Ecological basis of the relationship between forest diversity and resistance to pest insects

Hervé JACTEL, INRA, France

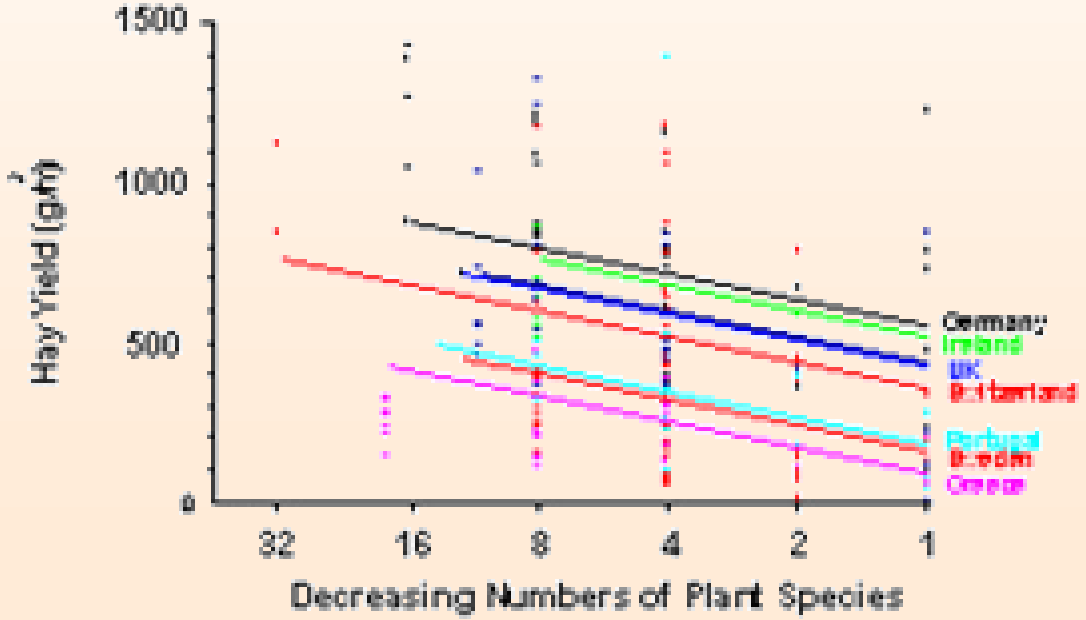
The functional significance of biodiversity in ecosystems

The idea that the number of species can influence ecosystem functioning is an old (Darwin, 1859) but still central issue in ecological sciences

(Tilman et al. 1996, McCann 2000, Loreau et al. 2001, Worm & Dufy, 2003)

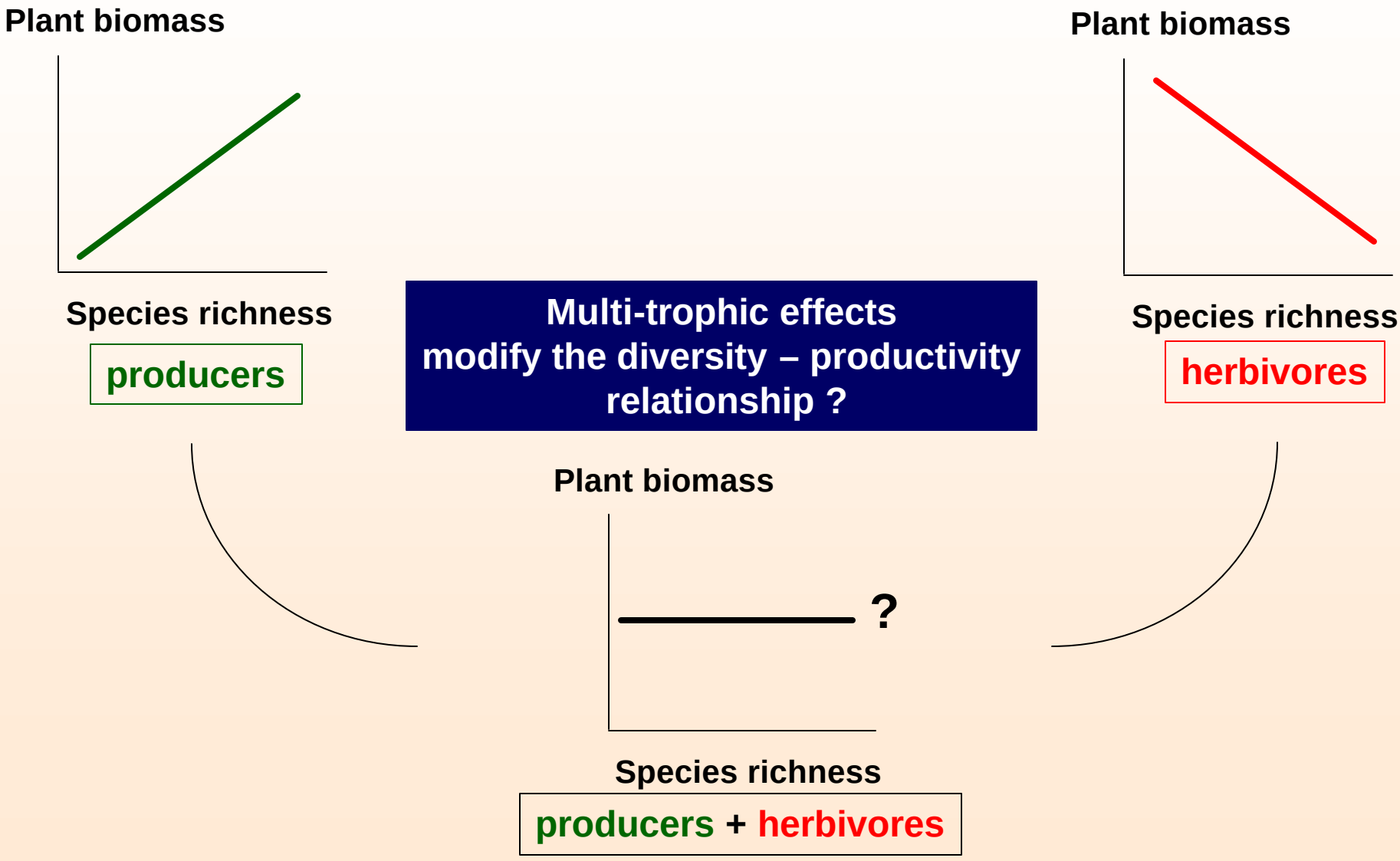
Pioneer studies demonstrated that ecosystem productivity increased with species richness

(Hector et al. 1999)



The functional significance of biodiversity in ecosystems

However, enhanced resource exploitation in higher trophic levels (consumers) can decrease productivity ***(Loreau et al. 2001, Aoki 2003)***



The practical relevance of biodiversity in pest management

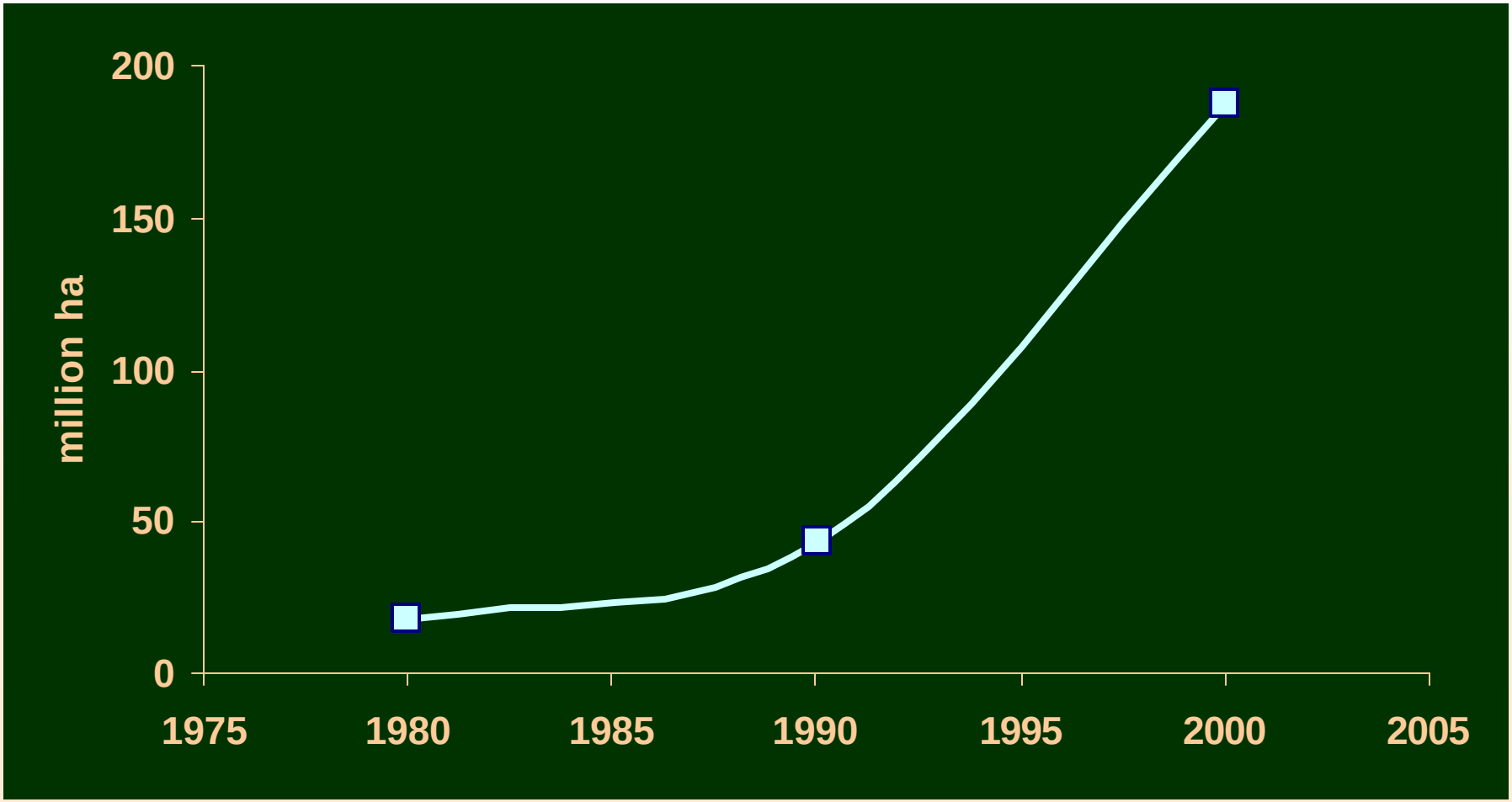
Two reviews - cumulating almost 200 studies - showed that diverse agrosystems had lower pest populations than monocultures in 62% of the cases
(Risch et al. 1983, Tonhasca & Byrne 1994)

The adoption of monoculture systems has directly led to an increase in the severity of pest in forest crops
(Gibson, I.A.S. & Jones, T. 1977)

The dogma stating that risks from pest attacks increase markedly in monocultures is well supported by the literature in tropical forestry
(Speight, M.R. 1997)

The practical relevance of biodiversity in pest management

The area of single-tree species (plantation) forests is expanding world-wide



The practical relevance of biodiversity in pest management

Single-species forests more prone to insect outbreaks than diverse forests ?

A new quantitative review to address the question

- **data mining -** bibliographic data bases, search engines
- **meta-analysis -** combining results of independent experiments

Unbiased effect size

$$d = J_{N_E, N_C} \frac{Mean_E - Mean_C}{Stdev_{E,C}}$$

C = control group
E = experimental group

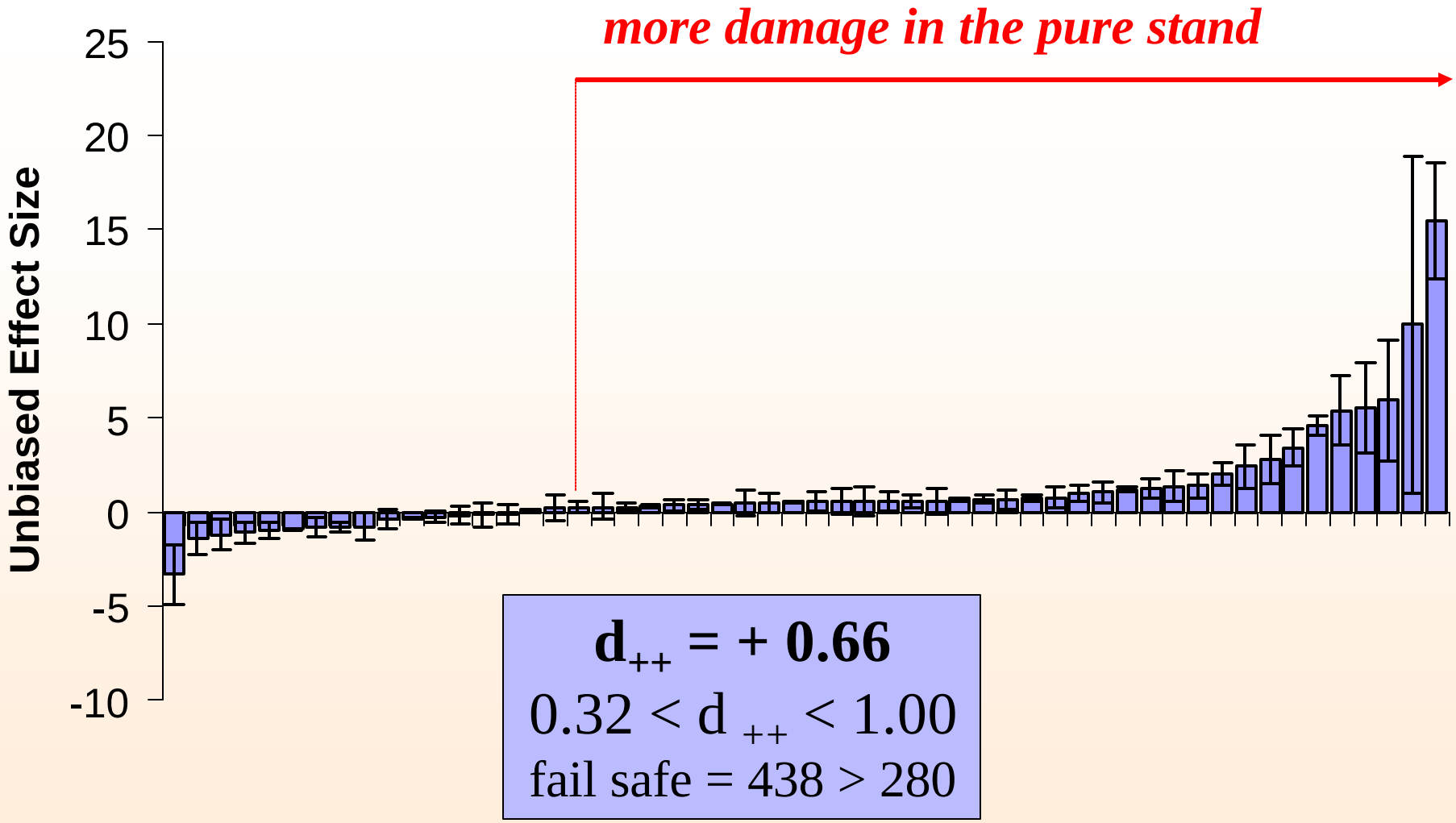
The meta-analysis

- **mean damage *or* abundance**
- **particular insect species (forest pest)**
- **particular tree species**

  single-species stand (E) vs. mixed-species stand (C)

29 experimental studies
28 pest insect species
30 tree species
54 insect - tree interactions

(Jactel, Brockerhoff and Duelli, *in press*)



$\mathbf{d_{++} = + 0.66}$

$0.32 < d_{++} < 1.00$

fail safe = 438 > 280

➔ **significant increase of forest pest insect damage when a tree species is grown in single-species stands**

Higher herbivory in forest monocultures:

➔ 3 main ecological mechanisms

---

1. Host accessibility

2. Impact of natural enemies

3. Host shift

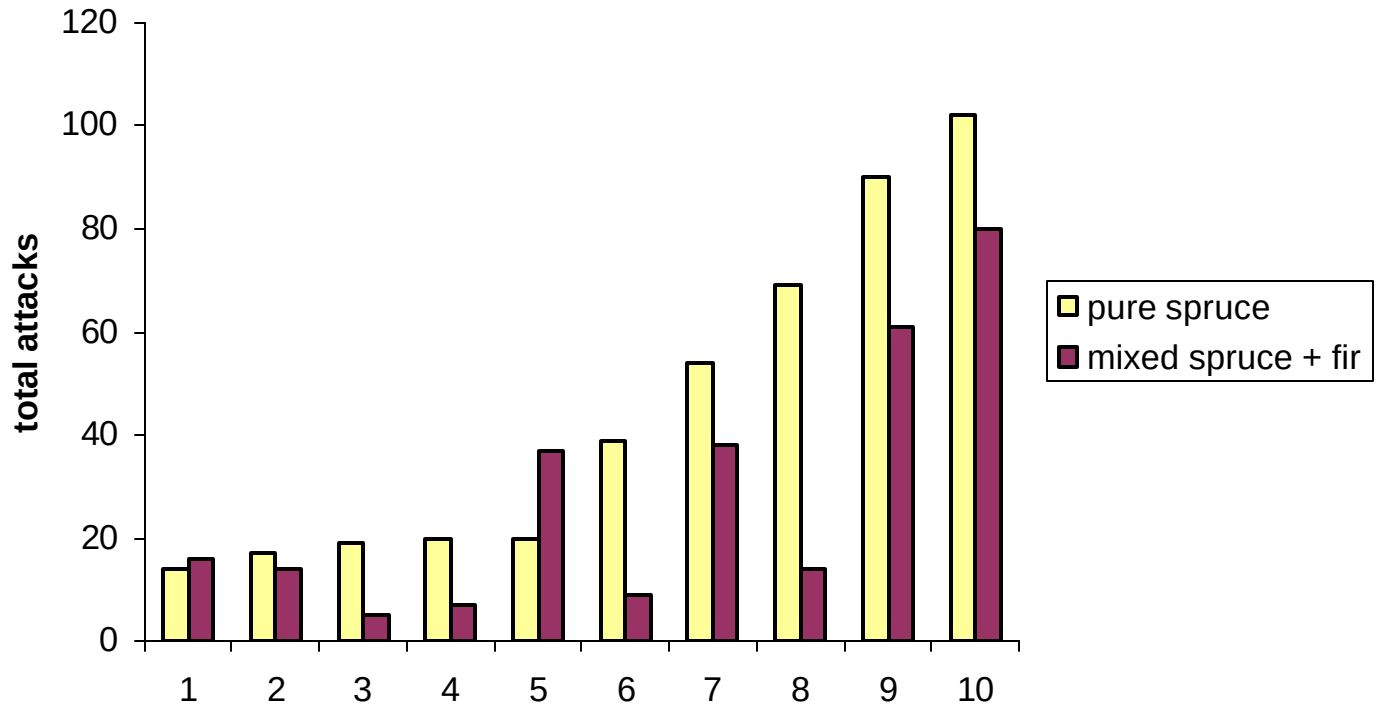
1. Accessibility of host trees

1.1. Increased and prolonged plant availability favors herbivores

eruptive pests, spreading from foci to cover large area
bark beetles

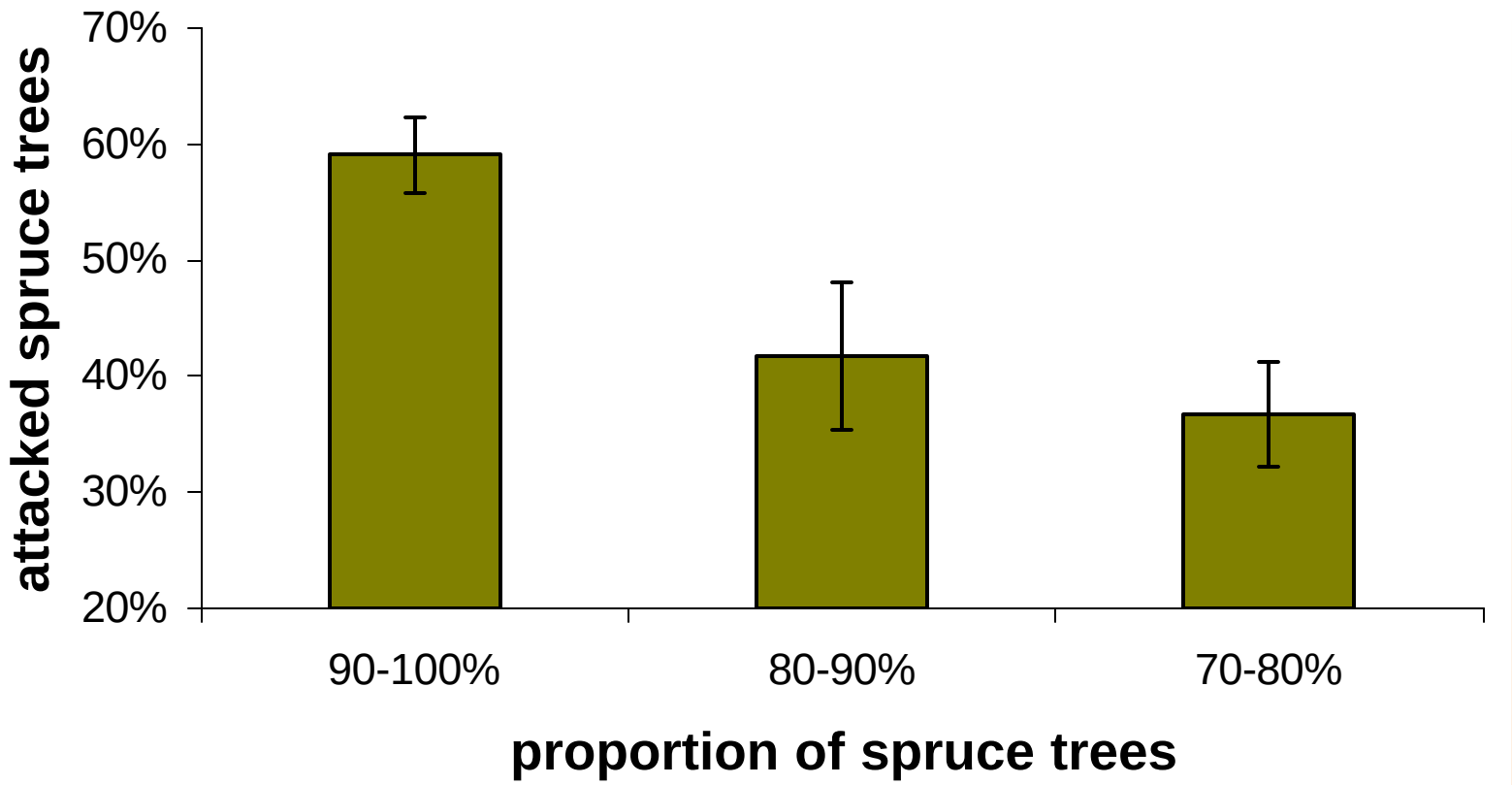
Dendroctonus frontalis

Dendroctonus micans damage in the same year, in the same stand in pure plots of spruce *vs.* mixed plots of spruce + fir



N = 10 pairs
Paired sample *t* test
Class variable: plot purity
t = 2.61 , *P* = 0.028

After data from Granet & Perrot (1977)



➔ ***More attacked trees in plots where the host resource is more concentrated***

1. Accessibility of host trees

1.1. increased and prolonged plant availability

1.2. lack of physical barriers favors host tree colonisation

- **no restriction of pest dispersal**
  wind-dispersed larvae
  (scale insects, gypsy moth, winter moth, spruce budworm)

- **no interruption of visual cues**
  recognition of tree silhouette

Acacia processionary moth
Ochrogaster lunifer

Thaumetopoea pityocampa

1. Accessibility of host trees

1.1. increased and prolonged plant availability

1.2. lack of physical barriers

1.3. lack of chemical barriers favors host tree localization

- **uniform olfactory signals more easily located**
- **no chemical inhibition by repellent stimuli of associated plants**
  bark beetles, stem borer

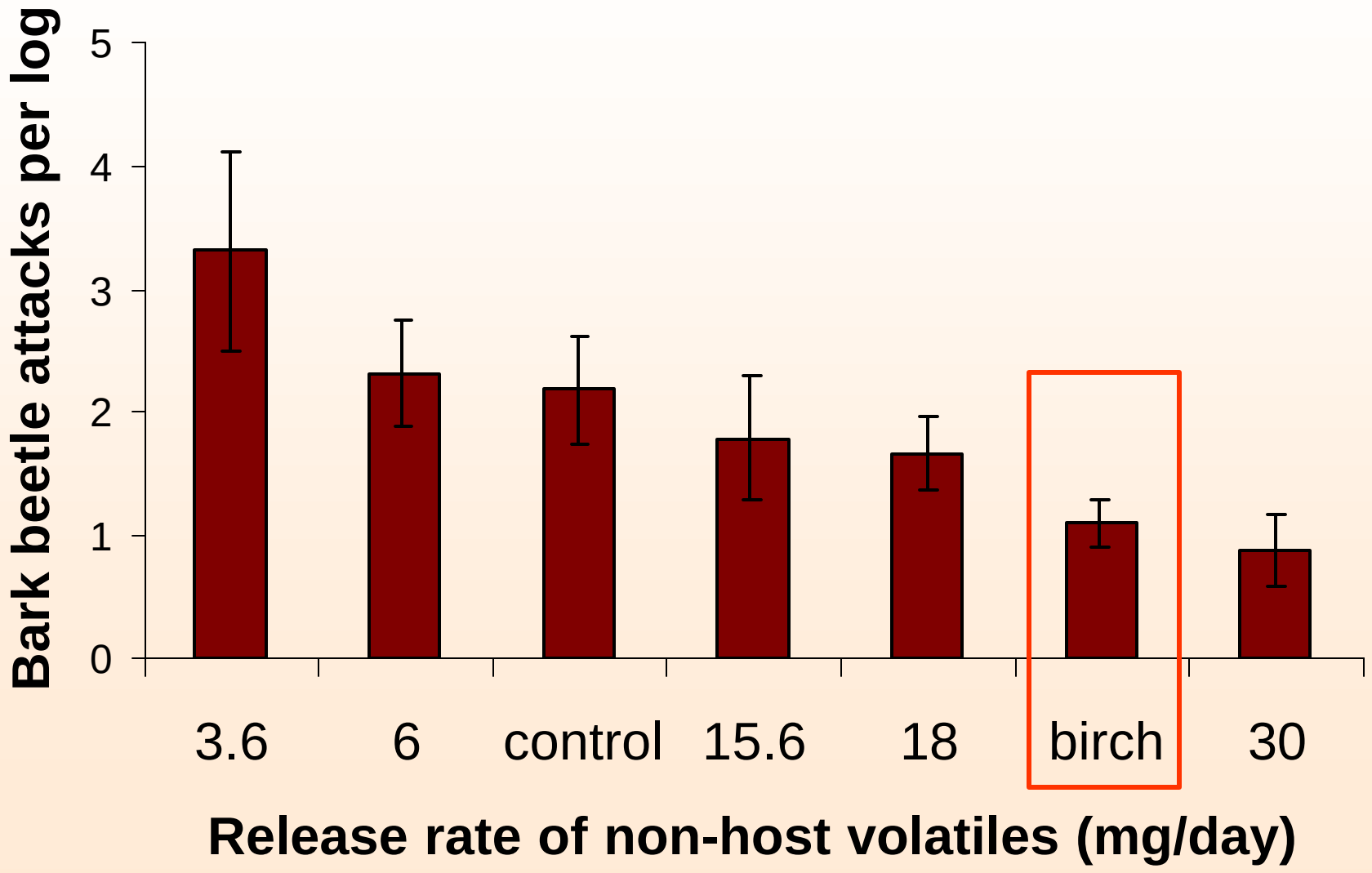
Preventing bark beetle attacks of maritime pine logs with Non-Host Volatiles extracted from birch (*Betula pendula*)

Ips sexdentatus

Repellents around pine logs

Birch trunks around a pheromone trap

Effect of birch volatiles on *Ips sexdentatus* attacks on maritime pine logs (Jactel et al. 2003)



1. Accessibility of host trees

1.1. increased and prolonged plant availability

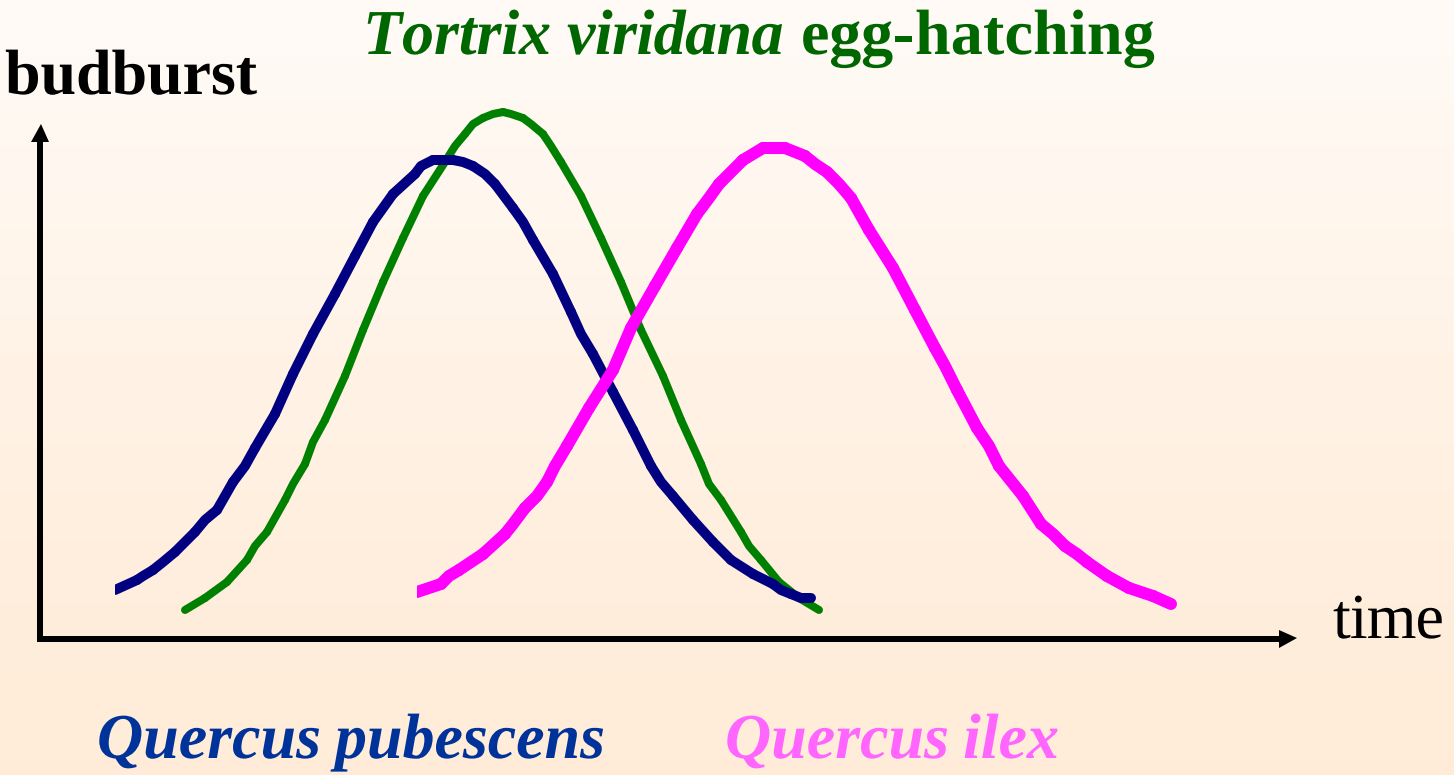
1.2. lack of physical barriers

1.3. lack of chemical barriers

1.4 lack of temporal barriers favours adjustment of life cycles

coincidence between insect and host plant phenology
egghatch and budburst (Tortrix viridana)

Population dynamics of green leaf-roller: coincidence with host phenology



DuMerle & Mazet, 1983

2. Lack of stable populations of natural enemies

2.1. fewer alternative hosts or prey for parasitoids & predators

lower abundance of prey (predators), lower diversity of hosts (parasitoids)
temporal misfits with arrival or seasonal increase of the pest

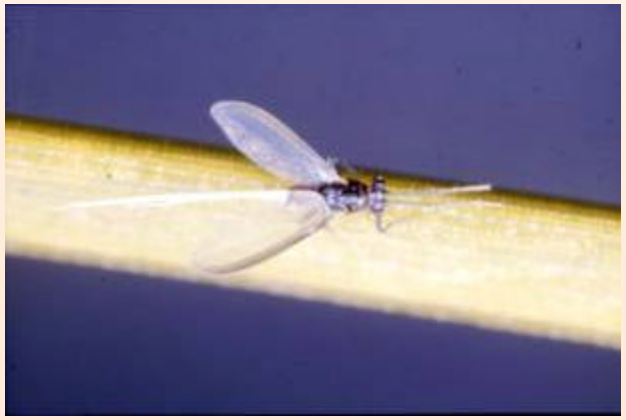
2.2. lack of shelter or refuges

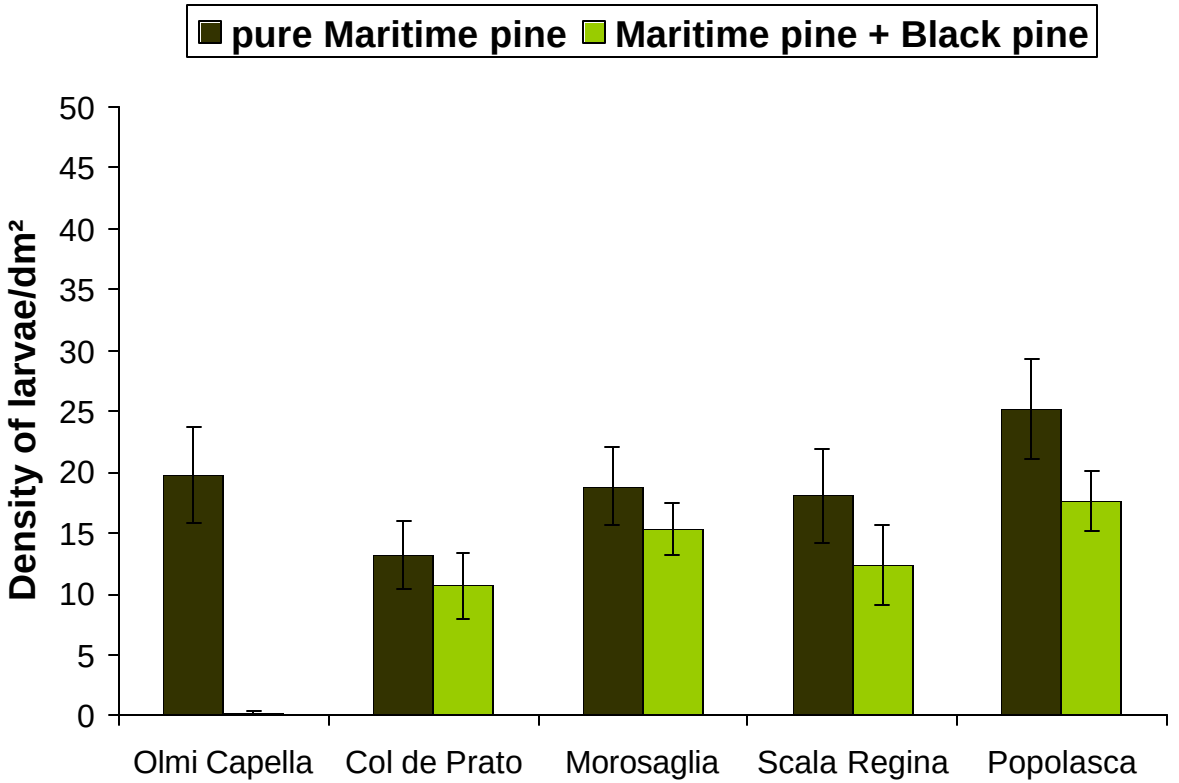
overwintering or oviposition sites
buffers against high temperature, low humidity

2.3. lack of critical food supply

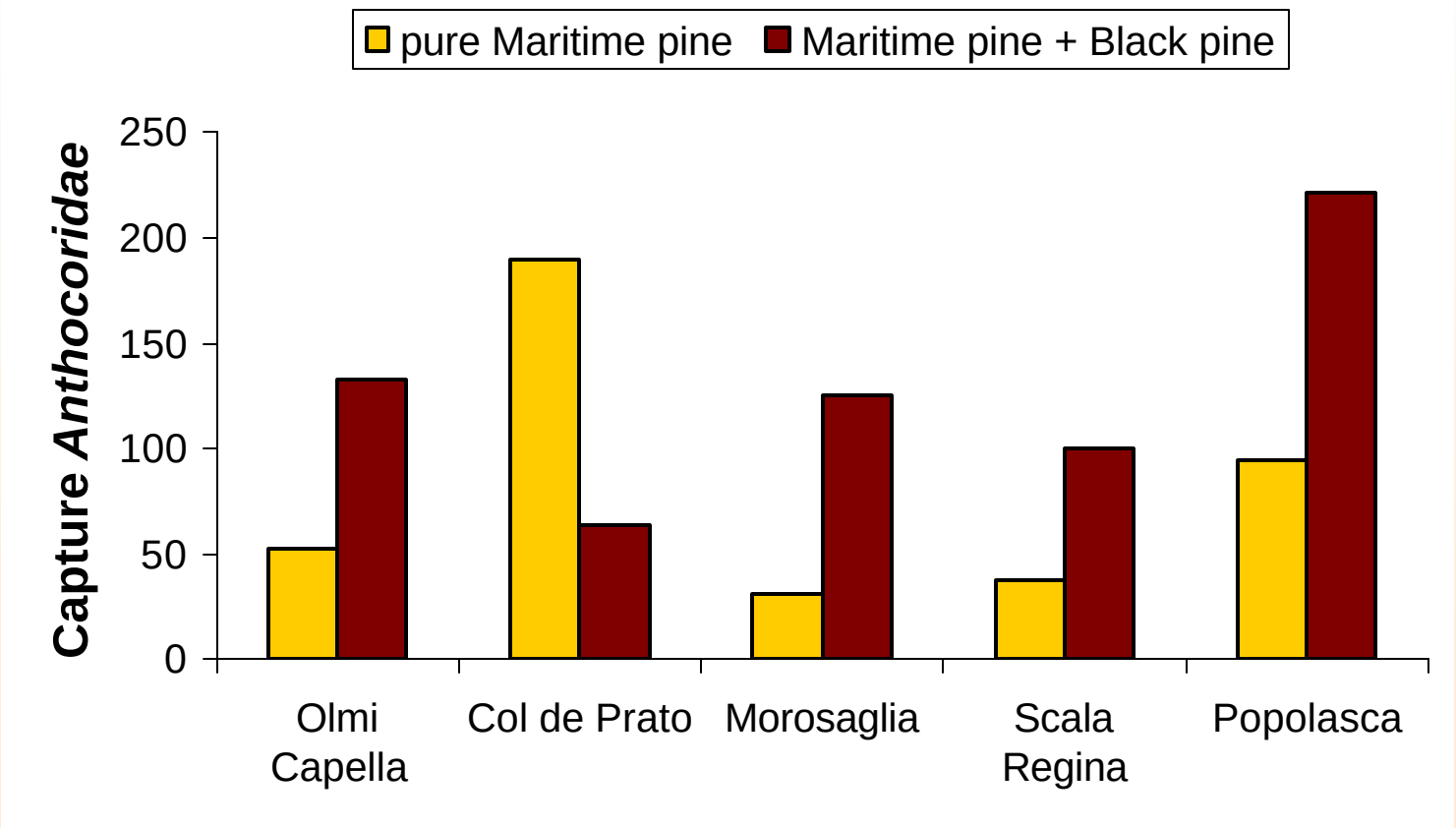
nectar, pollen, honeydew increase parasitoid longevity and fitness

The maritime pine bast scale *Matsucoccus feytaudi* causes more damage in pure maritime pine stands than in maritime pine – black pine mixtures

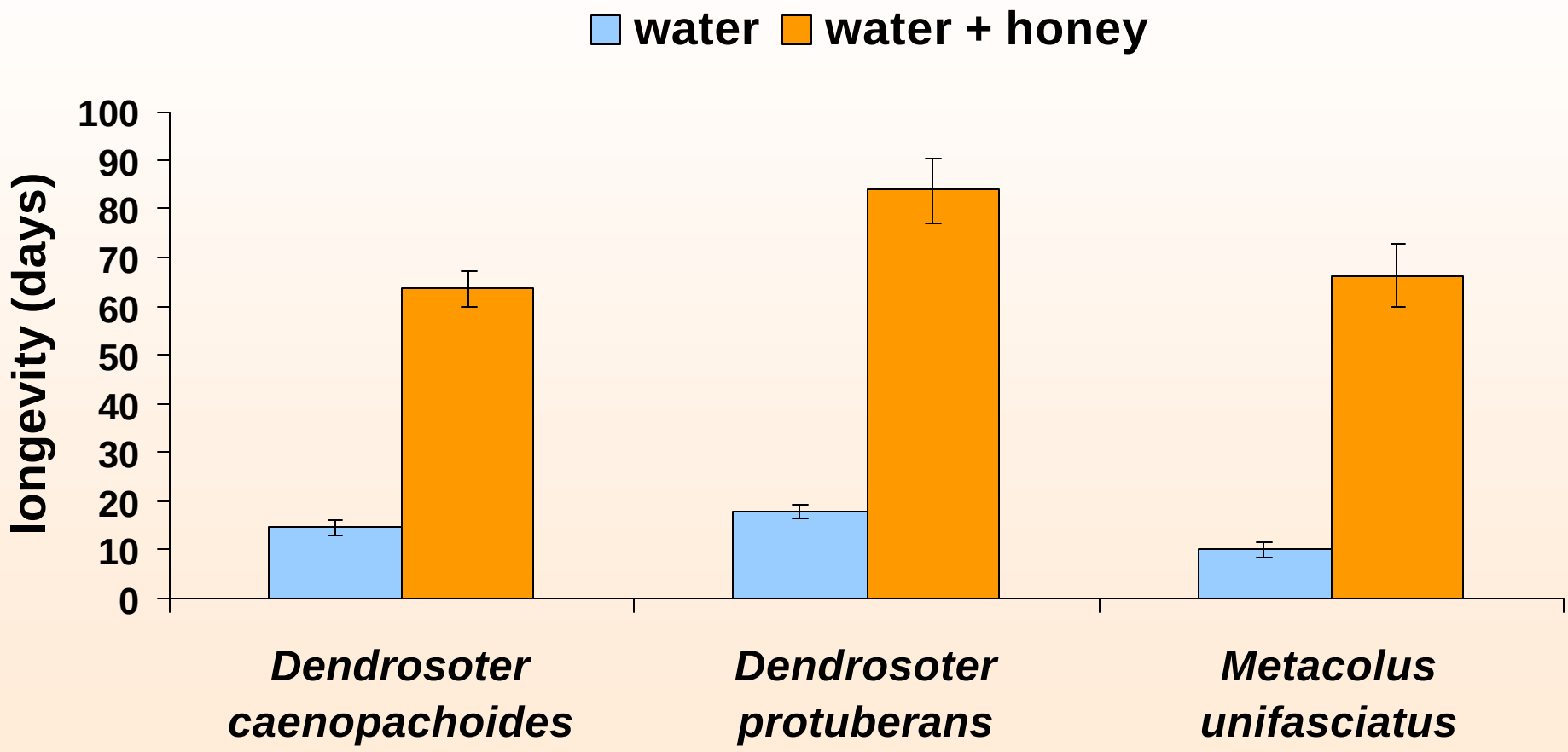




Elatophilus nigricornis (Anthocoridae) can prey on both *Matsucoccus pini* (Black pine) and *Matsucoccus feytaudi* (Maritime pine)



Effect of provision of food on longevity of bark beetle parasitoids



Mendel 1988

3. Host shifts during pest dynamics

3.1. Heteroecious pests

2 host species needed to complete life cycle

Adelgids

Pachypappa tremulae: spruce + aspen
Prociphilus fraxini: fir + ash
Pemphigus bursarius: poplar + grasses

SUCCESSION

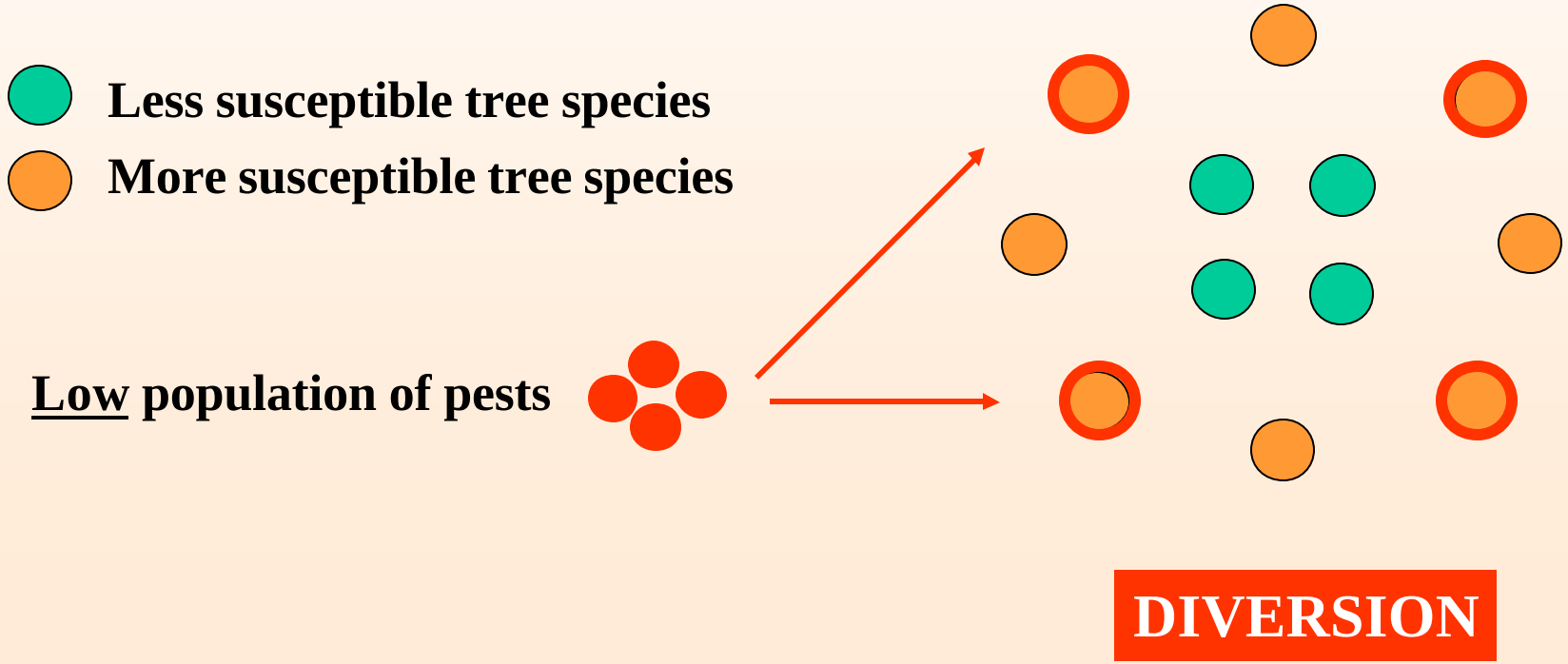
Adelges cooleyi
fir + spruce

3. Host shifts during pest dynamics

3.1. Heteroecious pests

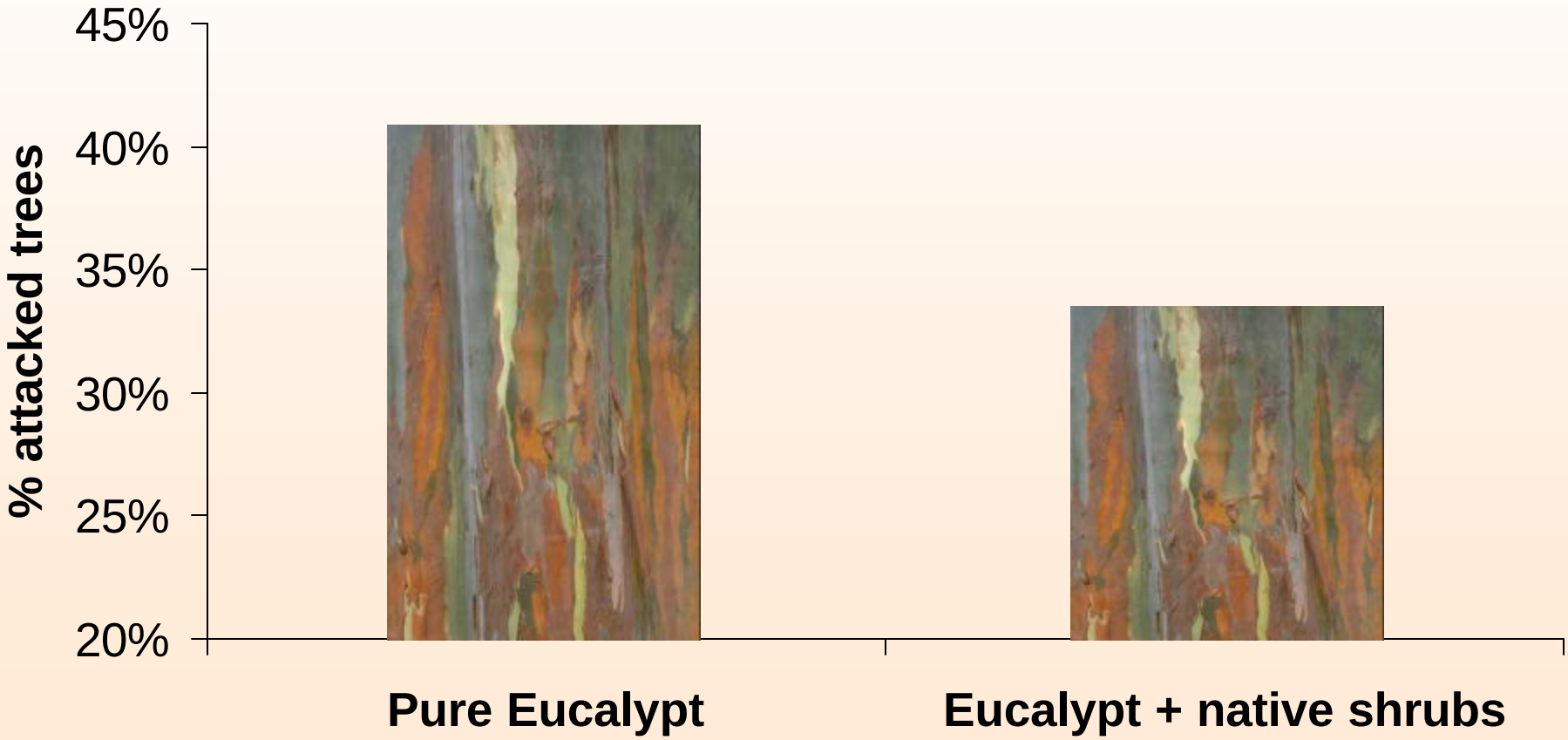
3.2. Diversion to other, more palatable tree species

mixture of more susceptible host trees
& low population of polyphagous pest



Amblypelta cocophaga in *Eucalyptus deglupta*

Bigger 1985



3. Host shifts during pest dynamics

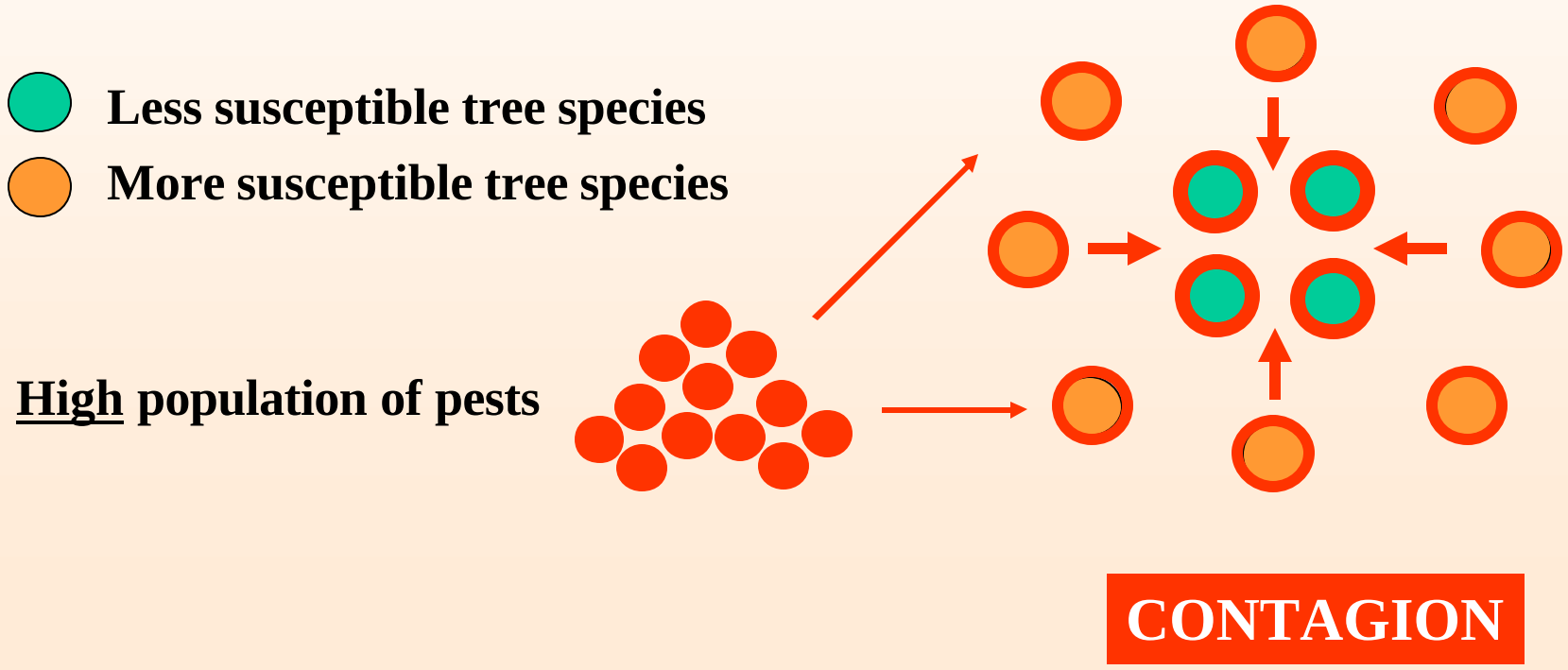
3.1. Heteroecious pests

3.2. Diversion process

3.3. Contagion from other, more palatable tree species

mixture of more susceptible host trees

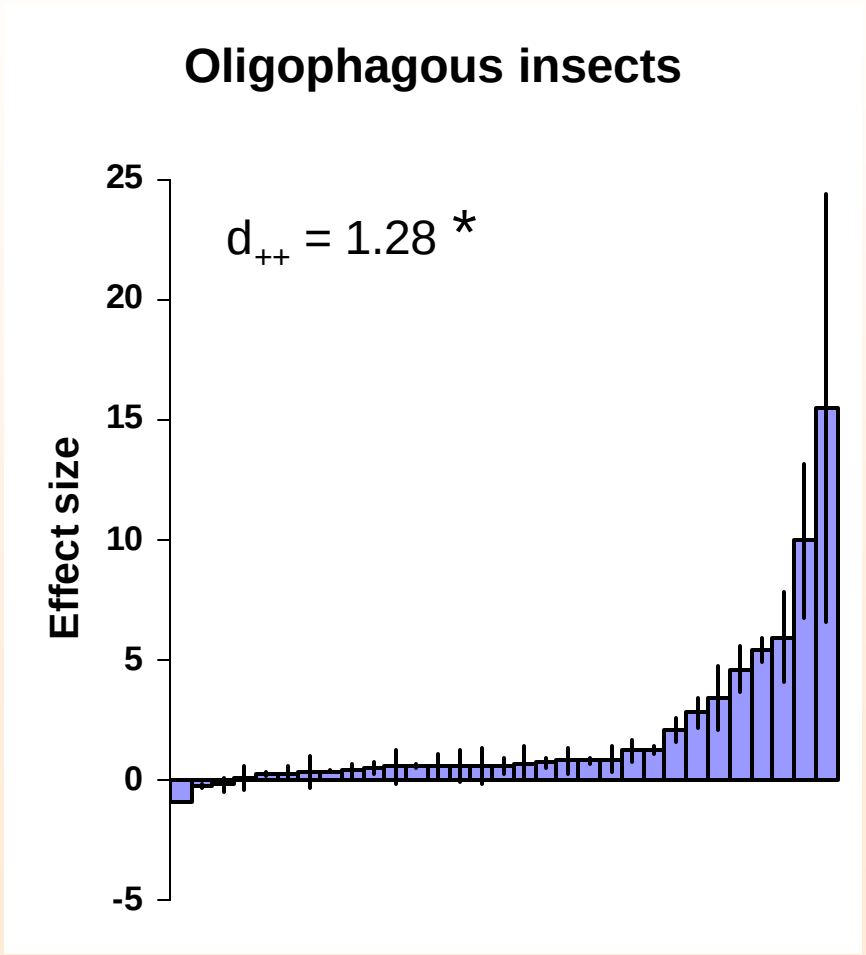
& high population of polyphagous pest

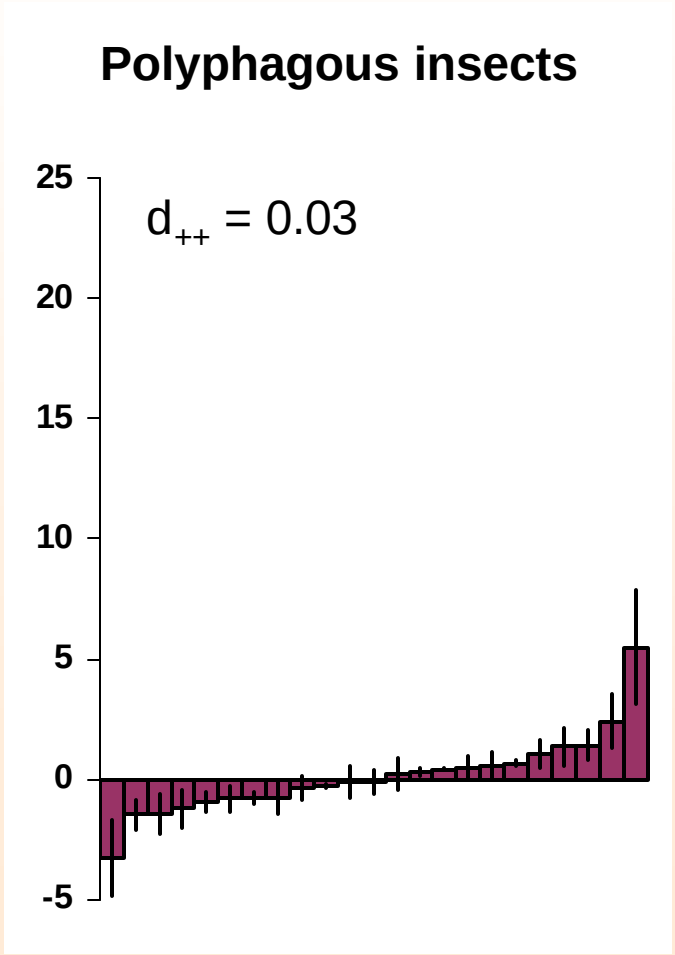


Fall cankerworm, *Alsophila pometaria* in pure *Populus* vs. *Populus* + *Acer negundo*

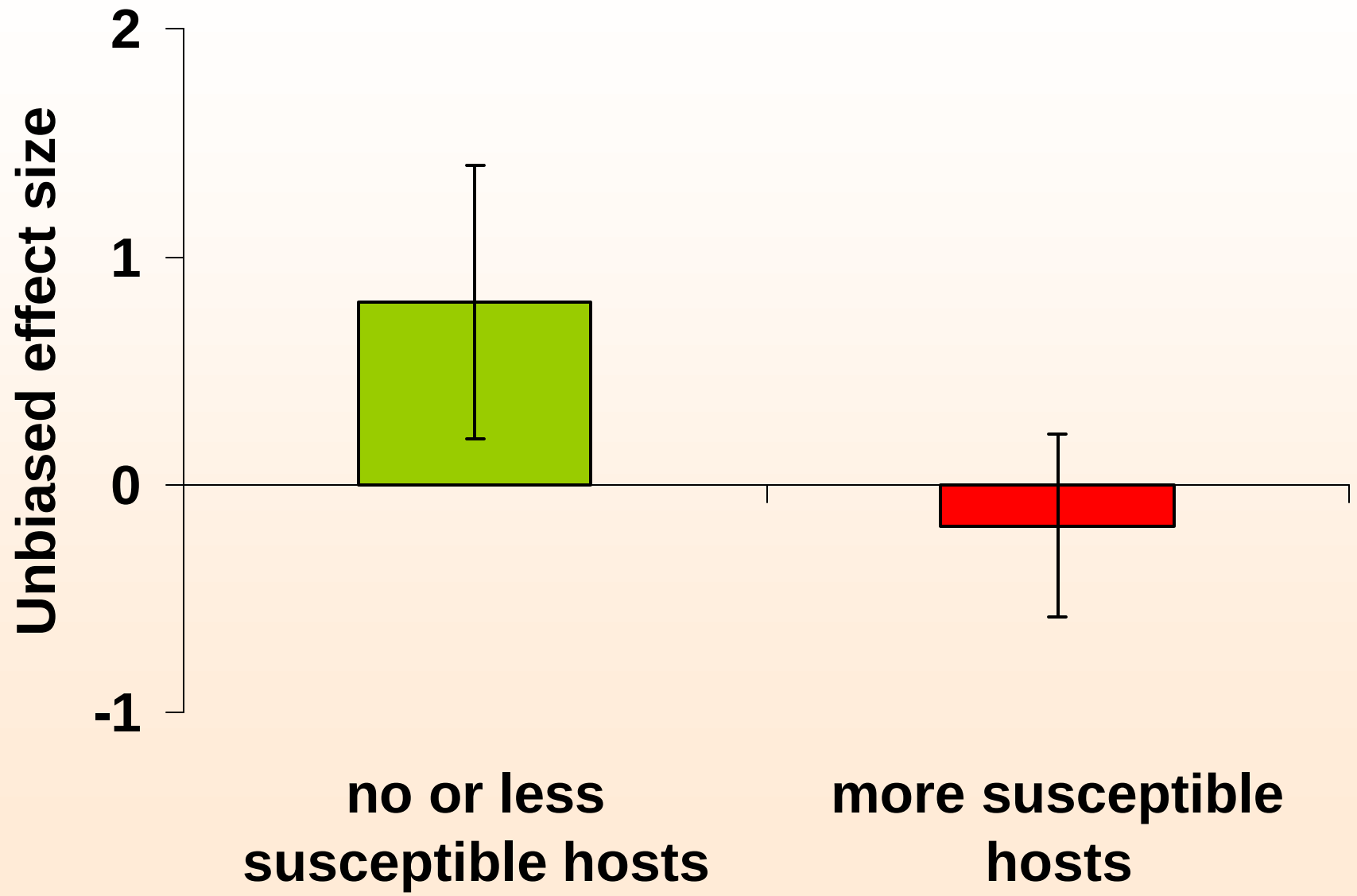
White & Whitham, 2000

Tree diversity – pest resistance relationship: the exception of the polyphagous insects

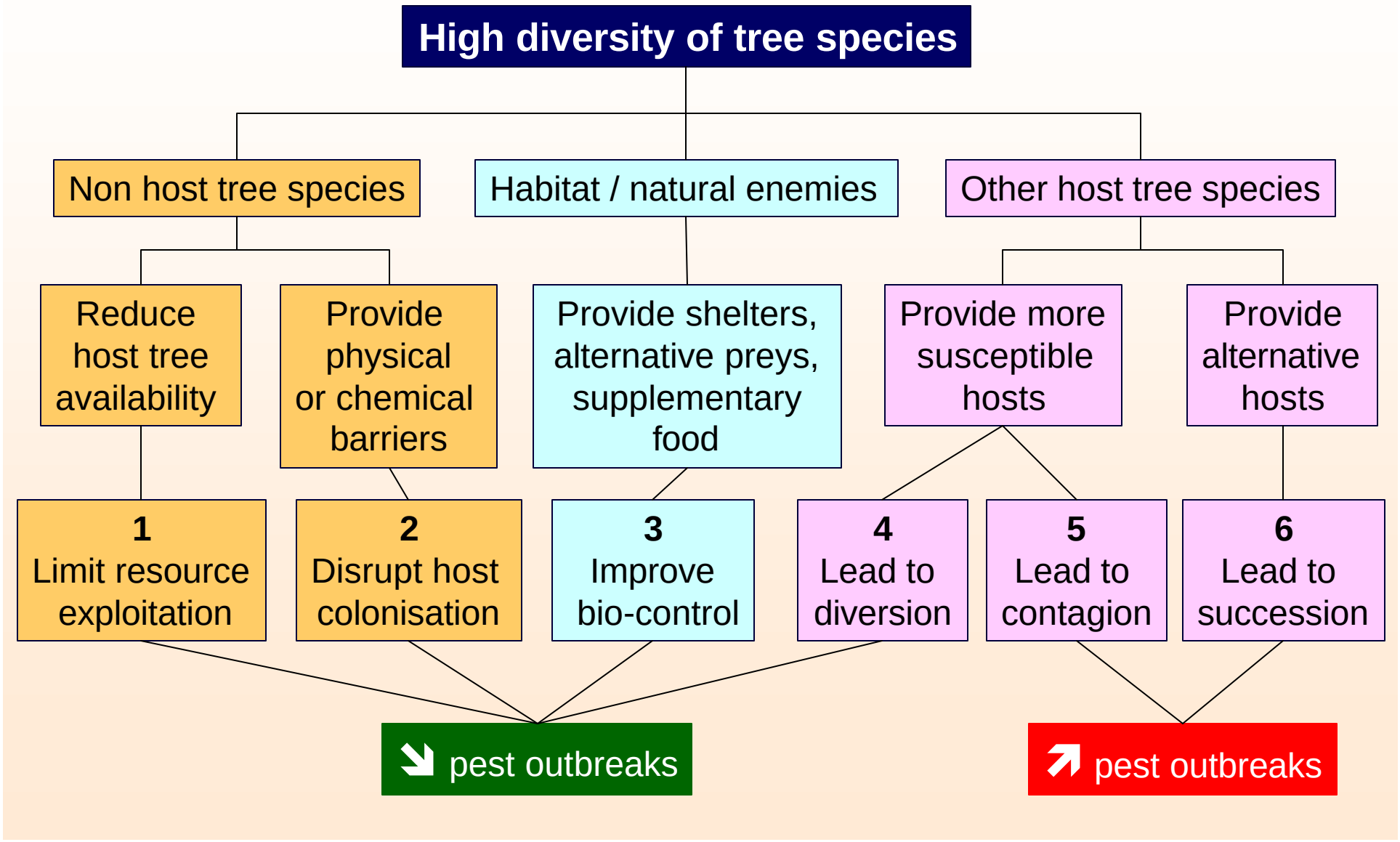




Presence in the mixture of other host trees more susceptible to polyphagous pests



Tree Diversity – Pest Resistance : The ecological mechanisms



Up-scaling the tree diversity – pest resistance relationship to the landscape level

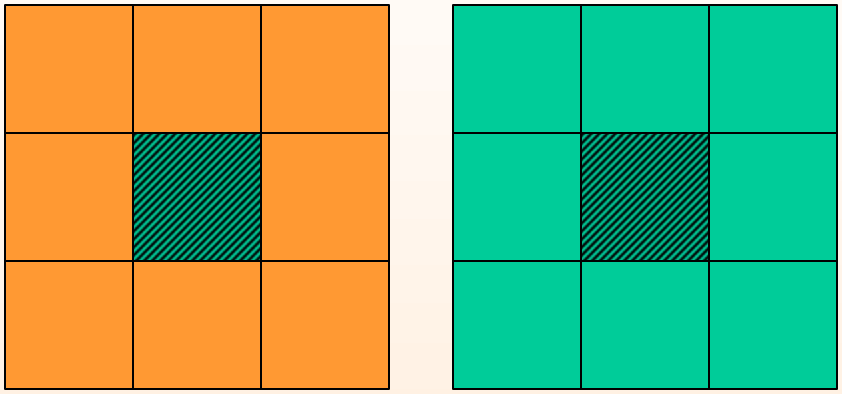
Forest: mosaic of stands = habitat patches

Forest insects :
meta-population dynamics

populations distributed among patches of suitable habitat, separated by unfavourable areas

Does habitat diversity (landscape heterogeneity) influence forest resistance to pest insects ?

Comparison of pure stands
within monoculture vs. surrounded by non-habitat patches



Spruce budworm

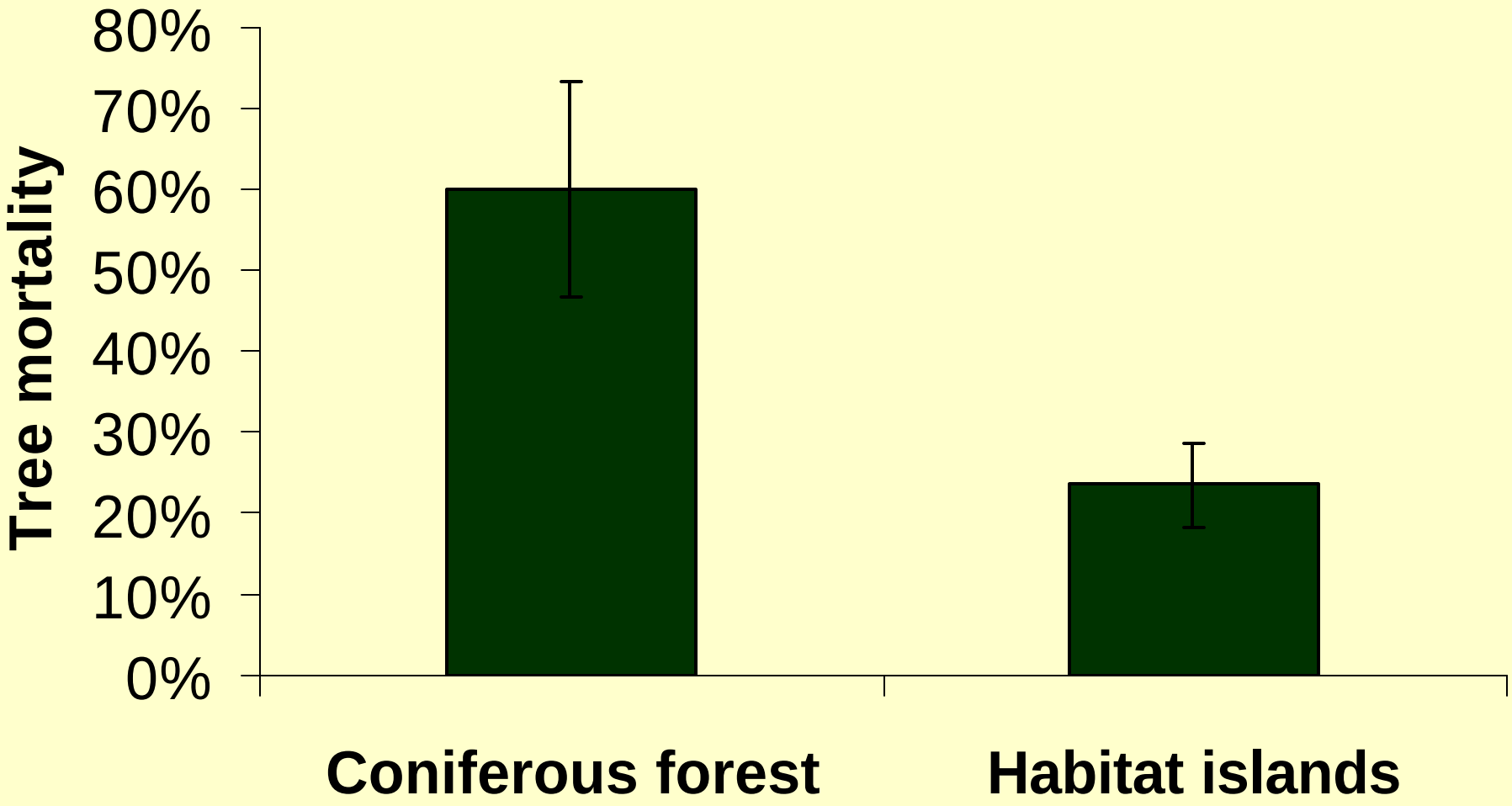
Non-habitat: deciduous forest

Habitat: Conifer dominated forest

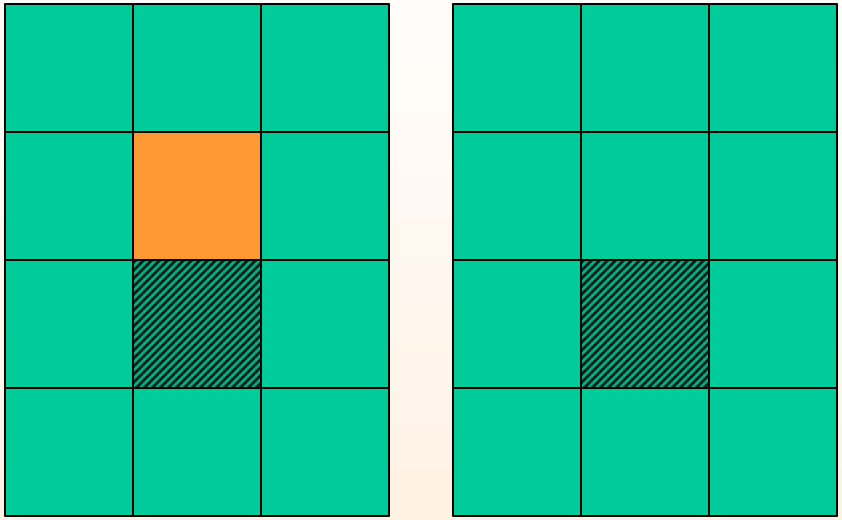
Habitat: Balsam fir stand

Spruce budworm, *Choristoneura fumiferana*
Balsam fir, *Abies balsamea*
(10 pairs)

Cappuccino *et al*. 1998



Paired comparisons of pure stands:
bordered by a non-habitat patch vs. among monoculture



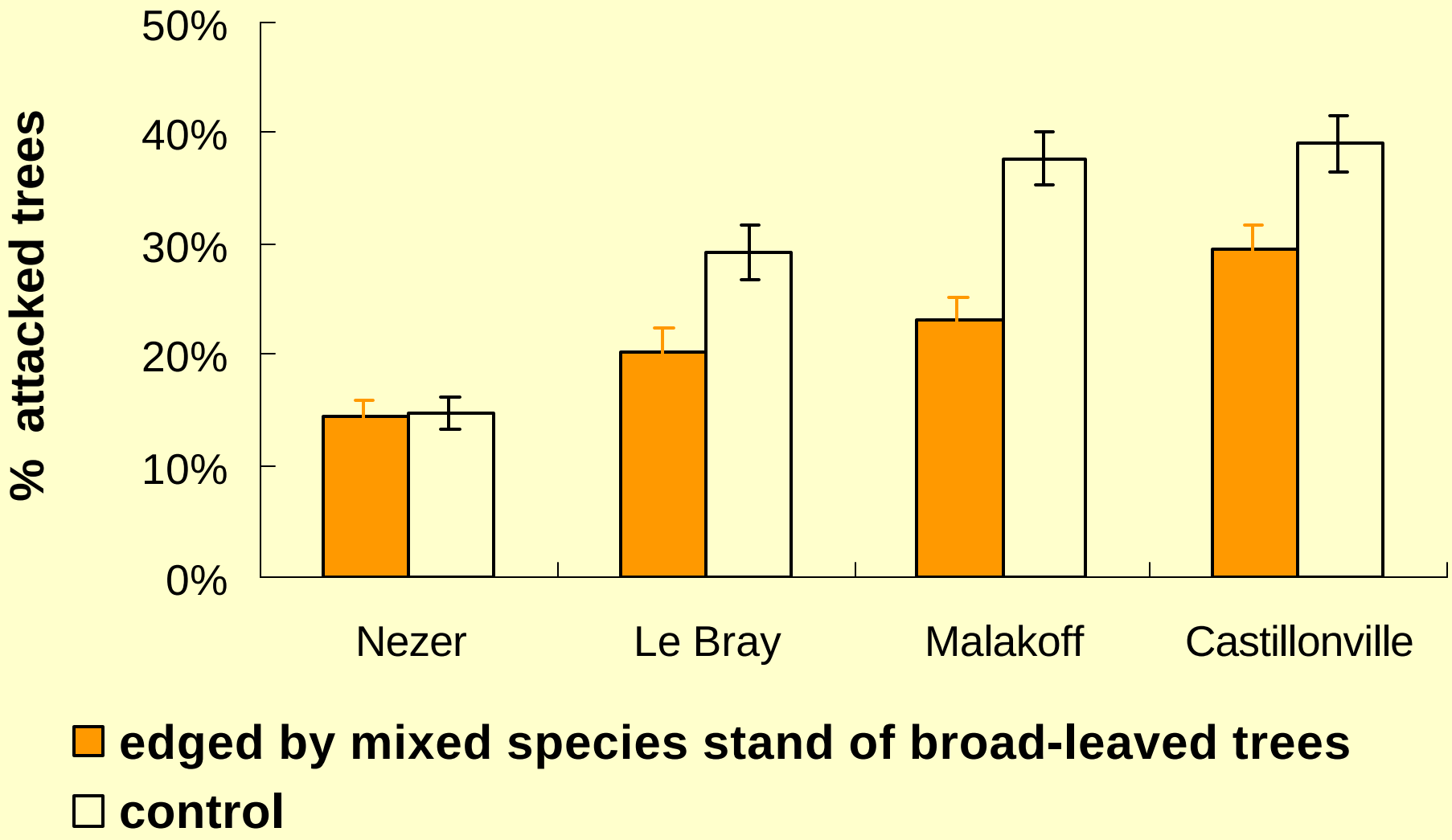
Non-habitat: oak stand

Habitat: maritime pine monoculture

Habitat: Experimental maritime pine stand

Dioryctria sylvestrella, the pine stem borer
Pinus pinaster, maritime pine
(4 pairs, 4224 trees)

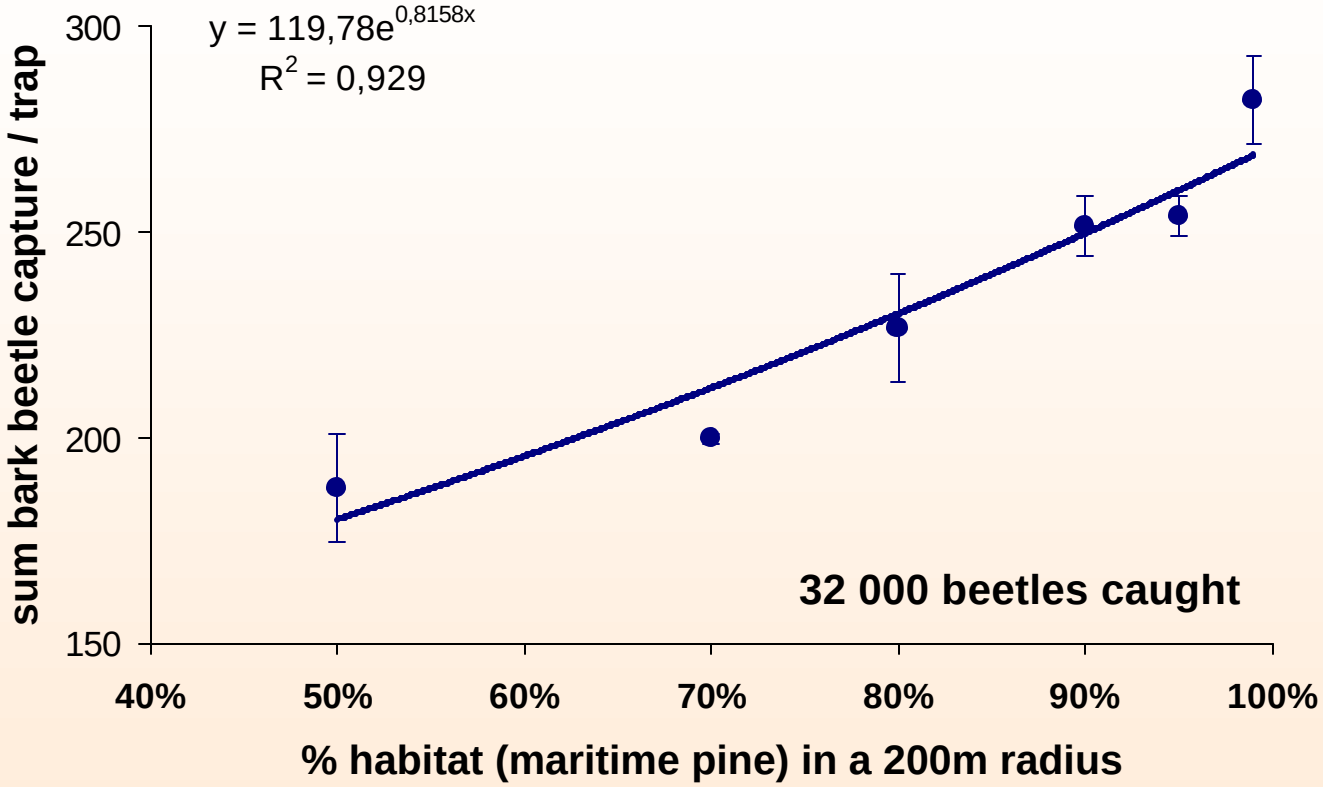
Jactel *et al.* 2002



Ecological mechanisms
1. Habitat accessibility

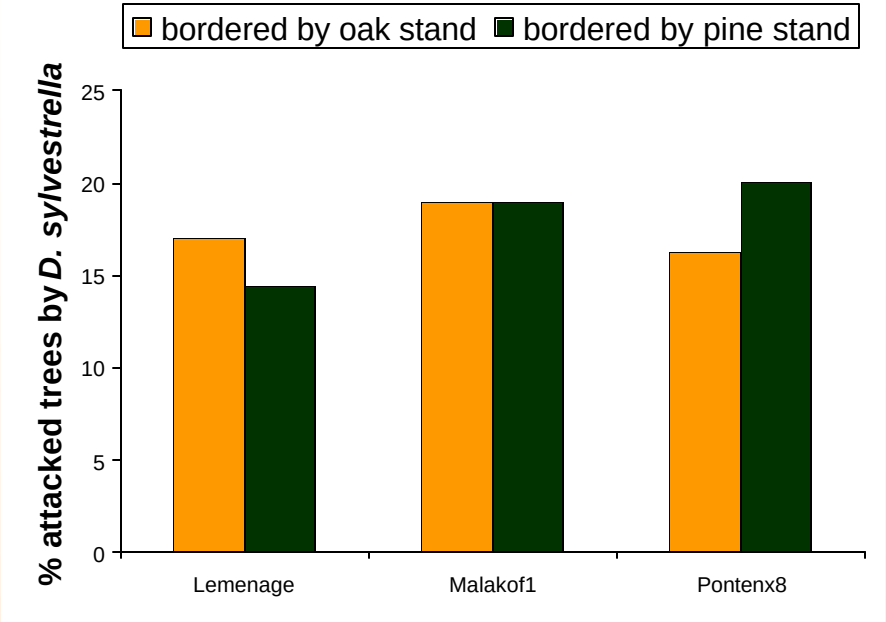
Grid (400m x 400m) sampling of bark beetles
in a 1000 ha maritime pine forest (July 2003)

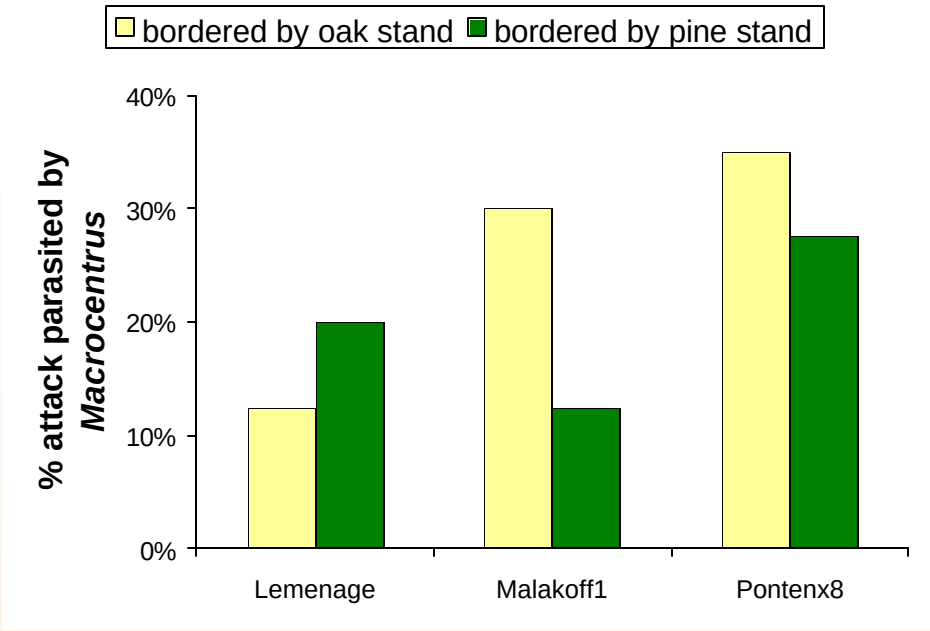
Ecological mechanisms
1. Habitat accessibility



➔ ***The population level of Ips sexdentatus in 53 sampled plots increased with habitat concentration around the plots***

Ecological mechanisms
2. Impact of natural enemies





Macrocentrus sylvestrellae **(Braconidae) specific parasitoid of *Dioryctria sylvestrella***

***M. sylvestrellae* larvae**

Ecological mechanisms
2. Impact of natural enemies

Effect of diet composition on *Macrocentrus sylvestrellae* longevity

3 main ecological mechanisms at both stand and landscape levels

1. **Host / Habitat accessibility**

   host / non host tree availability (stand purity)
   habitat / non habitat availability (landscape heterogeneity)

   barriers to host tree colonisation
   barriers to habitat colonisation (connectivity)

2. **Impact of natural enemies**

   Alternative prey, food supplementation or complementation
   Habitat supplementation or complementation

3. **Host / Habitat shift for polyphagous insects**

   diversion – contagion between more and less susceptible host species
   diversion – contagion between more and less suitable habitats

Tentative conclusions

1. Overall, tree diversity reduces outbreaks of insect herbivores

2. A major exception: high populations of polyphagous pests and associations of susceptible tree species

3. Complex ecological mechanisms

4. Likely to apply at the landscape level

5. Implications for pest control in plantation forests: preservation / restoration of mixed-species woodlands

IUFRO International Union of Forest Research Organizations

D8 Forest Environment

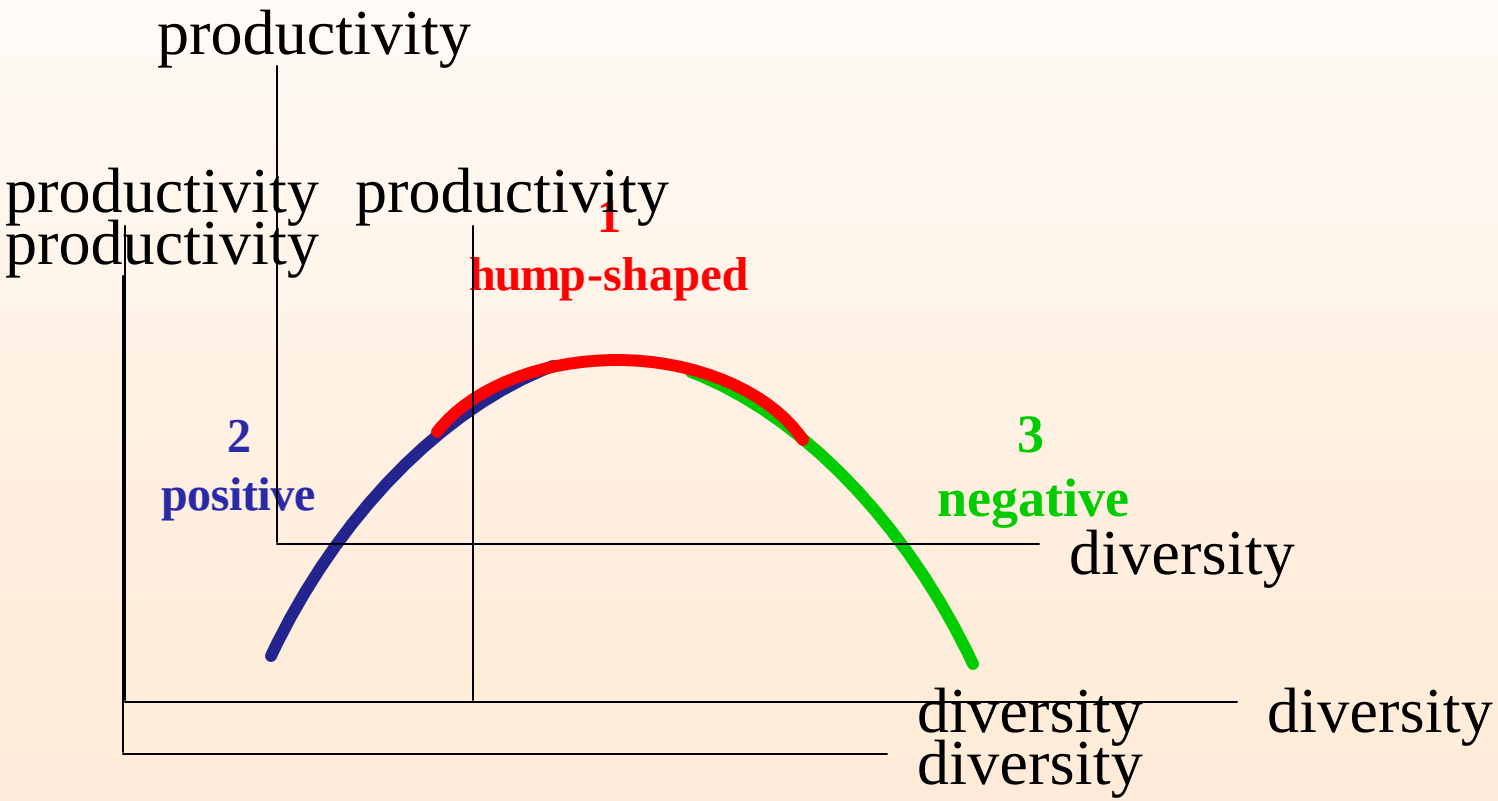
IUFRO Unit 8.07.02
Biodiversity effects on forest pest dynamics

Coordinator:
Hervé JACTEL, FRANCE

Deputy:
Eckehard BROCKERHOFF, NEW ZEALAND

The functional significance of biodiversity in ecosystems

Relationship between species richness and productivity in 171 studies
(Mittelbach et al., 2001)



HIGHER BIODIVERSITY

Higher species richness (species number)

New species composition (species identity)

Higher species richness (species number)

Complementarity effect

Selection (sampling) effect

Antagonism effect

Niche differentiation
Facilitation

Functional dominance

Competition
Allelopathy

Higher ecosystem productivity

Lower ecosystem productivity