Agroecology: modelling the resilience of agro-ecosystems

Cours 1

Corinne Robert (INRA, ENS) and David Claessen (ENS)
Agriculture
Historical context

From agricultural revolution to industrial revolution

**British Agricultural Revolution**: unprecedented increase in agricultural production in Britain due to increases in labour and land productivity between the mid-17th and late 19th centuries.

Attributed to social, economic and technology changes

- Crop rotation: Fodder crops, particularly turnips and clover, replaced leaving the land fallow
- Improved Chinese plough (pulled by fewer oxen or horses)
- Transportation infrastructures (roads, canals, railways)
- Land conversion, land drains and reclamation
- Increase in farm size
- Selective breeding

More and more food, less farmers: industrial revolution

Industrial revolution accelerated agricultural revolution:
- Tractors
History of corn yield
Green revolution

- 1930s-1960s
- Normal Borlaug (1940s)
- Breeding of high-yield crop varieties
- Synthetic fertilizers
- Synthetic pesticides
- Expansion of irrigation
- Modernization of management techniques
  - Monoculture, dependence on fertilizers and pesticides
  - Breeding under the assumption of fertilizers and pesticides
Plant selection: wheat example

• Ideotype: idealized plant type to achieve high yield in a specific environment and cropping system

• Traits:
  – short stem (no lodging... but less competitive)
  – fewer leaves (just enough to intercept available light)
  – single, nonbranching stem (don’t waste resources contesting space with neighbors)
  – early flowering (longer grain fill period)
  – high harvest index (more grain, less leaf+stem)
  – erect leaves (spreads available light over more leaf area)

From: Paul Gepts (UC Davis) http://www.plant sciences.ucdavis.edu/gepts/pb143/Lec13/PB143L13.htm
Pieter Breughel, 1565, *The Harvesters*
Wheat yield

United Kingdom

France

T (°C)

Yield

UK wheat yield (t ha⁻¹)

March-November mean temperature (°C)

Rendement (q/ha)

Year
Rice yield
Tilman et al 2002
80% of 1.5 billion has under monocultures
A CENTURY AGO
In 1903 commercial seed houses offered hundreds of varieties, as shown in this sampling of ten crops.

Width equals the number of varieties

80 YEARS LATER
By 1983 few of those varieties were found in the National Seed Storage Laboratory.*

* CHANGED ITS NAME IN 2001 TO THE NATIONAL
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Is agriculture resilient?

Soil erosion, drought
Is agriculture resilient?

Climate change

From IPCC (2014)
Is agriculture resilient?

Pests, diseases
### Evolutionary perspective

**Table 27.22 Past crop failures attributed to genetic uniformity**

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>CROP</th>
<th>CAUSE AND RESULT</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>Central America</td>
<td>Maize</td>
<td>Anthropologists speculate that the collapse of the Classic Meyen Civilization might have been a result of a maize virus</td>
<td>Rhoades, 1991</td>
</tr>
<tr>
<td>1846</td>
<td>Ireland</td>
<td>Potato</td>
<td>Potato blight led to famine in which 1 million died and 1.5 million emigrated from their homeland</td>
<td>Hoyt, 1988</td>
</tr>
<tr>
<td>Late 1800s</td>
<td>Sri Lanka</td>
<td>Coffee</td>
<td>Fungus wiped out homogenous coffee plantations on the island</td>
<td>Rhoades, 1991</td>
</tr>
<tr>
<td>1940s</td>
<td>USA</td>
<td>Rice</td>
<td>US crops lost to insects has doubled since the 1940s</td>
<td>Plucknett and Smith, 1986</td>
</tr>
<tr>
<td>1943</td>
<td>India</td>
<td>Rice</td>
<td>Brown spot disease aggravated by typhoon destroyed crop</td>
<td>Hoyt, 1988</td>
</tr>
<tr>
<td>1953-54</td>
<td>USA</td>
<td>Wheat</td>
<td>Wheat stem rust affected most of hard wheat crop</td>
<td>Hoyt, 1988</td>
</tr>
<tr>
<td>1960s</td>
<td>USA</td>
<td>Wheat</td>
<td>Stripe rust reached epidemic proportions in Pacific Northwest</td>
<td>Oldfield, 1984</td>
</tr>
<tr>
<td>1970s</td>
<td>USA</td>
<td>Maize</td>
<td>Decrease in yield of 15%, $1 billion lost*</td>
<td>NAS 1972, Tetury, 1971</td>
</tr>
<tr>
<td>1970s</td>
<td>Philippines &amp; Indonesia</td>
<td>Rice</td>
<td>HYV rice attacked by leafhoppers spreading tungro virus</td>
<td>Hoyt, 1988</td>
</tr>
<tr>
<td>1972</td>
<td>USSR</td>
<td>Wheat</td>
<td>Crop badly effected by weather</td>
<td>Plucknett et al., 1987</td>
</tr>
<tr>
<td>1974-77</td>
<td>Indonesia</td>
<td>Rice</td>
<td>Greasy stunt virus destroyed over 3 million tonnes of rice from the late 1960s to the late 1970s the virus plagued South and Southeast Asian rice production</td>
<td>Hoyt, 1988</td>
</tr>
<tr>
<td>1984</td>
<td>Florida</td>
<td>Citrus</td>
<td>Bacterial disease caused 135 nurseries to destroy 18 million trees</td>
<td>Rhoades, 1991</td>
</tr>
</tbody>
</table>

*Notes: * Davick (1986) reports that although the leaf blight attacked a widespread and uniform genotype, the problem was uniformity of cytoplasm introduced to eliminate the chore of detasseling - not the genetic material in the nucleus of the seed.

**Table 35.3 Past Crop Failures Due to Genetic Uniformity**

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<tr>
<th>Date</th>
<th>Location</th>
<th>Crop</th>
<th>Effects</th>
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<tbody>
<tr>
<td>1846</td>
<td>Ireland</td>
<td>Potato</td>
<td>Potato famine</td>
</tr>
<tr>
<td>1800s</td>
<td>Sri Lanka</td>
<td>Coffee</td>
<td>Farms destroyed</td>
</tr>
<tr>
<td>1940s</td>
<td>U.S.</td>
<td>U.S. crops</td>
<td>Crop loss to insects doubled</td>
</tr>
<tr>
<td>1943</td>
<td>India</td>
<td>Rice</td>
<td>Great famine</td>
</tr>
<tr>
<td>1960s</td>
<td>U.S.</td>
<td>Wheat</td>
<td>Rust epidemic</td>
</tr>
<tr>
<td>1970</td>
<td>U.S.</td>
<td>Maize</td>
<td>$1 billion loss</td>
</tr>
<tr>
<td>1970</td>
<td>Philippines, Indonesia</td>
<td>Rice</td>
<td>Tungo virus epidemic</td>
</tr>
<tr>
<td>1974</td>
<td>Indonesia</td>
<td>Rice</td>
<td>3 million tons destroyed</td>
</tr>
<tr>
<td>1984</td>
<td>U.S. (Florida)</td>
<td>Citrus</td>
<td>18 million trees destroyed</td>
</tr>
</tbody>
</table>

Is agriculture resilient?

Yield/ha is currently levelling-off

Diminishing returns of fertilization

Figure 2: Diminishing returns of fertilizer application imply that further applications may not be as effective at increasing yields. a, Trends in average global cereal yields; b, trends in the nitrogen-fertilization efficiency of crop production (annual global cereal production divided by annual global application of nitrogen fertilizer).
Pathogens evolve to undo pest control

- Pest-resistant maize hybrids last about 4 years
- Herbicide-resistant weeds often evolve in 10-20 years
- Insecticide-resistant insects often evolve in <10 y
- Resistant strains of bacterial pathogens appear within 1–3 years

Palumbi 2001, Tilman 2002
The futile chemical warfare against pests

- US agricultural losses to pests reached 32% between 1942-50 and 37% between 1984-1990

- More than 450 species of arthropods resistant to > 1000 different pesticides
From Altieri

Figure 18.4  This graph shows the number of species of insects, disease organisms, and weeds that are resistant to at least one pesticide.

Source: George P. Georgton, University of California, Riverside, 1990.
Is agriculture resilient?

• Modern agriculture may be consider to be resilient (according to some definition)
• Assuming the continued use of
  – Pesticides
  – Fertilizers
• And assuming their continued efficacy
  – Or: continued development of new pesticides
Is agriculture sustainable?

• Pollution of soil and water
• Loss of biodiversity through land-use change
• Climate change
• Dependence on phosphorus
What is resilience of agricultural systems?

- Constant production despite perturbations
- Absence of epidemics
- Production without pesticides or fertilizers
- Recovery of production after climatic extreme event perturbation (flooding, drought, hurricane, etc.)
Agroecology: modelling the resilience of agro-ecosystems

Corinne Robert (INRA, ENS) and David Claessen (ENS)
What is an agro-ecosystem?
What is an ecosystem?
What is biodiversity?
What is an ecosystem?

• The system of all organisms and the non-living components of their environment
  – i.e., “everything”
  – in a delimited space (lake, forest, prairie, valley, ocean…)

• In terms of
  – Energy flow
  – Matter cycling (C, N, P, …)
  – Food chain, food web: who eats whom?
  – Ecological interactions
Food chain (+recycling)
Food web (+recycling)
What is an agro-ecosystem?

• A simplified ecosystem
  – A single plant species: the crop
  – Genotype: artificially selected (optimized for performance under fertilization and pesticide treatments)
  – Modified environment to favor crop growth:
    • Increase nutrients (fertilization)
    • Reduce herbivores, disease and competitors (pesticides, fungicides, herbicides, plowing)
  – Harvesting: biomass export
  – Poor soil activity, high nutrient loss
Nutrients
Detritus
Plants
Herbi
Nutrients
PESTICIDES
EX PORT
NPK
Norwood Farm, UK (125 ha)

560 species
1501 interactions:
- Trophic
- Mutualistic
  (pollinisation)

Pocock et al 2012
### Characteristics of natural ecosystems, traditional and modern agriculture

<table>
<thead>
<tr>
<th></th>
<th>Natural ecosystems</th>
<th>Traditional agriculture</th>
<th>Modern agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species richness</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>On a plot scale</strong></td>
<td>One ha of tropical forest contains more than 100 tree species</td>
<td>Most cropping systems include several plant species</td>
<td>Most cropping systems have a sole crop</td>
</tr>
<tr>
<td><strong>On a global scale</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>Complex—variable</td>
<td>Complex</td>
<td>Simple—often monocanopy</td>
</tr>
<tr>
<td><strong>Dispersion of seeds</strong></td>
<td>Natural</td>
<td>–</td>
<td>Controlled</td>
</tr>
<tr>
<td><strong>Plant evolution and selection</strong></td>
<td>Natural</td>
<td>Selection</td>
<td>Mechanical seed-bed preparation</td>
</tr>
<tr>
<td><strong>Soil cover</strong></td>
<td>Permanent</td>
<td>Variable</td>
<td>Breeding, biotechnology</td>
</tr>
<tr>
<td><strong>Simultaneous presence of perennials and non-perennials</strong></td>
<td>Frequent</td>
<td>Frequent</td>
<td>Non-permanent</td>
</tr>
<tr>
<td><strong>Life form richness</strong></td>
<td>High</td>
<td>Variable</td>
<td>Rare</td>
</tr>
<tr>
<td><strong>Productivity</strong></td>
<td>Variable</td>
<td>Variable</td>
<td>High</td>
</tr>
<tr>
<td><strong>Use of external chemicals</strong></td>
<td>–</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Population control of plants and animals</strong></td>
<td>Natural</td>
<td>Use of natural processes</td>
<td>Use of pesticides</td>
</tr>
<tr>
<td><strong>Use of fossil energy</strong></td>
<td>–</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Exports (C, minerals)</strong></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Nutrient sources</strong></td>
<td>Recycling</td>
<td>Recycling, organic</td>
<td>Chemicals</td>
</tr>
<tr>
<td><strong>Nutrient loss</strong></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Resilience</strong></td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

Malézieux, 2012
What is biodiversity?

Diversity of:

- GENES
- SPECIES
- FUNCTIONS
Ecosystem “functions” and “services”

“FUNCTIONS”

Diversity of:

Genes

Species

Functions

Water cycle

Nutrient cycling

Carbon sequestration

Geochemistry

Primary production

Pollinisation

Trophic interactions

Pathogen transmission

“SERVICES”

Water quality

Air quality

Climate regulation

Soil stability

Fossil fuel energy

Natural resources

Soil fertility

Agricultural production

Resistance to invasion of exotic species

Epidemic risk

Pharmacology
Agroecology: modelling the resilience of agro-ecosystems

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What is agroecology?

- A social movement
  - Focus on tropical countries
  - Small scale, traditional agriculture
  - Focus on social justice, role of multinationals in world inequalities, peasant independence
  - Conservation of biodiversity, cultural diversity
  - Alternative economical, societal system, human well being

- An agricultural production system
  - Use ecological processes to improve production and reduce dependence on pesticides and fertilizers

- A scientific discipline
  - How to design sustainable agricultural systems using ecological principles and knowledge?
What are the scientific principles underlying agroecology?

- Use ecological processes to improve agricultural performance while reducing environmental impact
- Biodiversity: instead of using monocultures, use mixtures of species and varieties
- Use ecological interactions between species to regulate pests
- Use ecological processes to improve soil characteristics
Diversity, complexity, recycling, self-regulation (resilience?)
Bohan et al 2013

• Mimicry of natural ecosystems:
  – not expected to provide the yields obtained in modern agriculture,
  – Key ecological concepts in natural systems
    • resilience, stability and capacity for self-organization
  – not necessarily readily transferable or relevant to agroecosystems (Malézieux, 2011).

• Some key ecological principles should hold in agroecosystems
  – maintaining diverse complementary functional traits in species assemblages,
  – for sustaining the ‘predictable’ assembly of communities of species around a crop
  – for the management of the microbial, plant and animal species naturally present in the system.
Biological control

• Natural enemies of agricultural pests may be used to limit pest densities below economic thresholds (Costanza et al., 1997).
• Such regulation should allow pesticide inputs to be reduced and system resilience and sustainability to be enhanced.
• Under what conditions do we expect biological control to be effective, and in what type of network structure?
Common principles in agroecology

- High biodiversity (polyculture)
- Combining animal husbandry and crops
- Stimulate active, alive soils
- Optimize spatial organization (landscape)

- Optimal use of soil nutrients
- Positive effect on hydrology
- Buffer against unfavorable conditions
- Fertilization
- Weed control
- Herbivore control
- Nitrogen fixation
- Nutrient recycling
- Favorable hydrology
- Reduce pest and disease dispersal
- Reduce wind damage
- Reduce soil erosion
“Traditional” vs “Agroecological” view
Examples of agroecological systems
4. Rice-duck Co-culture System
The legumes red clover and Austrian winter pea are slower to establish in the fall and can allow weeds to get a foothold (A, B).

Under nitrogen-deficient conditions, canola growth is limited (C), reducing its weed suppression compared to canola with sufficient nitrogen available (G).

A mixture of slow-growing legumes (D) will be no better at suppressing weeds than a slow-growing legume monoculture.

A diverse mixture that includes a few fast-growing species will provide weed suppression while allowing for benefits such as nitrogen fixation and floral resources from the other species (H).

Achieving good weed suppression with cover crop mixtures.

Grasses like oats and rye are excellent weed suppressors (E, F) but even a small gap between drill passes can create a spot for weeds to take root (F).
Complementary growth forms:
- cereal rye and canola transition from short dense canopies to tall open canopies in the late spring,
- Austrian winter pea is vining, and red clover remains short and dense.
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Ecological network theory

• Bohan et al 2013
  – even if the provision of a specific ecosystem services may be maximized through the abundance of functionally important species (Gaston, 2010), such as honey bees as pollinators (Calderone, 2012; Hagen et al., 2012),
  – wider system resilience and ecosystem service provision relies directly on species diversity and functioning (Naeem et al., 2009).
“Resilience” though biodiversity (1)

• “A resilient agroecosystem will continue to provide a vital service such as food production if challenged by severe drought or by a large reduction in rainfall”

• The role of diversity in agroecosystems to functional capacity and resilience (Vandermeer and colleagues 1998):
  – Biodiversity enhances ecosystem function because different species or genotypes perform slightly different roles and therefore occupy different niches
  – Biodiversity is neutral or negative in that there are many more species than there are functions; thus, redundancy is built into the system.
  – Biodiversity enhances ecosystem function because those components that appear redundant at one point in time may become important when some environmental change occurs.
“Resilience” though biodiversity (2)

• The key here is that when environmental change occurs, the redundancies of the system allow for continued ecosystem functioning and provisioning of services.

• The insurance hypothesis (Yachi and Loreau 1999), which proposes that biodiversity provides an insurance, or a buffer, against environmental fluctuations because different species respond differently to change, leading to more predictable aggregate community or ecosystem properties.
5 The ecological role of biodiversity in agroecosystems

In agricultural systems, the level of existing biodiversity can make the difference between the system being stressed or resilient when confronting a biotic or abiotic perturbation. In all agroecosystems, a diversity of organisms is required for ecosystem function and to provide environmental services (Altieri and Nicholls 2004). When agroecosystems are simplified, whole functional groups of species are removed shifting the balance of the system from a desired to a less desired state, affecting their capacity to respond to changes and to generate ecosystem services (Folke 2006). Two categories of diversity can be distinguished in agroecosystems: functional and response diversity. Functional diversity refers to the variety of organisms and the ecosystem services they provide for the system to continue performing (Loreau et al. 2001). Response diversity is the diversity of responses to environmental change among species that contribute to the same ecosystem function. An agroecosystem that contains a high degree of response diversity will be more resilient against various types and degrees of shocks (Cabell and Oelofse 2012).

Biodiversity enhances ecosystem function because different species or genotypes perform slightly different functions and therefore have different niches (Vandermeer et al. 1998). In general, there are many more species than there are functions and thus redundancy is built into the agroecosystem. Therefore, biodiversity enhances ecosystem function because those components that appear redundant at one point in time become important when some environmental change occurs. The key here is that when environmental change occurs, the redundancies of the system allow for continued ecosystem functioning and provisioning of ecosystem services. On the other hand, a diversity of species acts as a buffer against failure due to environmental fluctuations, by enhancing the compensation capacity of the agroecosystem, because if one species fails, others can play their role, thus leading to more predictable aggregate community responses or ecosystem properties (Lin 2011).
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6.1 Plant diversity and resiliency

Diversified farming systems such as agroforestry, silvopastoral, and polycultural systems provide a variety of examples on how complex agroecosystems are able to adapt and resist the effects of climate change. Agroforestry systems are examples of agricultural systems with high structural complexity that have been shown to buffer crops from large fluctuations in temperature (Lin 2011), thereby keeping the crop closer to its optimum conditions. More shaded coffee systems have shown to protect crops from decreasing precipitation and reduced soil water availability because the over story tree cover is able to reduce soil evaporation and increase soil water infiltration (Lin 2007).
What provides “resilience”?

• Higher biodiversity
  – Insurance effect
  – Buffer against loss
  – Redundancy
  – Genetic variability (evolutionary potential)

• Heterogeneity
  – Spatial structure of the landscape
  – Mosaic vs homogenous space (monoculture)
The insurance hypothesis

Biodiversity vs stability: asynchronous dynamics stabilise total biomass dynamics

Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges


The ecological consequences of biodiversity loss have aroused considerable interest and controversy during the past decade. Major advances have been made in describing the relationship between species diversity and ecosystem processes, in identifying functionally important species, and in revealing underlying mechanisms. There is, however, uncertainty as to how results obtained in recent experiments scale up to landscape and regional levels and generalize across ecosystem types and processes. Larger numbers of species are probably needed to reduce temporal variability in ecosystem processes in changing environments. A major future challenge is to determine how biodiversity dynamics, ecosystem processes, and abiotic factors interact.

primary production in grassland ecosystems (20–23). Because plants, as primary producers, represent the basal component of most ecosystems, they represented the logical place to begin detailed studies. Several, although not all, experiments using randomly assembled communities found that primary production exhibits a positive relationship with plant species and functional-group diversity (Fig. 1).

These results attracted a great deal of interest, not only because they were novel,
Agroecology: modelling the resilience of agro-ecosystems

Corinne Robert (INRA, ENS) and David Claessen (ENS)
Useful ecological theory

- Ecology of infectious diseases
  - the role of diversity on epidemics
- Food web ecology:
  - stability of trophic networks
  - the role of diversity on stability/resilience
- Functional ecology:
  - ecosystem element cycling
- Evolutionary ecology, adaptive dynamics
  - Pest/pathogen/weed/predator/mutualist co-evolution
Ecological networks, stability and resilience

• Complexity vs stability of food webs: an old debate
  – 1950s-1970s: Elton, Odum, MacArthur, etc: more biodiversity $\rightarrow$ more stable (redundancy)
  – May (1973) etc: more populations in community $\rightarrow$ more risk of instability
The resilience of agroecological networks?

Figure 1.2 The impact of a disturbance on two hypothetical farm networks with high (A) and low (B) levels of connectivity between subunits. Each node represents a species and a line between two nodes indicates those two species interact in some way. Each subunit approximately corresponds to a habitat on the farm. In (A) a disturbance event (e.g. the spraying of an insecticide to control the species in the crop network) cascades through all other subunits of the network (thick black lines); in (B) the impacts are restricted to two subunits. Figures adapted from Macfadyen et al. (2011).
Modelling questions in agroecology

Figure 7.1 Major questions associated with pest control inside food webs.

Tixier et al. 2013
Figure 7.5 Major questions associated with the spatial management of pests at different scales.
Adaptive dynamics of pathogens

• Agro-ecosystems seasonally forced
• Important aspect in modelling
• Example: permits co-existence of plant pathogens
Adaptation to fertilization?

- Changed agricultural practices
- Reduce nitrogen fertilization

Pierre-Antoine Precigout, Corinne Robert and David Claessen (in prep)
Canopy level model

Age distribution of uninfected patches

$$\frac{\partial h(t, a)}{\partial t} + \frac{\partial h(t, a)}{\partial a} = -F(t, a)h(t, a)$$

$$h(t, 0) = \begin{cases} \rho \frac{A}{A + A_H}, & \text{if } 0 < T < T_{grow} \\ 0, & \text{otherwise} \end{cases}$$

Age distribution of infected patches

$$\frac{\partial n(t, a, b)}{\partial t} + \frac{\partial n(t, a, b)}{\partial a} + \frac{\partial n(t, a, b)}{\partial b} = 0$$

$$n(t, a, 0) = F(t, a)h(t, a)$$

$$n(t, 0, 0) = 0$$

Boundary conditions (patch birth)

Boundary conditions (new infections)

Force of infection

$$F(t, a) = \frac{\beta}{\Delta} \int_{x=0}^{\infty} \int_{b=0}^{\infty} \max\left(0, 1 - \frac{|x - a|}{\Delta}\right) \sigma(t, x, b)n(t, x, b) \, db \, dx$$

Common resource pool

$$\frac{dA}{dt} = \int_{a=0}^{\infty} \Psi R(t, a) \, da + \int_{a=0}^{\infty} \int_{b=0}^{\infty} \Psi R(t, a, b) \, db \, da - k \frac{A}{A + A_H} H(T_{grow} - T)$$

Spores pool

$$\frac{dP}{dt} = \int_{a=0}^{\infty} \int_{b=\lambda}^{\infty} \sigma(t, a, b)n(t, a, b) \, db \, da - \gamma_s P$$
Conclusions

How can we expect pathogens to evolve assuming decreasing fertilisation practices in the future?
Seasonal dynamics of competing strains

Stable coexistence of strains 1 and 2

Late dominance by long latent period

Early dominance by short latent period

Why?
Example: epidemics in polycultures

  - Polycultures of interplanted crops often support fewer pests at lower densities than monoculture and tend to increase number of natural enemies (Ludwig et al. 2011).
The effect of multicropping

• A simple SI-model

\[ S = \text{Susceptible part of the crop population} \]
\[ I = \text{Infected part of the crop population} \]
\[ \beta = \text{transmission efficiency} \]
\[ g(t) = \text{time-dependent crop growth} \]

\[
\frac{dS}{dt} = g(t) - \beta SI \\
\frac{dI}{dt} = \beta SI - \delta I
\]

Claessen and Robert, in prep
The effect of multicropping

• An SI-model of polyculture:

  \( k = \text{number of crops on field} \)

  NB each crop has its own, unique pathogen

  NB no effect of \( k \) on transmission \( \beta \)

  Identical dynamics of all crops and pathogens

\[
\frac{dS_i}{dt} = \frac{1}{k} g(t) - \beta S_i I_i \\
\frac{dI_i}{dt} = \beta S_i I_i - \delta I_i
\]
For an epidemic to occur:

\[
\frac{dI_i}{dt} > 0 \\
\iff \frac{\beta(k)S_i}{\delta} > 1
\]

Hence reducing either S or \( \beta \) can reduce epidemics

**Multicropping can do both**
2 crops, no disease

Linear crop growth between $t=0$ and $t=20$ wk
primary infection arrives at t=10 wks

K=100, beta = 0.01, delta = 0.05

linear crop growth between t=0 and t=20 wk
2 crops
5 crops
Even though $R_0$ is still $>1$, the epidemics are considerable reduced
The effect of multicropping (2)

- An SI-model of polyculture:
  
  effect of $k$ on transmission $\beta$
  
  $k =$ number of crops on field
  
  NB each crop has its own, unique pathogen

\[
\begin{align*}
\frac{dS_i}{dt} & = \frac{1}{k} g(t) - \beta(k) S_i I_i \\
\frac{dI_i}{dt} & = \beta(k) S_i I_i - \delta I_i \\
\beta(k) & = \beta_1 \left( 1 - \frac{k}{k_0} \right)
\end{align*}
\]
2 crops

No effect on dispersal

Dispersal/2
5 crops

No effect on dispersal

Here $R_0 < 1$, no epidemics
(How) does biodiversity promote resilience?

\[
\begin{align*}
\frac{dE}{dt} &= cI_{\text{max}} \frac{EH}{H + k_H} - \lambda_E E \\
\frac{dH}{dt} &= \alpha \frac{HP}{P + k_P} - I_{\text{max}} \frac{EH}{H + k_H} - \lambda_H H \\
\frac{dP}{dt} &= u \frac{PN}{N + k_N} - \alpha \frac{HP}{P + k_P} - \lambda_P P - y(t) \\
\frac{dN}{dt} &= \rho D - u \frac{PN}{N + k_N} - \lambda_N N + f(t) \\
\frac{dD}{dt} &= \lambda_P P + \lambda_H H + \lambda_E E - (\rho + \lambda_D) D
\end{align*}
\]
Crop

Crop, herbivores

Crop, herbivores, predators
Resilience?

• The subject of the Agroecology working group...

  – Does higher biodiversity make an agro-ecosystem less dependent on chemical input (fertilization, pesticides)?
  – Does a biodiverse agroecological system stock more carbon than industrial agriculture?
  – Does high biodiversity make an agroecosystems more resilient against emergent crop pathogens? Against water stress? Against soil degradation?
  – What is the specificity of an agro-ecosystem compared to a natural ecosystem and how does this influence resilience?
Figure 7.3 Diagram and outputs of the banana agroecosystem modelling framework (case study 1). The diagram on the left shows the structure of the model. The model includes banana and the cover crop, which compete for soil nitrogen, and four trophic groups. Double-line arrows indicate flows of nitrogen, single-line arrows indicate trophic links, and the dotted-line arrow indicates the feedback of the pest on crop functioning. On the right, the two graphs show dynamic outputs of soil-plant modules (biomass of banana and cover crop) (bottom) and food-web modules (population dynamics of each trophic group) (top).