# Biodiversity in the tropical rain forest

Ter Steege & Zagt, 2003

Dirk Hölscher, Tropical Forest Ecology and
Silviculture, University of Göttingen

Biological diversity → Biodiversity

Biodiversity: the word was generated in 1988 by E.O. Wilson

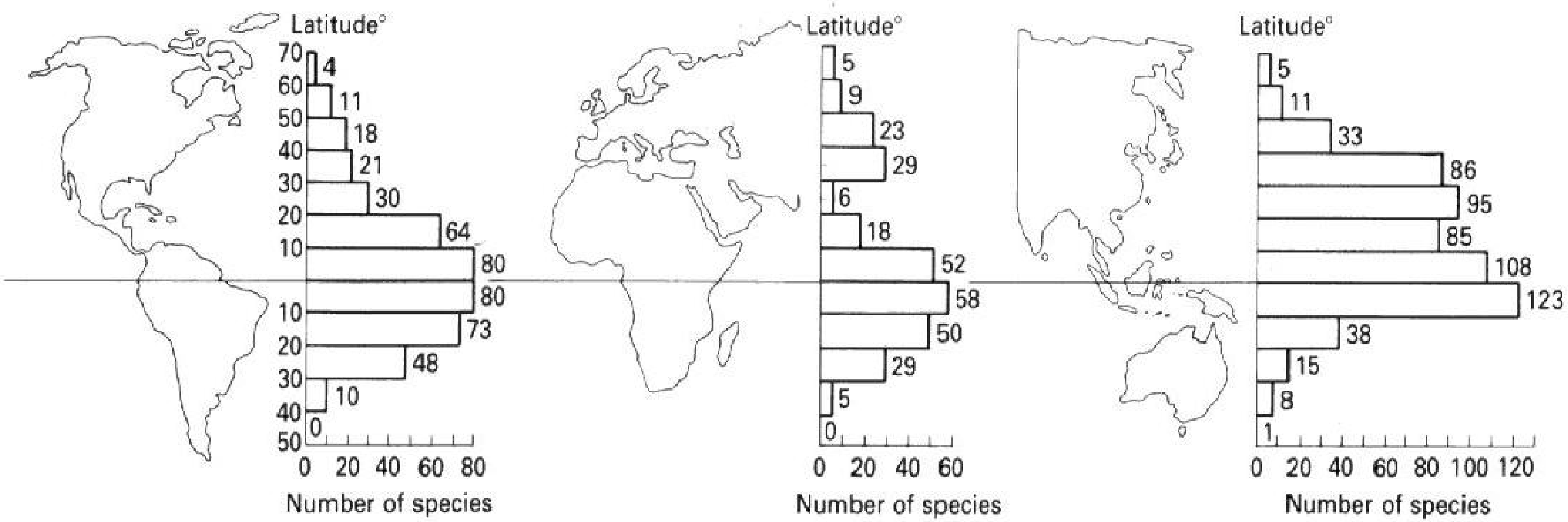
all aspects of variability evident within the living world, including diversity within and between individuals, populations, species, communities, and ecosystems.

# Pattern in biodiversity

- the latitudinal gradient in species diversity is arguably the most universal pattern in global biodiversity
- the lower the latitude, the higher the number of species in a given area.

This pattern, with biodiversity peaking in the tropics, is found in most taxonomic groups

Species numbers of swallowtail butterflies decrease away from the tropics




Collins and Morris 1985

# Species-rich habitats

- Moist forests in the tropics are in general the most species-rich terrestrial environments on earth.
- If recent estimates of the number of as yet unknown species, mainly insects, in tropical forests are accepted, these regions, which extend over perhaps 7% of the world's surface, may hold up to 90% of the world's species.

- If small insects are discounted, then coral reefs may be similarly rich in species
-For flowering plants: areas of Mediterranean climate in South Africa and southwest Australia, are also very rich in species

UNEP-WCMC, *Global Biodiversity Assessment*

# Kinds of diversity

- Alpha diversity: species richness within a habitat
- Beta diversity: species diversity along transects and gradients. E.g. the change in species diversity along an altitudinal gradient.
- Gamma diversity: species diversity of a larger geographical unit (e.g. islands)

# Indices for alpha diversity

All based on proportional species abundances, dominance and frequency may also be included

Abundance: numbers of individuals of a given species

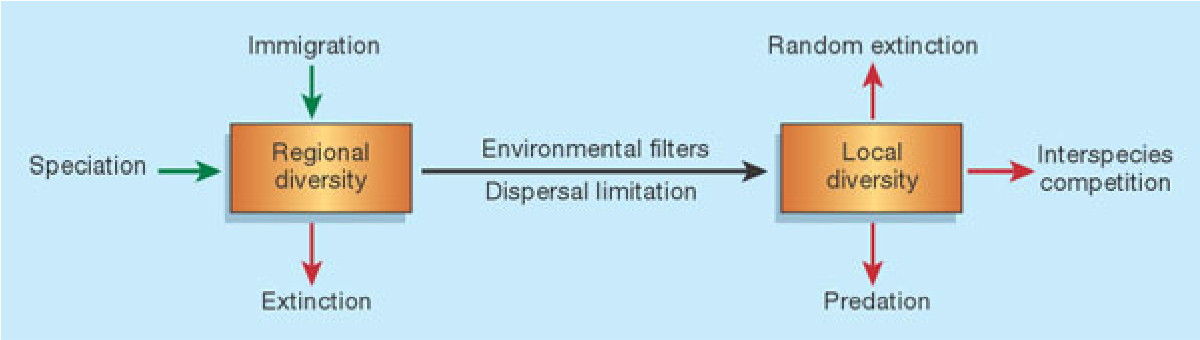
Frequency: occurrence or absence of a given species in a plot

Dominance: the degree of coverage of a given species, eg crown projected to the ground

Shanon, Simpson and others

Sörensen index may be calculated to estimate the similarity between plots

# Determinants of biodiversity




Ter Steege & Zagt, 2003

# Scale of study

- Global
- Regional
- Local

# Why are the tropics rich in species ?
## Factors controlling species richness at the global scale

A theory:

In the tropics: great ecological specialization

- geographical isolation of small populations for a long time promotes species formation
- the forests of the tropics have gone through cycles of fragmentation and reunion (glaciations at higher latitudes)
- this was mainly due to drier and wetter periods
- During wetter periods associated with interglacials, forests would expand and rejoin

# Distribution of tropical forest in South America

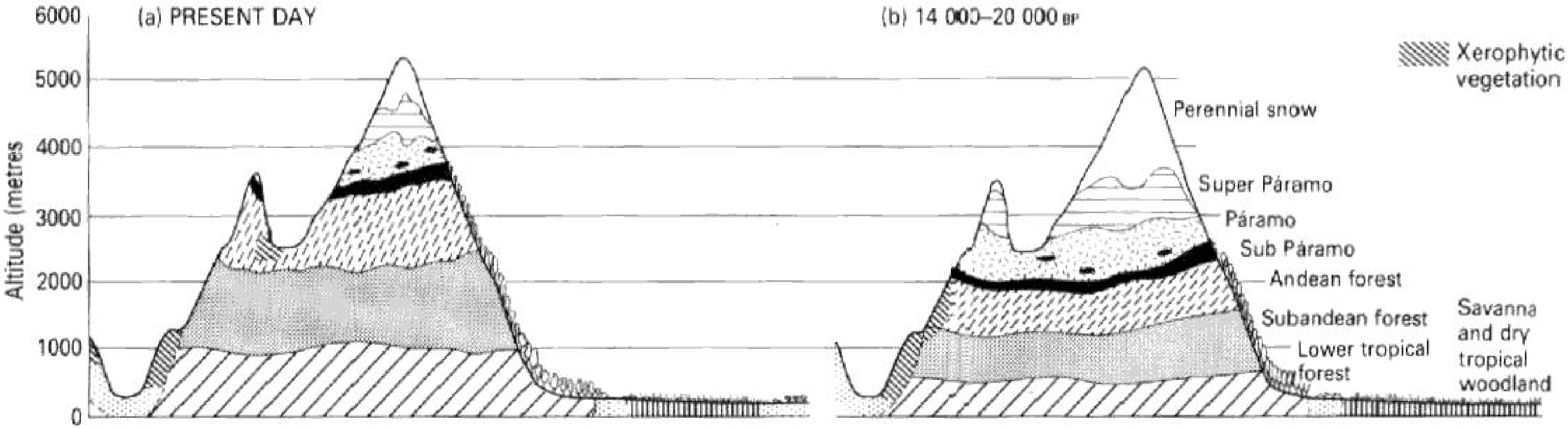
when last glaciation was at its highest

present

Prance 1981

# Vegetation zones of the Andes, Colombia

Compared to present day, the zones were depressed and compressed at the last glacial maximum




Van der Hammen 1979

# Species richness in the tropics
# - other possible explanations -

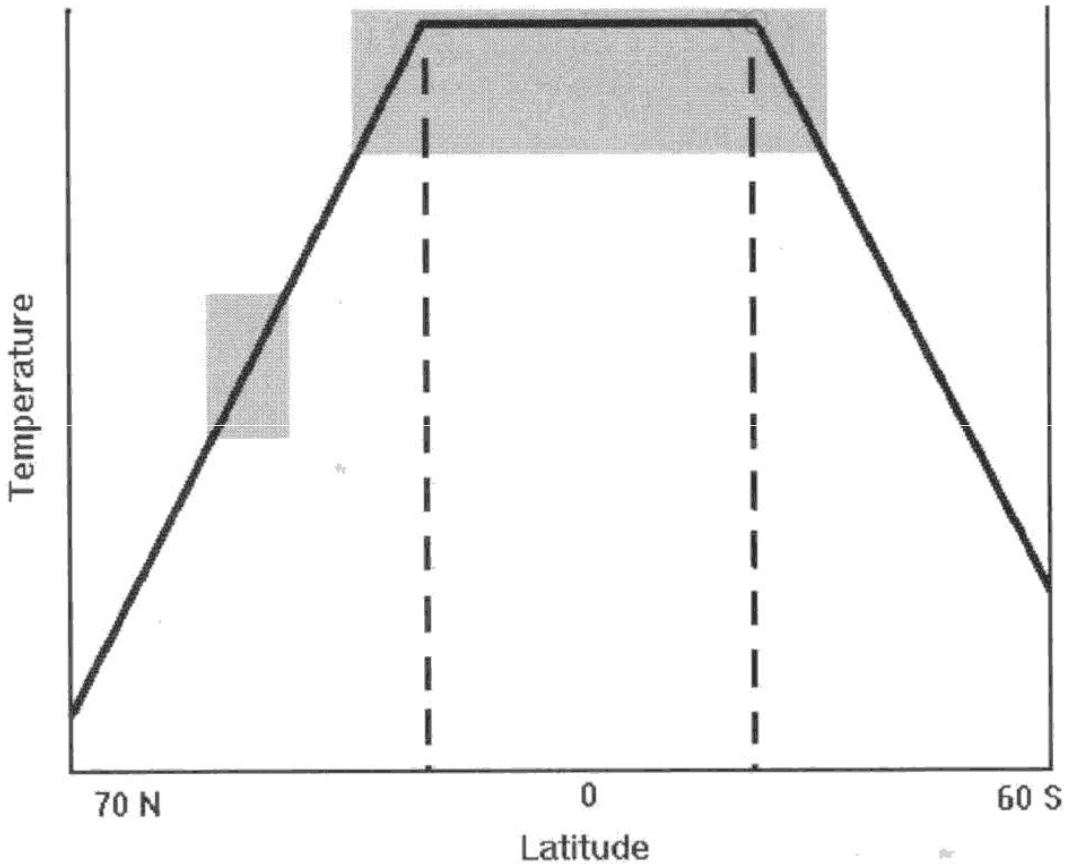
- high year-round productivity
- the lack of any need to adapt to harsh environment conditions
- In addition, specialization may favor further specialization, in a kind of runaway cycle

- strong correlations between species number and habitat area (Rosenzweig 1995):

Larger areas harbor more species than smaller ones

The region of the tropical rain forest is relatively large

# An explanation of higher tropical diversity




Based on
Terborgh 1973
Rosenzweig 2003

The shaded areas represent two species with an equal range of temperature tolerance; the tropical species has a much greater latitudinal range than the temperate species. This greatly increases the relative area of metacommunities in the tropics.

# Factors controlling species richness at the regional scale

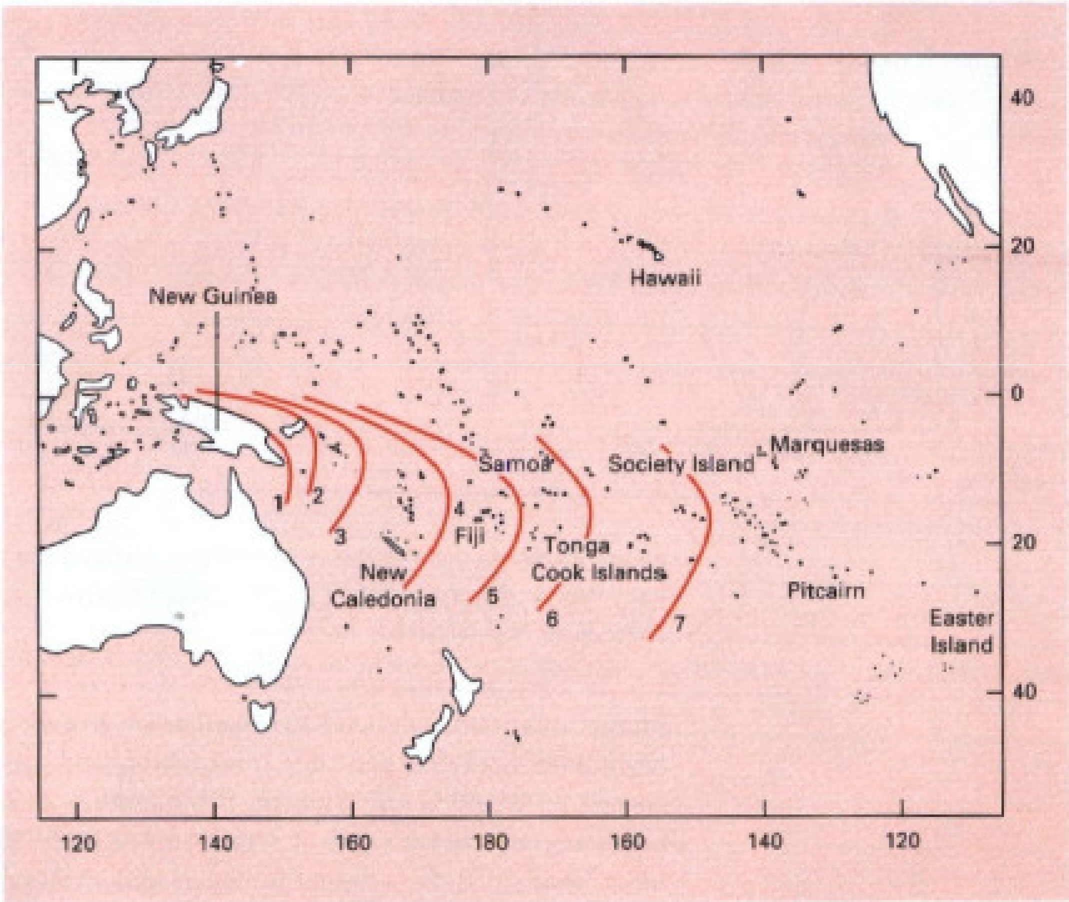
- Isolation, size of the habitat
- Resources
  - Rainfall
  - Nutrients

# Island biogeography, McArthur & Wilson (1976)

The equilibrium theory of island biogeography says basically

- The number of resident species on an island is controlled by immigration and extinction rate
- The larger the island the more species occur
- The more remote the island to a main (source) area is the less species occur

# Eastern limits of families and subfamilies of land and freshwater breeding birds found in New Guinea



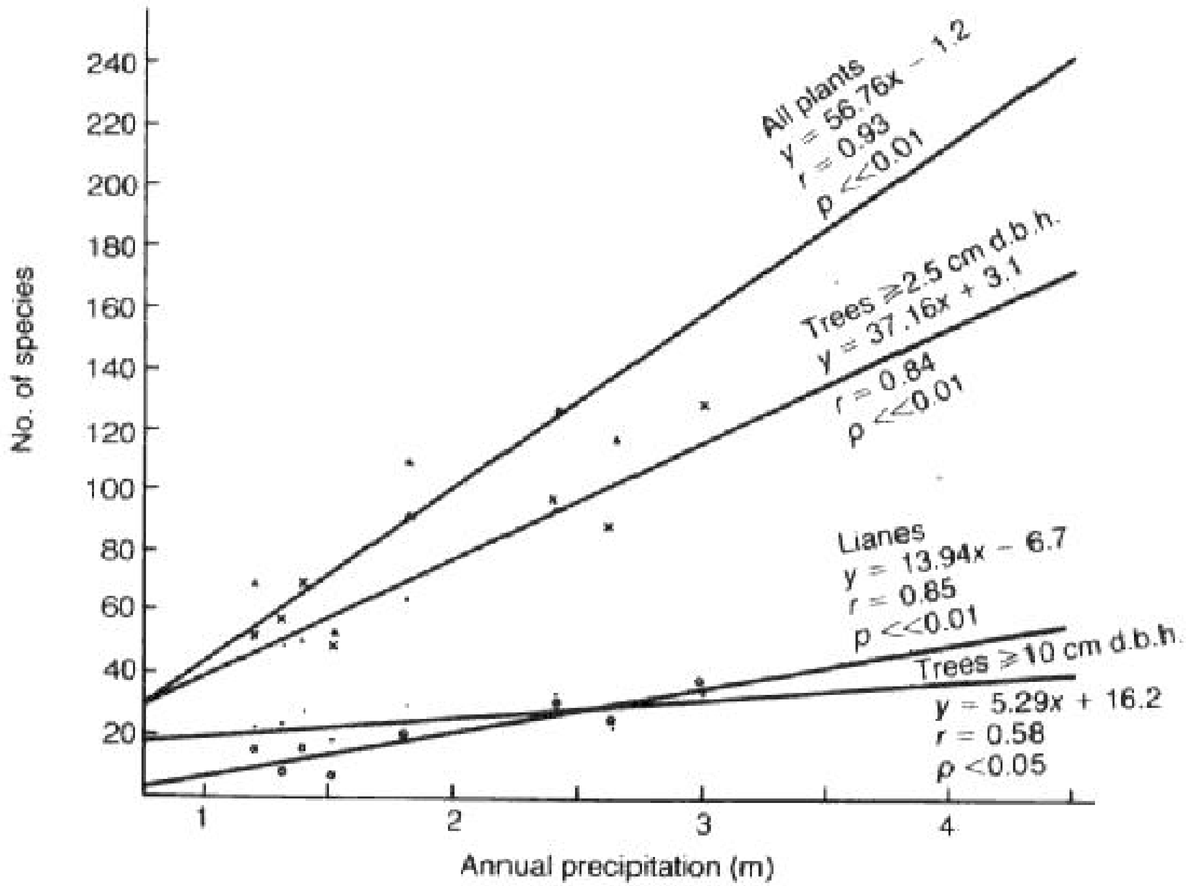

The decline in taxa is fairly smooth, and shows both differences in dispersal ability and a general decline in island size to the east.

dispersal ability and a general decline in island size to the east. (1) Not beyond New Guinea: pelicans, storks, larks, pipits, birds of paradise and nine others. (2) Not beyond New Britain and the Bismark Islands: cassowaries, quails and pheasants. (3) Not beyond the Solomon Islands: owls, rollers, hornbills, drongos and six others. (4) Not beyond Vanuatu and New Caledonia: grebes, cormorants, ospreys, crows and three others. (5) Not beyond Fiji and Niuafo'ou: hawks, falcons, turkeys and wood swallows. (6) Not beyond Tonga and Samoa: ducks, thrushes, waxbills and four others. (7) Not beyond the Cook and Society Islands: barn owls, swallows and starlings. Beyond (7), the Marquesas and Pitcairn group: herons, rails, pigeons, parrots, cuckoos, swifts, kingfishers, warblers and flycatchers. (After Firth & Davidson, 1945; from Williamson, 1981.)

# Factors controlling species richness at the regional scale

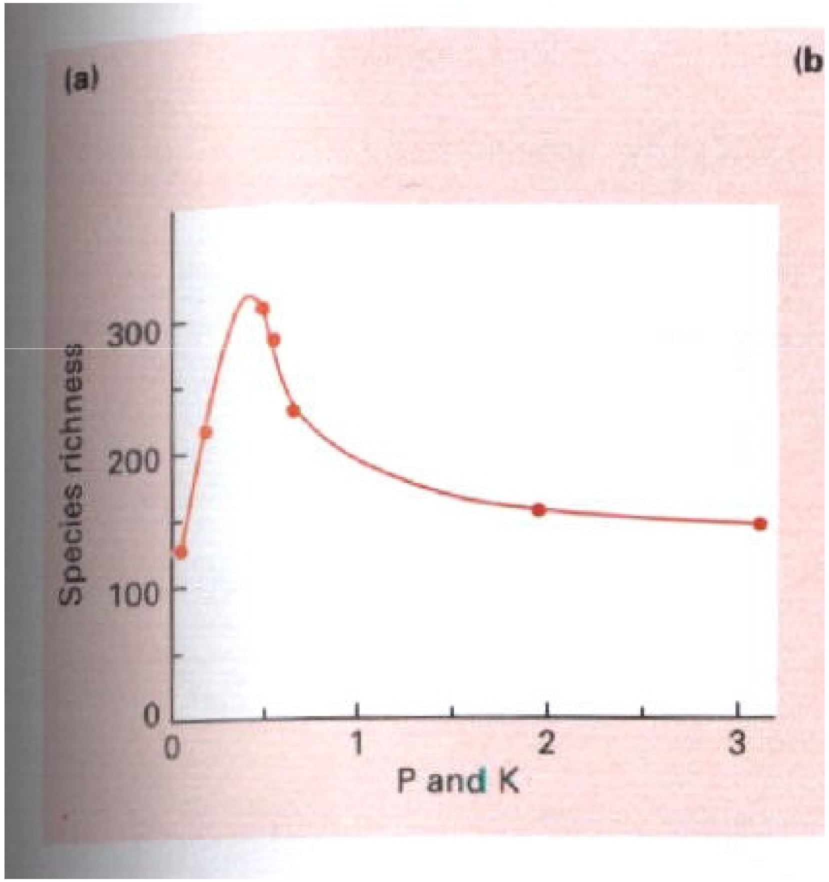
- Resources
  - Rainfall
  - Nutrients

# Species richness of vascular plants in tropical American lowland forest in relation to annual rainfall




(Gentry 1982)

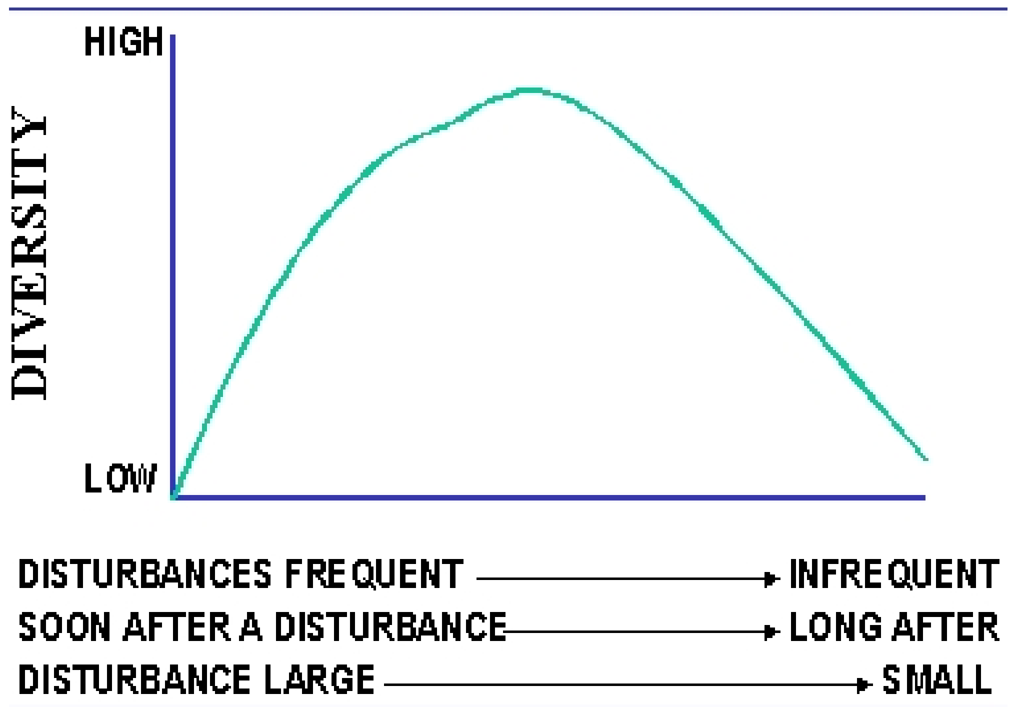
# Species richness of woody species in Malaysian rainforest vs an index of soil P and K (Tilman 1982)



# Factors controlling species richness at the plot scale

- Disturbance regime (intermediate would cause highest diversity)
- Productivity
- Competition

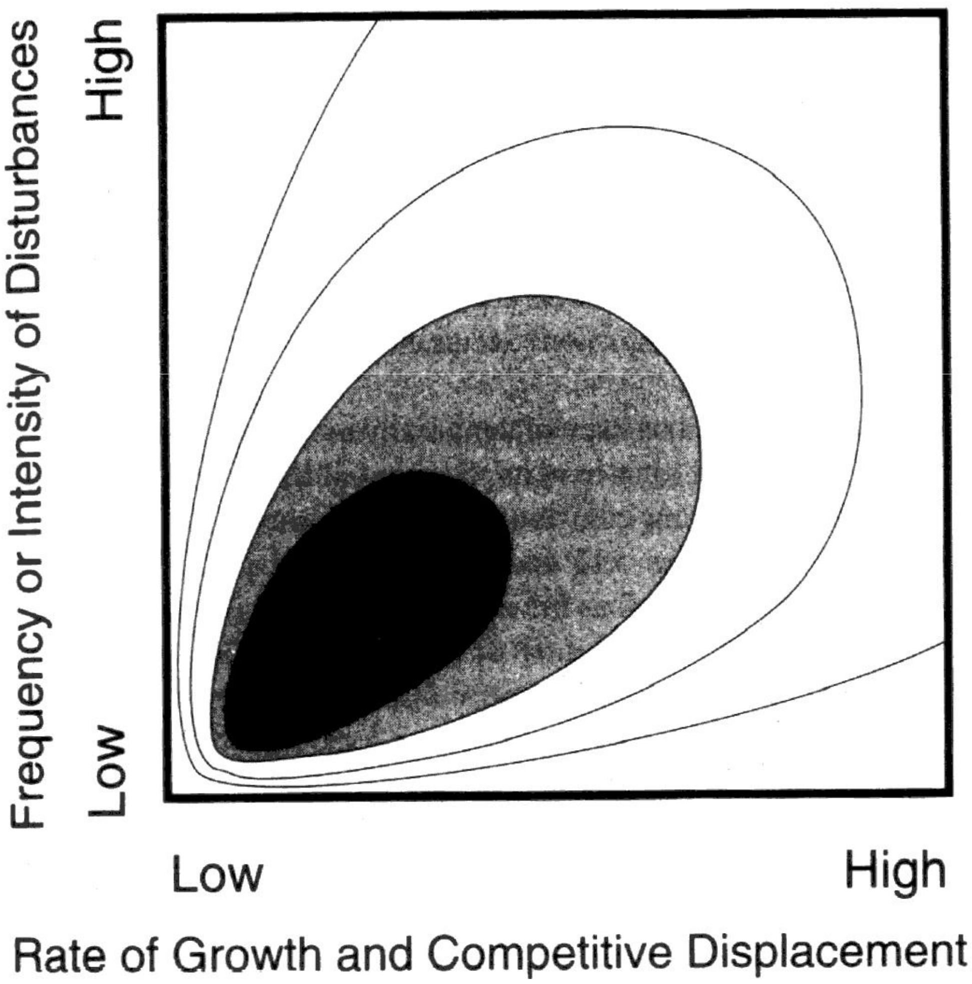
# The Intermediate Disturbance Hypothesis




Moderate disturbance counteracts competition

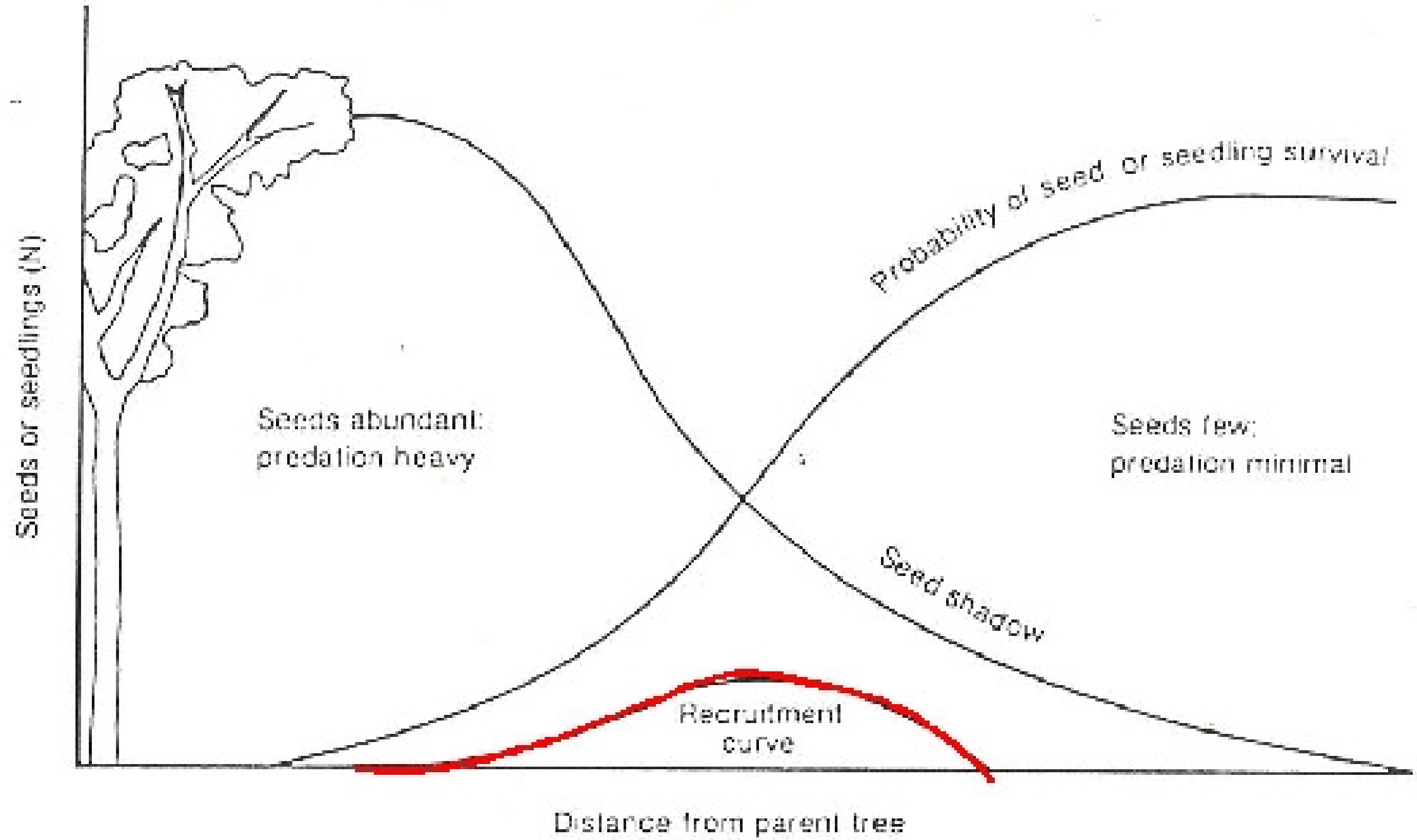
Connell 1978

# Local species diversity, competitive displacement and disturbance




Huston 1979

# Distance Hypothesis




Janzen 1970, 1971

# A case study

Alpha and beta diversity of plants and animals
along a tropical land-use gradient

Michael Kessler, Stefan Abrahamczyk, Merijn Bos, Damayanti Buchori, Dadang Dwi Putra, S. Robbert Gradstein, Patrick Höhn, Jürgen Kluge, Friederike Orend, Ramadhaniel Pitopang, Shahabuddin Saleh, Christian H. Schulze, Simone G. Sporn, Ingolf Steffan-Dewenter, Sri S. Tjitrosoedirdjo, Teja Tscharntke (2009)

Ecological Applications: Vol. 19, No. 8, pp. 2142-2156

# Alpha and beta diversity of plants and animals along a tropical land-use gradient

Assessing the overall biological diversity of tropical rain forests is a seemingly insurmountable task for ecologists. Therefore, researchers frequently sample selected taxa that they believe reflect general biodiversity patterns.

Usually, these studies focus on the congruence of α diversity (the number of species found per sampling unit) between taxa rather than on β diversity (turnover of species assemblages between sampling units).

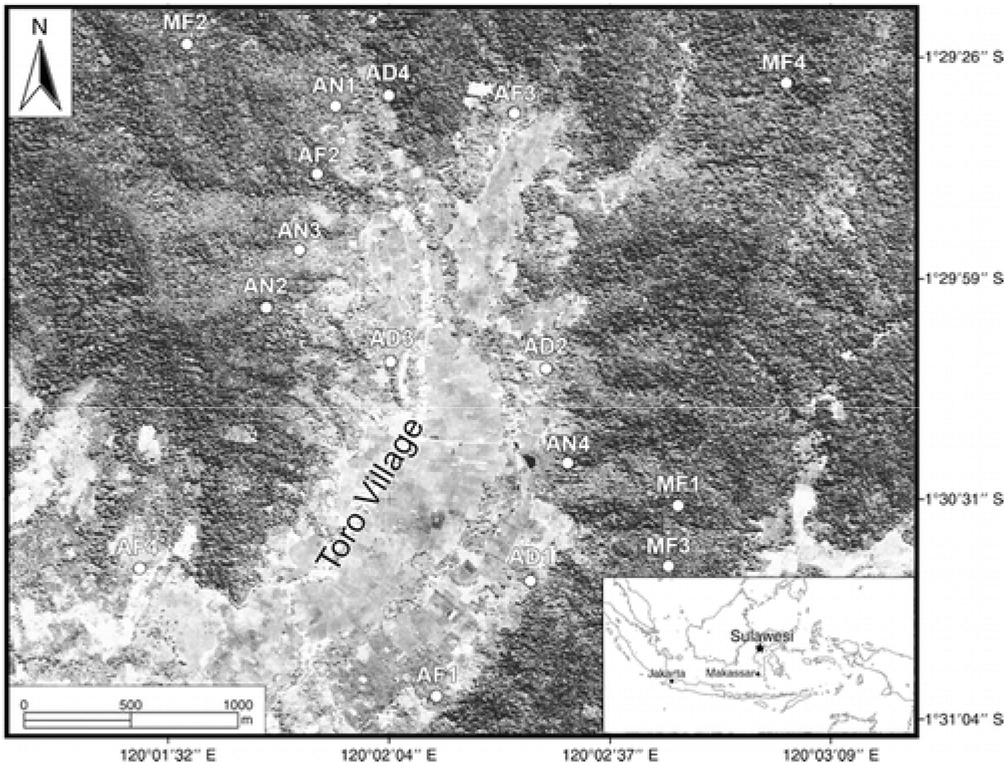
Such approaches ignore the potential role of habitat heterogeneity that, depending on the taxonomic group considered, can greatly enhance β diversity at local and landscape scales.

We compared α and β diversity of four plant groups (trees, lianas, terrestrial herbs, epiphytic liverworts) and eight animal groups (birds, butterflies, lower canopy ants, lower canopy beetles, dung beetles, bees, wasps, and the parasitoids of the latter two) at 15 sites in Sulawesi, Indonesia,

Natural rain forest and three types of cacao agroforests differing in management intensity.

Kessler et al. 2009

# Location of the study sites




Kessler et al. 2009

Mature forest (MF) and different agroforestry systems (AN, agroforest with natural shade trees; AD, agroforest with diverse planted shade trees; AF, agroforest with few planted shade tree species) around Toro Village in the Kulawi Valley, Central Sulawesi, Indonesia.

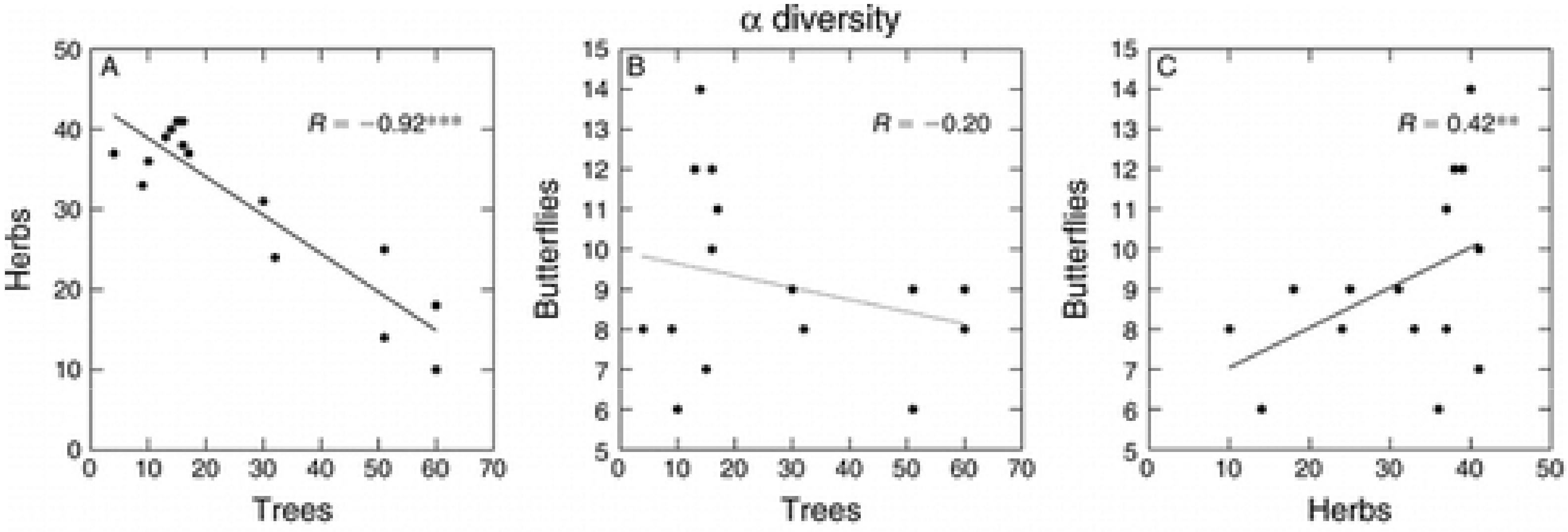
# Species for the 12 study groups

| Group | $S_{obs}$ | $S_{est}$ | SC study region (%) | SC plots (%) |
|---|---|---|---|---|
| Trees | 185 | 248 | 75 | 32–54 |
| Lianas | 35 | 76 | 46 | 27–47 |
| Herbs | 163 | 261 | 62 | 41–87 |
| Liverworts | 37 | 58 | 64 | 32–62 |
| Birds | 87 | 108 | 81 | 55–67 |
| Butterflies | 38 | 78 | 49 | 18–60 |
| Ants | 44 | 69 | 64 | 43–64 |
| Canopy beetles | 198 | 679 | 29 | 11–23 |
| Dung beetles | 25 | 29 | 86 | 67–88 |
| Bees | 9 | 11 | 89 | 72–100 |
| Wasps | 24 | 27 | 82 | 73–96 |
| Parasitoids | 18 | 30 | 60 | 39–67 |

15 study sites
Number of observed ($S_{obs}$) species,
total number of species in the study region estimated through the Chao2 estimator ($S_{est}$),
sampling completeness (SC; %$S_{obs}$ of $S_{est}$) for the study region and range of SC for the individual plots

Kessler et al. 2009

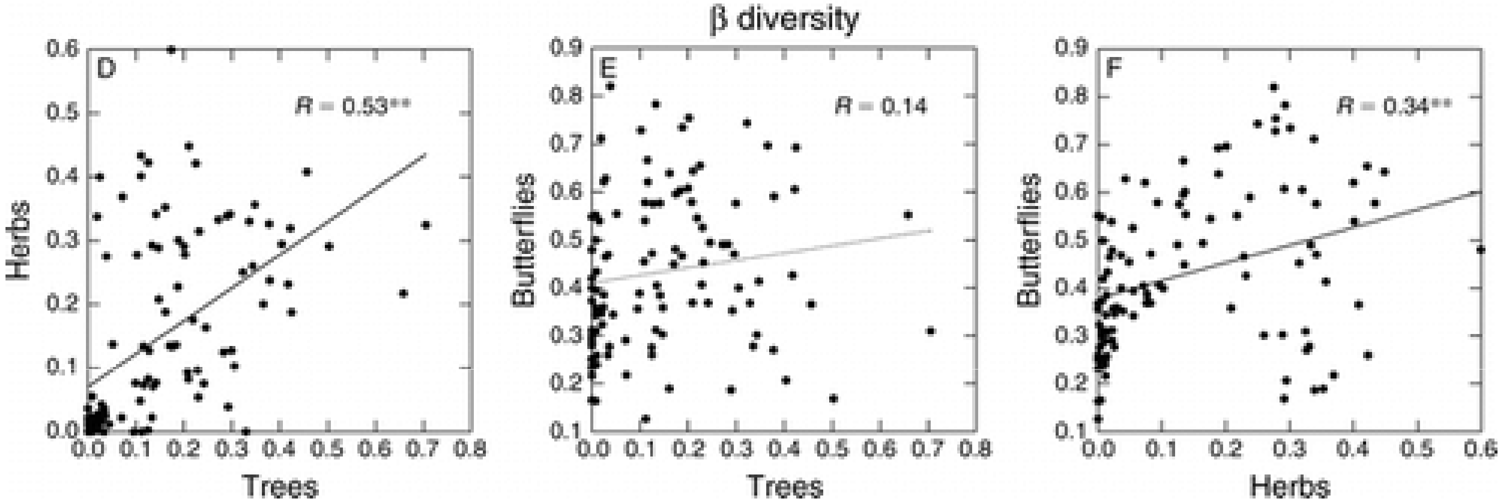
# Examples of the relationships of α diversity (the number of species found per sampling unit) between different taxa




The species richness of trees and herbs are closely inversely correlated due to the high abundance of herbs in open plantations with few shade trees. This high species richness of herbs in turn correlates positively with the species richness of butterflies (C), many of which use the herbs as food plants. Species numbers of trees and butterflies are not significantly correlated.
Trend lines in nonsignificant relationships are shown by dotted lines for clarity (B). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Kessler et al. 2009

Examples of the relationships of β diversity (the turnover of species assemblages between sampling units) between different taxa




In contrast to α diversity, β diversity is positively correlated between trees and herbs (D) as well as between herbs and butterflies (F), and slightly, but not significantly so, between trees and butterflies (E).

Thus, changes in land use affect β diversity of different taxa in roughly the same way, whereas trends in α diversity can be completely unrelated or even opposite

Kessler et al. 2009

# Mean determination coefficients ($R^2$ values) of a given study group relative to the other 11 study groups

| | $\alpha_{obs}$ | | $\alpha_{est}$ | | $\Delta\alpha_{obs}$ | | $\Delta\alpha_{est}$ | | $\beta_{obs}$ | | $\beta_{est}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | − | + | − | + | − | + | − | + | − | + | − | + |
| Trees | 0.33 | −0.14 | 0.25 | −0.07 | 0.28 | −0.14 | 0.19 | −0.03 | 0.15 | 0.15 | 0.21 | 0.20 |
| Lianas | 0.07 | 0.01 | 0.06 | 0.00 | 0.05 | 0.01 | 0.04 | −0.01 | 0.11 | 0.11 | 0.15 | 0.15 |
| Herbs | 0.29 | −0.02 | 0.30 | 0.00 | 0.25 | −0.02 | 0.26 | 0.00 | 0.17 | 0.17 | 0.25 | 0.25 |
| Liverworts | 0.05 | −0.02 | 0.05 | 0.00 | 0.05 | −0.02 | 0.05 | 0.00 | 0.01 | 0.00 | 0.02 | 0.01 |
| Birds | 0.21 | −0.09 | 0.20 | −0.05 | 0.18 | −0.09 | 0.19 | −0.07 | 0.14 | 0.13 | 0.21 | 0.20 |
| Butterflies | 0.05 | 0.00 | 0.05 | 0.03 | 0.04 | 0.00 | 0.04 | 0.03 | 0.07 | 0.07 | 0.12 | 0.12 |
| Ants | 0.07 | 0.04 | 0.09 | 0.05 | 0.07 | 0.04 | 0.08 | 0.05 | 0.03 | 0.03 | 0.08 | 0.08 |
| Canopy beetles | 0.15 | 0.04 | 0.18 | 0.06 | 0.12 | 0.04 | 0.13 | 0.05 | 0.19 | 0.19 | 0.28 | 0.28 |
| Dung beetles | 0.17 | −0.04 | 0.14 | −0.02 | 0.12 | −0.02 | 0.11 | 0.01 | 0.10 | 0.10 | 0.17 | 0.17 |
| Bees | 0.07 | 0.05 | 0.10 | 0.09 | 0.08 | 0.06 | 0.08 | 0.07 | 0.04 | 0.04 | 0.09 | 0.09 |
| Wasps | 0.29 | −0.01 | 0.27 | 0.05 | 0.25 | 0.01 | 0.21 | 0.04 | 0.27 | 0.27 | 0.31 | 0.31 |
| Parasitoids | 0.27 | 0.02 | 0.21 | 0.08 | 0.26 | 0.03 | 0.18 | 0.06 | 0.22 | 0.22 | 0.31 | 0.31 |
| Means | 0.17 | −0.01 | 0.16 | 0.02 | 0.15 | 0.00 | 0.13 | 0.02 | 0.13 | 0.12 | 0.18 | 0.18 |

*Notes:* Because the directions of the relationships (negative, positive) are lost when $R$ values are squared, $R^2$ values were calculated both not maintaining the original signs (−) and maintaining them (+). Abbreviations are: $\alpha_{obs}$, observed alpha diversity, i.e., the counted species number per plot; $\alpha_{est}$, estimated alpha diversity, i.e., the estimated total species number per plot; $\Delta\alpha_{obs}$, the difference between the $\alpha_{obs}$values of two plots; $\Delta\alpha_{est}$, the difference between the $\alpha_{est}$ values of two plots; $\beta_{obs}$, observed beta diversity, i.e., the observed similarity in species composition between two plots; $\beta_{est}$, estimated beta diversity, i.e., the estimated similarity in species composition between two plots.

Kessler et al. 2009

Although primary forests (left) have many more tree species than cacao plantations (right), this does not translate into equally high species numbers for many other plant or animal groups in natural forests. Instead, the good light conditions on the forest floor in plantations favor the growth of herbs and associated fauna.

Kessler et al. 2009

# Summary

In total, we recorded 863 species.

Patterns of species richness per study site varied strongly between taxonomic groups.

Only 13–17% of the variance in species richness of one taxonomic group could be predicted from the species richness of another, and on average 12–18% of the variance of β diversity of a given group was predicted by that in other groups, although some taxon pairs had higher values (up to 76% for wasps and their parasitoids).

The degree of congruence of patterns of α diversity was not influenced by sampling completeness, whereas the indicator value for β diversity improved when using a similarity index that accounts for incomplete sampling.

The indication potential of α diversity for β diversity and vice versa was limited within taxa (7–20%) and virtually nil between them (0–4%).

We conclude that different taxa can have largely independent patterns of α diversity and that patterns of β diversity can be more congruent.

Thus, conservation plans on a landscape scale need to put more emphasis on the high heterogeneity of agroforests and the overarching role of β diversity shaping overall diversity patterns.

Kessler et al. 2009

Photo: J. Epstein 2005.
Copyright Wildlife Trust

Malayan Flying Fox (*Pteropus vampyrus*)

is native to Malaysia and the Indonesian archipelago and is heavily hunted for food, sport, traditional medicine and as an agricultural pest in Peninsular Malaysia.

# The function of biodiversity

# History of BioDiversity–Ecosystem Functioning (BD–EF) research

Darwin and Wallace 1858: diversity enhances ecosystem productivity

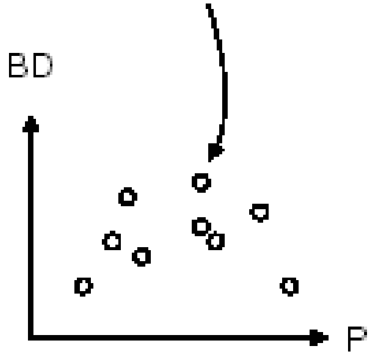
MacArthur 1955, Elton 1958: diversity enhances ecosystem stability

Harper 1977: best monoculture is always better than best mixture

May 1973: inverse relationship between ecosystem complexity and stability

Grime 1973, Huston 1979:

highes species richness at intermediate ecosystem productivity

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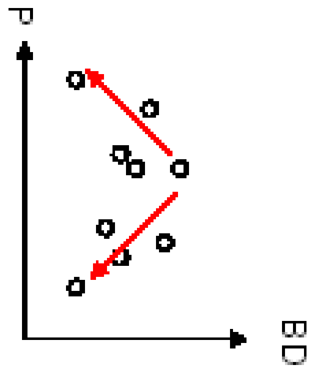
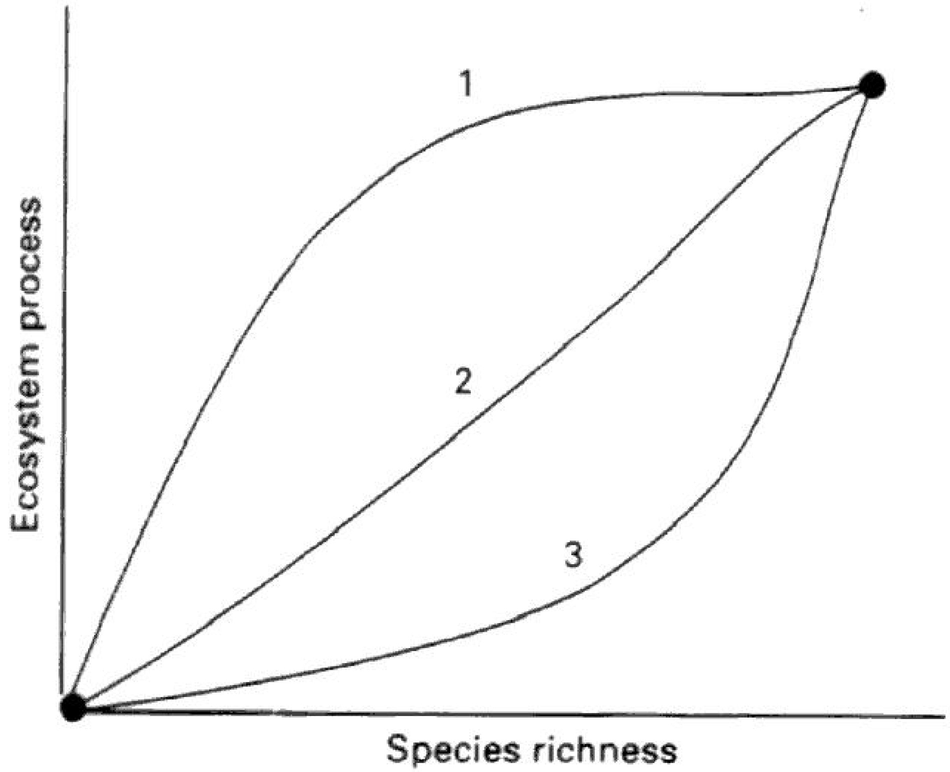
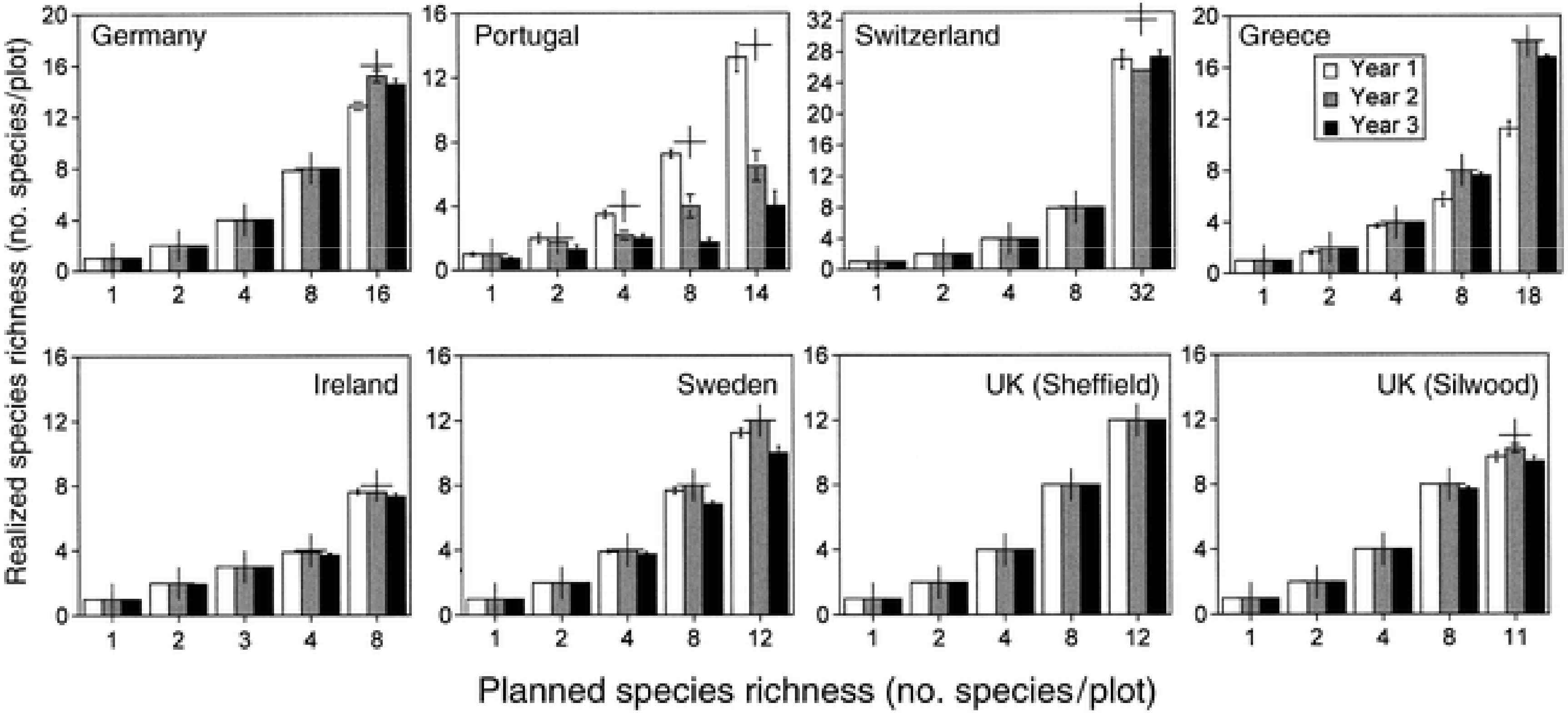



1994 – experiments:
what happens if species richness is experimentally reduced?

# Hypothetical relationships between species richness and ecosystem processes I

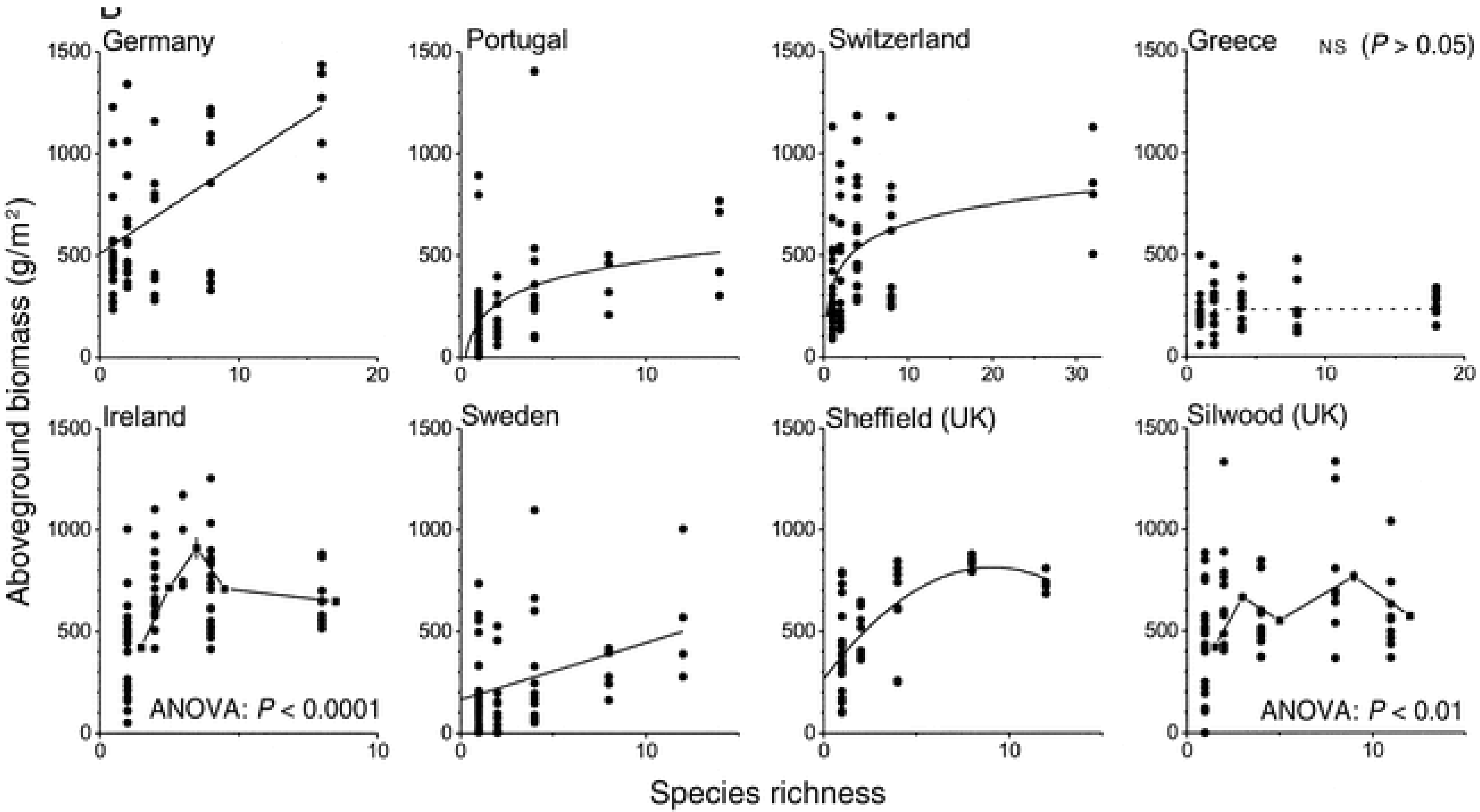


# The experimental setup of biodepth
## - function of biodiversity in European grasslands -



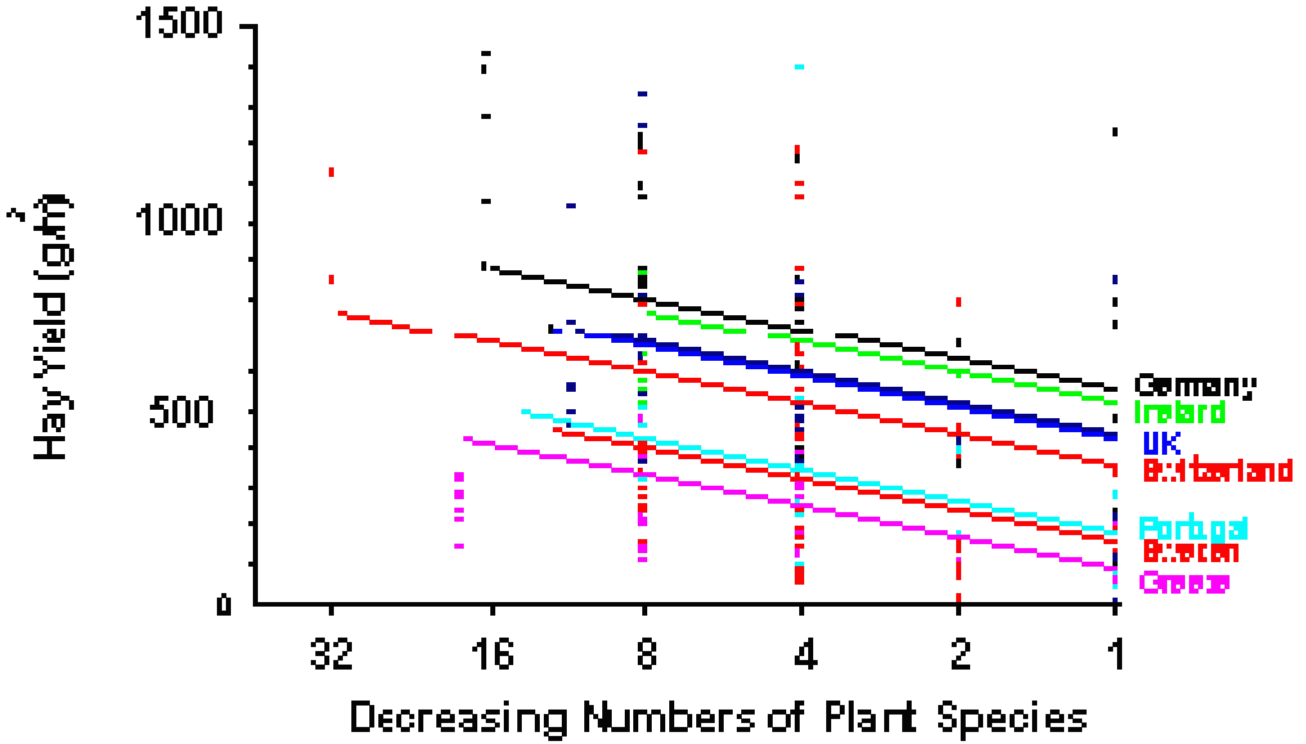

Spehn et al. 2005

# Experimental plot
# - Jena, Germany -

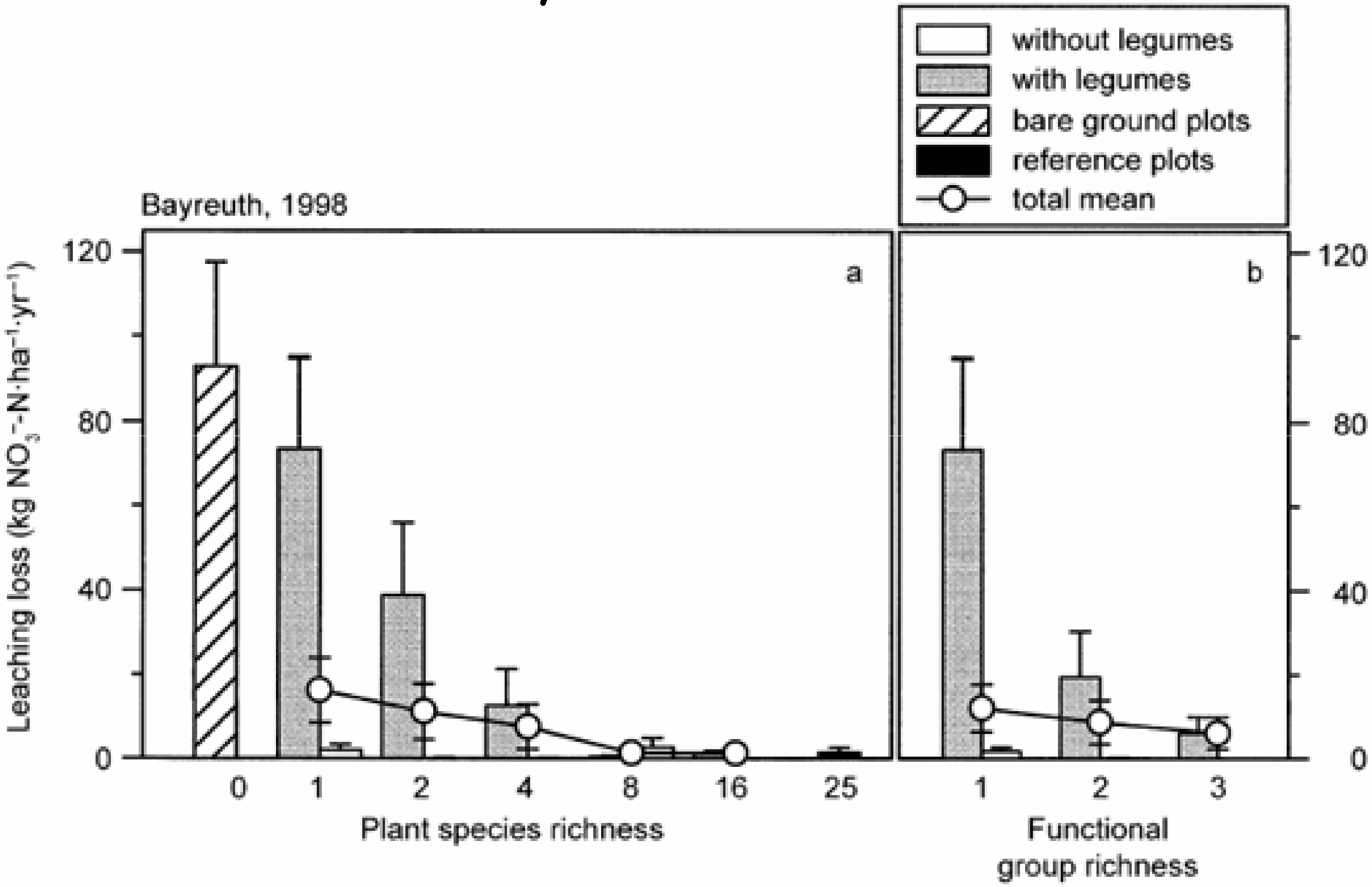



Spehn et al. 2005

# Productivity decreased with decreasing species number in experimental European grasslands



# Nitrate leaching from grasslands with different diversity




Scherer-Lorenzen et al. 2003

# Functional groups

Functional groups are used by ecologists to categorize the roles that species might play in an ecosystem. For example nitrogen fixing trees

# Function of biodiversity
# - proposed mechanisms -

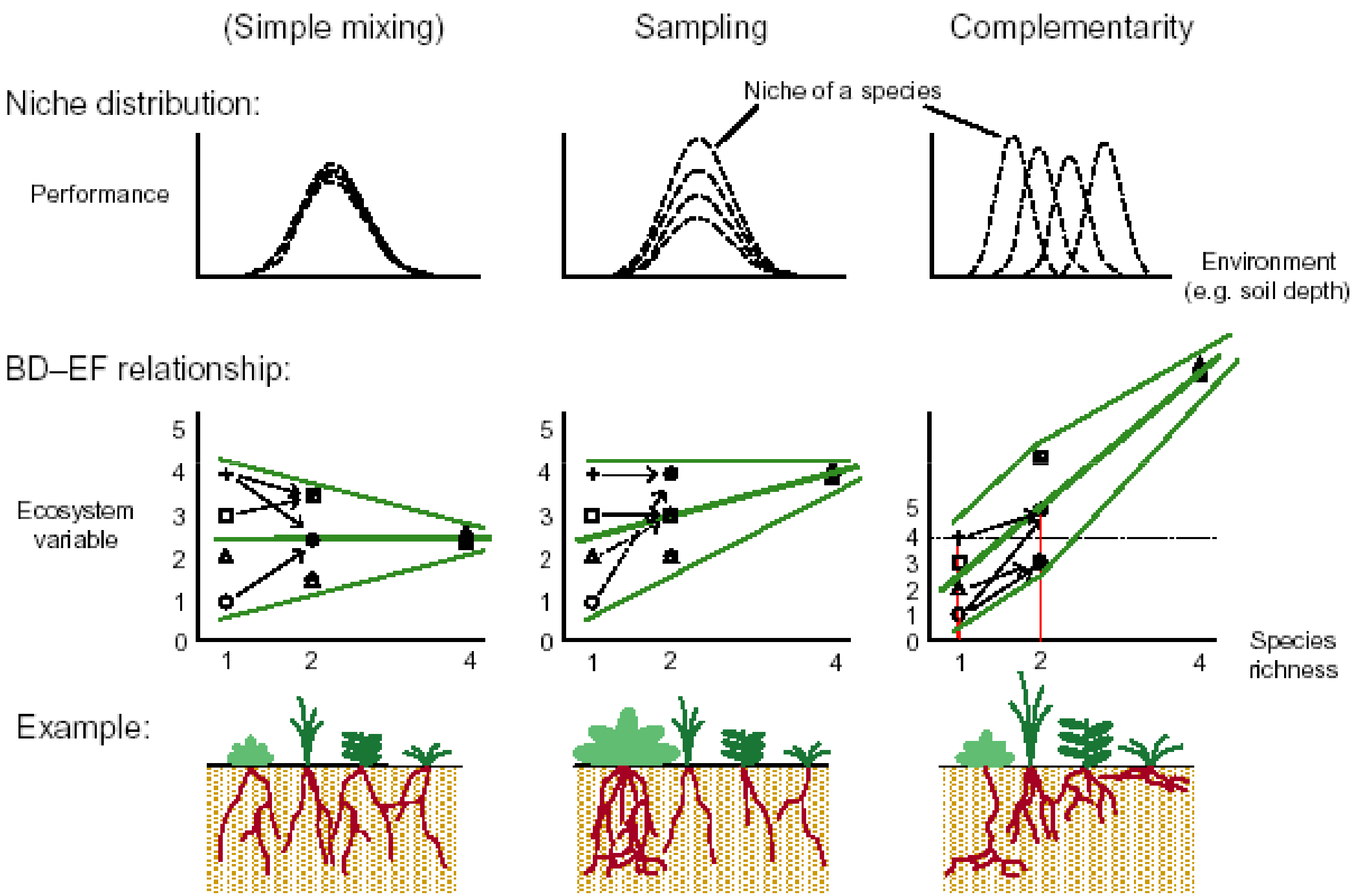
**Complementarity of resource use**

- if species complement one another in their resource use,
- increasing numbers of species increases the total resource use of the community (niche differentiation)

**Sampling effect**

- increasing numbers of species increases the probability of including highly productive species in a community

# Analyzing the results: potential mechanisms



# Magnitude and direction of biodiversity effects

Coloured bars show differential effects of trophic level manipulated:
green, primary producers

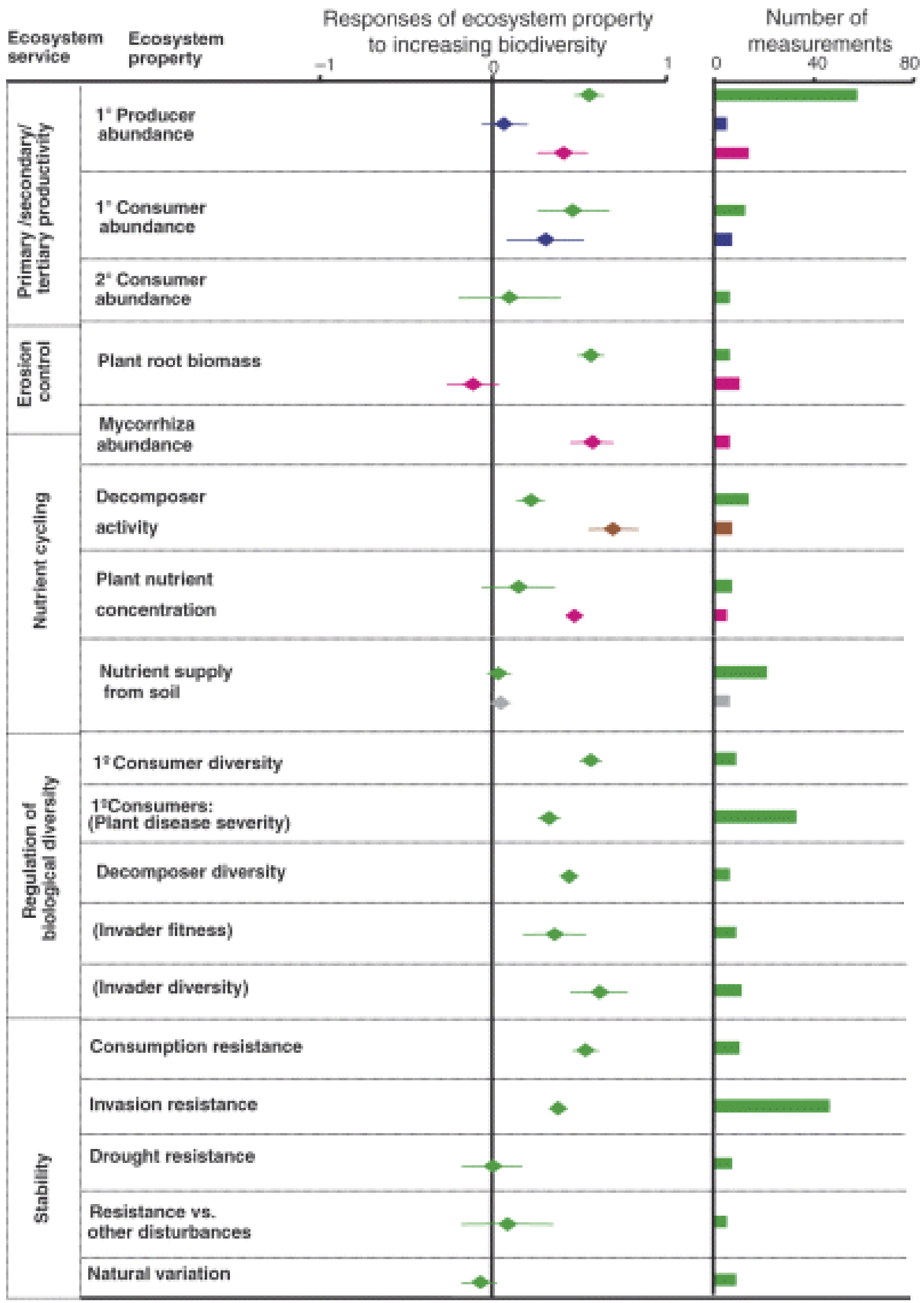
blue, primary consumers

pink, mycorrhiza

brown, decomposer;

grey, multitrophic

Balvanera et al. 2006



# Results and conclusions

## biodiversity effects on ecosystem functioning

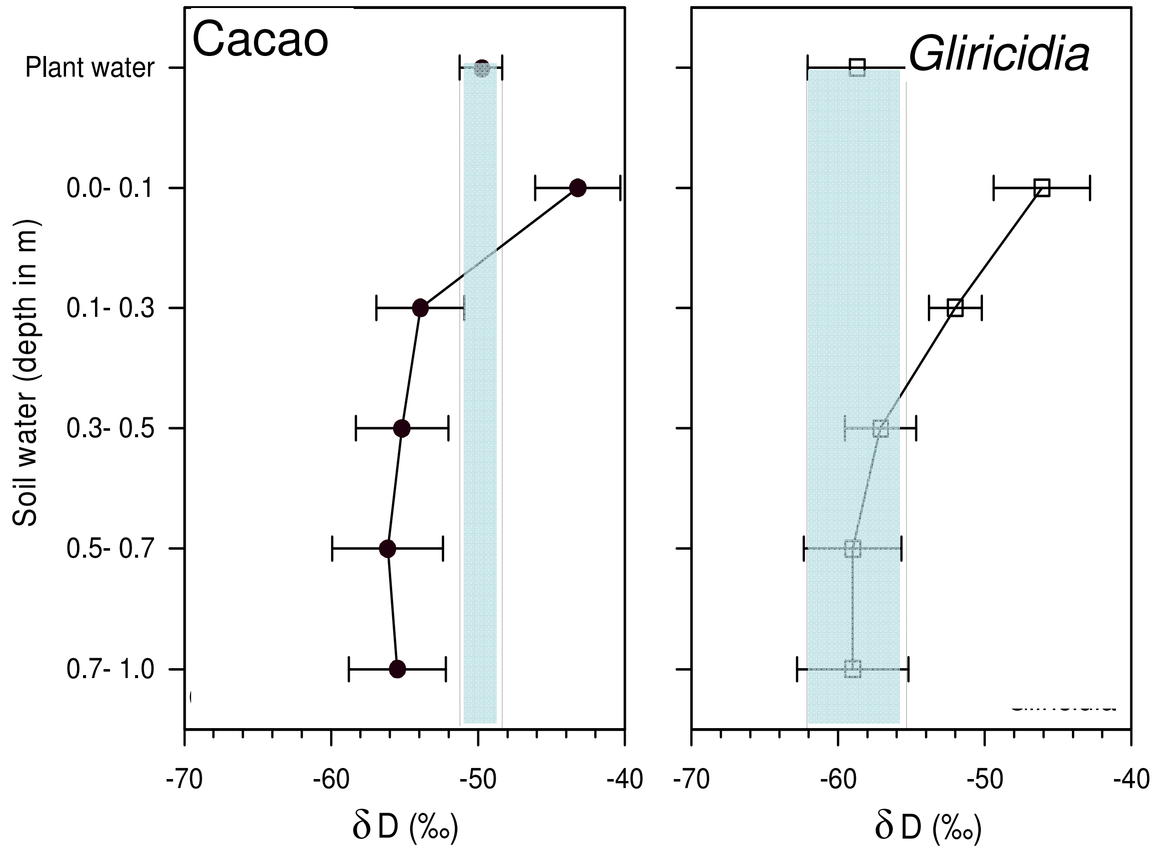
- *For those ecosystem services which could be assessed here, there is clear evidence that biodiversity has positive effects on most*

Balvanera et al. 2006

and what do we do?

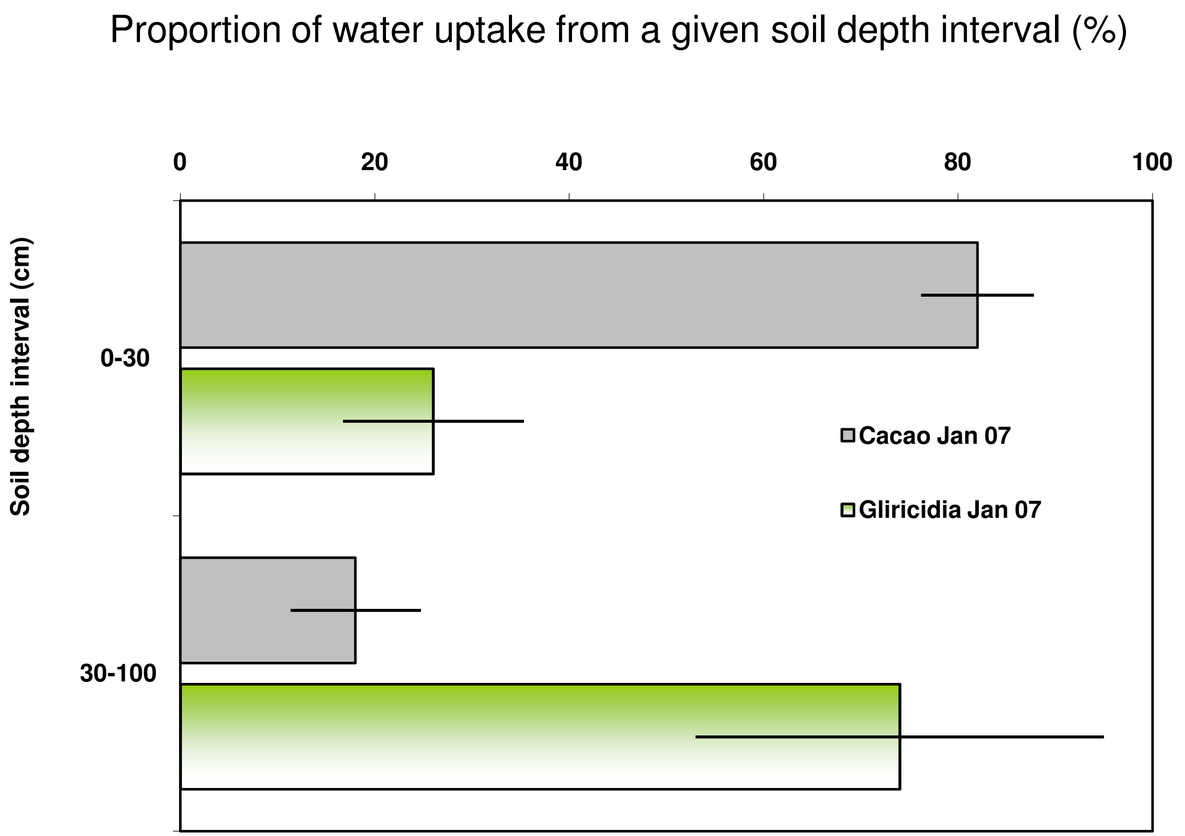
e.g.: Cacao-*Gliricidia* agroforest

# Complementary use of soil water
## deuterium signal




Schwendenmann et al. 2009

# Water uptake depth cacao and Glricidia



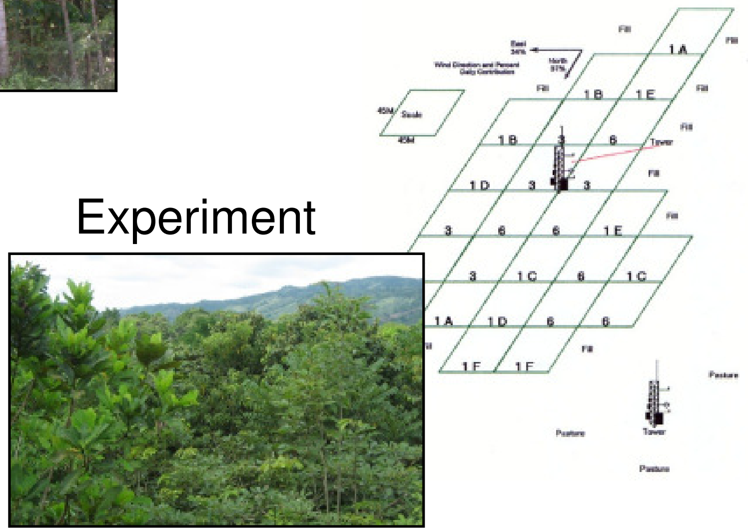

Schwendenmann, unpublished

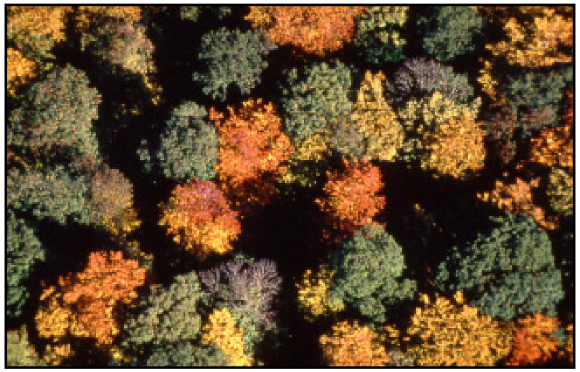
# Other projects in my group on Biodiversity – Ecosystem function

- Philippines
- Panama
- Germany

Rainforestation

Experiment





Old-growth forest

Thanks for attention !