Biodiversity services in changing agricultural landscapes

Teja Tscharntke
Agroecology, University of Göttingen, Germany

“Farming for Ecosystem Services”, Michigan State University, East Lansing, April 15-16, 2015

Ecosystem services & disservices in agricultural landscapes

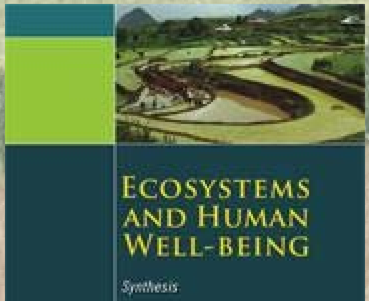
Existing services
Supporting services
(soil fertility, nutrients, water)
Regulating services
(biocontrol, pollination)

Resulting services
Provisoning services
(food, fuel, timber, wildlife resources)
Cultural services
(aesthetic landscapes)

Agroecosystems & Agricultural Landscapes

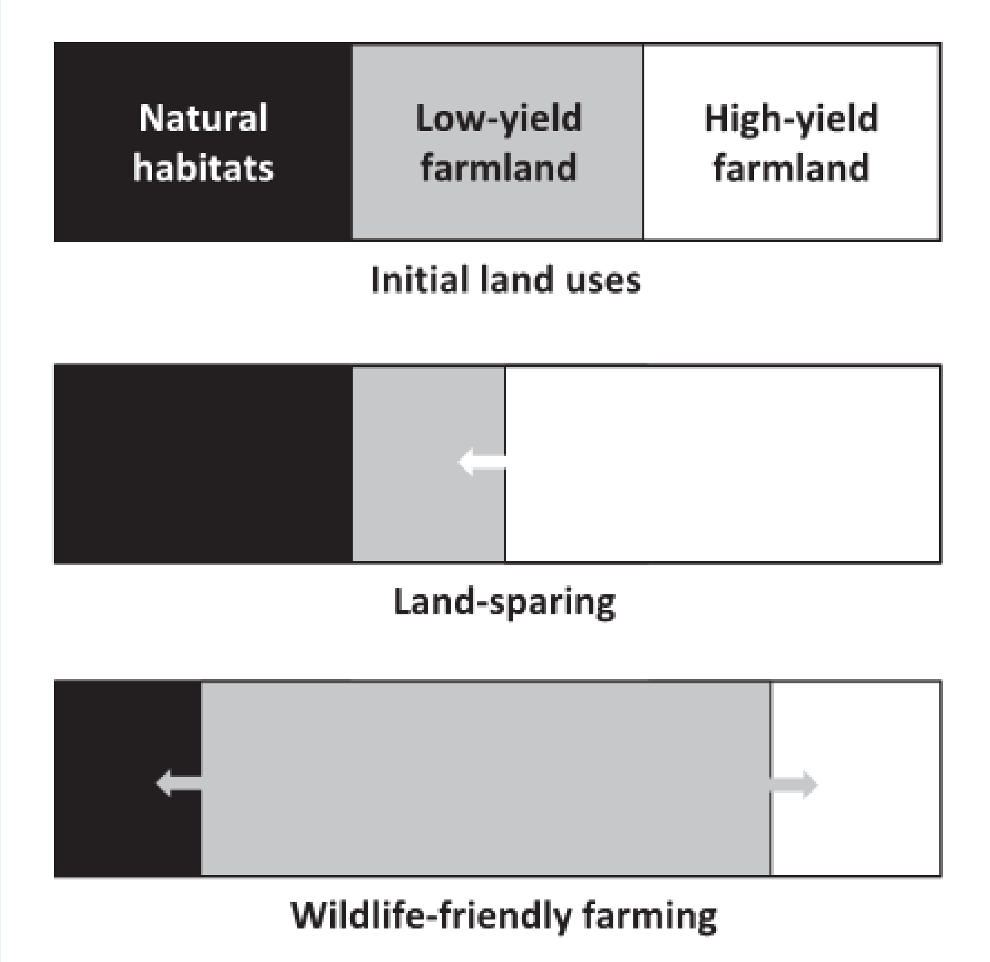
Existing disservices
Regulating disservices
(pests, pathogens, competition for water)

Resulting disservices
Supporting disservices
(Soil degradation, N leaching, pesticide drift)
Regulating disservices
(Greenhouse gas emission, functional biodiversity loss)



Millenium Ecosystem Assessment 2005;
Zhang et al. 2007, Ecol Econ; Tscharntke et al. 2012, Biol Conserv

Land sharing instead of land sparing?



The concept: Under increasing food demands,
agricultural intensification increases
amount of land spared for natural habitats

Phalan et al. 2011, Food Policy & Science; Hodgson et al. 2010, Ecol Letters; Green et al. 2005, Science

Is agriculture only in contrast to conservation of biodiversity services?

Integrate agriculture & conservation – 7 arguments

(1) Biodiversity conservation needs the human-dominated matrix

(2) Agriculture shapes landscapes: cultural ecosystem services

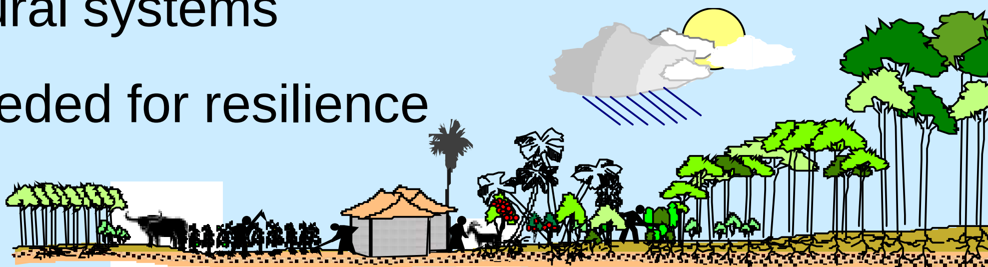
(3) Agroecosystem functioning requires biodiversity services

(4) Agroecosystems need functionally important common species, but often also a diversity of species

(5) Biodiversity services: final services count, not intermediate services. Discrete trophic interactions or food web approach?

(6) Landscape perspective needed: scale mismatch due to spillover across managed and natural systems

(7) Crop yield-biodiversity tradeoffs needed for resilience



Tscharntke et al. 2012, Biol Conserv

(1) Biodiversity conservation needs the human-dominated matrix

Agricultural land = 40% of terrestrial area (protected reserves = 12%):

Effectiveness of protected reserves in reducing deforestation?

Even inside tropical forest reserves: high erosion of biodiversity

Laurance et al. 2012, Nature

(1) Biodiversity conservation needs the human-dominated matrix

Landscape configuration matters

Levin‘s metapopulation model

Local populations tend to go extinct with

$$P = 1 - e/m$$

(e = extinction rate, m= colonization rate)

Hence, in landscapes without dispersal, extinction is the dominant process

Tscharntke & Brandl 2004, Ann Rev Entomol
Andrea Holzschuh et al. 2009, Ecol Appl
Urs Kormann et al. 2015, subm.

(1) Biodiversity conservation needs the human-dominated matrix

Conservation needs pristine habitats, but cannot be restricted to it

Most wild species including large carnivores need a connectivity matrix



Linnell et al. 2005, Island Press, Perfecto & Vandermeer 2010, PNAS

Harapan Rainforest Restoration Project in Sumatra http://harapanrainforest.org/




Without immigration, extinction is the only force (Levin‘s classical metapopulation model)

(2) Agriculture shapes landscapes: Cultural ecosystem services

Synanthropic species:
hares, hamsters, storks, arable "weeds"

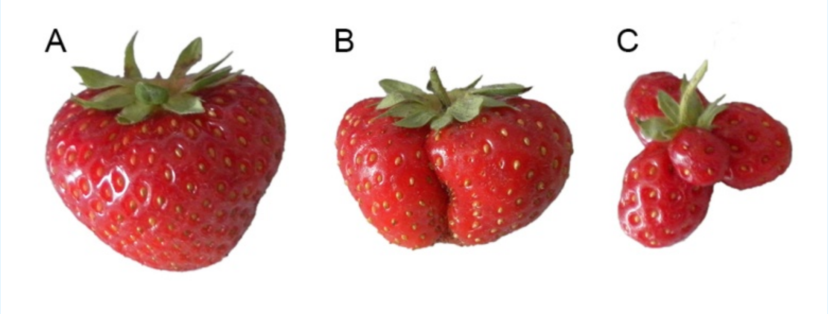
Common farmland birds = "endangered" ?
Whittingham 2011, J Appl Ecol

People love their countryside biodiversity

(3) Agroecosystem functioning needs agrobiodiversity: pollination of crops

Limiting factor for reproduction in 88% of natural plant populations
Improves production of 70% of globally important crops, influences 35% of global human food supply

Alexandra Klein et al. 2007, Proc Roy Soc London B



Pollination increases fruit quality and crop shelf life!
Strawberry colour, brightness, acid-sugar ratio and firmness

Bjoern Klatt et al 2014, Proc Roy Soc B; 2014 Agric Food Security

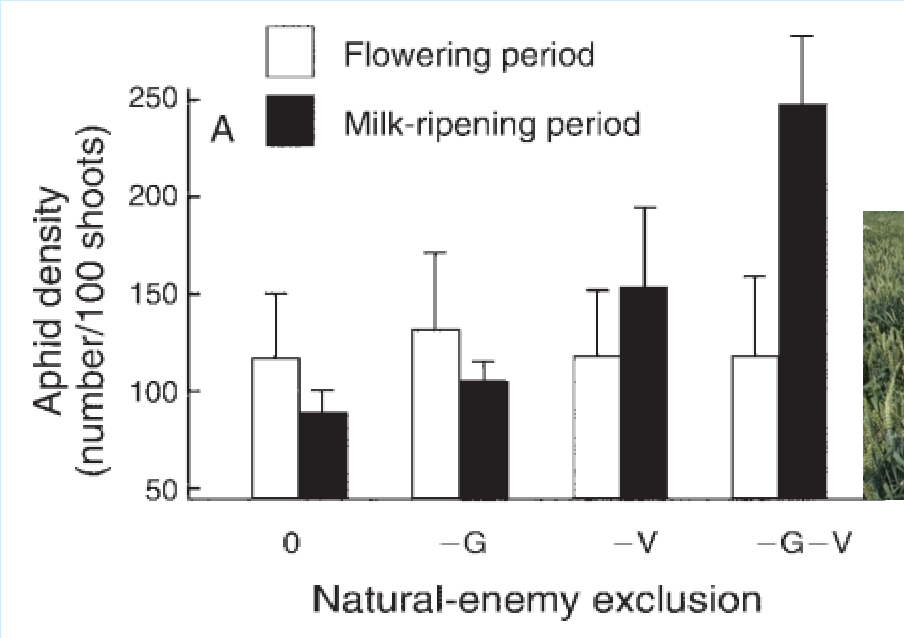
Semi-natural habitat, wild bees und yield correlated: cherry pollination

Andrea Holzschuh et al .2012, Conserv Biol

Wild bees drive crop yield, not honeybees (less efficient pollinators)

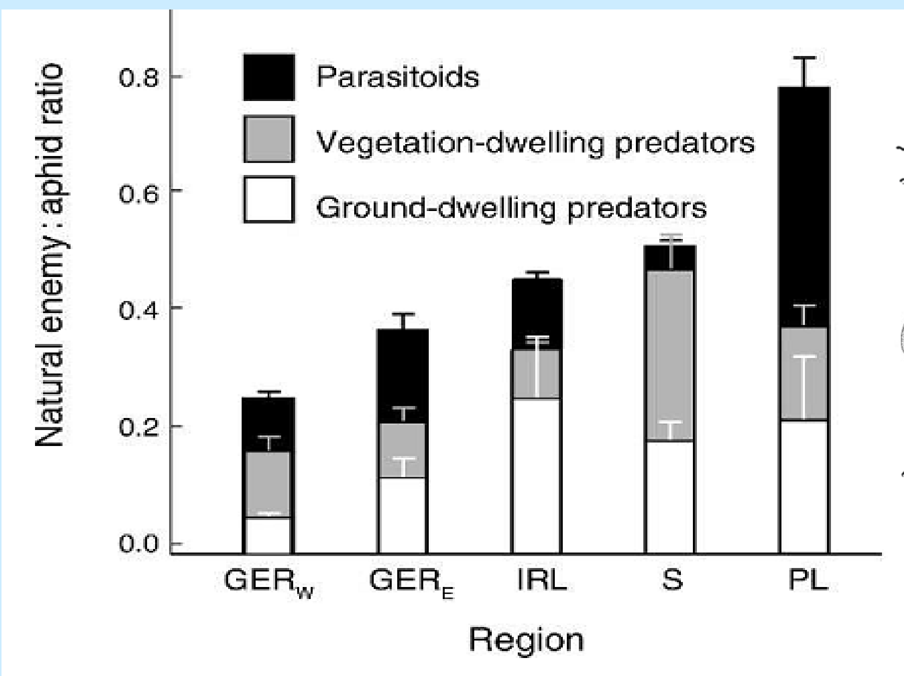
Meta-analysis with 41 crop species across the globe
Lucas Garibaldi et al 2013, Science

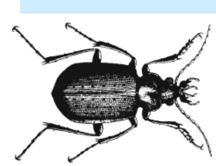
(3) Biocontrol of cereal aphids across Europe



Cereal aphid densities 28%, 97% & 199% higher

- **Functional complementarity**
- Not additive, but synergistic





Across regions,

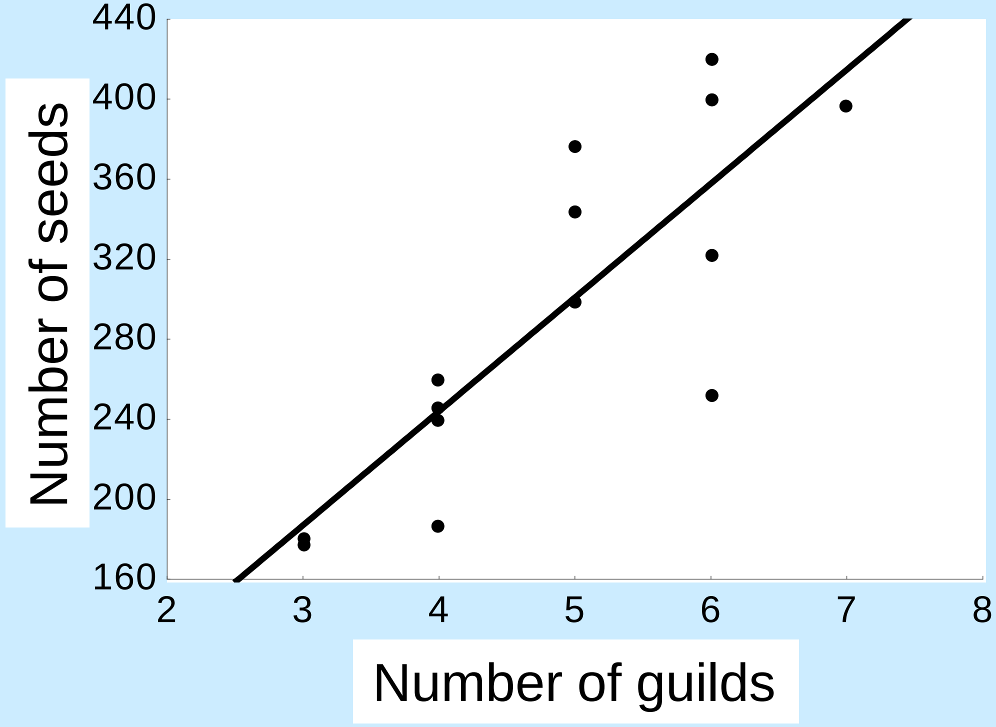
- Relative importance of group identity differs
- **Functional redundancy** (insurance value) in changing environments

Carsten Thies et al 2011, Ecol Appl

(4) Services provided not only by common species:

Bee functional diversity and pollination

Experimental pumpkin patches in Indonesia; land-use intensity & bee diversity gradient (18 sites: rainforest, agroforestry, grassland)

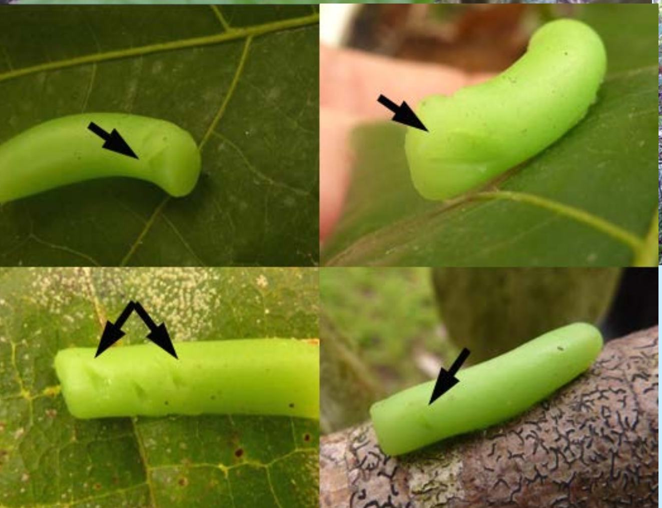


Functional grouping: **# species *vs* # guilds: r^2= 32% *vs* 45%**

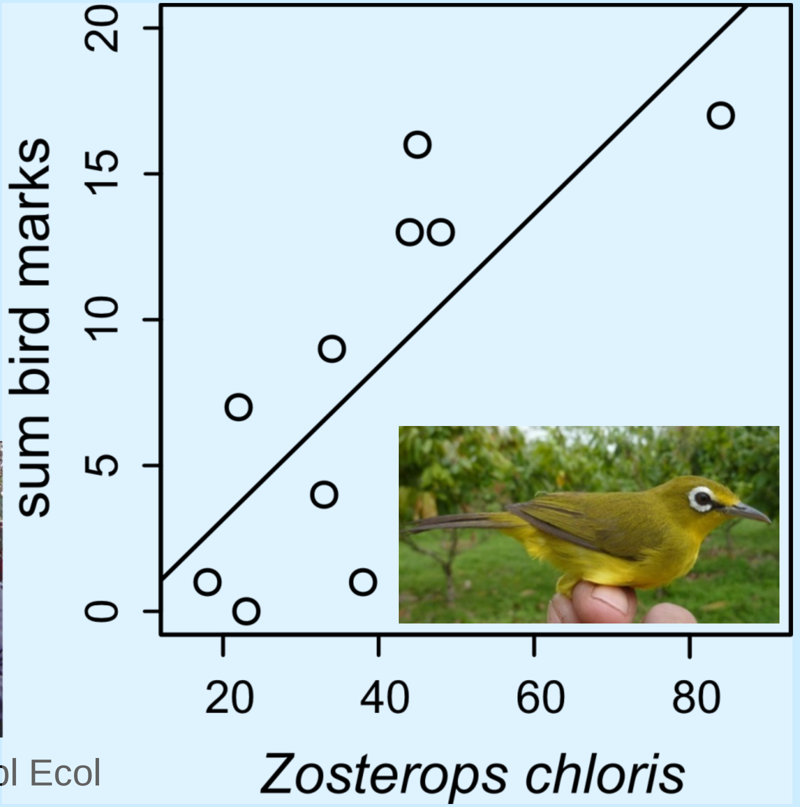
- body size
- time of flower visitation
- height of flowers visited

Patrick Hoehn et al. 2008, Proc Roy Soc London B.

(4) Agroecosystems need common species
Bird predation in Indonesian agroforstry



Predation activity on cacao trees:
dummy caterpillars on 10 sites



Bea Maas et al. 2015 J Appl Ecol

Species identity mattered & the most common species decreased in density with forest distance

(5) Biodiversity services: only final services, not intermediate services?

Mace et al. 2012, Trends Ecol Evol

Disentangling services & disservices in ant communities
in Indonesian cacao agroforestry (ca. 160 spp.)
Exclusion experiments & manipulation of ant species dominance

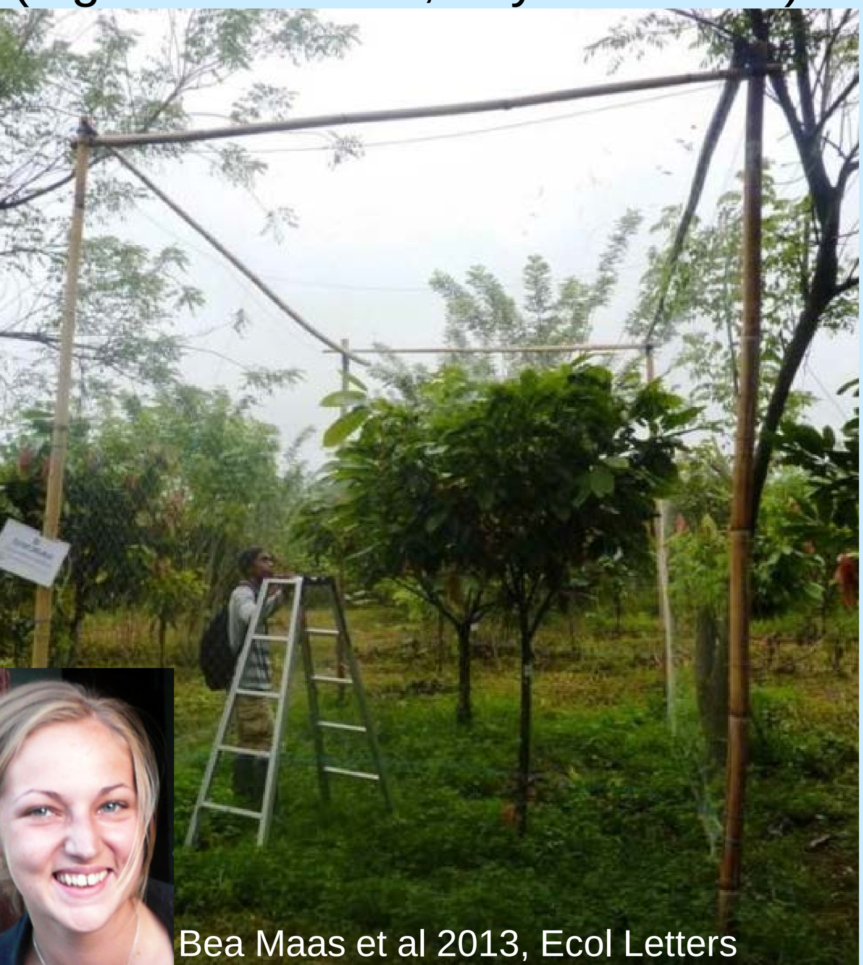
(i) **ecosystem services**
less leaf herbivory & fruit damage, indirect pollination facilitation
(ii) **ecosystem disservices**
more mealybugs & phytopathogens & indirect pest promotion
(iii) **intermediate vs final service**: crop yield in agriculture:
Ant exclusion or invasive ants: 27-34% reduced cocoa yield.
Diverse and even ant communities needed!

Arno Wielgoss et al.
2014, Proc Roy Soc B
2012, J Appl Ecol

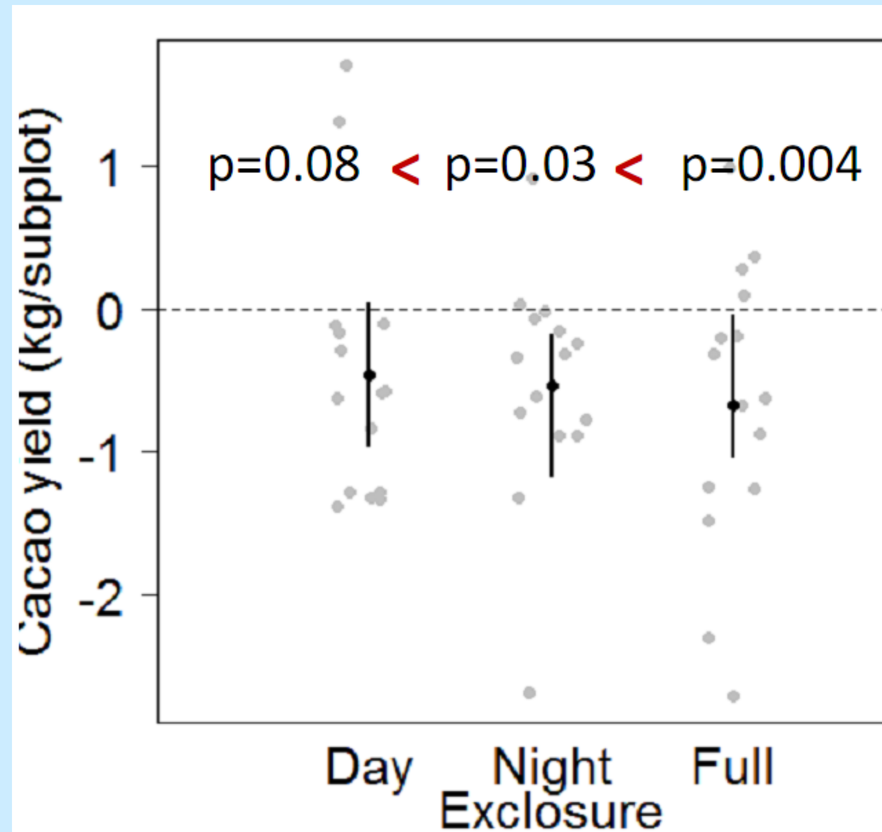
(5) Biodiversity services: only final services, not intermediate services?

Birds & bats enhance crop yield in cacao agroforestry

31% cocoa yield reduction (= 730$/ha/y)
(bird/bat exlosures, 15 sites, 15 months)
(night excl.= 22%, day excl.= 9%)

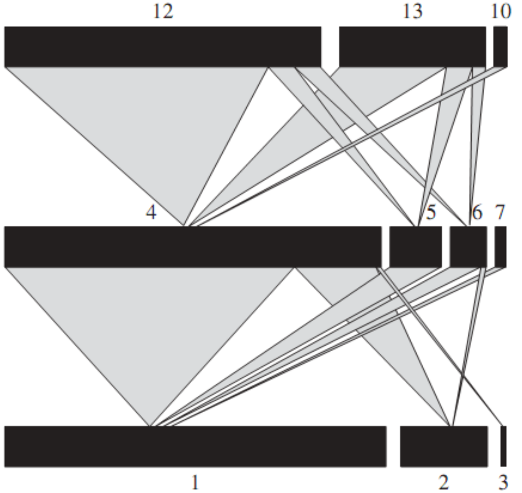


Bea Maas et al 2013, Ecol Letters

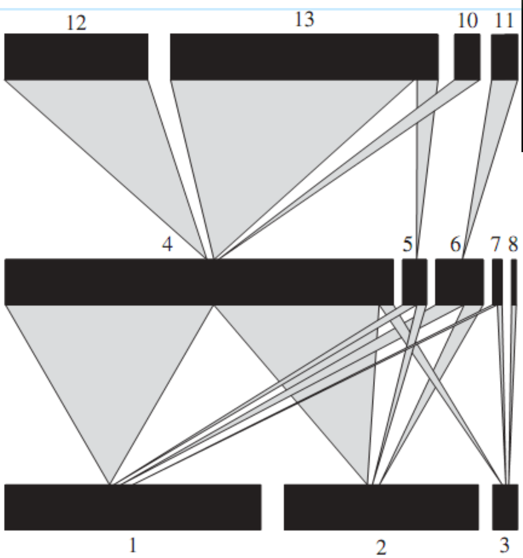


(5) Biodiversity services: Discrete trophic interactions or food web approach?

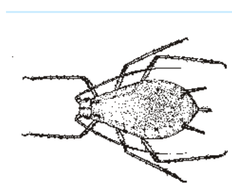
Complex landscapes



Simple landscapes



Sito – Meto - Rhopa



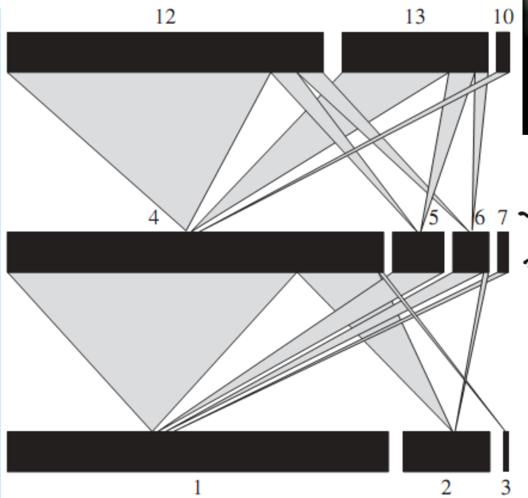
Complex landscapes:
organic wheat fields, 58% arable land
Simple landscapes:
conventional wheat, 90% arable land

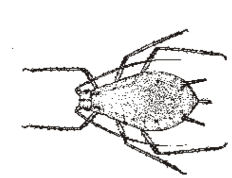
Simple landscapes =
Higher linkage density,
interaction diversity & generality

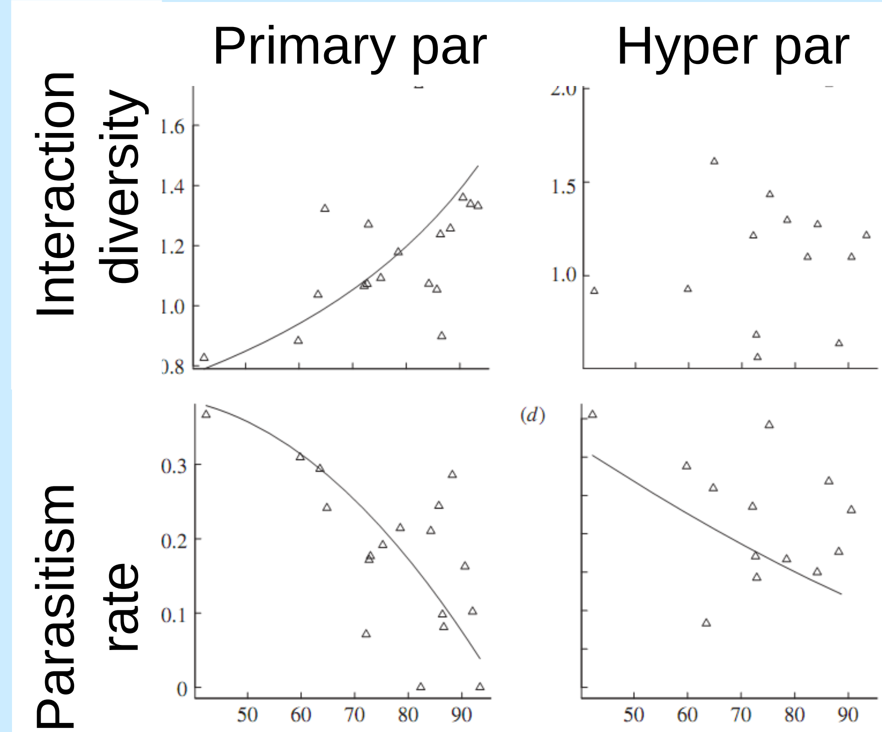
Vesna Gagic et al.
Proc Roy Soc B 2011
Oecologia 2012

(5) Biodiversity services: Discrete trophic interactions or food web approach?

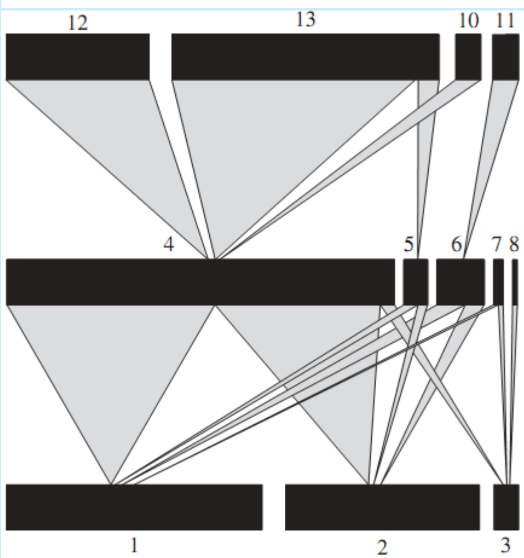
Complex landscapes

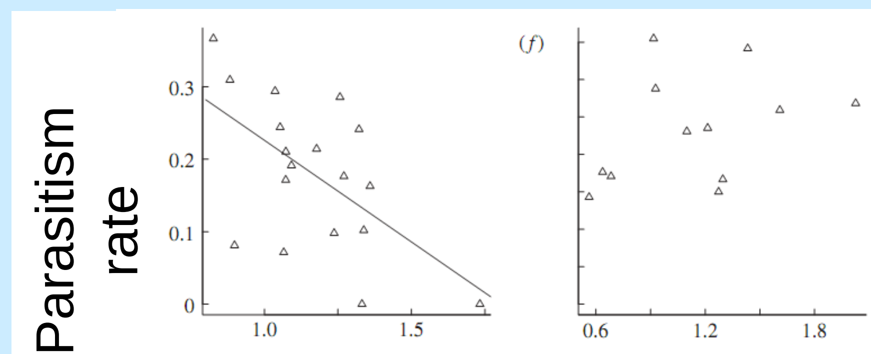






Simple landscapes





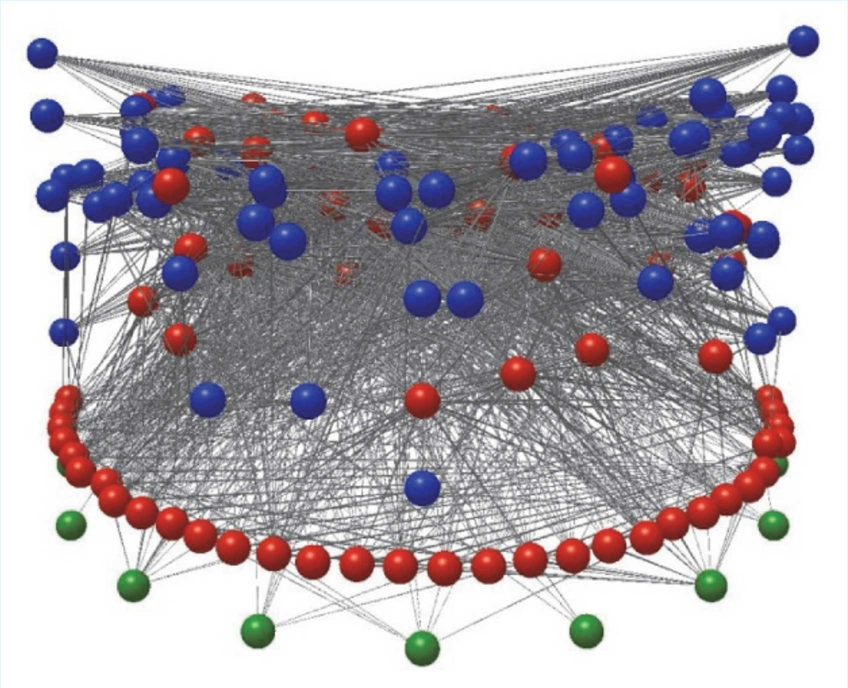
Sito – Meto - Rhopa

Vesna Gagic et al.
Proc Roy Soc B 2011
Oecologia 2012

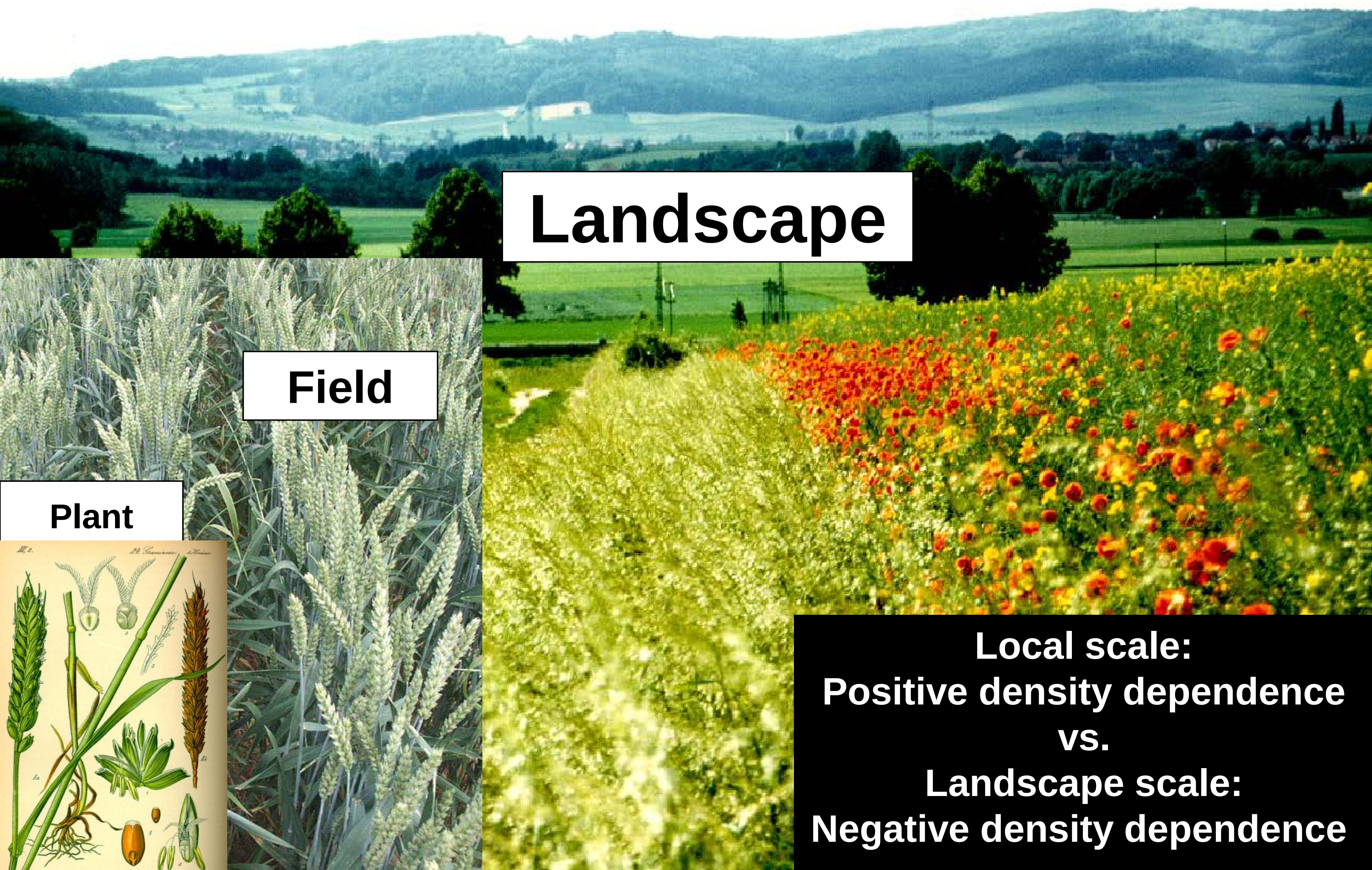
(5) Biodiversity services: Discrete trophic interactions or food web approach?

Cereal aphid-parasitoid-hyperparasitoid food webs:
Lower complexity of food webs, but higher primary parasitism,
as well as higher hyperparasitism, in complex landscapes

General importance or indicator values of food web complexity for ecosystem functioning?



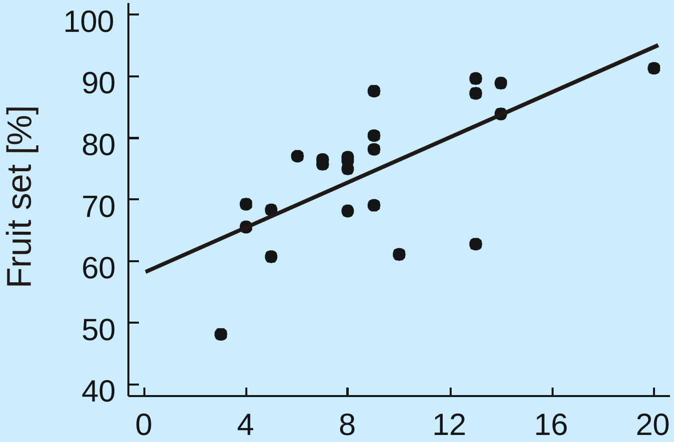
(7) Biodiversity services: Scale mismatch

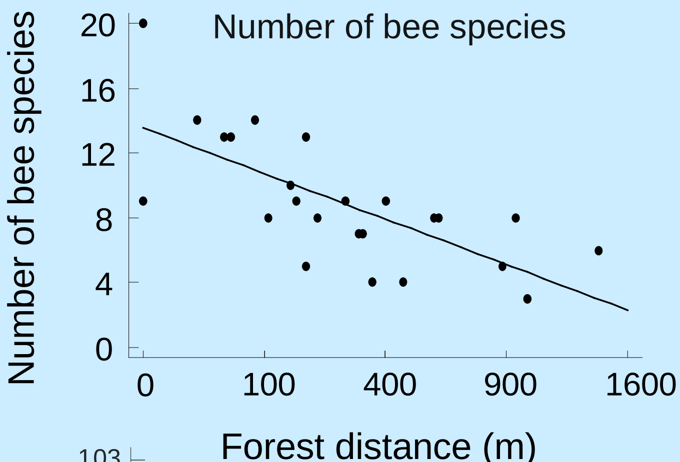


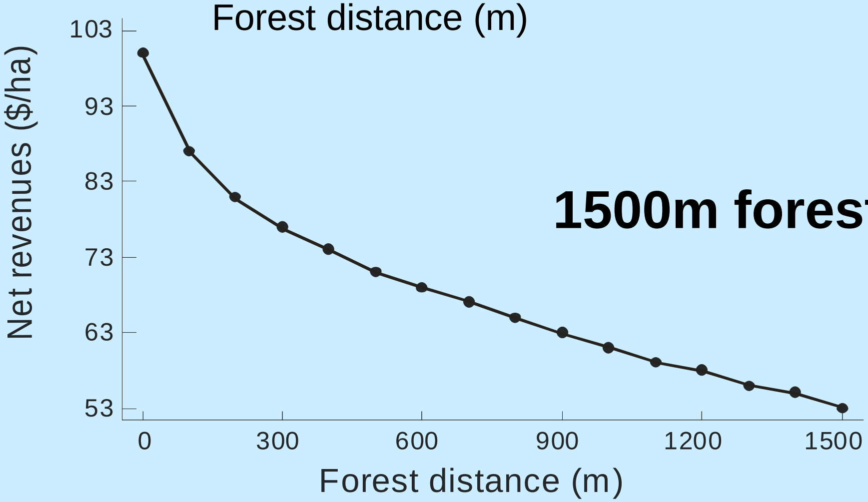
Local scale:
Positive density dependence
vs.
Landscape scale:
Negative density dependence

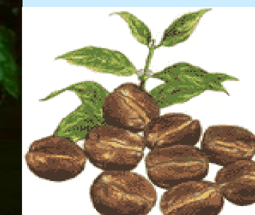
(6) Scale mismatch:
Pollination and fruit set in coffee agroforestry

(6) Bee diversity increases coffee yield (Indonesia)







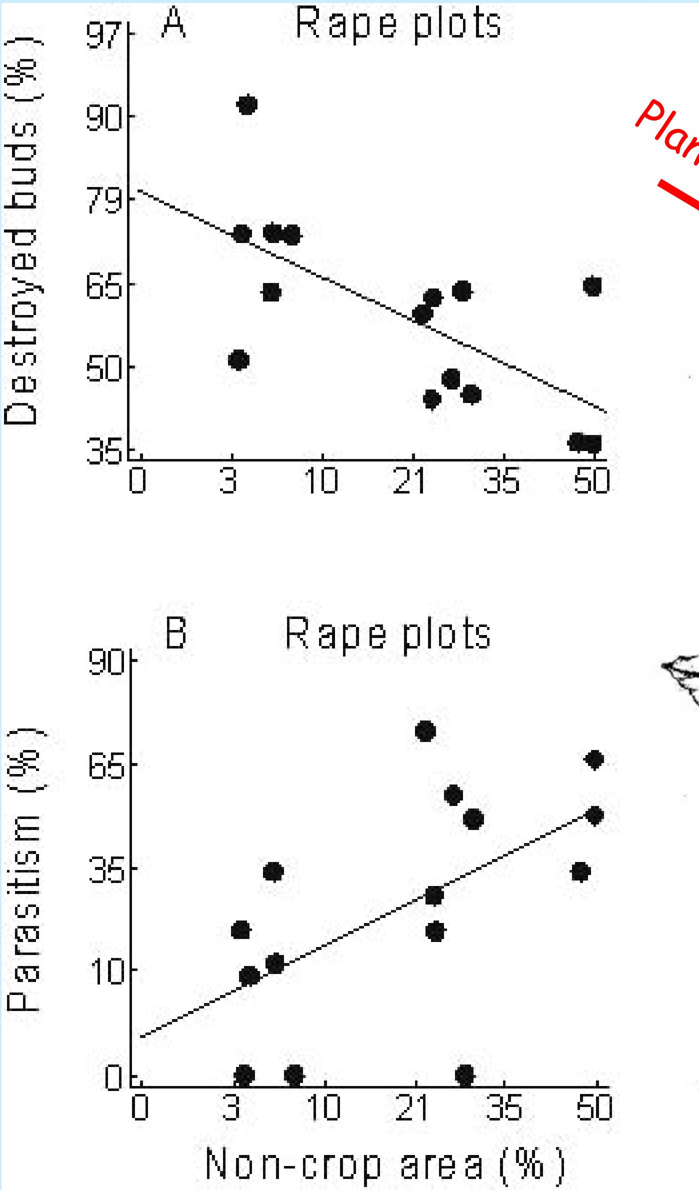


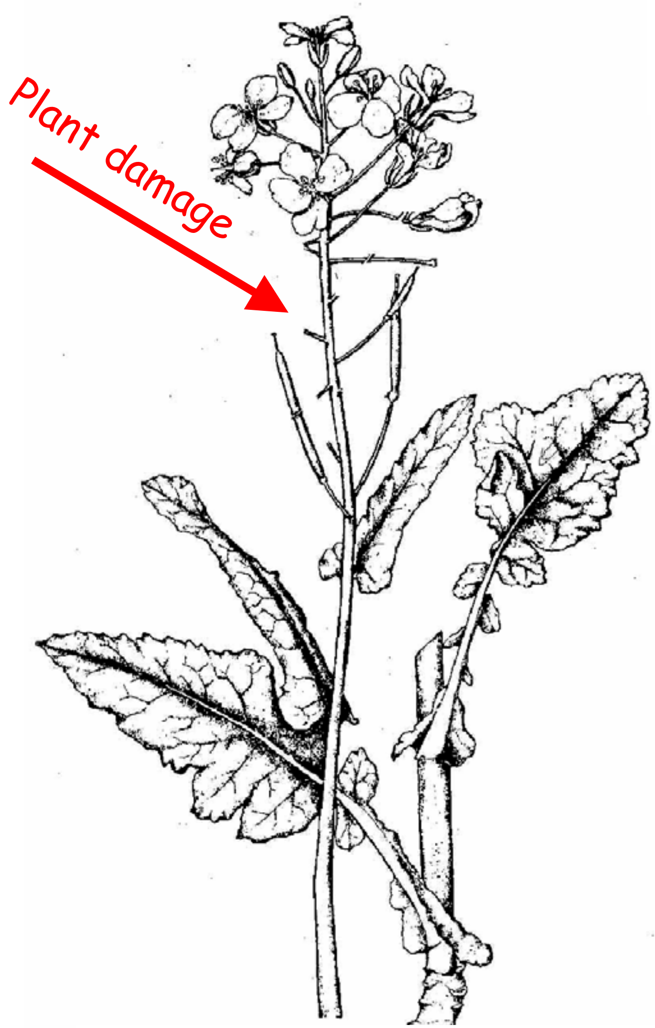
1500m forest distance = 60% fruit set,
78% berry weight,
55% coffee yield

Klein et al. 2003, Proc Roy Soc London B
Olschewski et al. 2006, Ecol Soc
Priess et al. 2006, Ecol Appl

(6) Scale mismatch: Field margin strips enhance biological control in oilseed rape *Brassica napus*

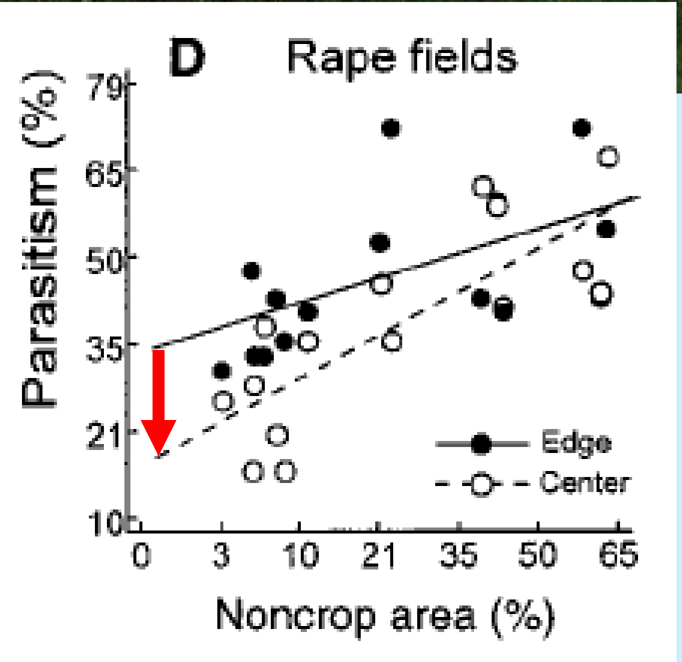
(6) Complex landscapes: reduced oilseed rape damage & increased parasitism





Thies & Tscharntke 1999, Science
Tscharntke et al. 2002, Ecol Appl

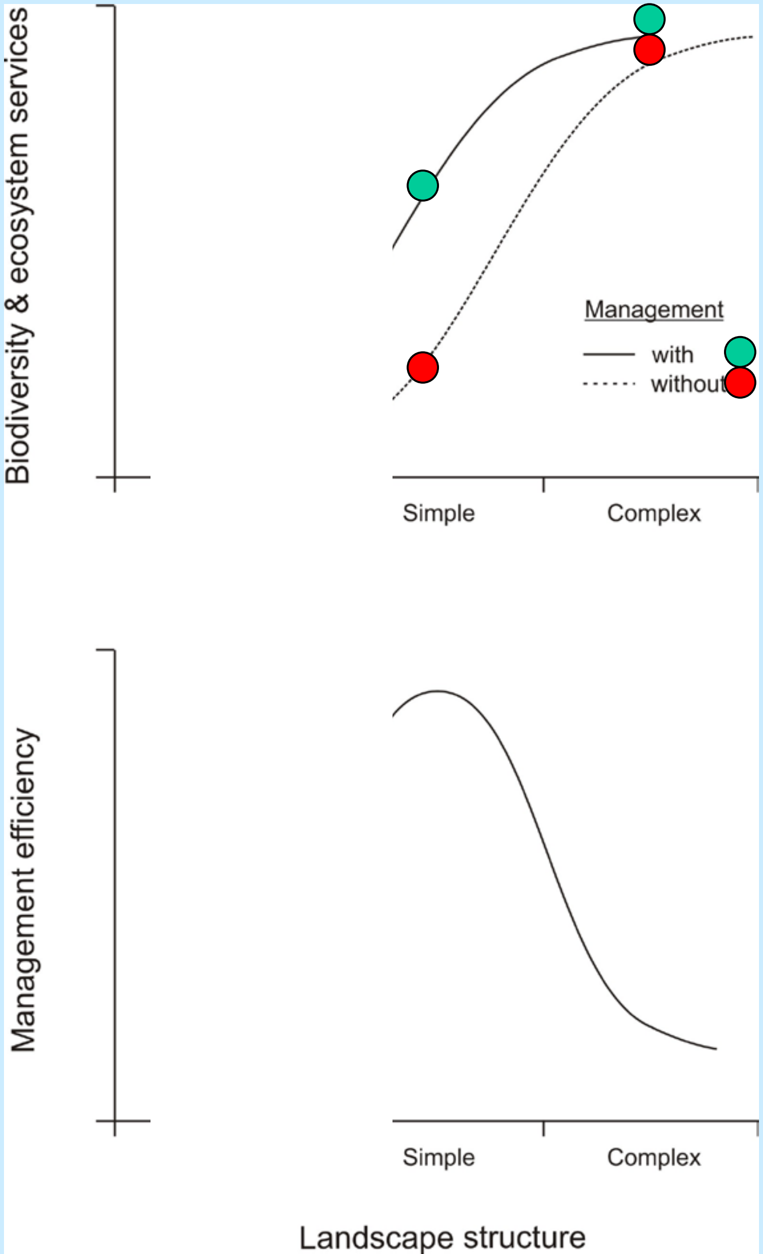
(6) Complex landscapes: reduced rape damage & increased parasitism



Edge effects only in simple landscapes!

Thies & Tscharntke 1999, Science
Tscharntke et al. 2002, Ecol Appl

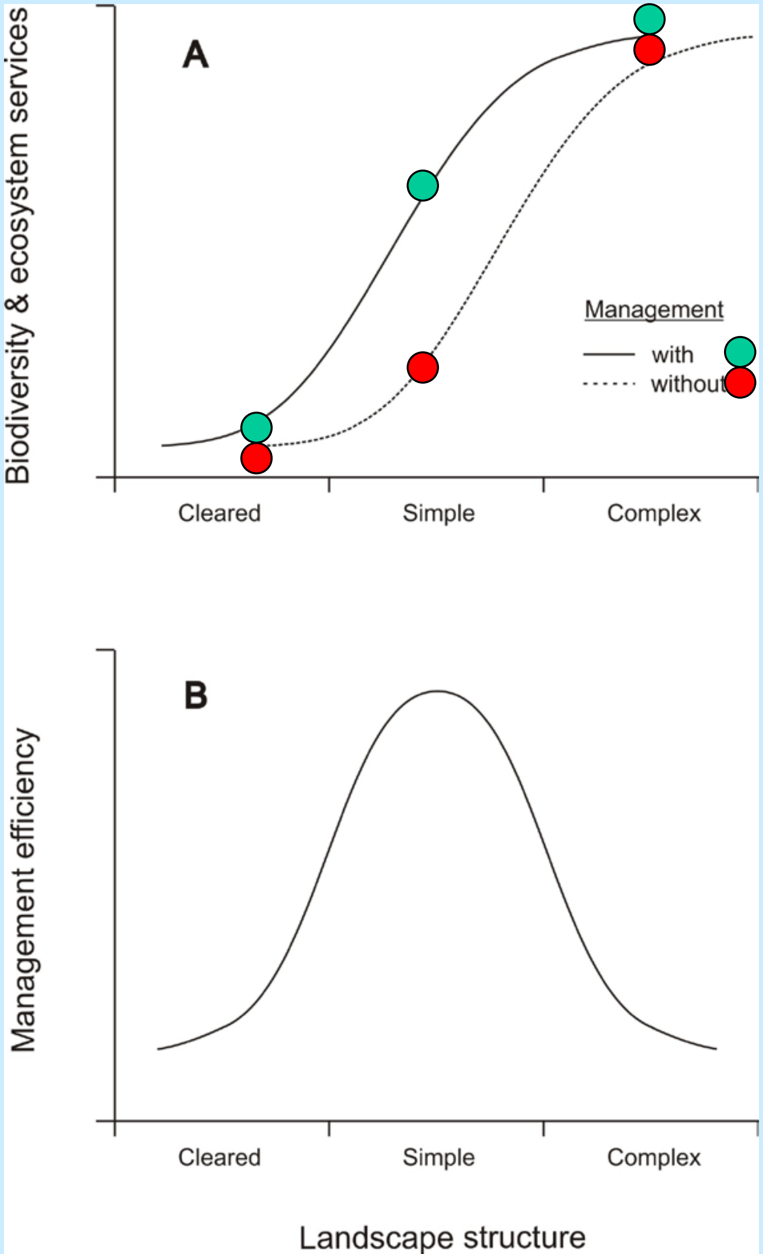
The intermediate landscape-complexity hypothesis



In simple landscapes, effectiveness of agri-environment management is highest (biodiversity, pest control)

Tscharntke et al. 2005, Ecol Letters
Tscharntke et al. 2012, Biol Reviews

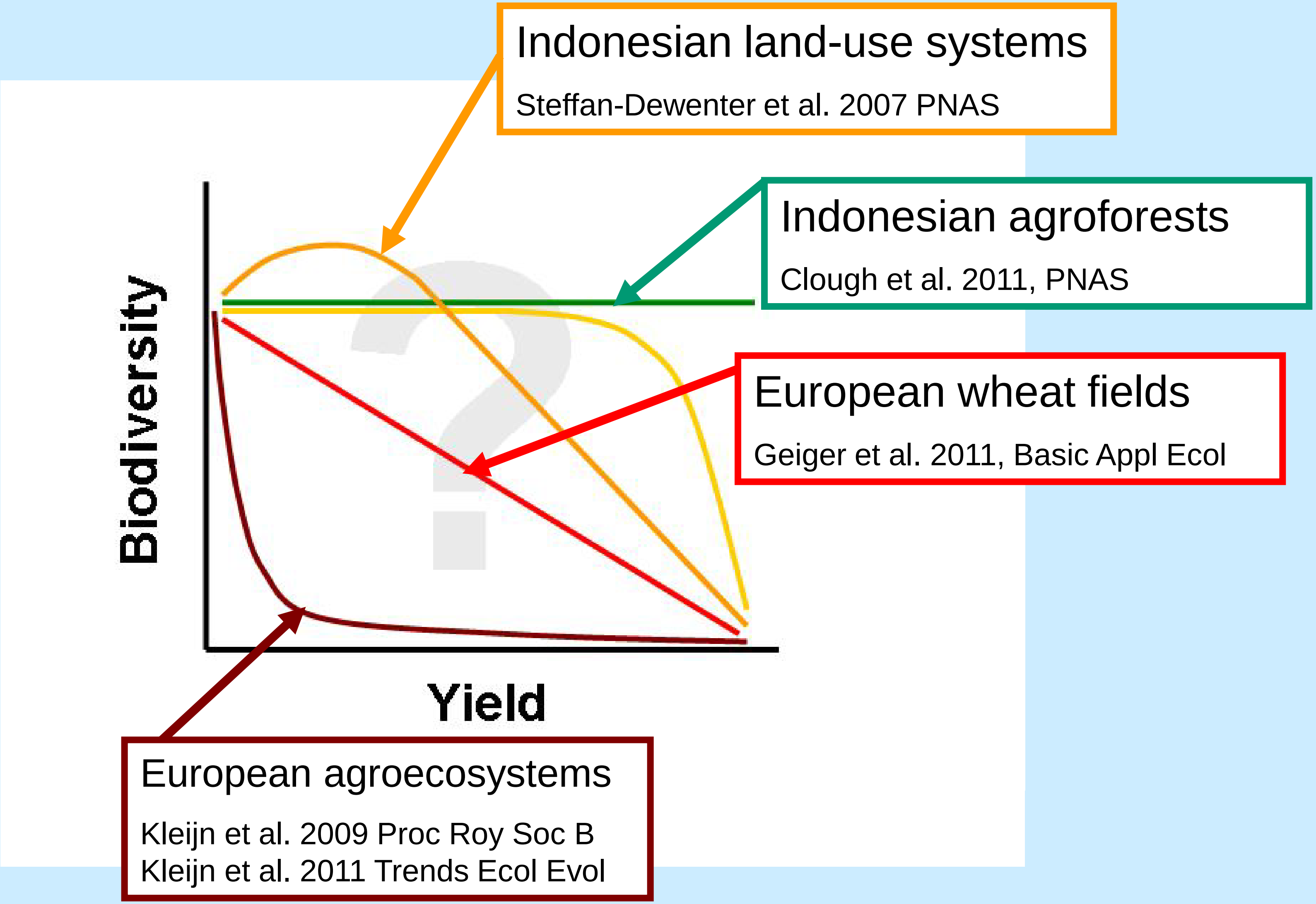
The intermediate landscape-complexity hypothesis



In simple landscapes, effectiveness of agri-environment management is highest (biodiversity, pest control)

Tscharntke et al. 2005, Ecol Letters
Tscharntke et al. 2012, Biol Reviews

(7) Are crop yield-biodiversity tradeoffs needed for resilience?

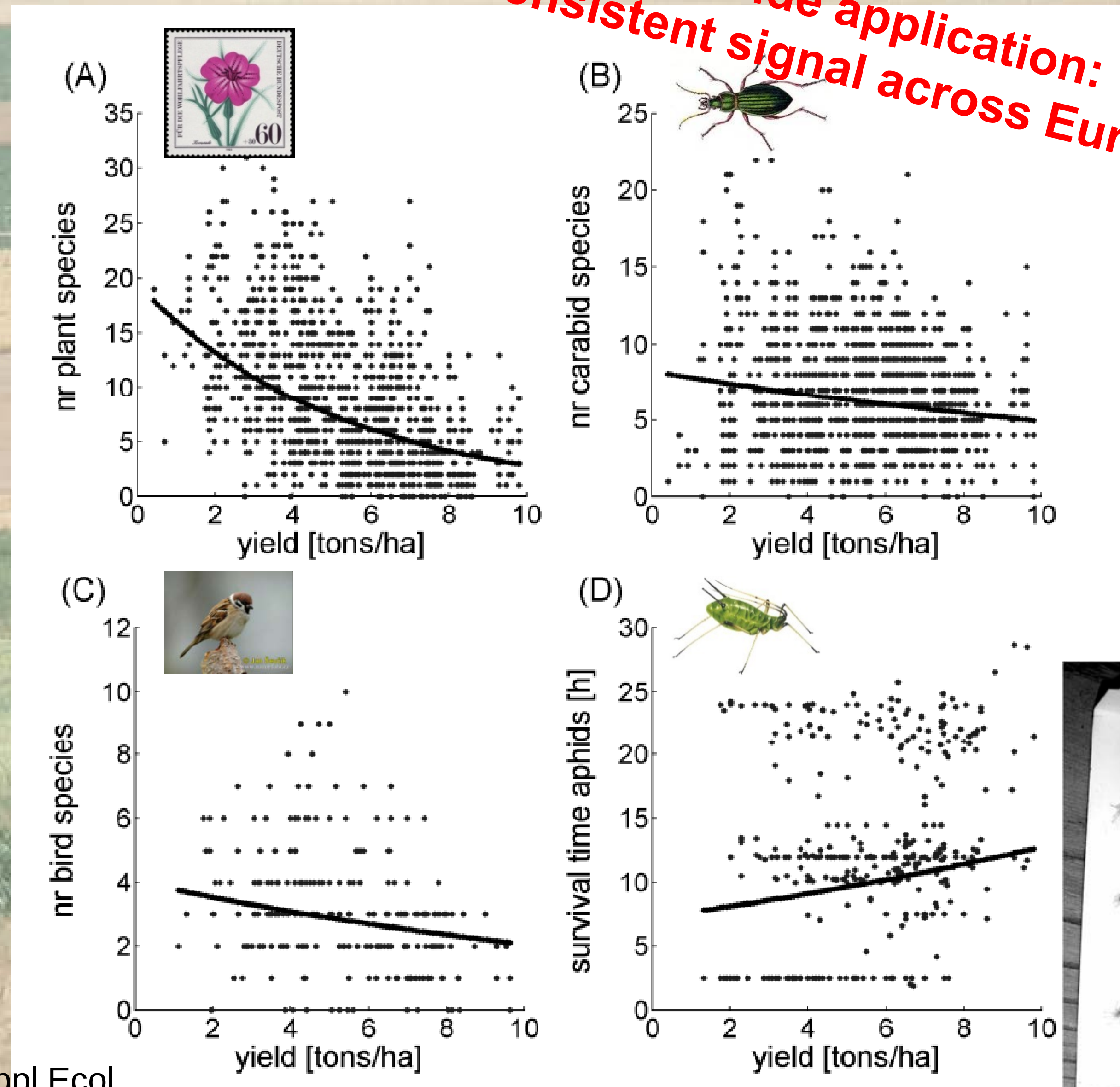


(7) Negative yield-biodiversity relation: which cause?

Side effects of pesticides on functional biodiversity and biocontrol

Pesticide application:
Consistent signal across Europe

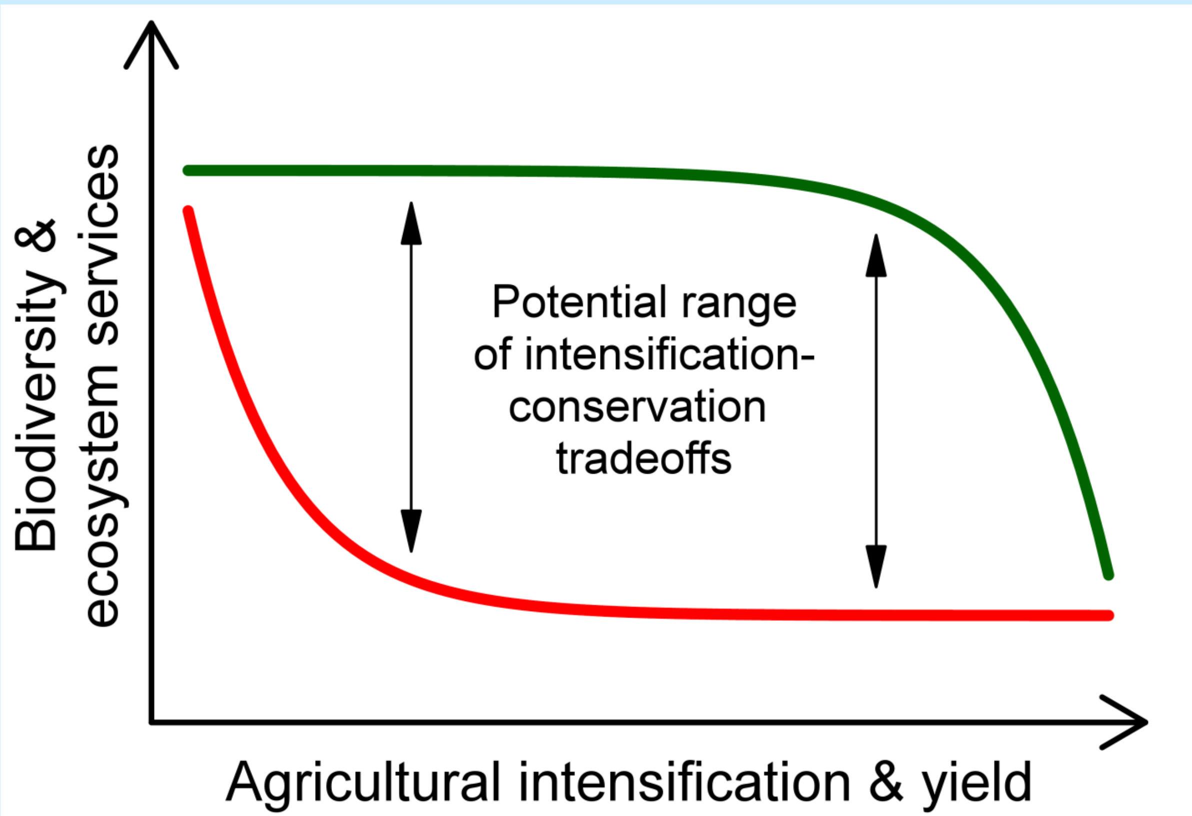
1350 wheat fields
9 EU regions
13 local &
9 landscape
predictor variables



Flavia Geiger et al. 2010, Basic Appl Ecol

(7) Ecological-economic trade-offs

Low cost-high benefit approaches for resilience



Crop diversification:
spatially, varieties species, landscapes
temporally, crop rotation, policy/market changes

Bianchi et al. 2006 Proc Roy Soc B,
Letourneau et al 2011 Ecol Appl

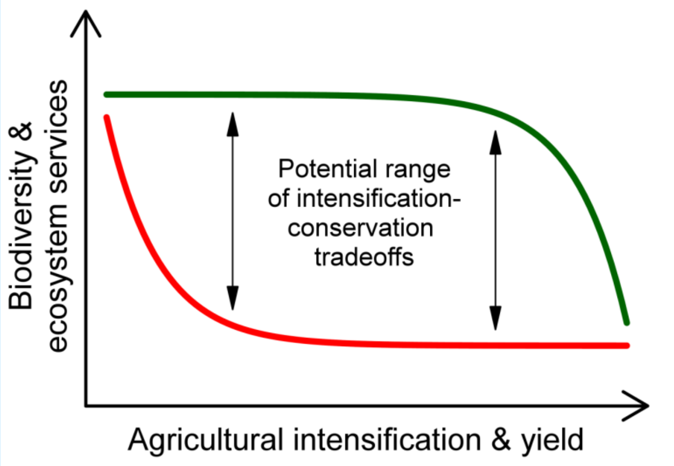
Socio-ecomomic context:
risk management, household vulnerability, traditions

Tscharntke et al. 2012, Conserv Biol
Cumming et al. 2014, Nature

(7) Ecological-economic trade-offs

The need of long-term ecological research & risk avoidance:

- ✓ unpredictability of policy & market changes
- ✓ ever changing cropping patterns
- ✓ boom-and-bust cycles in cacao
- ✓ natural & social shocks (climate/pests/fatalities)



Damaging crop-associated biodiversity services up to a tipping point only?

- ✓ Increasing corn for US biofuel production by 19%
  = 24% losses in biocontrol of soybean aphid causing higher insecticide use
  Landis et al. 2008 PNAS, Meehan et al. 2011 PNAS
- ✓ Extinction debt of biodiversity services? Kuussaari et al. 2009 Trends Ecol Evol
- ✓ Non-linearity of long-term biodiversity service losses!?
  Transient functional compensation by redundancy (hiding losses in functional redundancy & response diversity that reduce resilience)

Clough et al. 2009 Conserv Letters, Tscharntke et al. 2012 J Appl Ecol, Tscharntke et al. 2012, Conserv Biol, Cumming et al. 2014, Nature

Management conclusions

(1) Agriculture has shaped landscapes and biodiversity:
cultural ecosystem services

(2) The agricultural matrix drives functional landscape connectivity
for biodiversity services

(3) Agroecosystems need functional biodiversity (land sharing):
crop pollination, biocontrol

(4) Quantitative interaction webs: functional value often unclear

(5) Intermediate *versus* final services (crop yield)

(6) Scale mismatch in agrobiodiversity management: local vs. landscape scales,
the intermediate landscape complexity hypothesis

(7) Ecological-economic trade-offs with *agroecological* intensification,
long-term ecological research needed in ever-changing environments,
non-linearity of responses may cause sudden losses in resilience