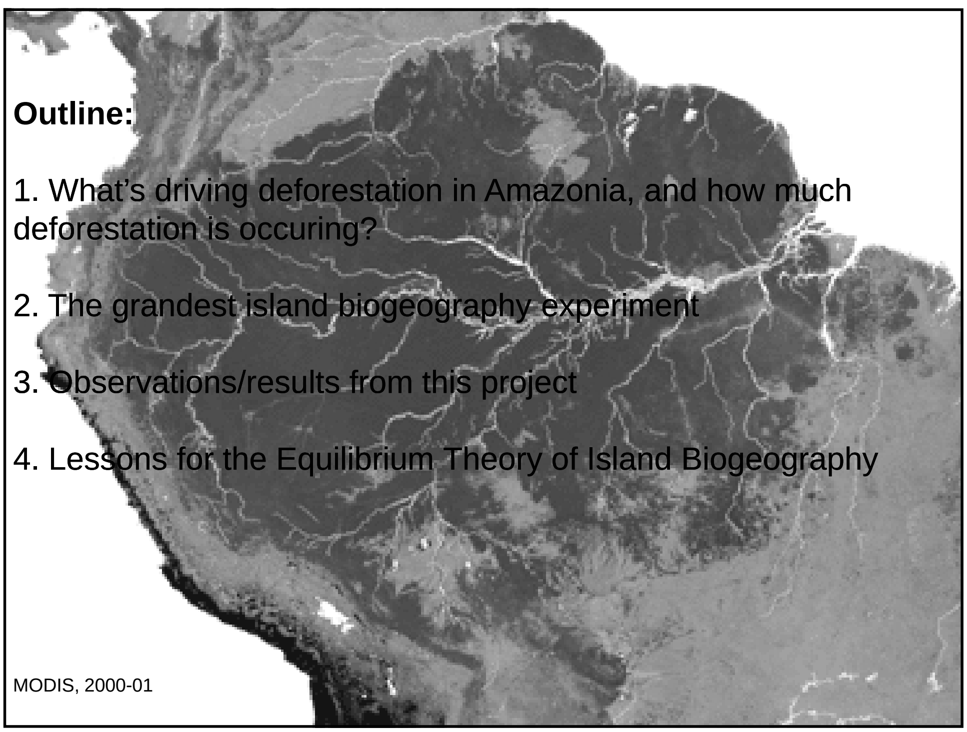
Concerns about habitat fragmentation and biodiversity: example from Amazonia



Outline:

1. What's driving deforestation in Amazonia, and how much deforestation is occuring?

2. The grandest island biogeography experiment

3. Observations/results from this project

4. Lessons for the Equilibrium Theory of Island Biogeography

Why: Principal Drivers of Amazon Deforestation

1. **Clearing for cattle pasture**

(in turn, driven by currency devaluation, road infrastructure, real estate interest rates, land tenure laws, export market)

Why: Principal Drivers of Amazon Deforestation

2. Subsistence crop farming (squatters rights)

Vicious cycle:

- **Burn**
- **Plant (bananas, palms, manioc, corn, rice)**
- **Deplete soils**
- **Abandon**
- **Burn new land**

Small-scale Subsitance Farm Field - Amazonas

Why: Principal Drivers of Amazon Deforestation

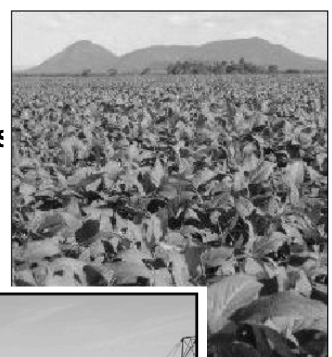
3. Road infrastructure

Why: Principal Drivers of Amazon Deforestation

4. Commercial Agriculture: Soybeans!

1990's boom.
annual increas
35-85% in
states.

Barge & Ship Loading Facilities - Cargill Floating Port, Santarem



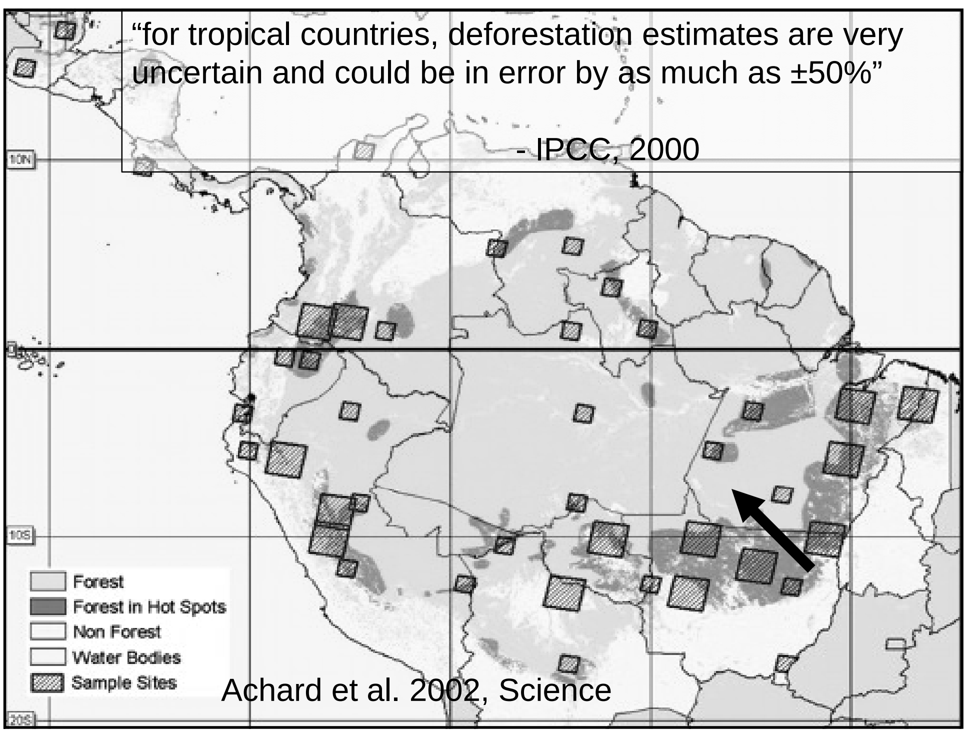
Amazon Floating Port - Itacoatiara

Estimated 2.0 Million Tons of Soybeans shipped in 2003 (Grup

Bunge Rail Spur & Grain Terminal - Estreito, Maranhao

Why: Principal Drivers of Amazon Deforestation

5. **Timber extraction.**
   - **Strict licensing, lax enforcement.**



"for tropical countries, deforestation estimates are very uncertain and could be in error by as much as ±50%"

- IPCC, 2000

Achard et al. 2002, Science

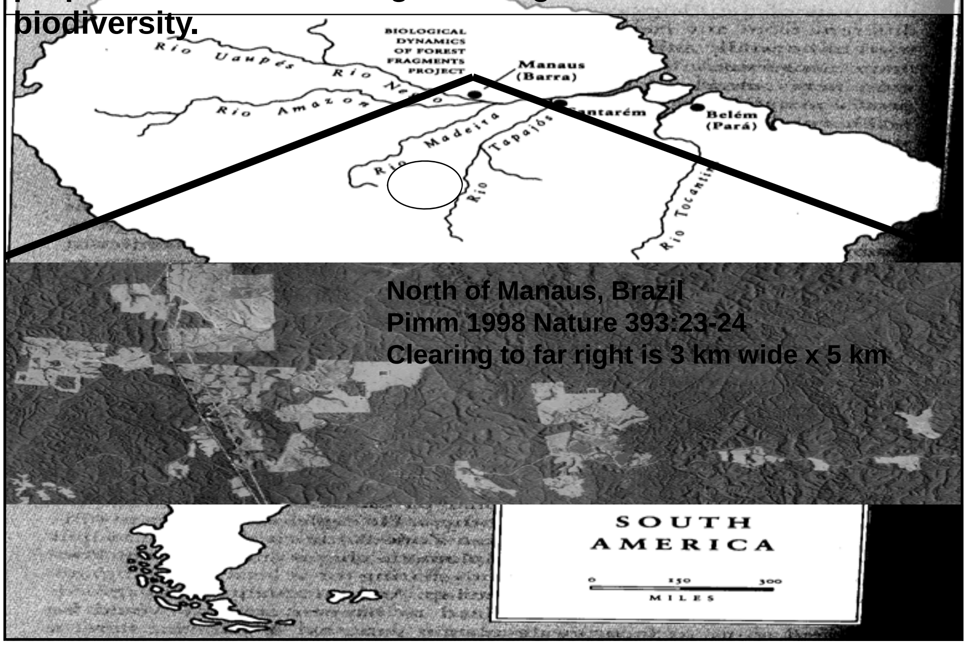
Even the low estimates of tropical deforestation are large.

Table 3. Annual deforestation rates, as a percentage of the 1990 forest cover, for selected areas of rapid forest cover change (hot spots) within each continent.

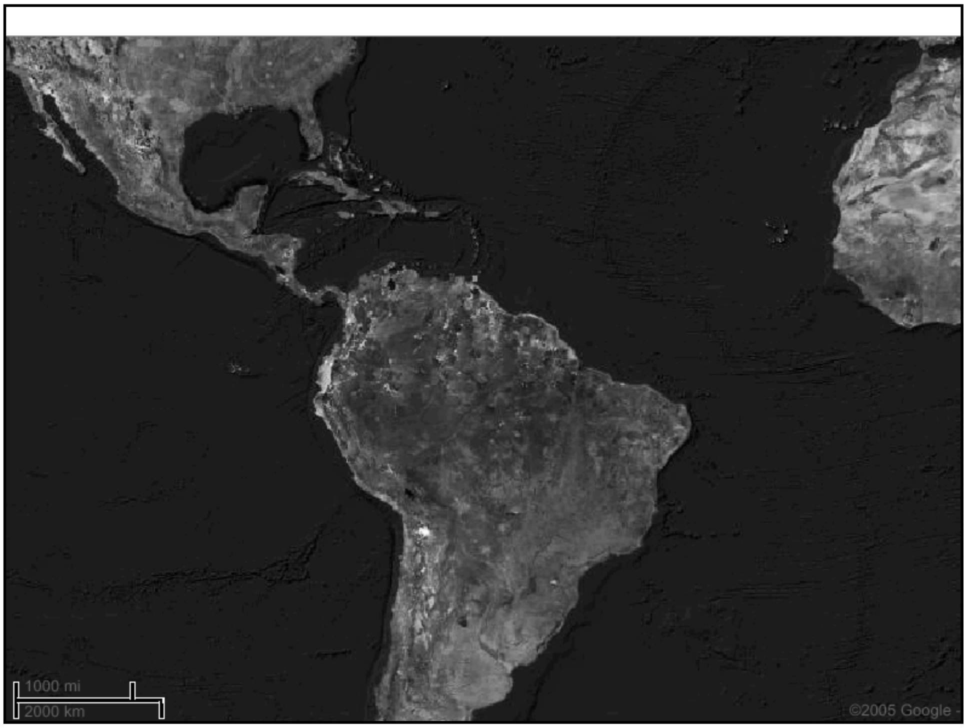
Hot-spot areas by continent	Annual deforestation rate of sample sites within hot-spot area (range)
Latin America	0.38%
Central America	0.8-1.5%
Brazilian Amazonian belt	
Acre	4.4%
Rondônia	**3.2%**
Mato Grosso	1.4-2.7%
Pará	0.9-2.4%
Colombia-Ecuador border	~1.5%
Peruvian Andes	0.5-1.0%
Africa	0.43%
Madagascar	1.4-4.7%
Côte d'Ivoire	1.1-2.9%
Southeast Asia	0.91%
Southeastern Bangladesh	2.0%
Central Myanmar	~3.0%
Central Sumatra	3.2-5.9%
Southern Vietnam	1.2-3.2%
Southeastern Kalimantan	1.0-2.7%

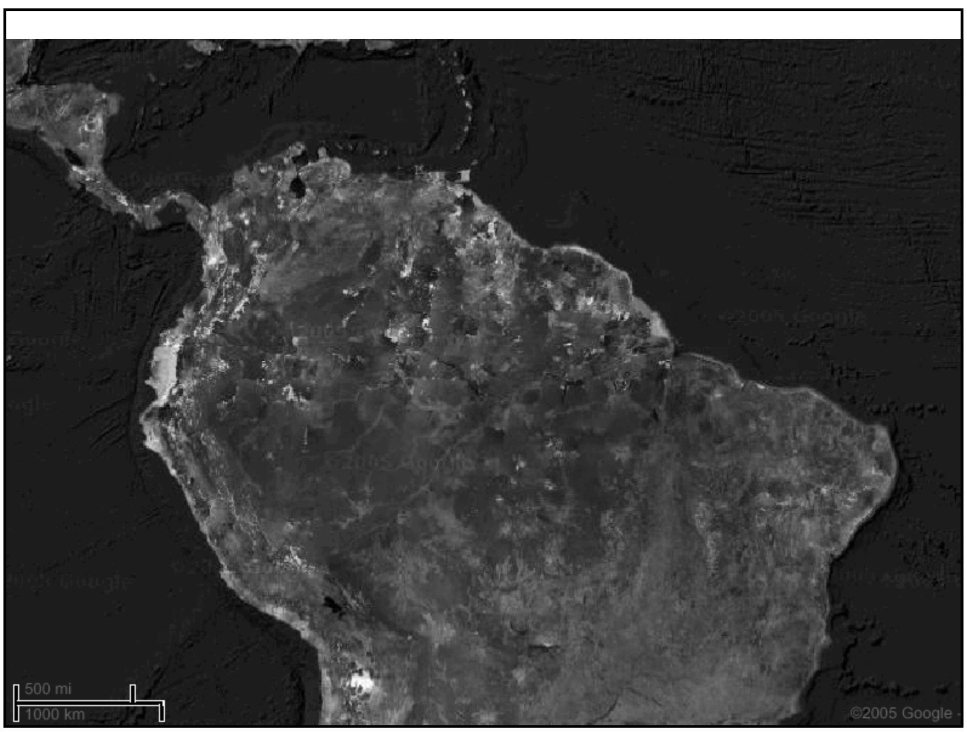
Achard et al. 2002 Science

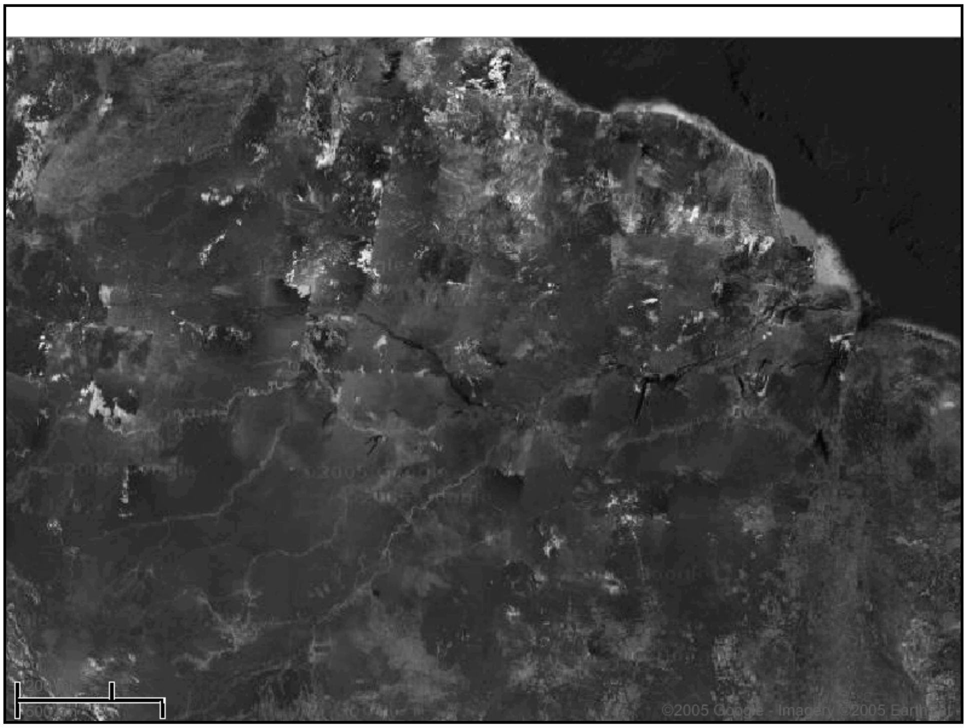
Ecologists have been carving up forests too. But for the purpose of understanding how fragmentation affects biodiversity.



North of Manaus, Brazil
Pimm 1998 Nature 393:23-24
Clearing to far right is 3 km wide x 5 km


1000 mi
2000 km
©2005 Google


500 mi
1000 km
©2005 Google




2000 ft
1 km
©2005 Google - Imagery ©2005 DigitalGlobe

-Idea conceived 1976 by Thomas Lovejoy as direct result of Equilibrium Theory debate.

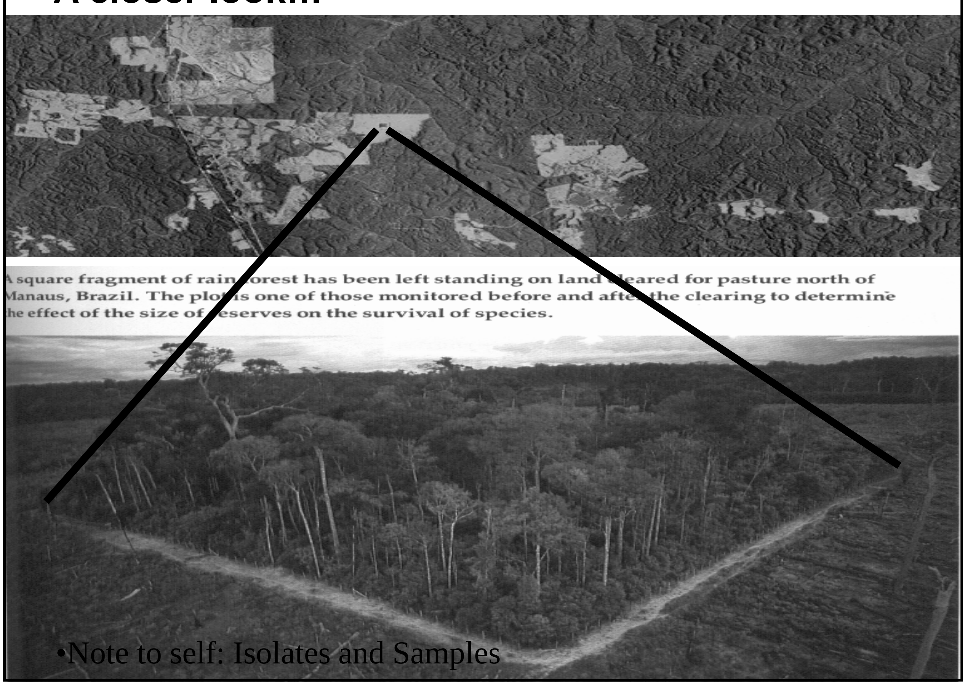
-Mission: "*Determine ecological consequences of habitat destruction and fragmentation in the Amazon, and to disseminate this information widely in such a way as to foster conservation and rational use of forest resources*"

-Collaboration between Brazilian Institute for Research in the Amazon (INPA) and Smithsonian

-opportunistic use of the Manaus Free Zone "50% provision"

-pre-sampling 1979, isolates created starting 1980.

A closer look…



•Note to self: Isolates and Samples

Study Layout: Variation across scale important for evaluating equilibrium theory (why?)

Fragment size (ha)	1	10	100	1000	Mainland
Edge (km)	0.1	0.3	1.0	3.1	-
No. fragments	8	9	5	2	1
Currently under study	8	8	5	2	1
Currently isolated	5	4	2	0	0

Appears very neat, clean, cartesian, but…

Masks a great deal of habitat heterogeneity, even within "lowland terra firma rainforest":

Reserve 2303 (100 ha): "Bisected terrain. High hill to NW, draining with valleys to SE. Swamp area long S edge. Soil with more sand than other reserves, as well as thicker/shorter canopy. Extensive area NW has poor drainage, lots of edges w/ young trees, few large trees, no palms…"

"Mainland" Control: "Several forest physionomic types, several streams, 2 lakes…", peculiar soil types.

Observations from this project:

•Smaller ‘islands’ lost far more species.

•Due to both range size requirements and edge effects (dry winds drying out interior)

•Lots of ‘secondary effects’ – “trophic cascades”

- e.g. Peccaries leave, no wallow pools, three species of frog couldn’t breed anymore and went extinct, beetles that feed on frog waste disappeared, etc. etc.

It would be nice if these effects could be predicted in advance…

It could help us decide how big we need to make reserves.

Lessons from this project:

•Some consistency with equilibrium theory, but many more ‘autecological’ results and edge effects.
•Sloss debate not settled in probably the cleanest experiment that could address it.
•Some studies flat out say equilibrium theory irrelevent (Barbara Zimmermann frogs):

“The inescapable conclusion [is that MacArthur/Wilson] has taught us little that can be of real value planning real reserves in real places”

Nevertheless, this project has yielded a great deal of information on the many impacts of habitat fragmentation over 25 yrs, and would never have been conducted if it weren’t for the equilibrium theory.

GE/BI307
Reserve Design: The SLOSS debate and Beyond

Outline

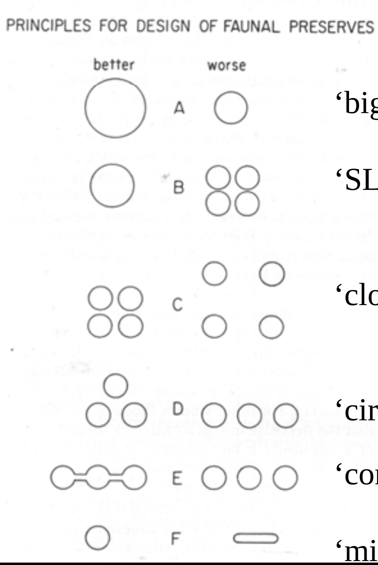
1. **Island theory and the SLOSS question.**
2. **Point and counterpoint**
3. **Beyond SLOSS: what have we learned about reserve design?**

1. Island theory and the SLOSS question.

Species-Area relationship predicts larger areas contain more species.

Taken at face value, this suggests that 1 large reserve should contain more species than several smaller reserves totaling the same area.

Touching off the debate: Diamond J. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biological Conservation 7:129-146.



‘bigger is better’

‘SL better than SS’

‘closer better’

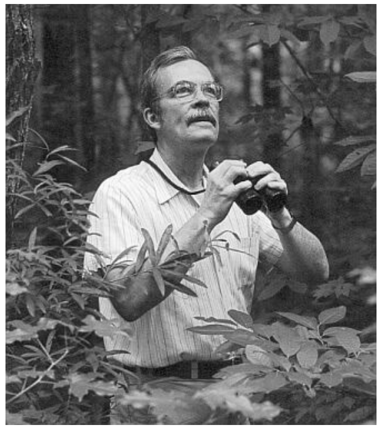
‘circular better than linear’

‘connected better than isolated’

‘minimize edges’

Other key ‘pro-SL>SS paper:

Terborgh J. 1976. Island Biogeography and conservation: Strategy and Limitations. Science 193:1029-1030.



Contrarians: Simberloff DS, Abele LG. 1976. Island Biogeography theory and conservation practice. Science 191:285-286.

Daniel Simberloff –
U. Tennessee (via Fl. State)

Lawrence Abele –
Florida State University

Simberloff argument:

When z<1 (always the case) half the area preserves more than half the species.

Thus, two reserves of ½ area may contain more than the species in the full area.

What key assumption does this depend on?

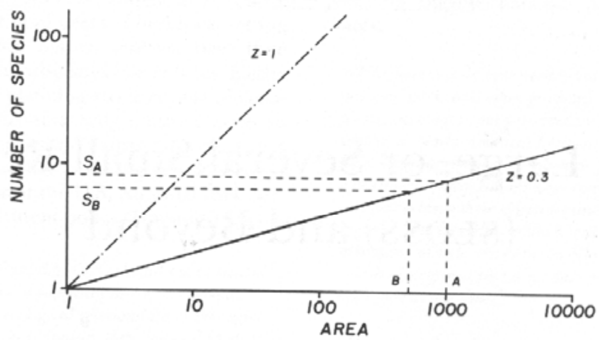


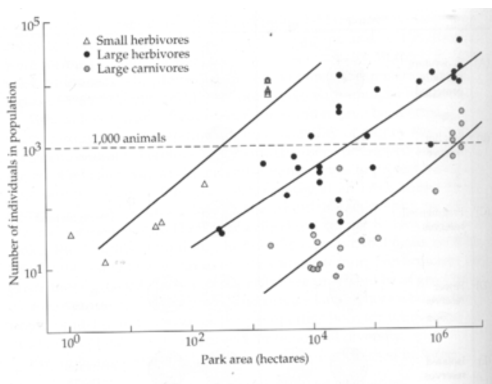
Figure 40. Plot of a species-area relationship using log transformed species numbers and areas (i.e., a log-log plot). The dot-dash line is a species-area relationship with a slope of 1 (z = 1), reflecting a constant return in species number regardless of tract size. The solid line with a slope of 0.3 (z = 0.3) is the situation frequently found in real landscapes. A slope less than 1 indicates a decreasing return in number of species per unit area with increasing area.

Point A on the *x*-axis represents a nature reserve with area A, and point B on the *x*-axis a reserve with area $B = A/2$. The dashed lines project these areas onto the species-area curve of z = 0.3 and then to the vertical axis so the number of species in each reserve can be found as points S_A and S_B on the *y*-axis. The small distance between points A and B on the *x*-axis indicates that setting aside half the area will conserve more than half the species; therefore, two small reserves of area $B = A/2$ may harbor more species than a reserve of area *A*. Abele and Connor's (1979) above argument was an early one in the subsequent long controversy known as Single Large Or Several Small reserves (SLOSS). (From Abele and Connor 1979.)

Response from Diamond:

Larger areas are more likely to contain the wide-ranging species that are often most threatened.

The sum of species in small areas may exceed a large area, but may be composed of generalists and weeds.



10 000 ha or four reserves of 2500 ha each? The proponents of large

Why several small can be better than single large:

1. Habitat diversity.
2. Focal species conservation, e.g Cape Floral Province

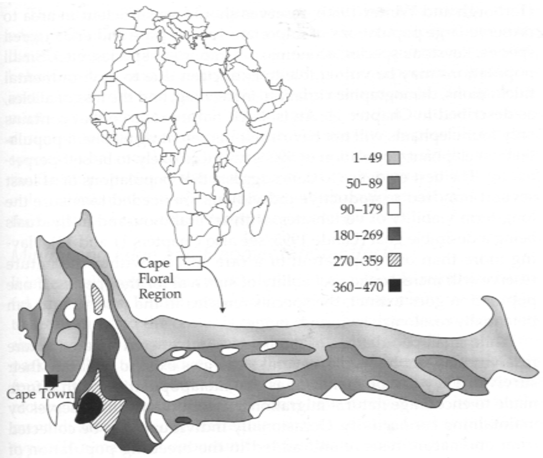
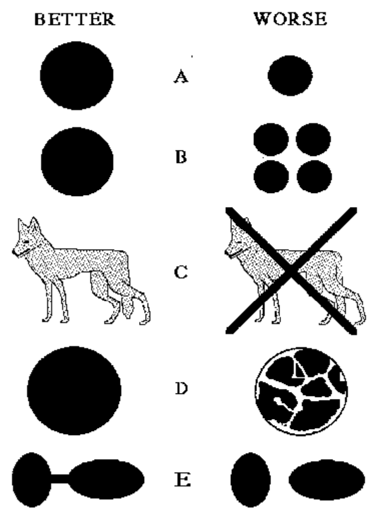


Figure 16.5 Species richness for flowering plants increases to an incredible level in the fynbos vegetation of the southwest corner of the Cape Floral Province in South Africa. The map shows the number of species in characteristic and endemic plant families, such as the Proteaceae, Ericaceae, and Restionacae. (From Rebelo and Siegfried 1990, based on Oliver et al. 1983.)

Cape Floral Province:
-68% of species are endemic
-53 species of endemic Proteacea species restricted to 1 or 2 populations
-Each population occupies 5 km2 or less, contains less than 1000 individuals.
-A few large parks would completely miss many of these species.
-Many smaller, scattered parks would be more effective in this case.

Whatever the merits of Diamond’s geometric reserve design recommendations, all would agree that these simple rules have been adopted uncritcally (e.g. 1980 World Conservation Strategy, World Conservation Union)



“I suspect workers are growing more weary of it than approaching any agreement on its resolution”

– Craig Shafer
Nature Reserves: Island Theory and Conservation Practice 1990

I wholeheartedly agree…

Beyond SLOSS

Consensus:

Strategies for conservation depend on the group of species under consideration and specific circumstances. (shift to autecological focus from synecological focus).

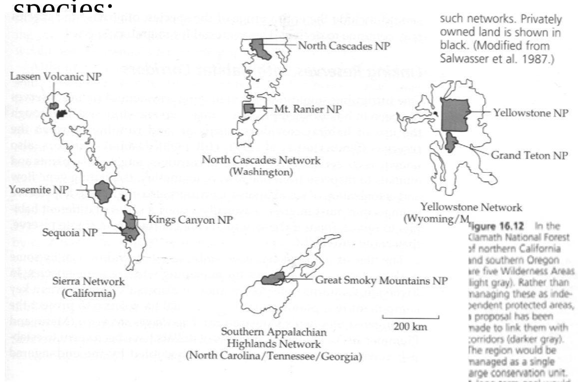
Corralary: There has been a shift away from Equilibrium Theory and toward Minimum Viable Population/ Minimum critical size analysis.

Large reserves are desirable, but well-managed small reserves have an important role in protecting focal species of value.

Types of focal species:

1. Keystone species: many others depend on it (e.g. Beaver)
2. Umbrella species: large range protects many other species (bear)
3. Flagship species: public appeal (e.g. great blue heron)
4. Indicator species (frogs)
5. Vulnerable species: Endangered Species List.

Recognizing the importance of buffers and corridors for focal species:



Effective corridors must be designed with care – e.g., many animals move along riparian zones but not other pathways.

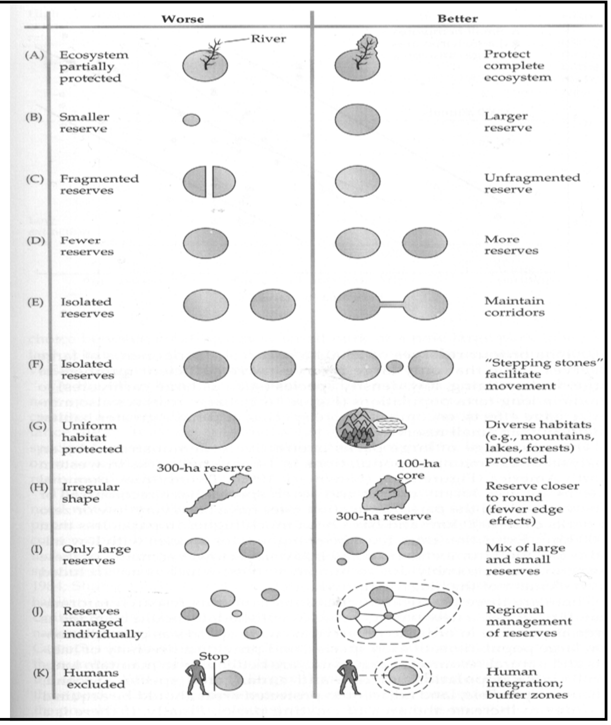
Marine reserves:

•Most island biogeography theory has been applied to conservation of terrestrial habitats, not marine.

•Aquatic reserves largely under-studied.
- Dispersal mechanisms, characteristics largely unknown.
- Pollution may have more subtle/widespread effects in aquatic systems than in terrestrial

Conservation strategies
-Primack

-The role of humans



Humans and Nature Apart:

"Protected areas are a seductively simple way to save nature from humanity. But sanctuaries admit a failure to save wildlife and natural habitat where they overlap with human interests, and that means 95% or more of the earth's surface. Conservation by segregation is the Noah's Ark solution, a belief that wildlife should be consiged to tiny land parcels for its own good and because it has no place in our world. The flaw in this view is obvious: those land parcels are not big enough to to avert catastrophic species extinciton by insulratization or safe enough to protect resources from the poor and the greedy. Simply put, if we can't save nature outside protected areas, not much will survive inside; if we can, protected areas will cease to be arks".

D. Western et al. 1989.

GE/BI 307 April 10, 2007

Minimum Viable Populations and Population Viability Analysis

1. **What is MVP?**
2. **What factors determine MVP?**
3. **What is PVA?**
4. **How are PVA's conducted? Case study.**

---

1. **What is MVP?**

Shafer 1981: "A MVP for any given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1000 yrs despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes"

- **Not a fixed quantitative definition; other percentages and time periods may be used.**

- **Analagous to flood control measures. Plan for extreme events rather than mean conditions.**

1. What is MVP?

Related to Minimum Dynamic Area:

Once MVP is estimated, characteristic population densities (# individuals per area) can be used to determine minimum area requirements.

Similar to the Insular Distribution Function described earlier (but that function includes isolation)

1. What is MVP?

Thus, MVP 'inverts' a core question addressed by the equilibrium theory:

Instead of: "How many species exist in X area?"

MVP asks: "How much area is needed for Species X?"

1. **What is MVP?**

Estimates range from 500-10,000, but single numbers can be (and have been) very misleading.

But there have been interesting and suggestive observations…

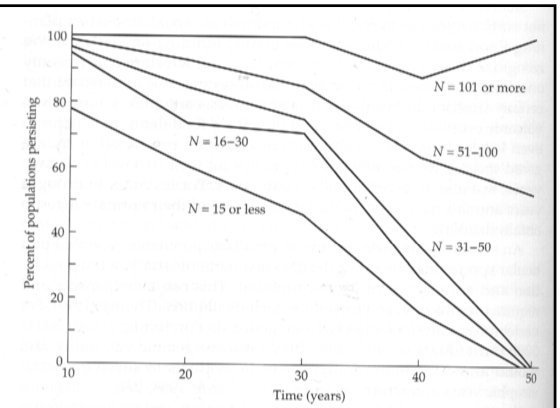
Bighorn sheep, SW US

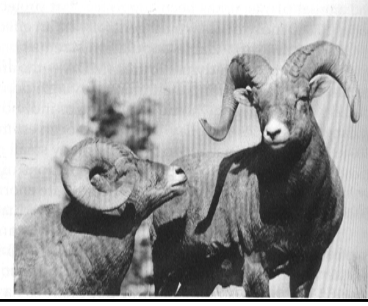
50 individuals appears to be a threshold for century scale survival.

No single cause apparent – likely several factors.

What are possible factors?

(figures from Primack)





onship between the size
ɔrn sheep and the per-
that persist over time.
ıph indicate population
lations with more than
'ond 50 years, while pop-
ı 50 individuals died out
Berger 1990; photograph

2. What factors determine MVP?

Deterministic factors: **logging, hunting, pollution, etc. Things we can control.**

Stochastic factors:

- **Genetic problems associated with low population sizes (genetic drift, impoverishment, inbreeding depression)**
- **Demographic fluctuations (variation in birth, death rates and offspring gender distribution)**
- **Environmental stochasticity (catastrophes, floods, drought, fires, etc.)**

Often these factors add to the genetic extinction vortex.

More on demographic effects:

Recall effective population size:

$Ne = 4x\ N_m \times N_f/(N_m + N_f)$

This is for breeding animals, not all animals!

Age, health, behavior (e.g. monogamy vs. polygamy) may all affect breeding patterns.

Effective populations can therefore be much smaller than actual populations.

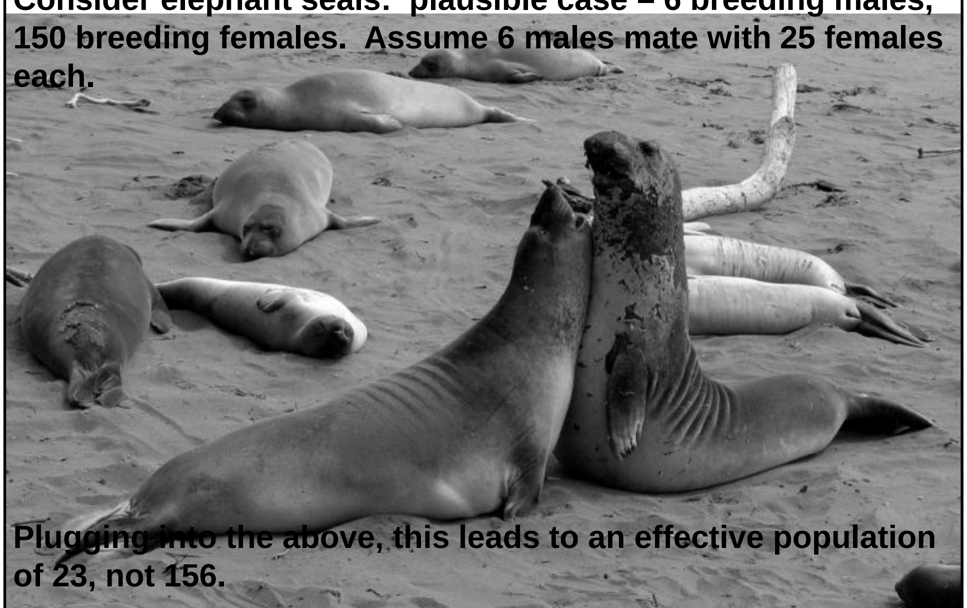
E.g. 1000 alligators may only have 10 animals, 5 male, 5 female that are of the right age and health to breed. Effective population is 10, not 1000.

More on demographic effects:

Not just the number of breeding animals matters, but the sex ratio as well.

$Ne = 4x\ N_m \ x\ N_f/(N_m + N_f)$

Consider elephant seals: plausible case – 6 breeding males, 150 breeding females. Assume 6 males mate with 25 females each.



Plugging into the above, this leads to an effective population of 23, not 156.

Thus, polygamy is discounted in Ne, and reflects the limited genetic variation due to unequal sex ratio.

More on demographic effects:

Effective population can be computed over generations:

Ne = t/(1/N1 + 1/N2 + 1/N3 +…)

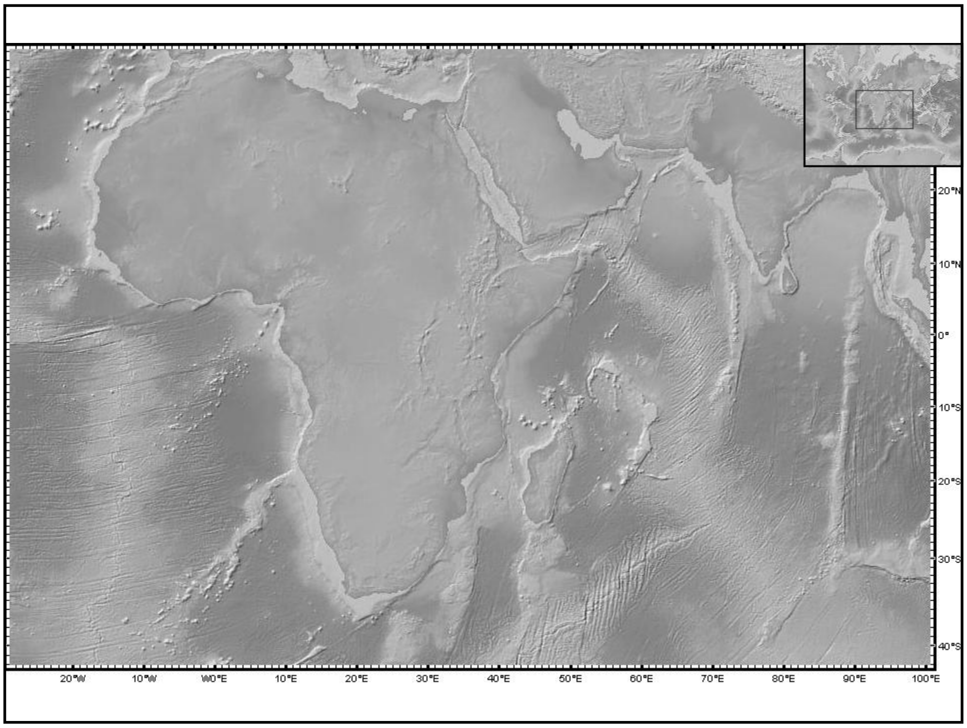
Where t= number of generations
Nx = Ne at year x.

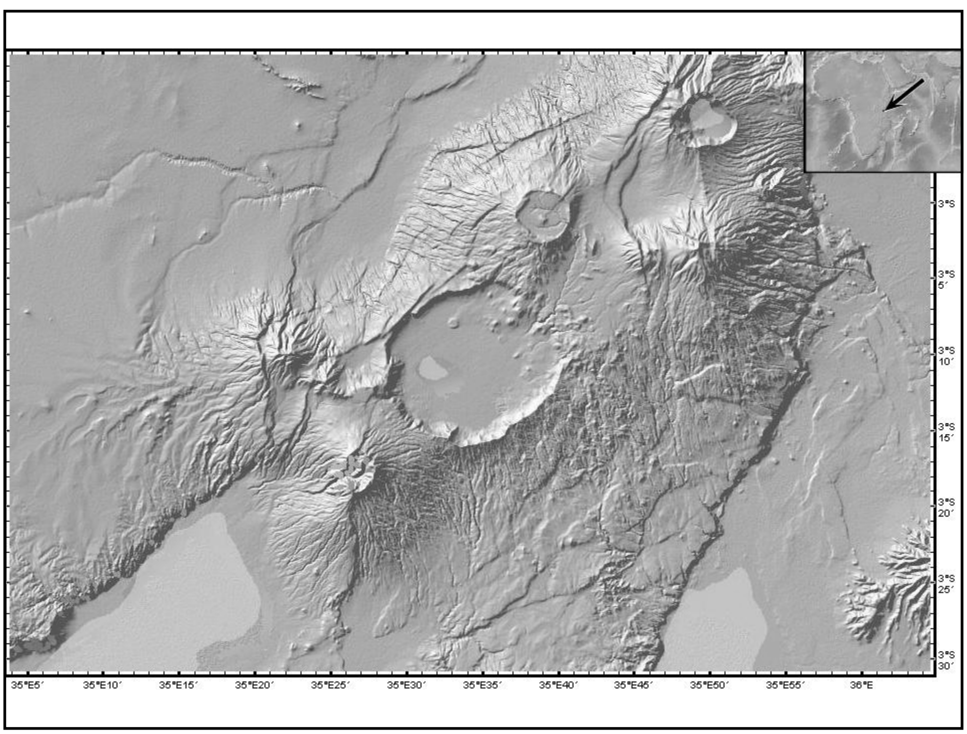
Example: 5 generations of endangered butterfly, with 10, 20, 100, 20, and 10 breeding individuals.

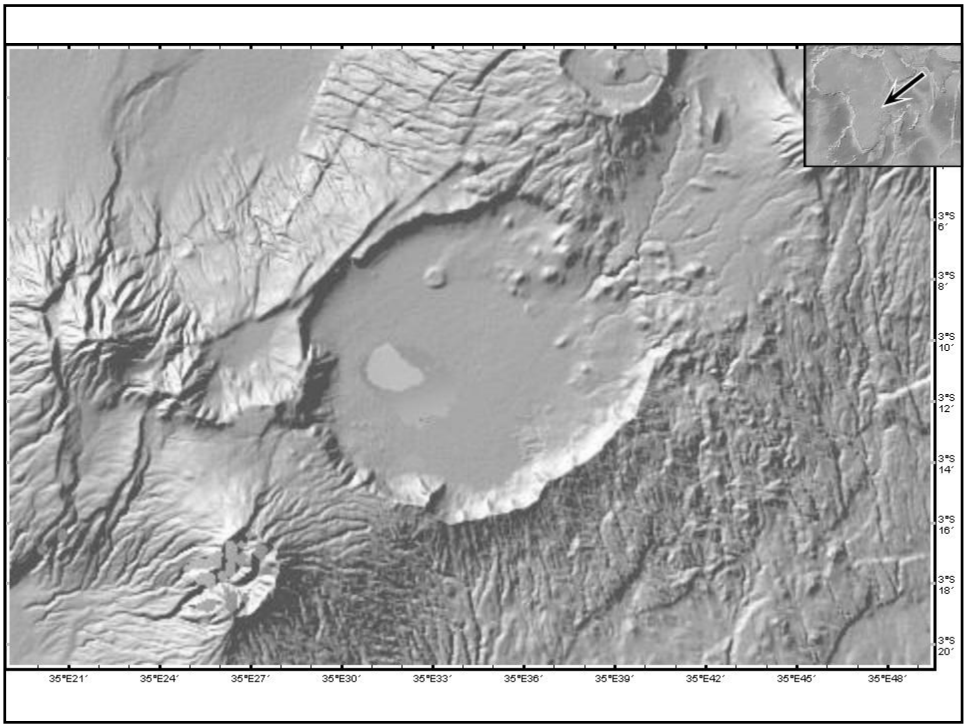
Ne = 5/(1/10 + 1/20 + 1/100 + 1/20 + 1/10) = 5/(31/100) = 16.1

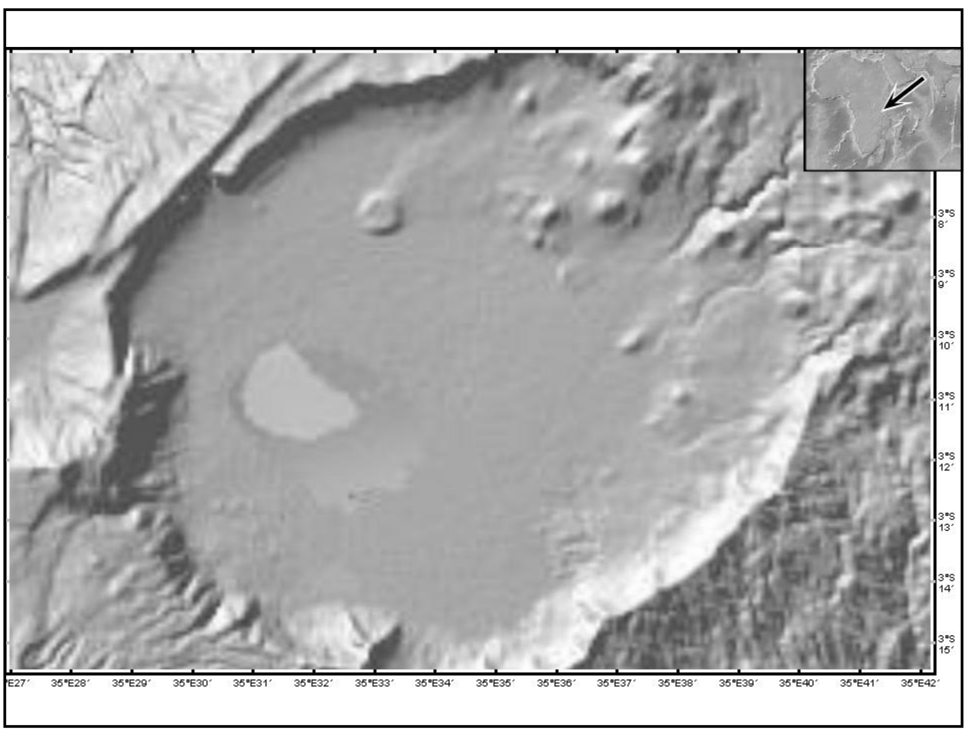
Note: if there were 500 individuals in year 3, we would get only 16.6. Thus, effective population sizes integrated over time are impacted much more by the "lean" years – "population bottleneck"

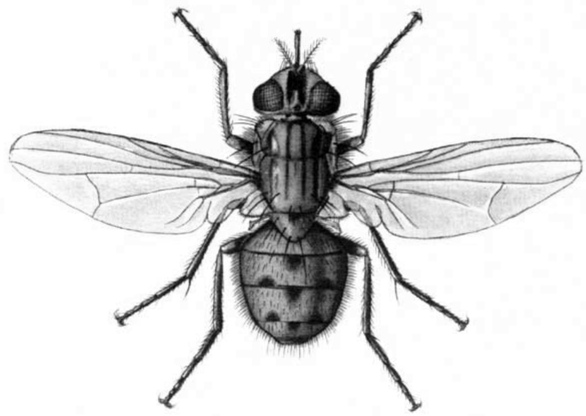
Example of "genetic bottleneck" – Lions in Ngorongoro Crater, Tanzania


20°N
10°N
0°
10°S
20°S
30°S
40°S
20°W
10°W
W0°E
10°E
20°E
30°E
40°E
50°E
60°E
70°E
80°E
90°E
100°E


3°S
3°S 5′
3°S 10′
3°S 15′
3°S 20′
3°S 25′
3°S 30′
35°E5′
35°E10′
35°E15′
35°E20′
35°E25′
35°E30′
35°E35′
35°E40′
35°E45′
35°E50′
35°E55′
36°E

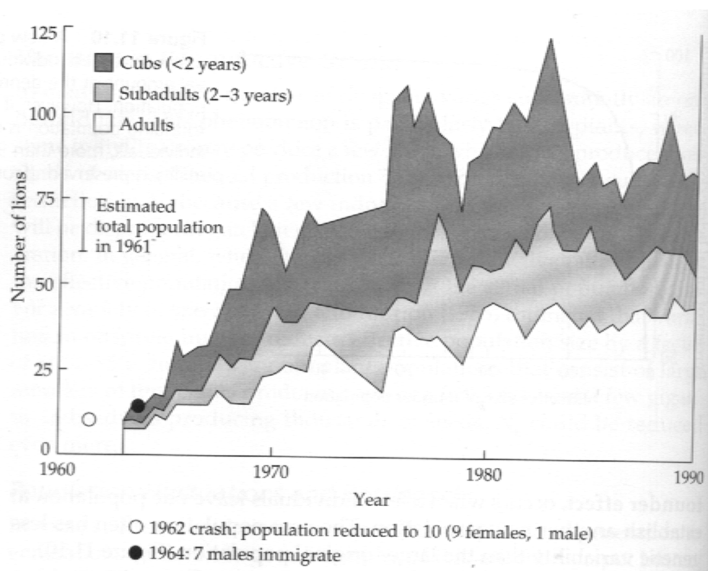

3°S 6´
3°S 8´
3°S 10´
3°S 12´
3°S 14´
3°S 16´
3°S 18´
3°S 20´
35°E21´
35°E24´
35°E27´
35°E30´
35°E33´
35°E36´
35°E39´
35°E42´
35°E45´
35°E48´

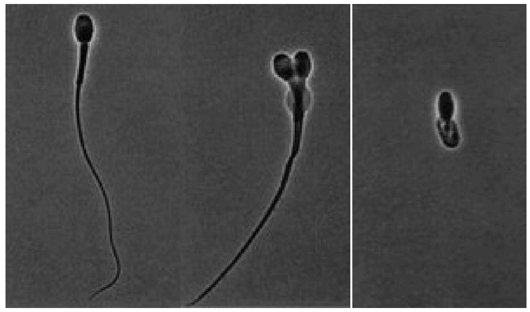

3°S 8´
3°S 9´
3°S 10´
3°S 11´
3°S 12´
3°S 13´
3°S 14´
3°S 15´
35°E28´
35°E29´
35°E30´
35°E31´
35°E32´
35°E33´
35°E34´
35°E35´
35°E36´
35°E37´
35°E38´
35°E39´
35°E40´
35°E41´
35°E42´



Stomoxys calcitrans
Biting fly 1961-62

igure 11.11 The Ngorongoro Crater lion opulation was about 1 individuals in 1961 efore crashing in 1962. ince that time the population has returned to s original numbers, but he isolated location and ck of immigration since 964 have apparently reated a genetic bottleeck. (From Packer et al. 991.)





Ominous telltales, sperm from crater males (middle and right) show abnormalities when compared with a normal sample. Reproductive physiologist David Wildt and his colleagues at Washington's National Zoo found structural deformities in more than half the sperm of each male tested, strong evidence of inbreeding. The continuous decline of genetic diversity since 1969 is perhaps linked to a falling reproductive rate.

photo credits: David Wildt and Jo Gayle Howard,
source: National Geographic, July 1992, p.133

The 50/500 “rule” (Soule and Gilpin):

A variety of breeding studies suggested that inbreeding depression becomes a major factor driving extinction in sexually reproducing populations less than 50 (effective pop. Size).

And that the genetic impoverishment (loss of alleles) occurs below effective population sizes of 500.

This rule has been taken very literally and was sometimes used to justify not protecting very small populations because they were considered doomed. (Simberloff complaint).

Never intended to be taken so literally.

Recall genetic extinction
Vortex from before.
Add:
Demographic stochasticity

Environmental
Stochasticity

Thus, Situation can get
Even worse.

Including genetic,
Demographic, and
Environmental factors
All together is done
In Population Viability
Analyses

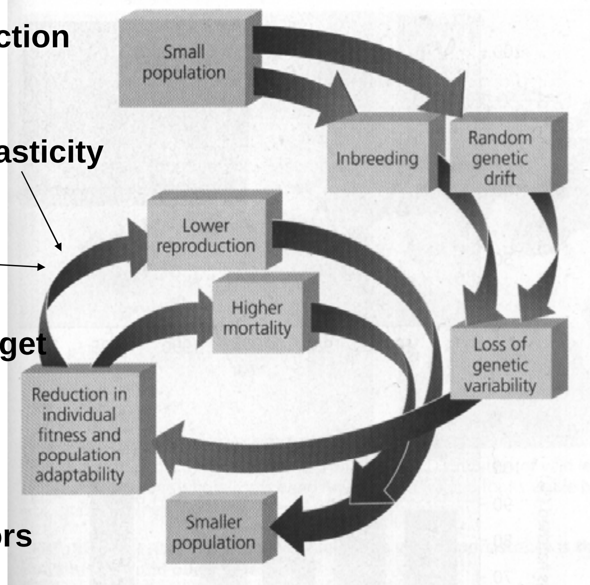


FIGURE 55.10 The extinction vortex of the small-population approach. Small populations can fall into a vortex of positive feedback loops leading to smaller and smaller population size.

3. What is Population Viability Analysis?

- **A much more integrative framework for determining MVP.**

- **Goal: determine in an integrative manner how deterministic and genetic, demographic, and environmental factors together determine the probability of extinction for a population, and thereby guide practical, specific conservation strategy.**

- **Spurred by very practical problems (Gilpin and Soule) – how to save specific species in specific situations.**
  - how to justify conservation of species at even very low numbers (beyond the 50/500 rule).

- No standardized methodology at present, case by case.