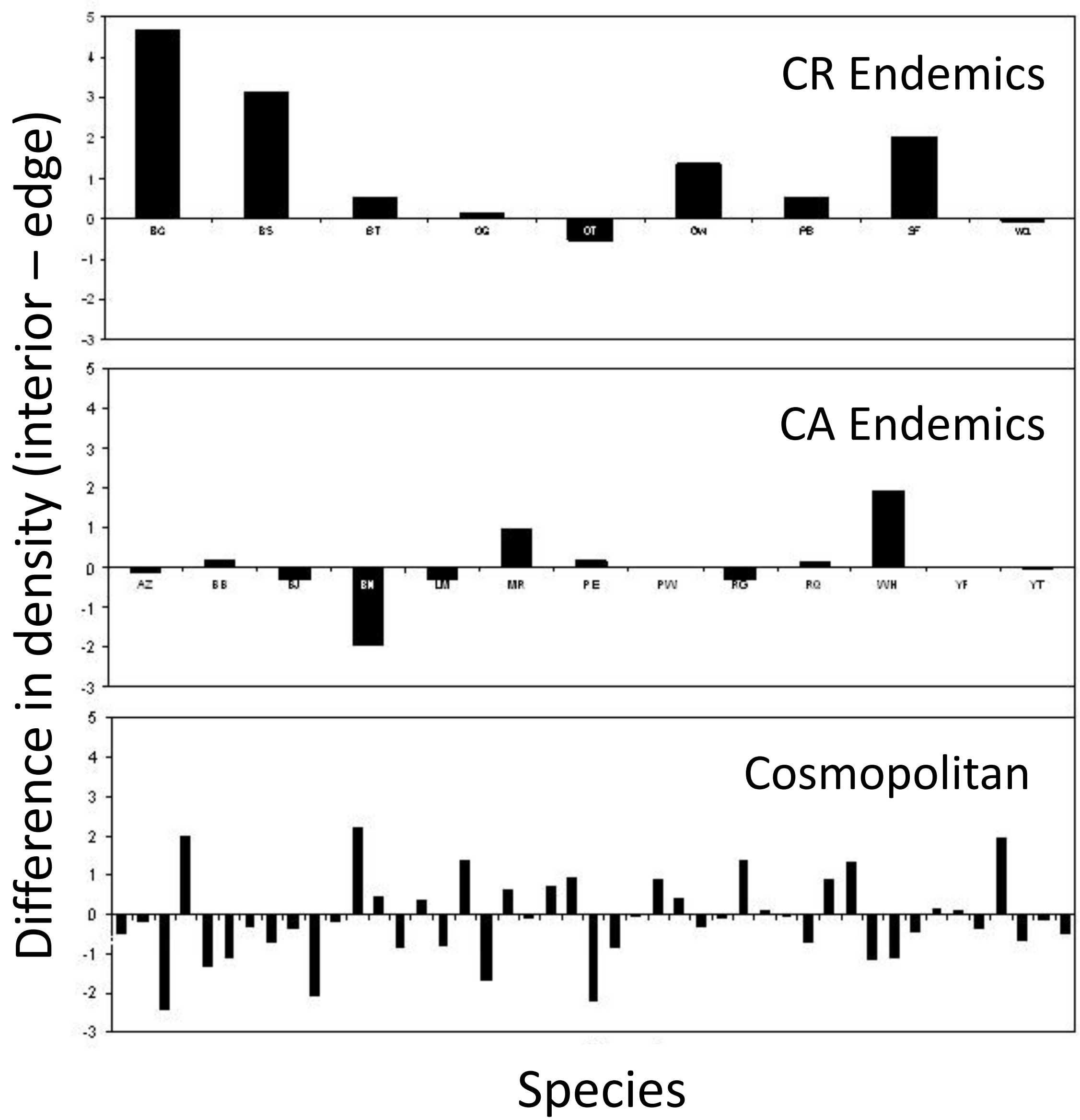
Edge effects and climate change in cloud forests

Shows differences in density between edge and interior habitats for endemic and cosmopolitan species

Positive values =
higher density at interior points

Negative values =
higher density at edge points

Generally, endemic species do not tolerate forest edges



Kyle et al. *in Prep*

Connectivity, Corridors & SLOSS

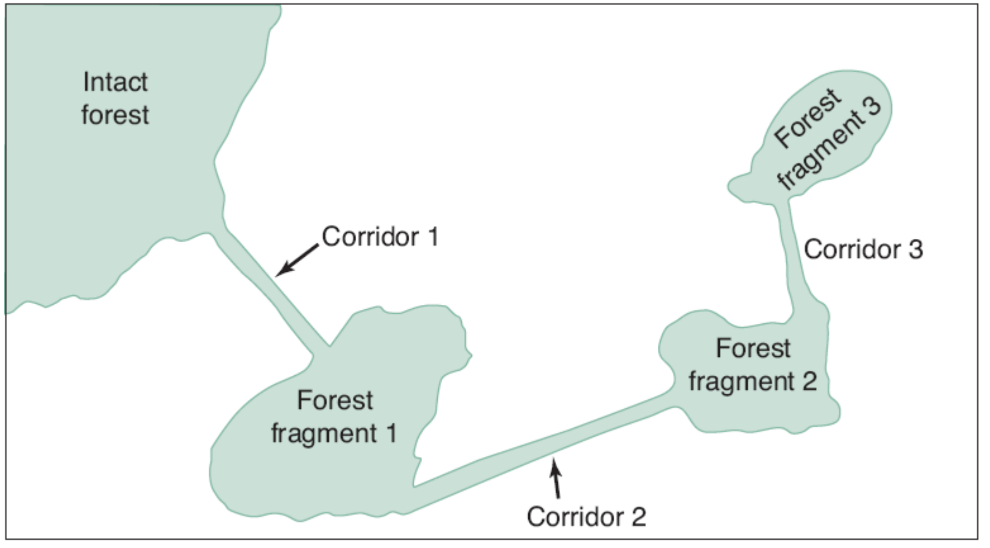
Corridors are important features that can increase connectivity and movement of species

Yet even uncut forests of 1,000 hectares may not be enough to meet requirements of certain species (apex predators)

SLOSS debate among conservation biologists – "single large or several small" areas. Little argument that large protected areas are best

Natural corridors between isolated fragments can provide connectivity and reduce isolation of populations

It is clear that **area matters**, and *minimal critical size* varies among species



Connectivity, Corridors & SLOSS

Many tropical species are sensitive to fragmentation and ecological processes can be substantially altered by fragmentation

Edge effects and the surrounding habitat matrix influence how biodiversity responds in isolated fragments, and fragments are highly dynamic