Agroecology: modelling the resilience of agro-ecosystems. Cours 3

Corinne Robert (INRA, ENS) and David Claessen (ENS)
Agroecology and the design of climate change-resilient farming systems

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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 confronted with 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

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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 → more stable (redundancy)
  - May (1973) etc: more populations in community → more risk of instability
The resilience of agroecological networks?

See lecture by Elisa Thébault

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 pathgens

- Agro-ecosystems seasonally forced
- Important aspect in modelling
- Example: permits co-existence of plant pathogens

Adaptation to fertilization?

- Changed agricultural practices
- Reduce nitrogen fertilization

Precigout, Claessen and Robert (Phytopathology 2017)
**Example: epidemics in polycultures**

  - Wheat–barley mixtures resulted in greater disease reduction in wheat than did applications of fungicide Vilich-Meller (1992)
  - 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:

The number of new infections over an infection’s average life time should be >1

Which is referred to as $R_0$

Hence reducing either $S$ or $\beta$ can reduce epidemics

**Multicropping can do both**

\[
\frac{dI_i}{dt} > 0
\]

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

\[
\frac{\beta(k)S_i}{\delta} = R_0
\]
2 crops, no disease

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

Linear crop growth between $t=0$ and $t=20$ wk

K=100, beta = 0.01, delta = 0.05
2 crops

![Graphs showing healthy and infected states over time for Crop 1 and all crops.](image)
5 crops
10 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 $\beta$
  - $k = \text{number of crops on field}$
  - NB each crop has its own, unique pathogen

\[
\frac{dS_i}{dt} = \frac{1}{k} g(t) - \beta(k)S_iI_i
\]
\[
\frac{dI_i}{dt} = \beta(k)S_iI_i - \delta I_i
\]

\[
\beta(k) = \beta_1 \left(1 - \frac{k}{k_0}\right)
\]
2 crops

No effect on dispersal

Dispersal/2
5 crops

No effect on dispersal

Here $R_0 < 1$, no epidemics