Climate change, biodiversity, and ecosystem services: the view from plant pathology

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SANREM CRSP

Outline

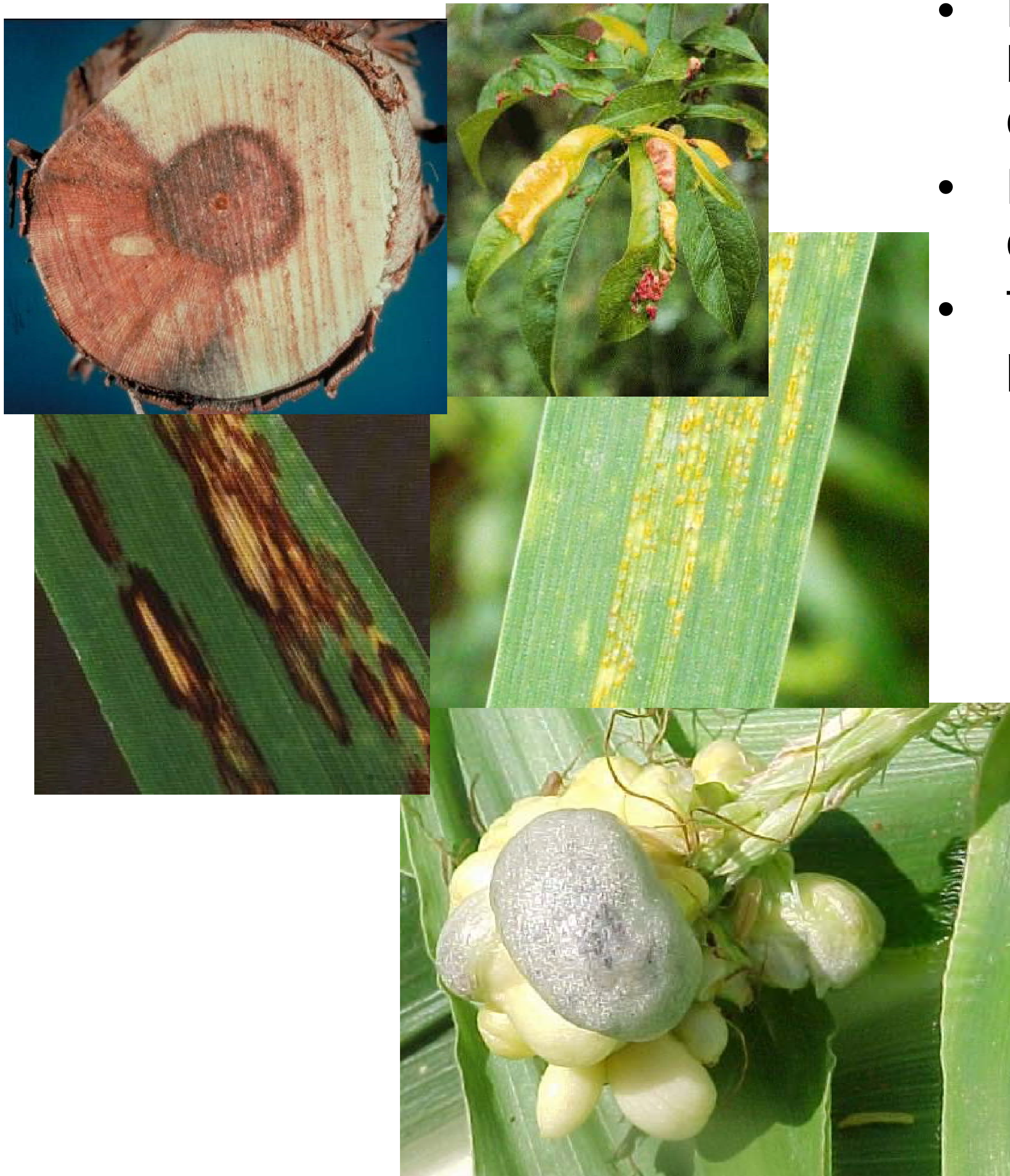
Climate change

Biodiversity

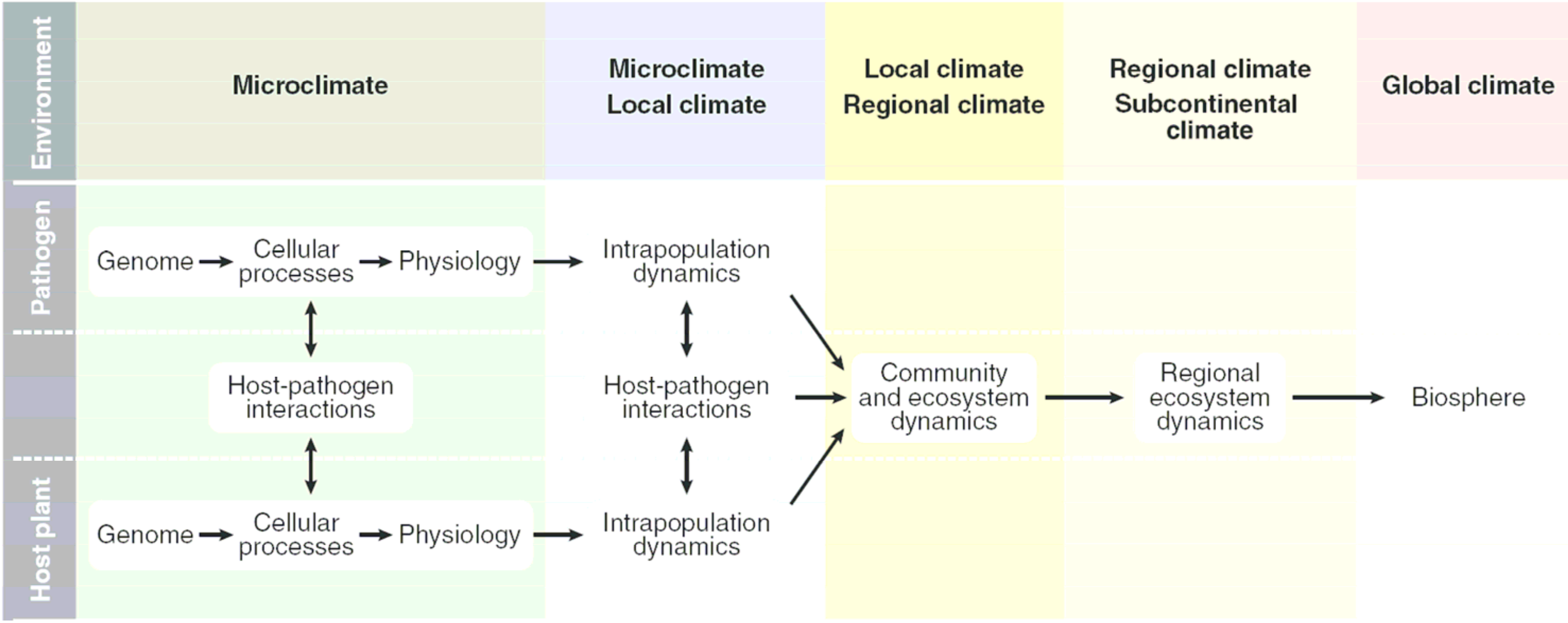
Ecosystem services

Plant disease

Plant Disease

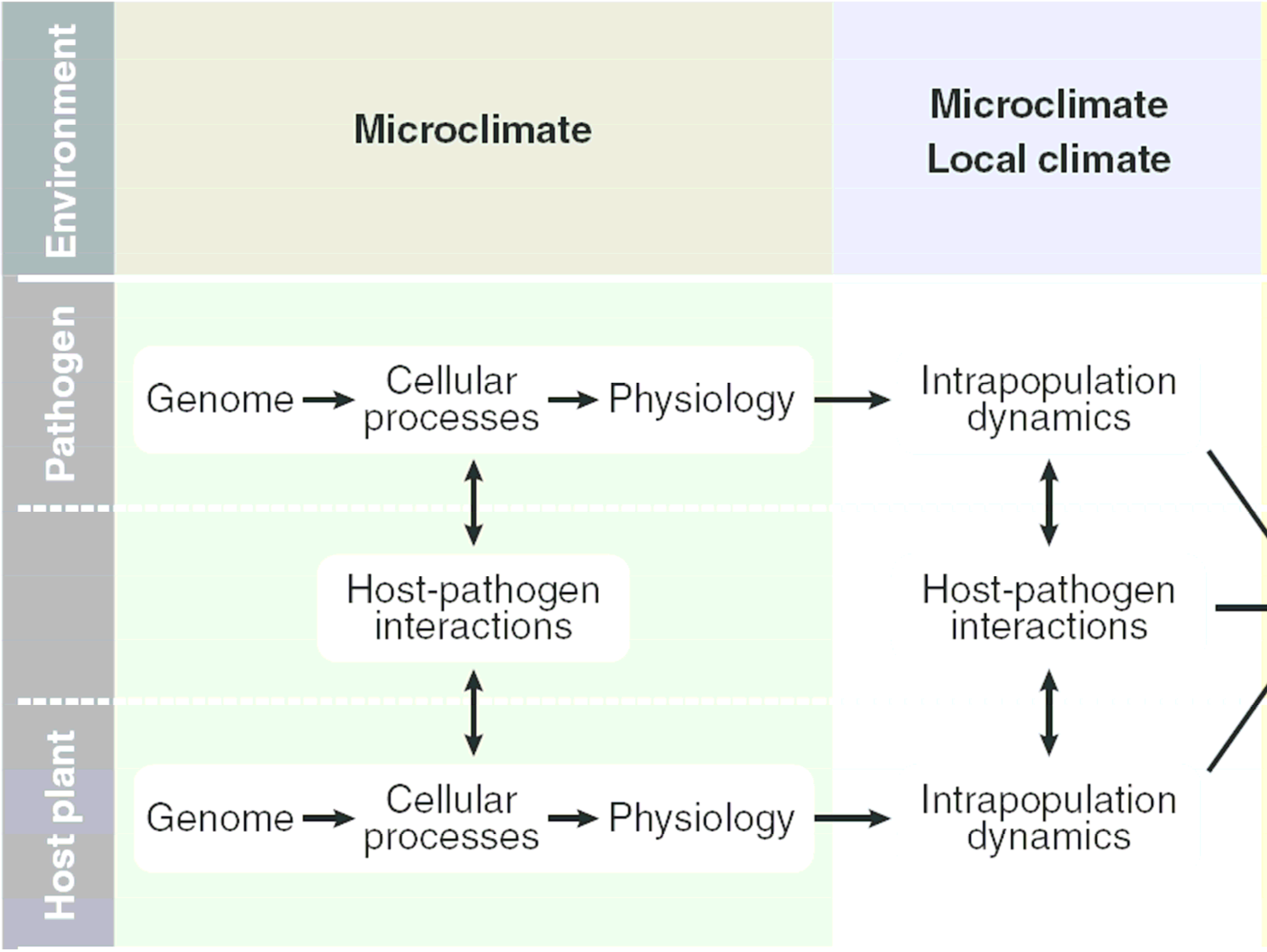


- Plant pathogens include bacteria, fungi, viruses, and oomycetes
- Plant disease is a natural part of ecosystems
- The incidence and severity of plant disease are influenced by
  - Susceptibility of host
  - Pathogen's ability to infect
  - For pathogens with vectors, the vector's ability to transmit the pathogen
  - The degree of conduciveness of the environment
    - For example, leaf surface wetness favors infection for many foliar pathogens
  - The spatial and temporal distribution of host, pathogen and vectors



Garrett, Dendy, Frank, Rouse, Travers 2006
Annual Review of Phytopathology

PDF available through publication link at www.ksu.edu/pdecology



Environment
Microclimate
Microclimate
Local climate
Pathogen
Genome
Cellular processes
Physiology
Intrapopulation dynamics
Host-pathogen interactions
Host-pathogen interactions
Host plant
Genome
Cellular processes
Physiology
Intrapopulation dynamics

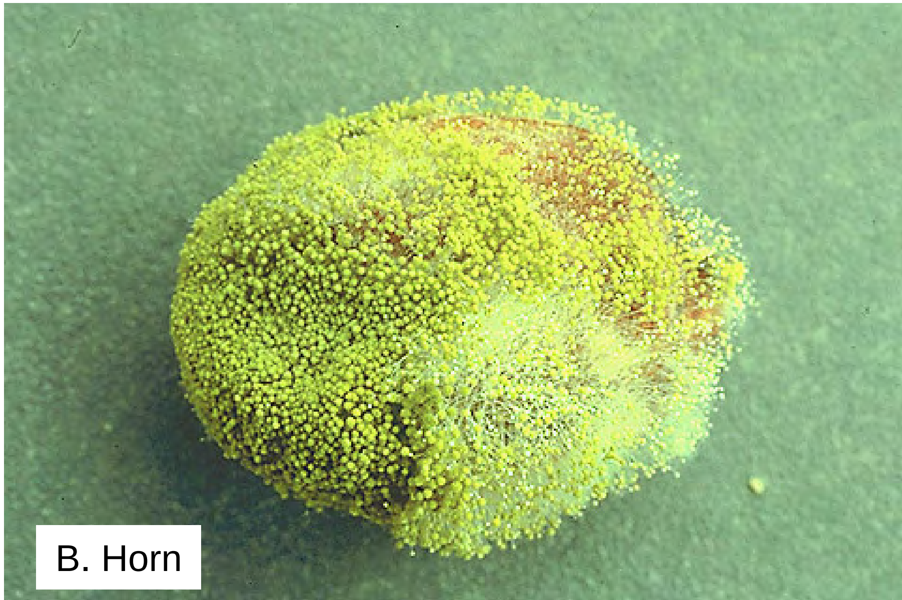
Downregulation of HR and other genes in tallgrass prairie grass in response to simulated precipitation change

Travers et al. 2007

Peanut gene expression response to drought and *Aspergillus* (Luo et al. 2005)

Need to better understand gene expression in plants and pathogens in response to climatic factors

Need integrated ‘omic studies of host and pathogen responses, as well as communities of soil and plant-assocated microbes


B. Horn

Stomatal closure and leaf growth inhibition during drought (e.g., Chaves et al. 2003)

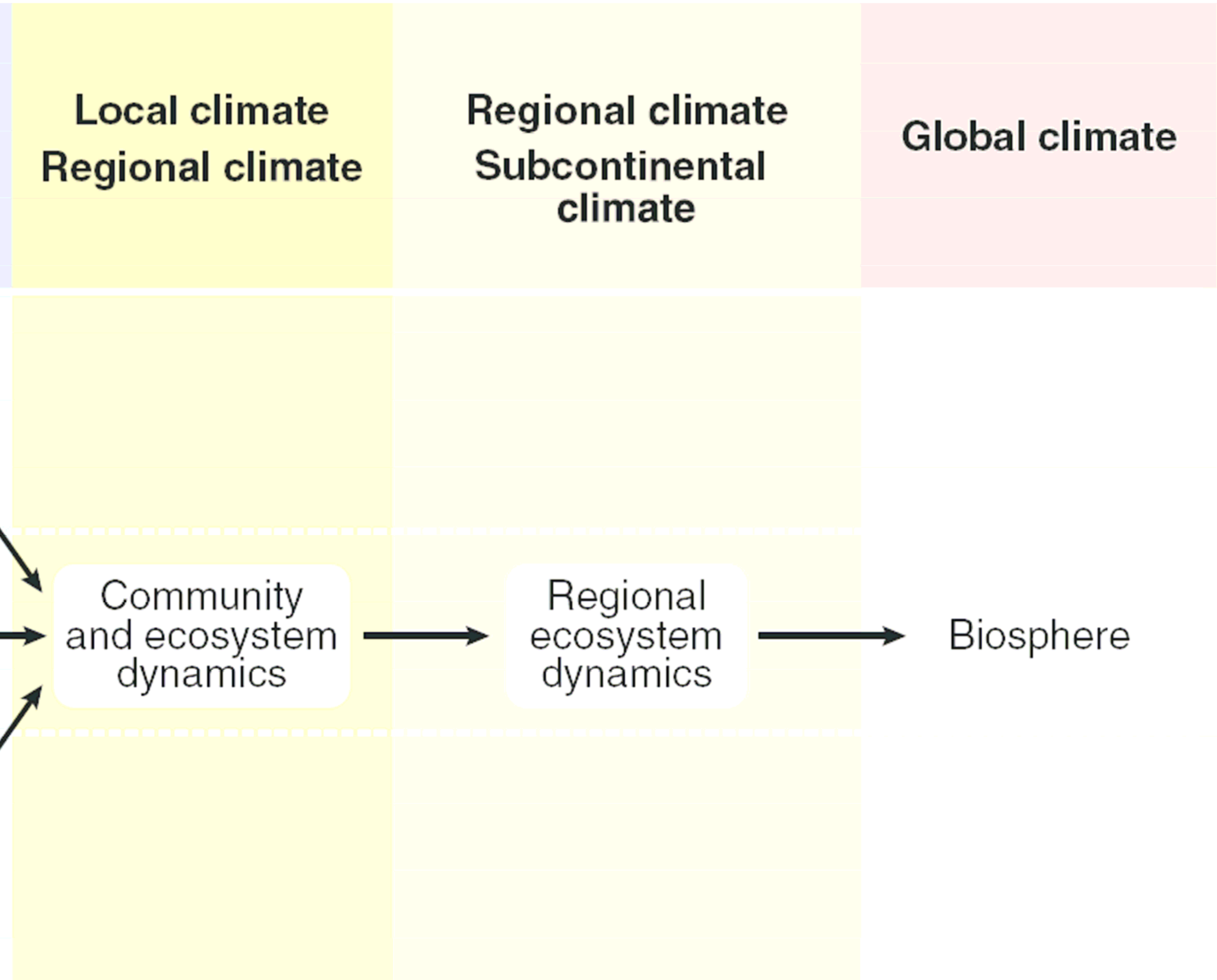
Plant structural changes in response to CO_2 (Pritchard et al. 1999)

Need multifactor studies of climate change effects

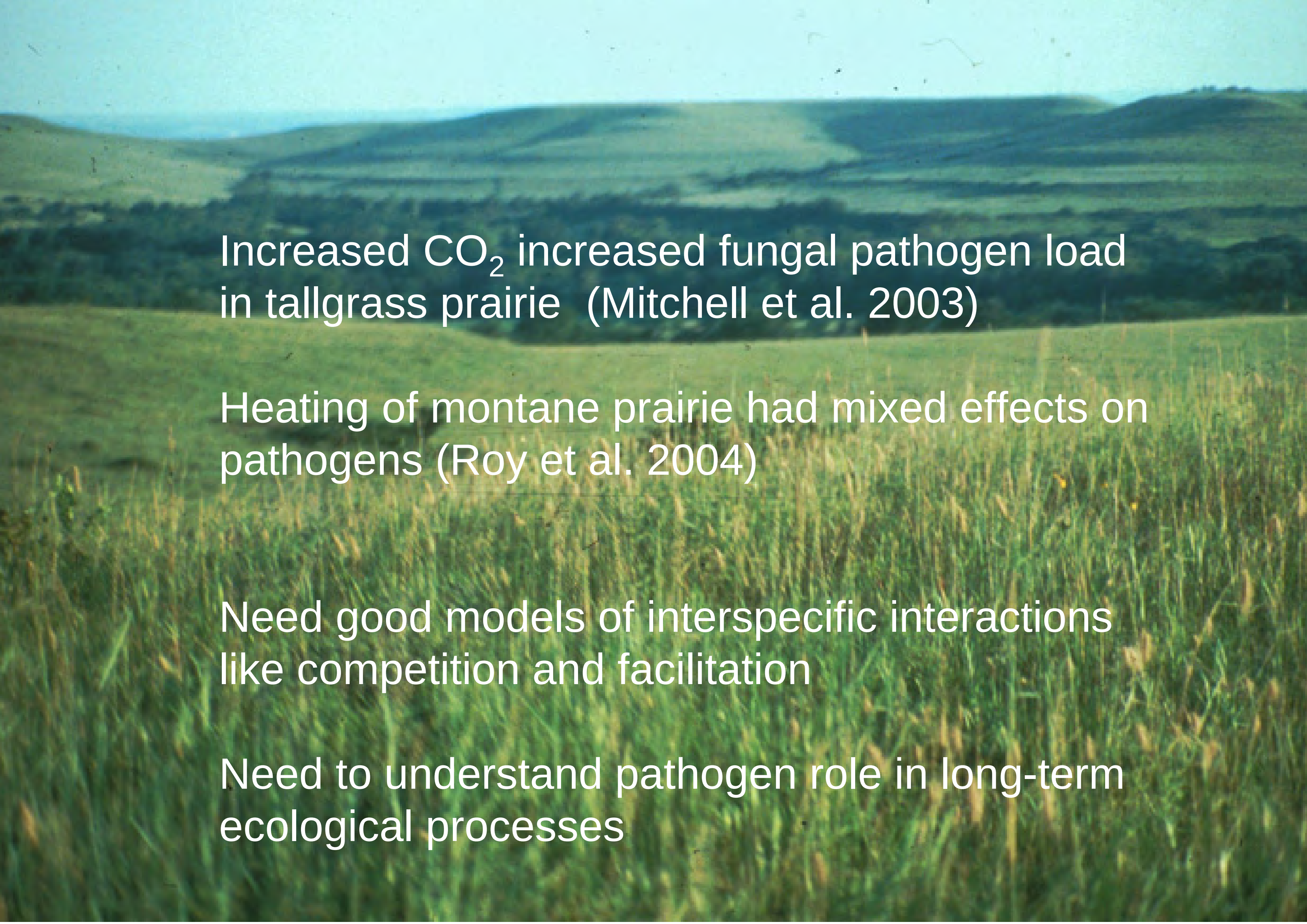
Higher fecundity of *Colletotrichum gloeosporioides* under increased CO_2 (Chakraborty and Datta, 2003)

Need better models of adaptation rates

Need better data and models related to dispersal, current levels of intraspecific diversity, strength of selection under different climate change scenarios, and heritability of traits



Local climate
Regional climate
Regional climate
Subcontinental climate
Global climate
Community and ecosystem dynamics
Regional ecosystem dynamics
Biosphere



Increased CO_2 increased fungal pathogen load in tallgrass prairie (Mitchell et al. 2003)

Heating of montane prairie had mixed effects on pathogens (Roy et al. 2004)

Need good models of interspecific interactions like competition and facilitation

Need to understand pathogen role in long-term ecological processes

Needle blight moving northward in North America as precipitation patterns change (Woods et al. 2005)

Phytophthora cinnamomi predicted expansion in Europe due to temperature change (Bergot et al. 2004)

Need long-term large-scale records of pathogen and host distributions

Need models of regional processes that incorporate disease

Need data and models describing dispersal of propagules and vectors

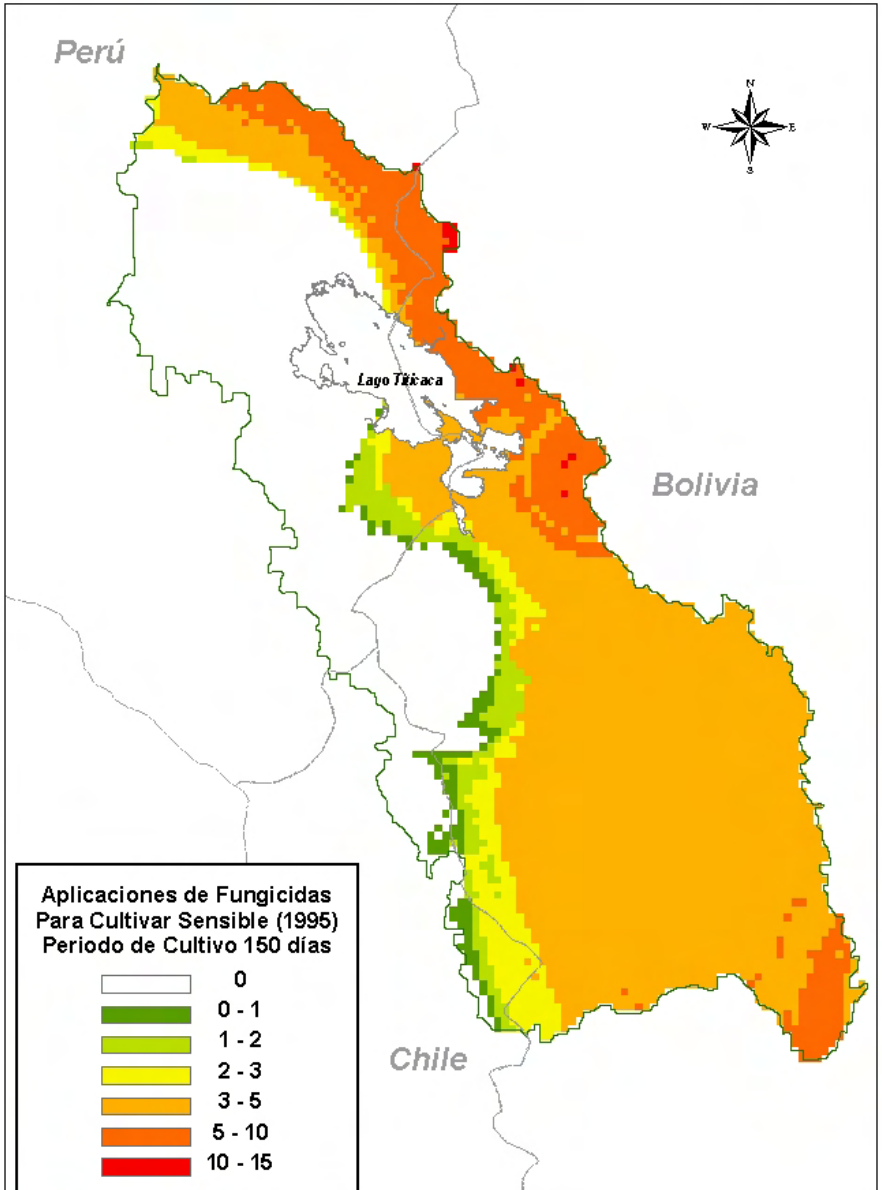
Soybean rust pathogen immigration to US potentially via hurricane

Need integrated multi-disciplinary international networks for data collection and synthesis

SANREM CRSP

How will our SANREM project address climate change and the management of pests and diseases?

Fungicide applications as a function of climate



Forbes, Raymundo

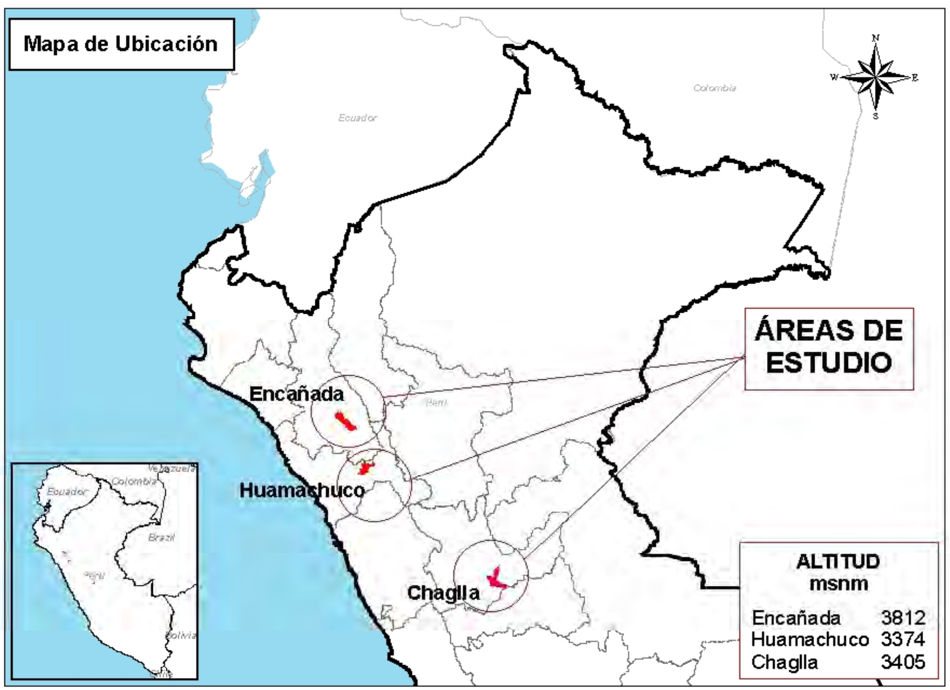
First: Development of initial estimates of regional reliance on fungicides for late blight (using GIS)

Next: Test of models for potato tuber moth using GIS

• CENTRO INTERNACIONAL DE LA PAPA • CIP •

New USDA project with CIP building on SANREM collaboration

Study sites in Peru



Drivers of varietal change: assessing impact of late blight resistant cultivars

Incorporating predicted climate change scenarios

To include Peru, Uganda, and China

Forbes, Sparks, Thiele, Winters

• CENTRO INTERNACIONAL DE LA PAPA • CIP

A baseline for population dynamics in response to climate change for the potato tuber moth and Andean potato weevil in the Bolivian altiplano

Team includes Baltazar, Calle, Gonzales, Gomez, Jarandilla, Paz, Peñaranda

Outline

Climate change → Plant disease

Biodiversity ↔ Plant disease

Ecosystem services ↔ Plant disease

How does plant biodiversity affect plant disease?

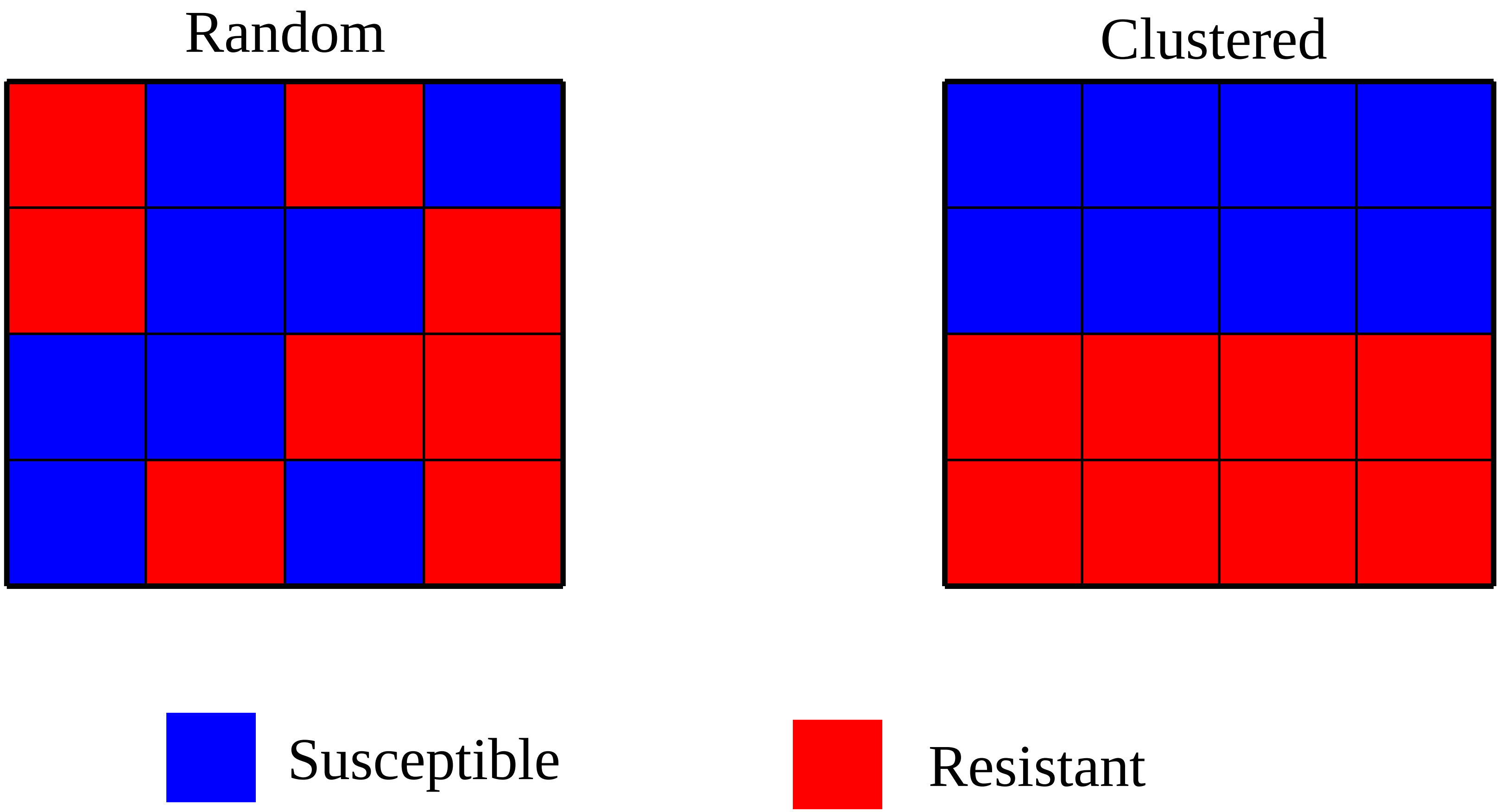
Perhaps most importantly, a more diverse plant population can dilute host tissue so more pathogen propagules are 'wasted'

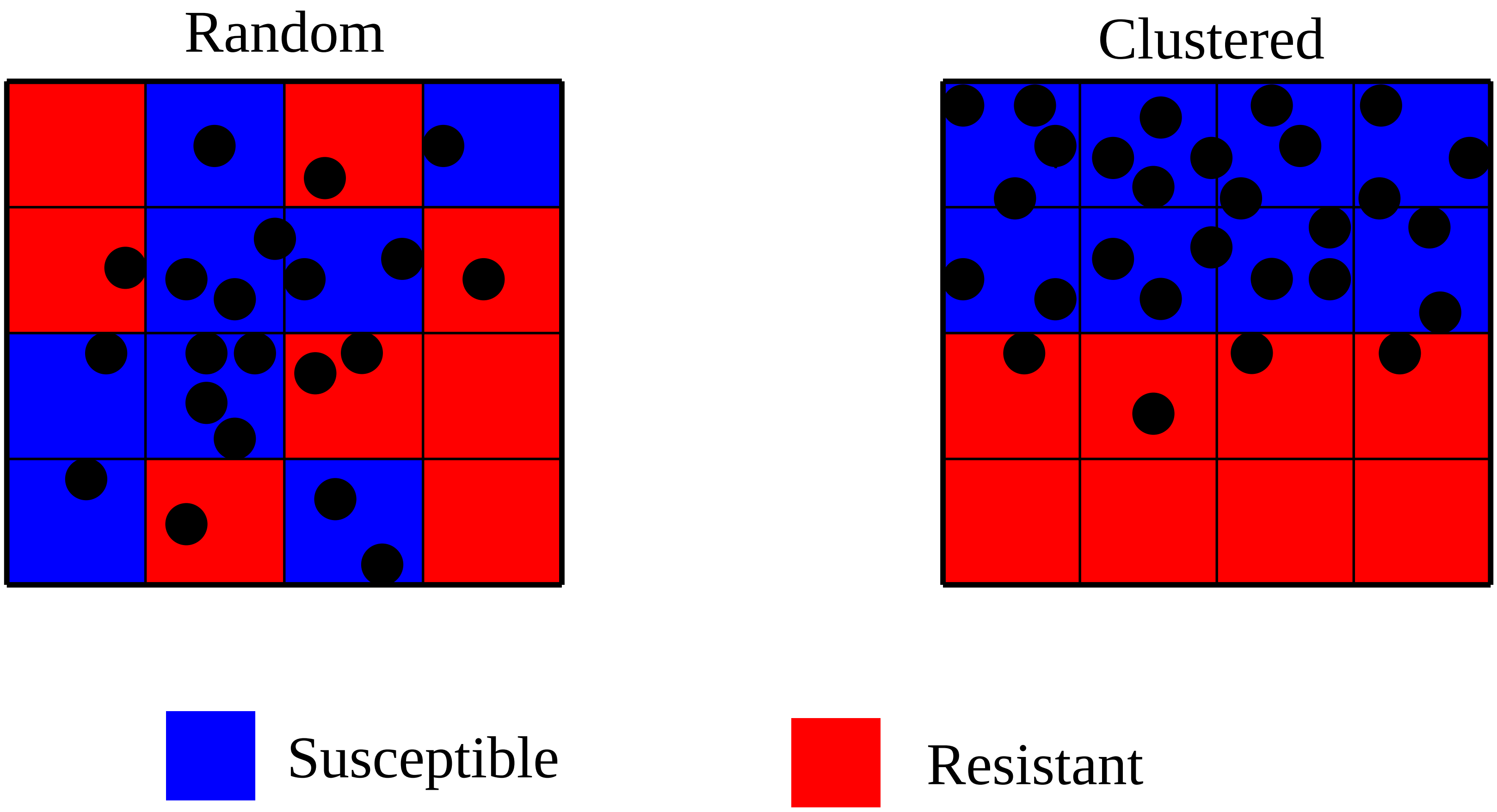
Also, inclusion of more plant species or genotypes can alter the microclimate

Reviews of the effects of plant mixtures on disease

Garrett and Mundt 1999 Phytopathology
PDF available through publications link at www.ksu.edu/pdecology

Mundt 2002 Annual Review of Phytopathology


Random
Clustered
Susceptible
Resistant


Random
Clustered
Susceptible
Resistant

Natural enemies of insects

Population response in polyculture:
percentage studies finding effects

	Lower	Higher	Variable	No effect	Total species
Predators	12%	43%	30%	16%	90
Parasitoids	3%	75%	15%	8%	40

Andow 1991

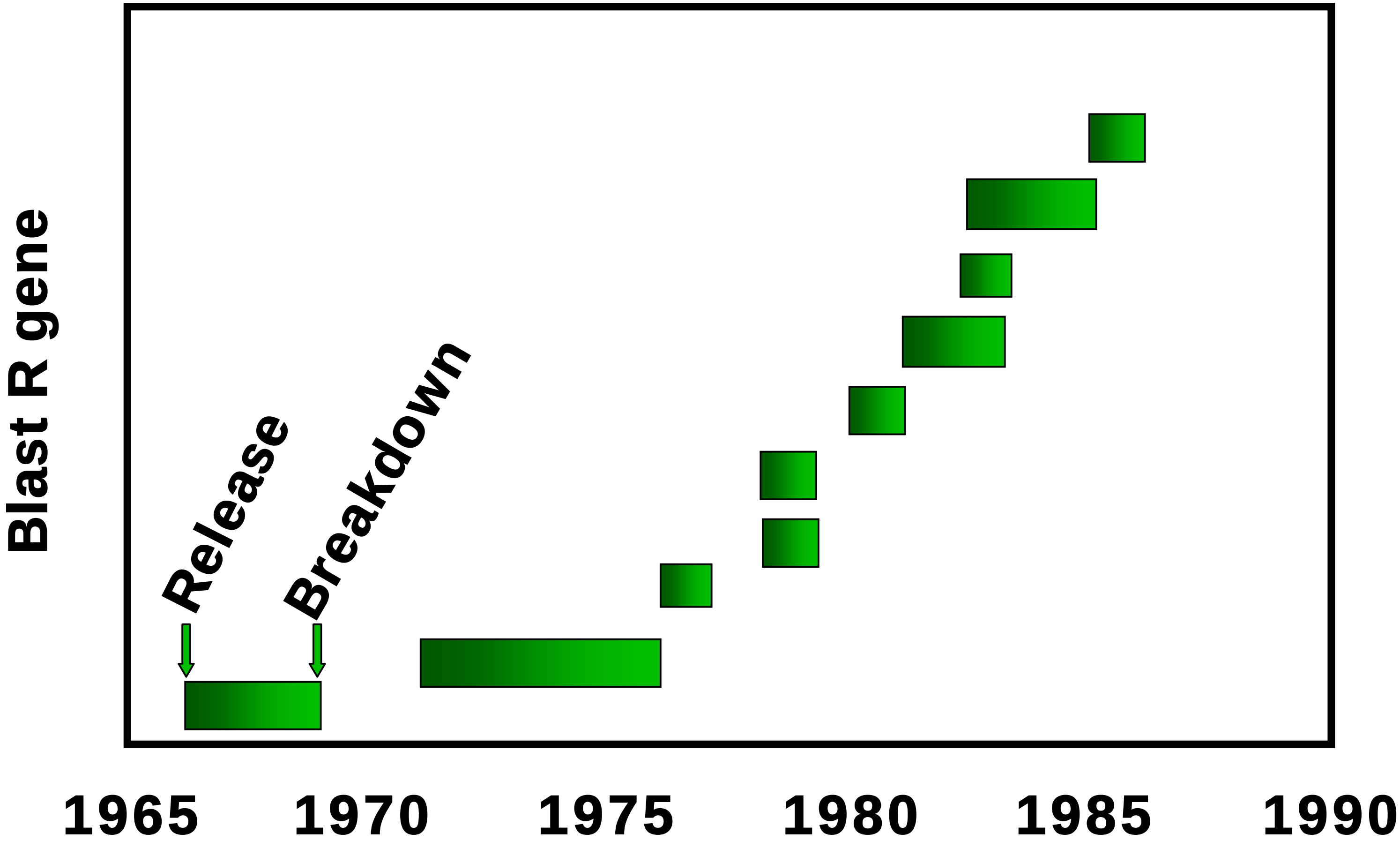
Biodiversity in Agricultural species

Host Productivity

- Intraspecific mixtures
  - Example: rice mixtures to manage rice blast
- Interspecific mixtures
  - Example: bean and maize mixtures to manage rust species
- Crop rotation
  - Intraspecific rotations; Ex: soybean variety rotation and SCN
  - Interspecific rotations

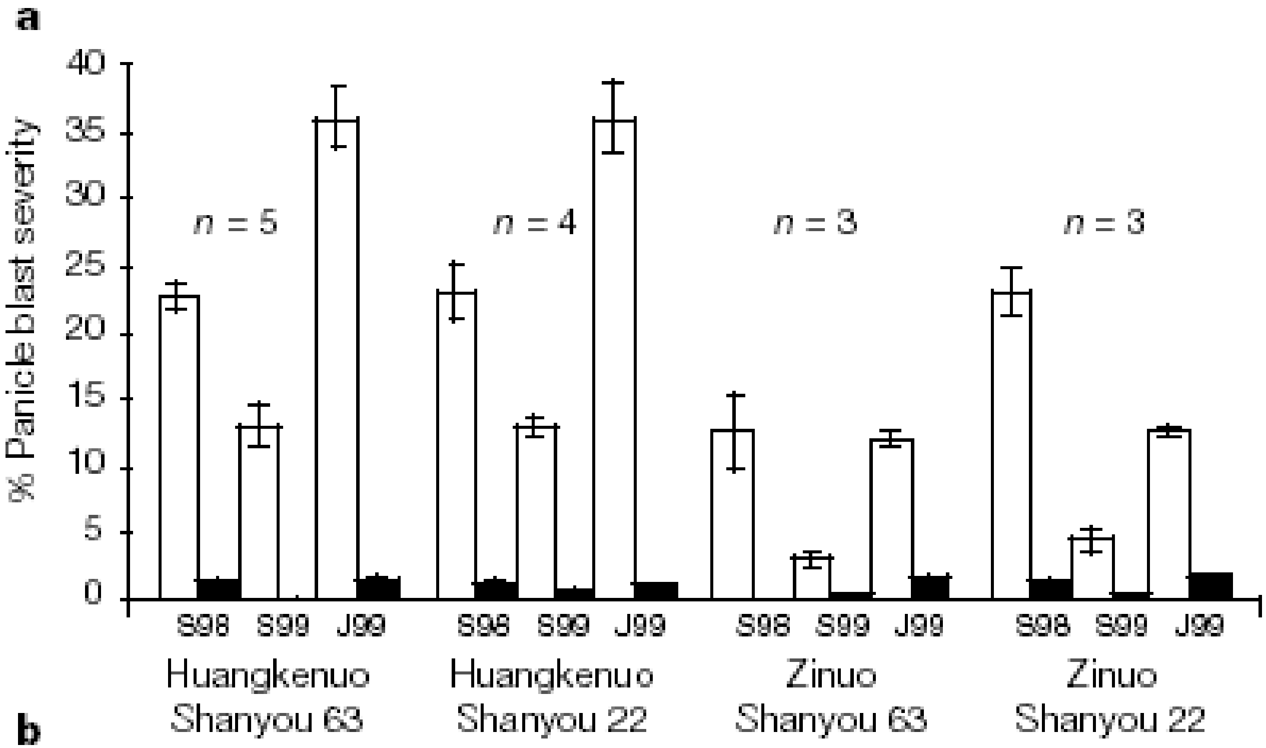
Environmental Health Perspectives
Union Agricultural Institute
International Rice Research Institute

For rice blast, single R genes have not offered long-lasting protection



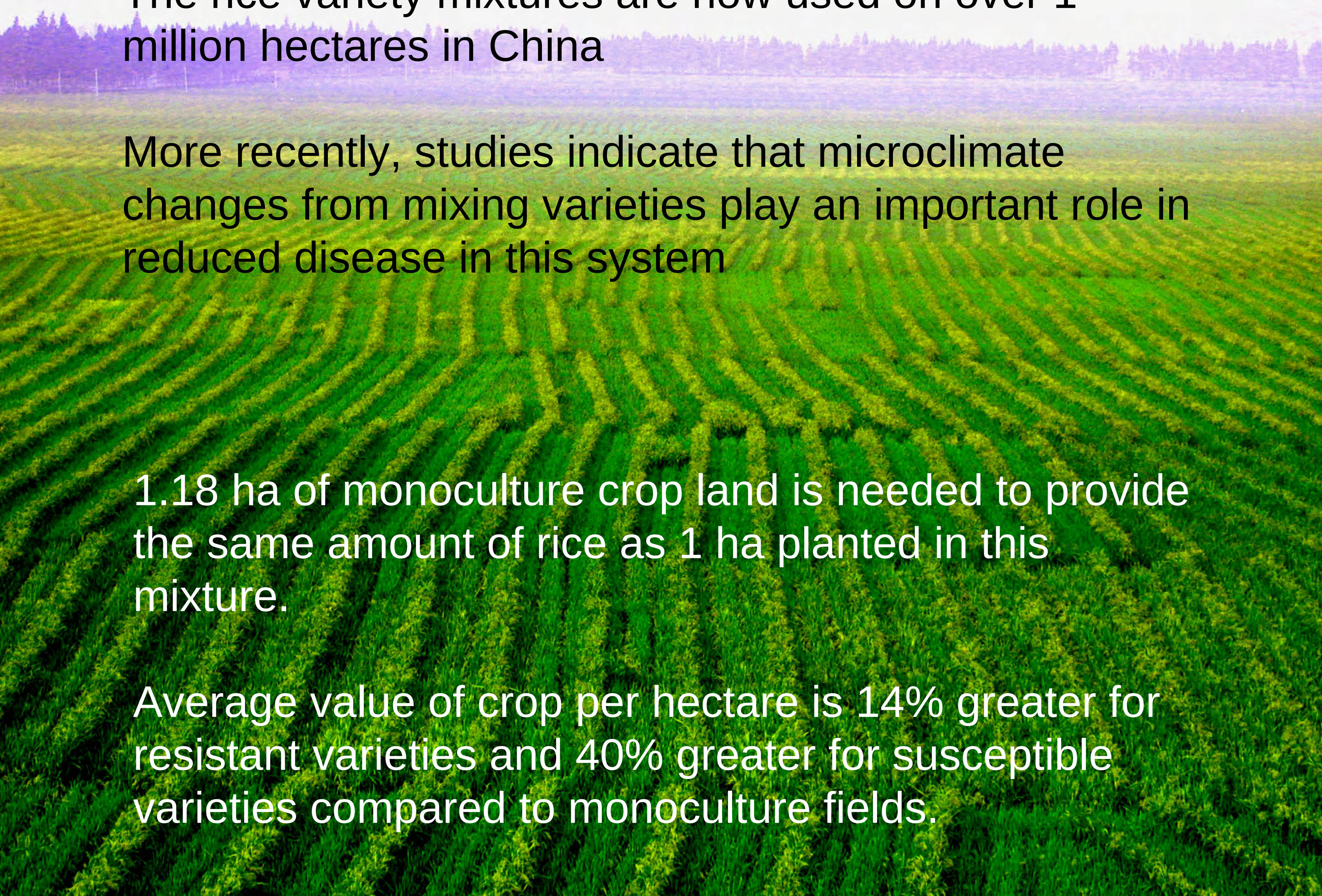
Adapted from Lee and Cho, International Rice Research Conference, Seoul, 1991

Rice blast management through variety mixtures (Yunnan Province)



Here advances in resistance are combined with the use of rice mixtures to produce an effective solution to a disease problem

Zhu et al. 2000 Nature



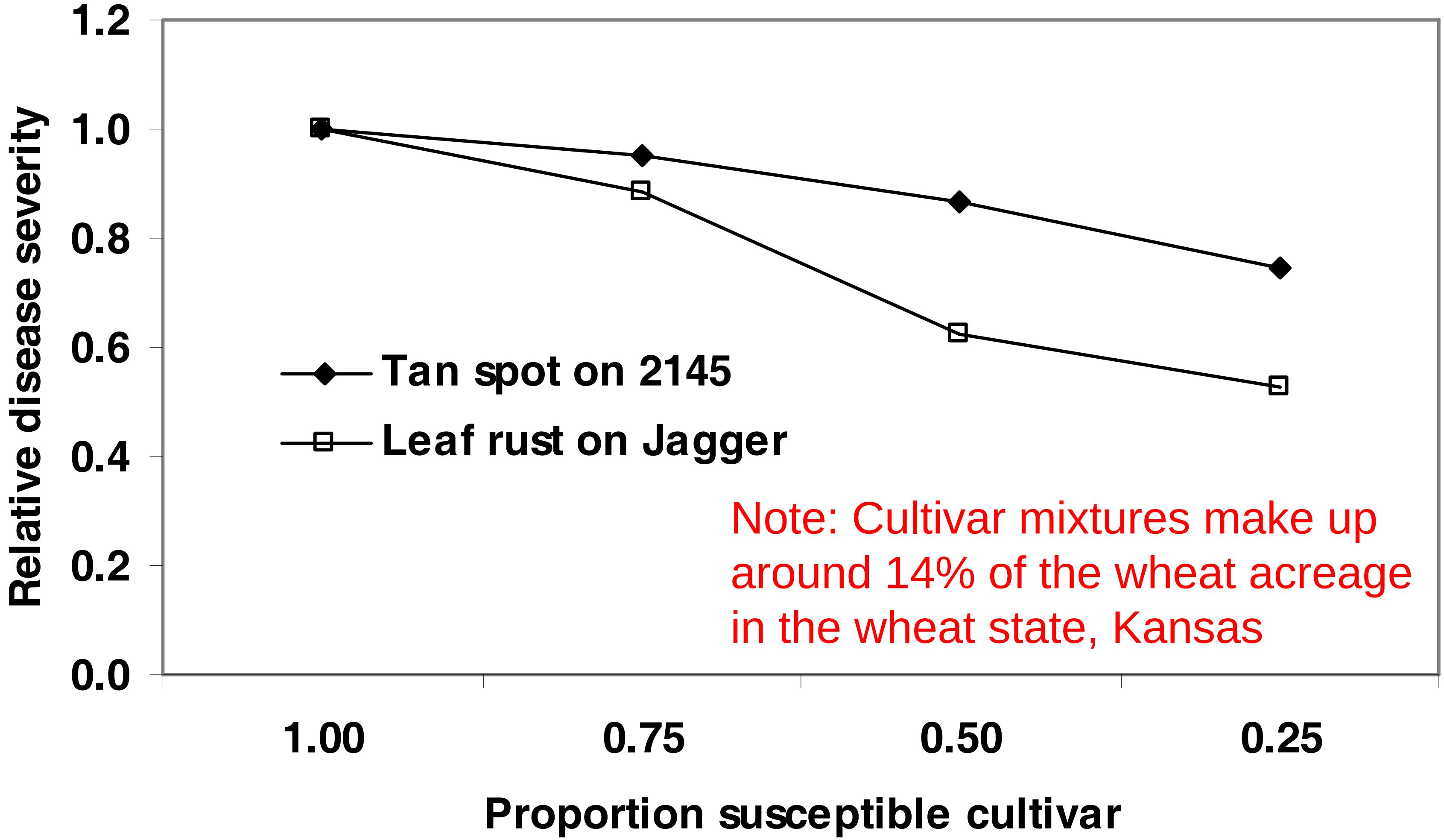
The rice variety mixtures are now used on over 1 million hectares in China

More recently, studies indicate that microclimate changes from mixing varieties play an important role in reduced disease in this system

1.18 ha of monoculture crop land is needed to provide the same amount of rice as 1 ha planted in this mixture.

Average value of crop per hectare is 14% greater for resistant varieties and 40% greater for susceptible varieties compared to monoculture fields.

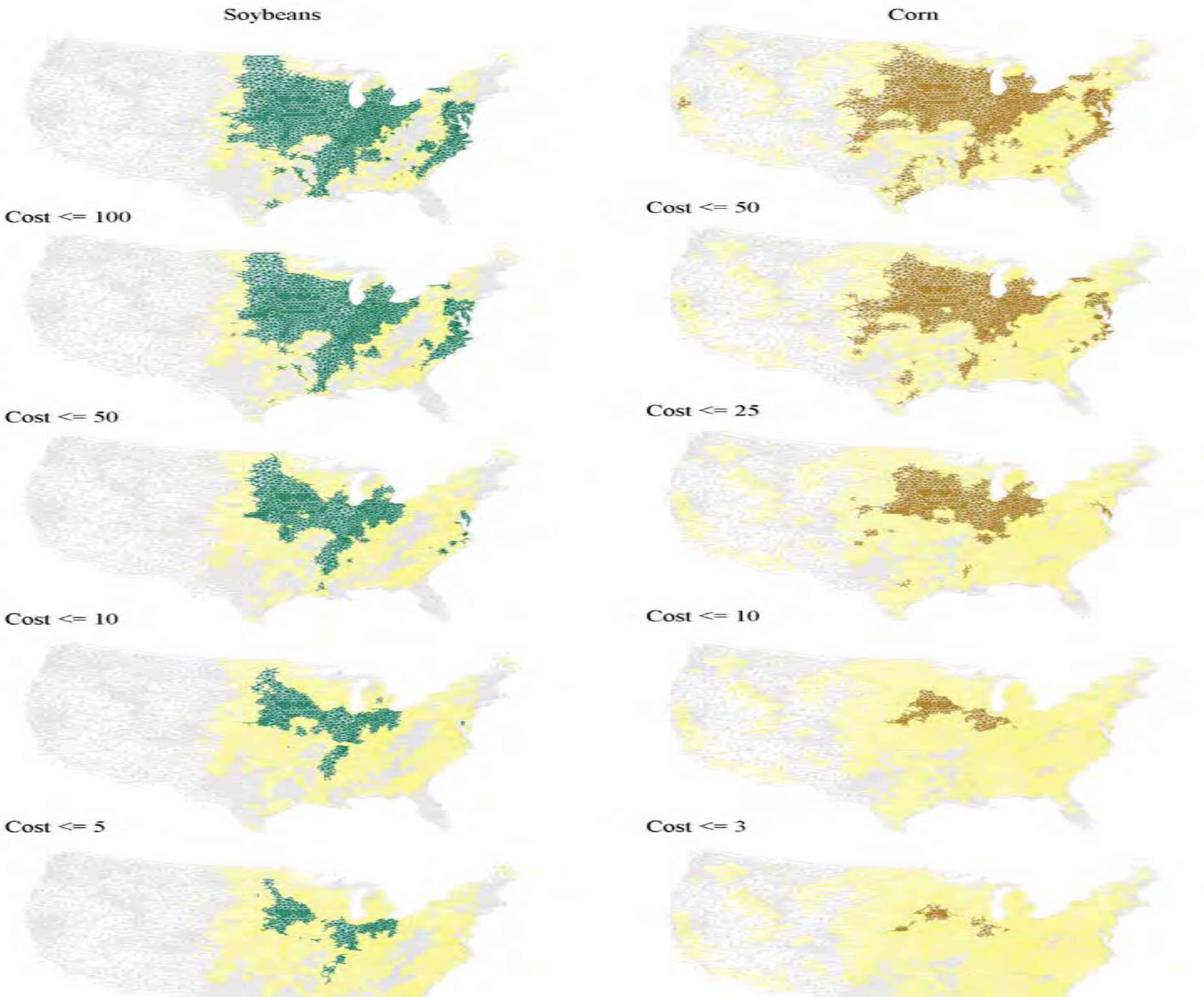
Effects of susceptible host abundance on disease severity for two wheat pathogens with different life histories



Cox, Garrett, Bowden, Fritz, Dendy, and Heer 2004 Phytopathology

Connected regions for pathogens with different 'cost of movement' tolerances

Margosian, Hutchinson, With, and Garrett



Biodiversity of non-agricultural species in agricultural systems

- Weeds (native and introduced)
  - Case study: Wheat streak mosaic virus in wheat and weeds
  - Example: Stem rust of wheat and barberry
- Biocontrol species

Figure 1. Wheat streak mosaic virus infected wheat plant illustrating the yellow and green striping of the leaves.

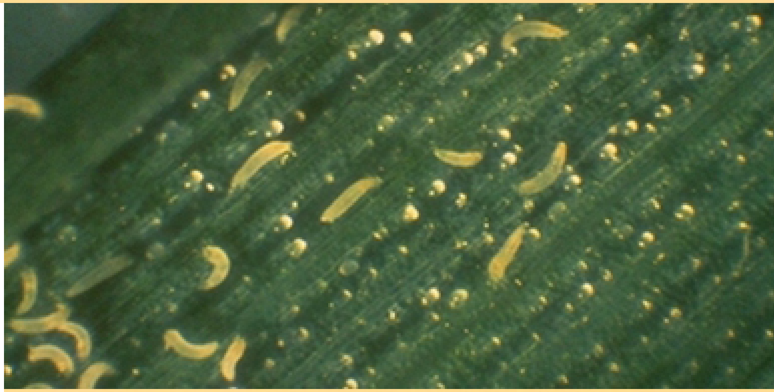
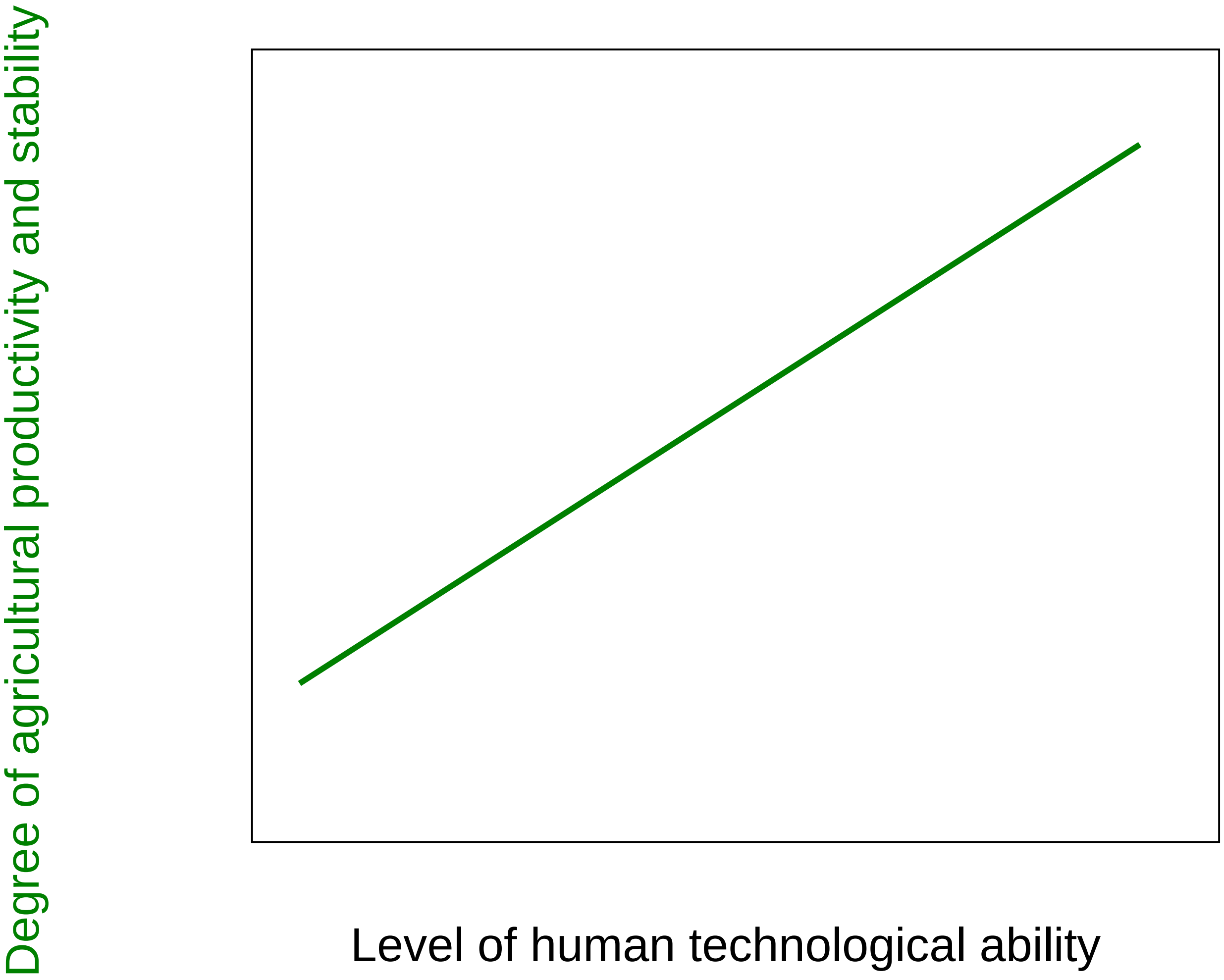


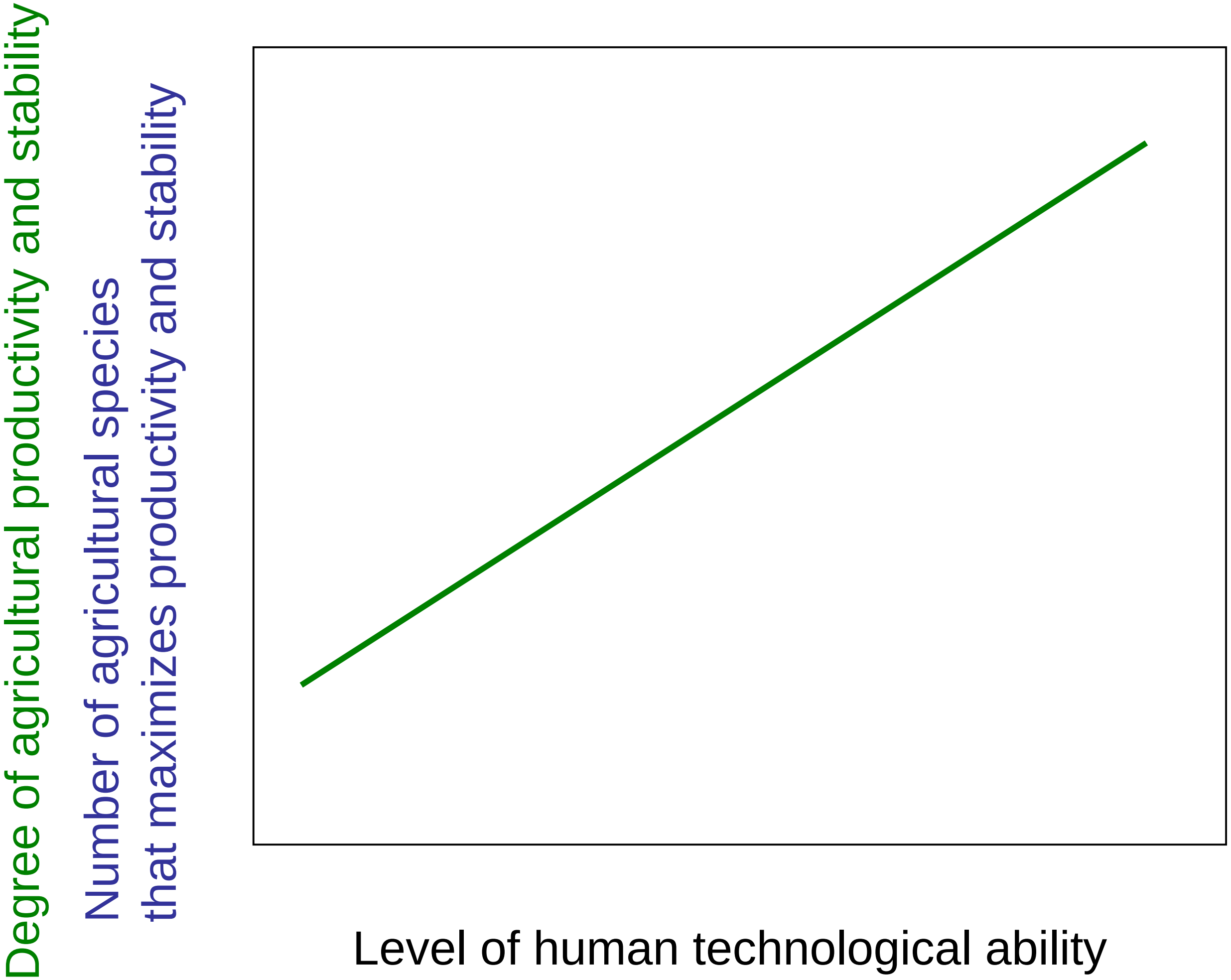
Figure 2. Wheat curl mite on small grain leaf. University of Minnesota

A form of technology optimism



Garrett and Cox (in press)

A form of technology optimism



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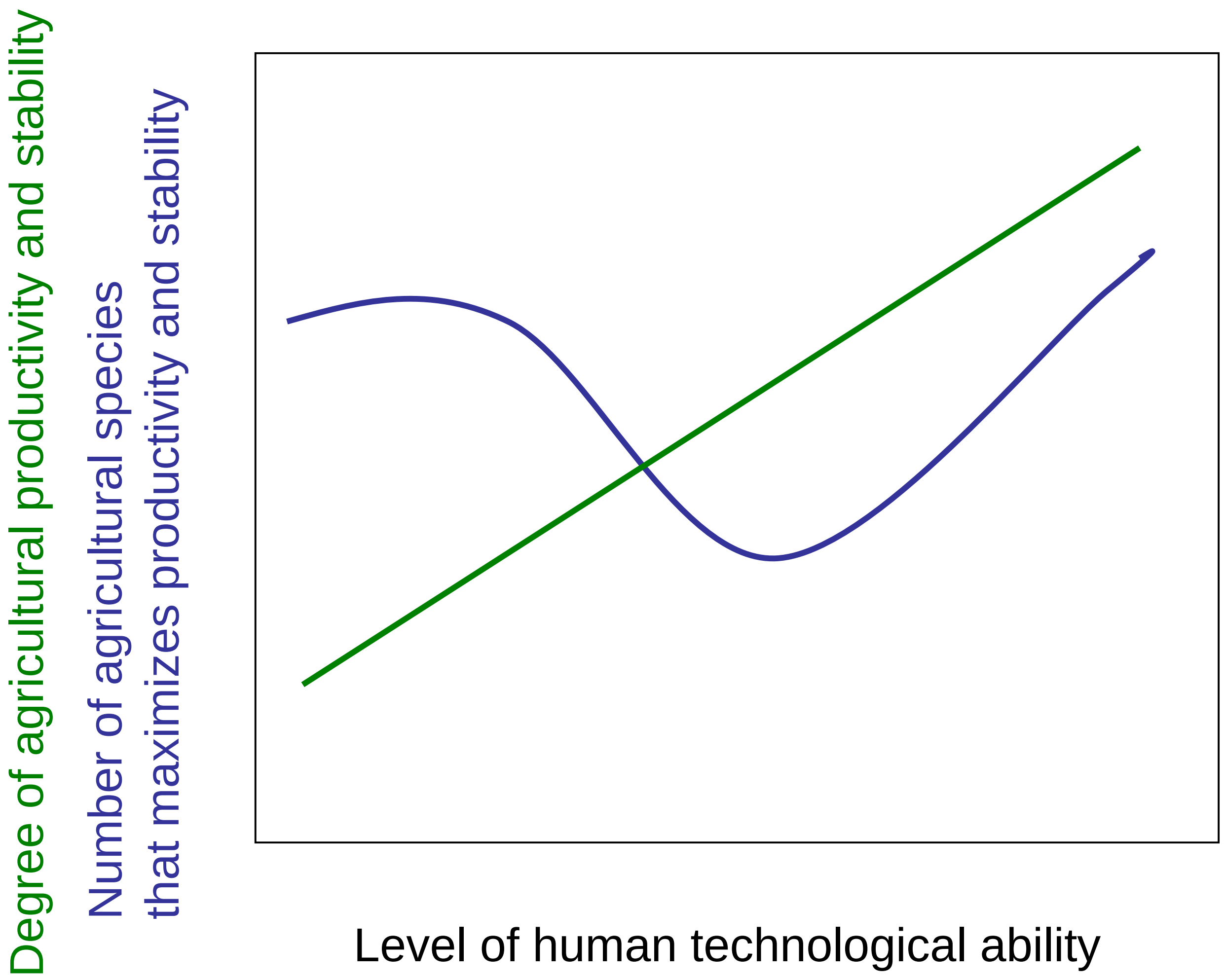

It may be the case that…

… low technology requires many agricultural species

…intermediate technology can only optimize use of a smaller number of ag species

… higher technology can make optimal use of many ag species

Garrett and Cox (in press)

Need for genetic resources to respond to changing climates

Quinoa varieties in Umala

Photo: P. Motavalli

Team led by Chambilla

Participatory evaluation of 5 introduced varieties and 1 native variety in 4 communities and future studies of IPM/IDM

Evaluation of traditional potato and oca varieties

Team includes Baltazar, Cusicanqui, Gonzales, Mamani, Sarmiento

Outline

Climate change → Plant disease

Biodiversity ↔ Plant disease

Ecosystem services ↔ Plant disease

The value of the world's ecosystem services and natural capital

Robert Costanza*†, Ralph d'Arge‡, Rudolf de Groot§, Stephen Farber‖, Monica Grasso†, Bruce Hannon¶, Karin Limburg#☆, Shahid Naeem, Robert V. O'Neill††, Jose Paruelo‡‡, Robert G. Raskin§§, Paul Sutton‖‖ & Marjan van den Belt¶¶**

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‡‡ Department of Ecology, Faculty of Agronomy,
§§ Jet Propulsion Laboratory, Pasadena, Califor
‖‖ National Center for Geographic Information a
USA
¶¶ Ecological Economics Research and Applicati

The services of ecological systems
Earth's life-support system. They
part of the total economic value of t
for 16 biomes, based on published
which is outside the market) is est
US$33 trillion per year. Because of
gross national product total is aro

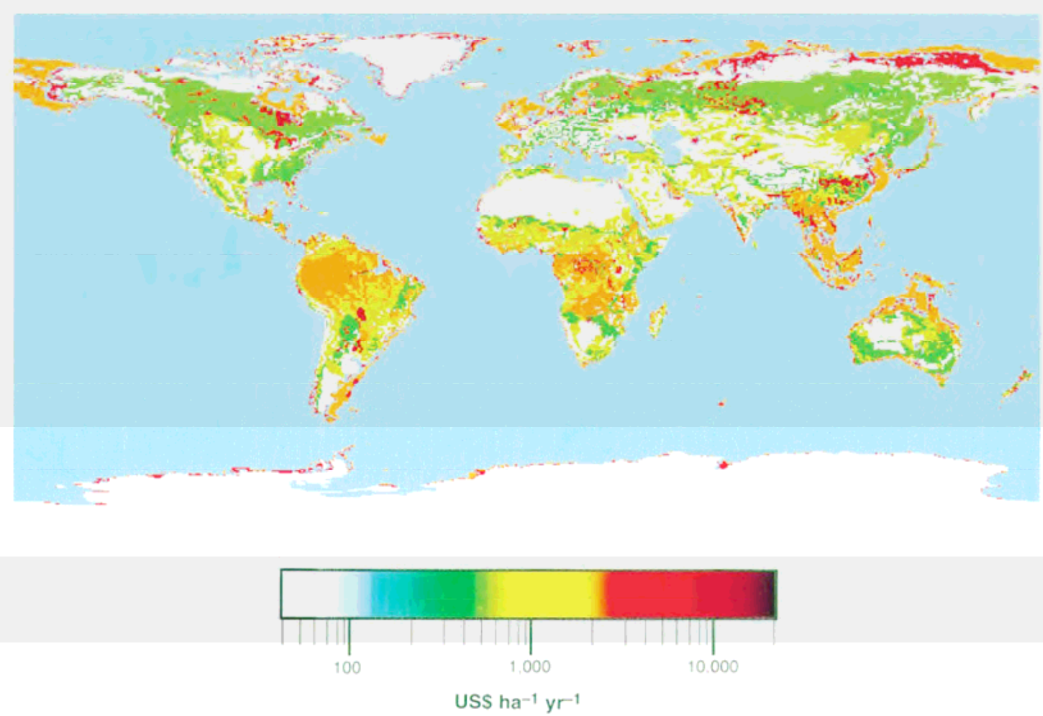
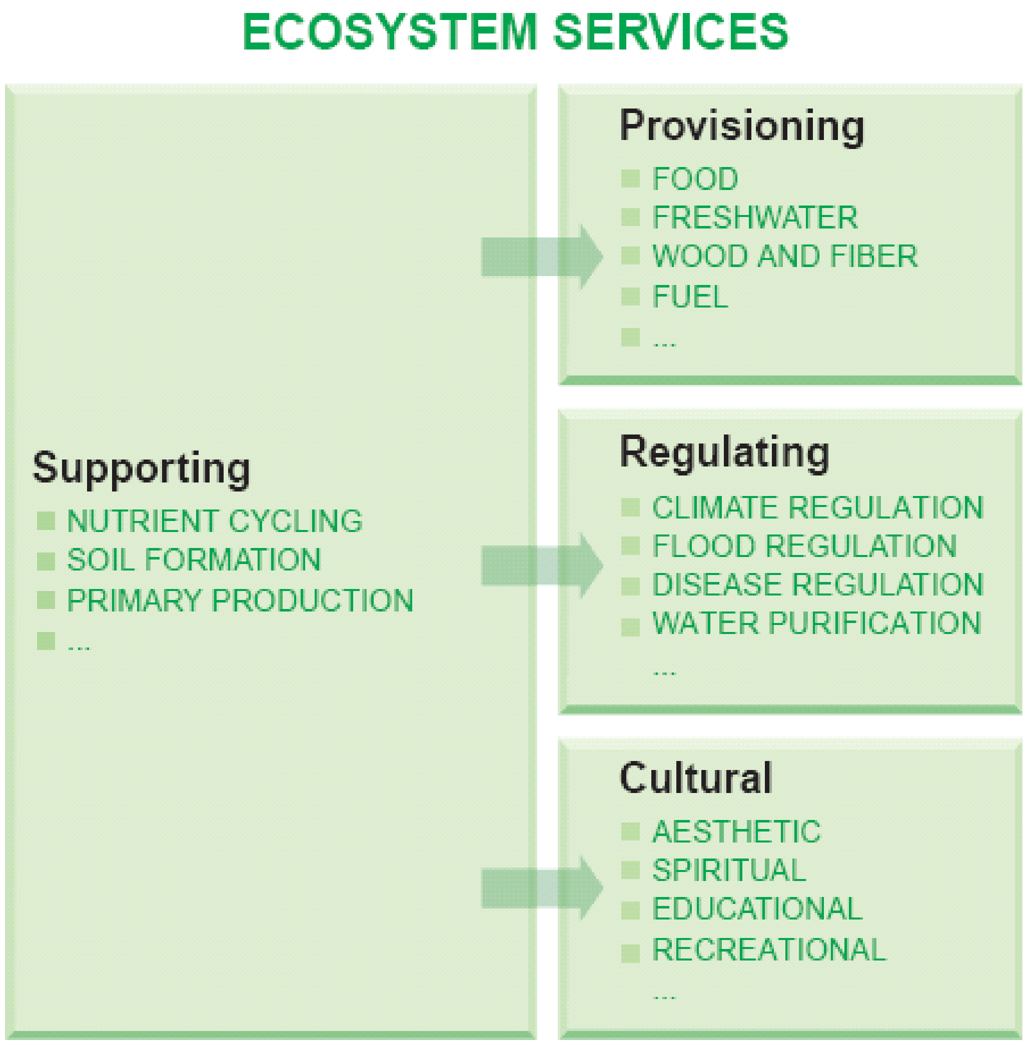


Figure 2 Global map of the value of ecosystem services. See Supplementary Information and Table 2 for details.

Ecosystem Services
The benefits people obtain from ecosystems

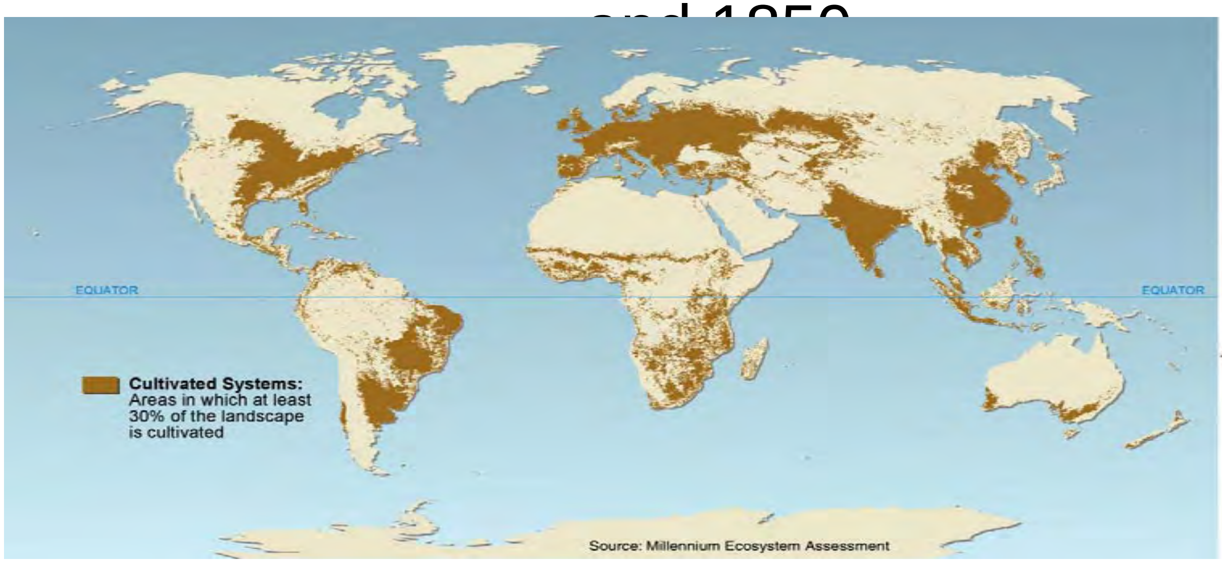


Finding #1 from Millennium Ecosystem Assessment

- – Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history
- – This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth

Unprecedented change in structure and function of ecosystems

More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850

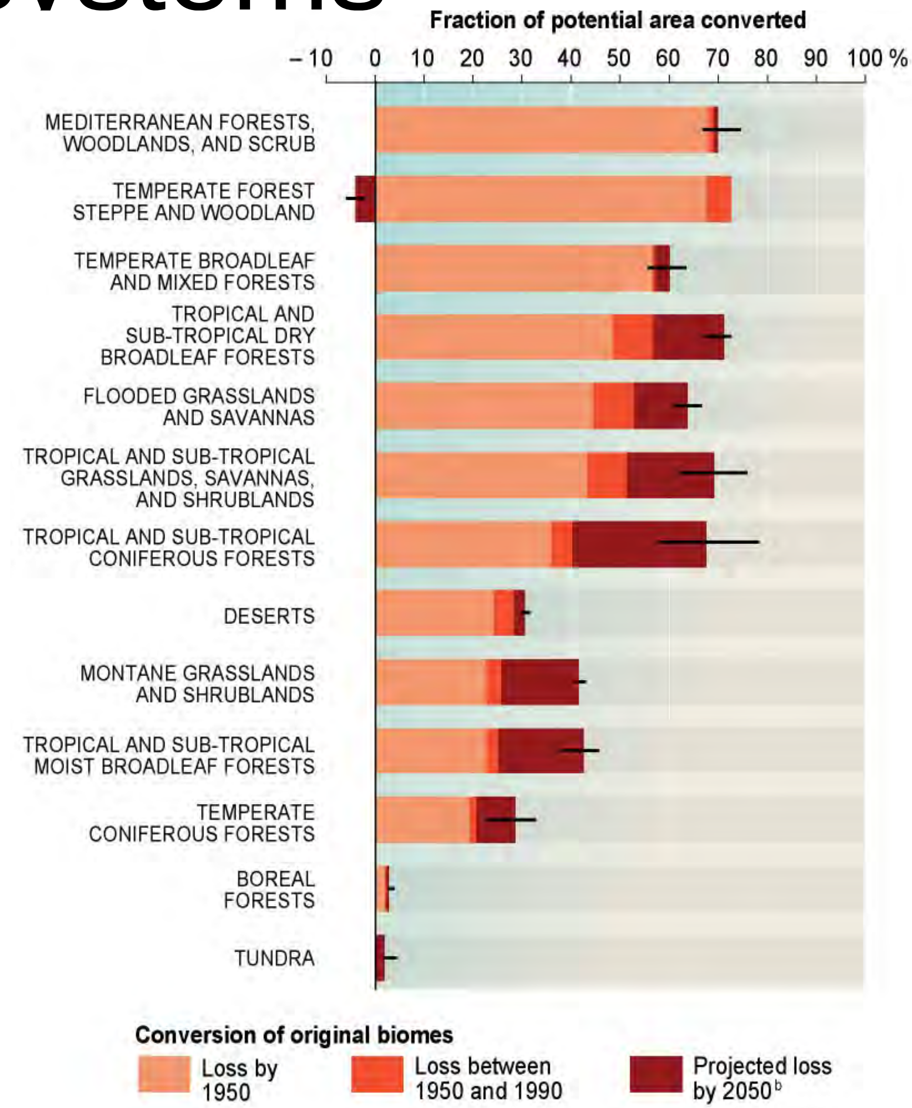


Cultivated Systems in 2000 cover 25% of Earth’s terrestrial surface

Young (1999) estimates 75% of *arable* land in developing countries is in cultivation

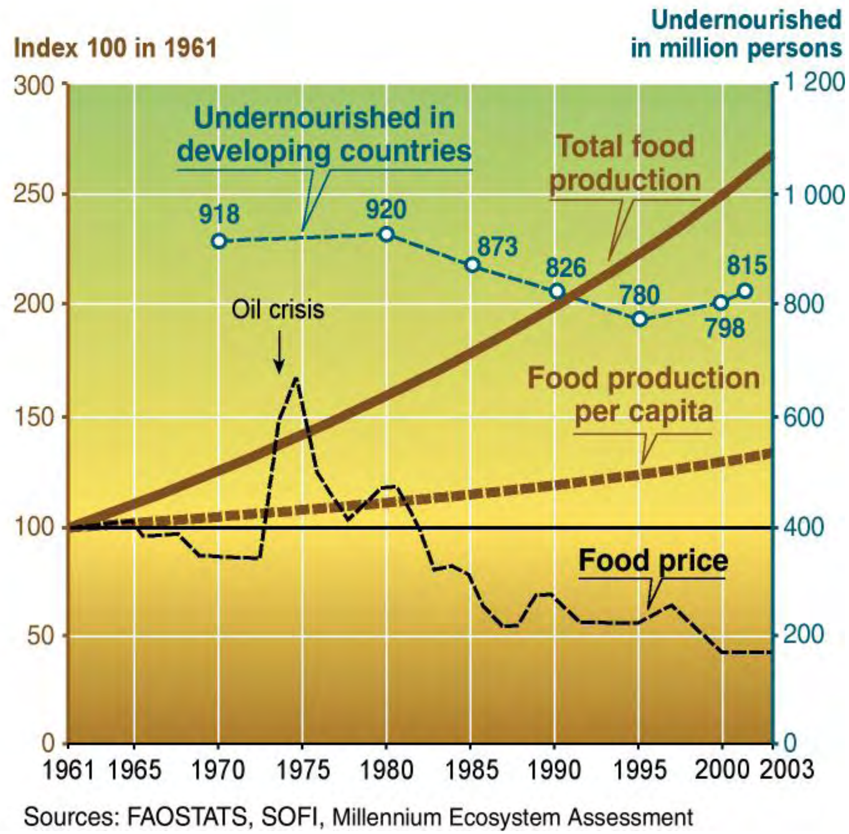
Unprecedented change: Ecosvstems

- 5-10% of the area of five biomes was converted between 1950 and 1990
- More than two thirds of the area of two biomes and more than half of the area of four others had been converted by 1990



Changes to ecosystems have provided substantial benefits

- Food production has more than doubled since 1960
- Food production per capita has grown
- Food price has fallen



Industries based on ecosystem services still the mainstay of many economies

- Contributions of agriculture
  - Agricultural labor force accounts for 22% of the world’s population and half the world’s total labor force
  - Agriculture accounts for 24% of GDP in low income developing countries
- Market value of ecosystem-service industries
  - Food production: $980 billion per year
  - Timber industry: $400 billion per year
  - Marine fisheries: $80 billion per year
  - Marine aquaculture: $57 billion per year
  - Recreational hunting and fishing: >$75 billion per year in the United States alone

Degradation and unsustainable use of ecosystem services

- Approximately 60% (15 out of 24) of the ecosystem services evaluated in the Millennium Ecosystem Assessment are being degraded or used unsustainably
- The degradation of ecosystem services often causes significant harm to human well-being and represents a loss of a natural asset or wealth of a country

14 / 22 Adversely affected

Service	Sub-category	Status	Notes
Provisioning Services			
Food	crops	▲	substantial production increase
	livestock	▲	substantial production increase
	capture fisheries	▼	declining production due to overharvest
	aquaculture	▲	substantial production increase
	wild foods	▼	declining production
Fiber	timber	+/–	forest loss in some regions, growth in others
	cotton, hemp, silk	+/–	declining production of some fibers, growth in others
	wood fuel	▼	declining production
Genetic resources		▼	lost through extinction and crop genetic resource loss
Biochemicals, natural medicines, pharmaceuticals		▼	lost through extinction, overharvest
Fresh water		▼	unsustainable use for drinking, industry, and irrigation; amount of hydro energy unchanged, but dams increase ability to use that energy
Regulating Services			
Air quality regulation		▼	decline in ability of atmosphere to cleanse itself
Climate regulation	global	▲	net source of carbon sequestration since mid-century
	regional and local	▼	preponderance of negative impacts
Water regulation		+/–	varies depending on ecosystem change and location
Erosion regulation		▼	increased soil degradation
Water purification and waste treatment		▼	declining water quality
Disease regulation		+/–	varies depending on ecosystem change
Pest regulation		▼	natural control degraded through pesticide use
Pollination		▼[a]	apparent global decline in abundance of pollinators
Natural hazard regulation		▼	loss of natural buffers (wetlands, mangroves)
Cultural Services			
Spiritual and religious values		▼	rapid decline in sacred groves and species
Aesthetic values		▼	decline in quantity and quality of natural lands
Recreation and ecotourism		+/–	more areas accessible but many degraded

Plant disease and ecosystem services

- Plant disease may directly or indirectly remove plants that are providing ecosystem services
  - Introduced pathogens may extirpate host populations or even drive species to extinction
    - For example, chestnut blight removed a major source of food for mammals in the eastern US
  - In order to reduce disease risk, farmers may remove weeds and/or use tillage to remove plant residues
- Plant disease may increase plant diversity on an evolutionary time scale by contributing to reduced fitness for species that become very abundant

An American chestnut tree in Virginia. *Photo courtesy Paul Sisco, American Chestnut Foundation.*

Agricultural system – Ecosystem services

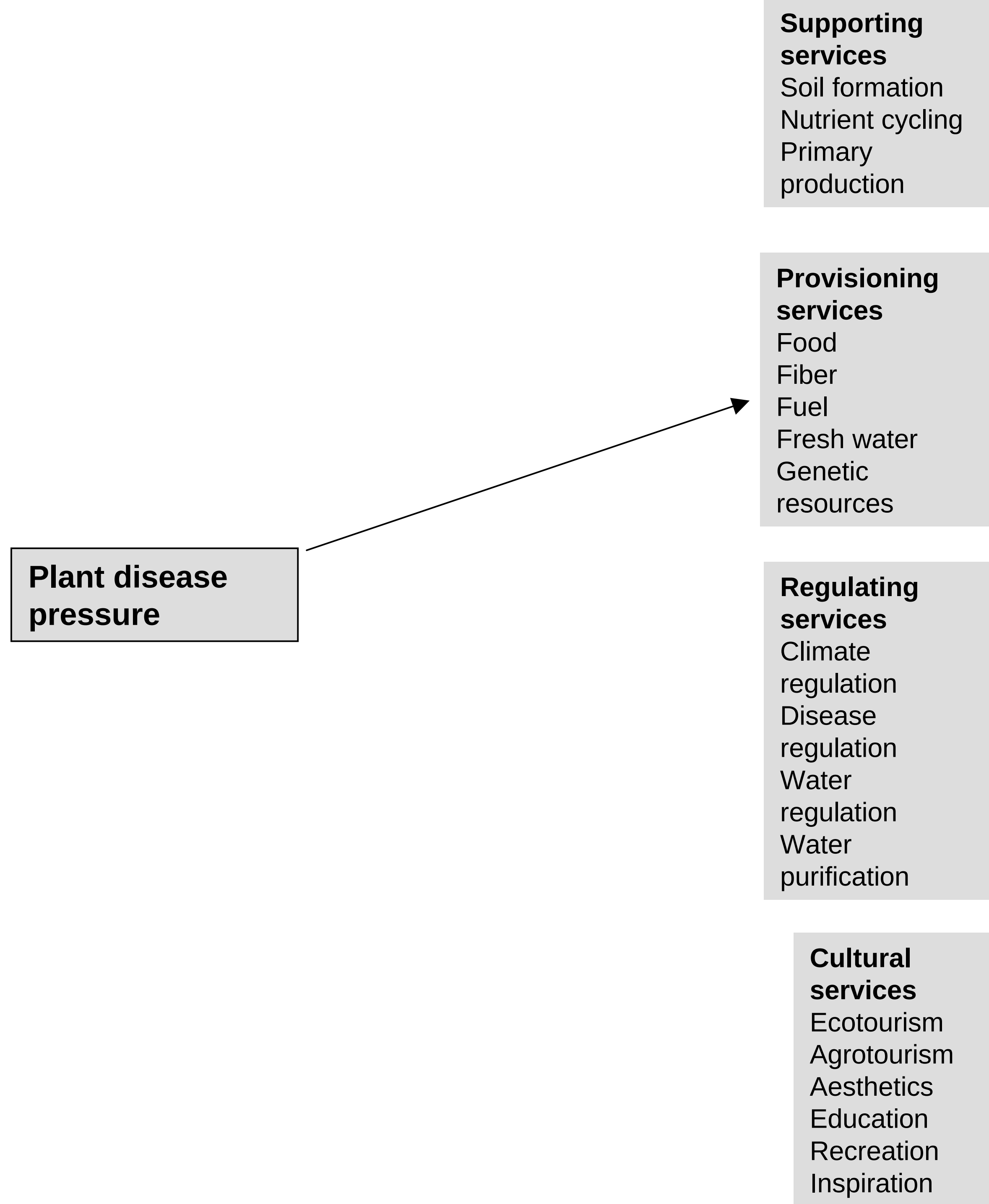
Supporting services
Soil formation
Nutrient cycling
Primary production

Provisioning services
Food
Fiber
Fuel
Fresh water
Genetic resources

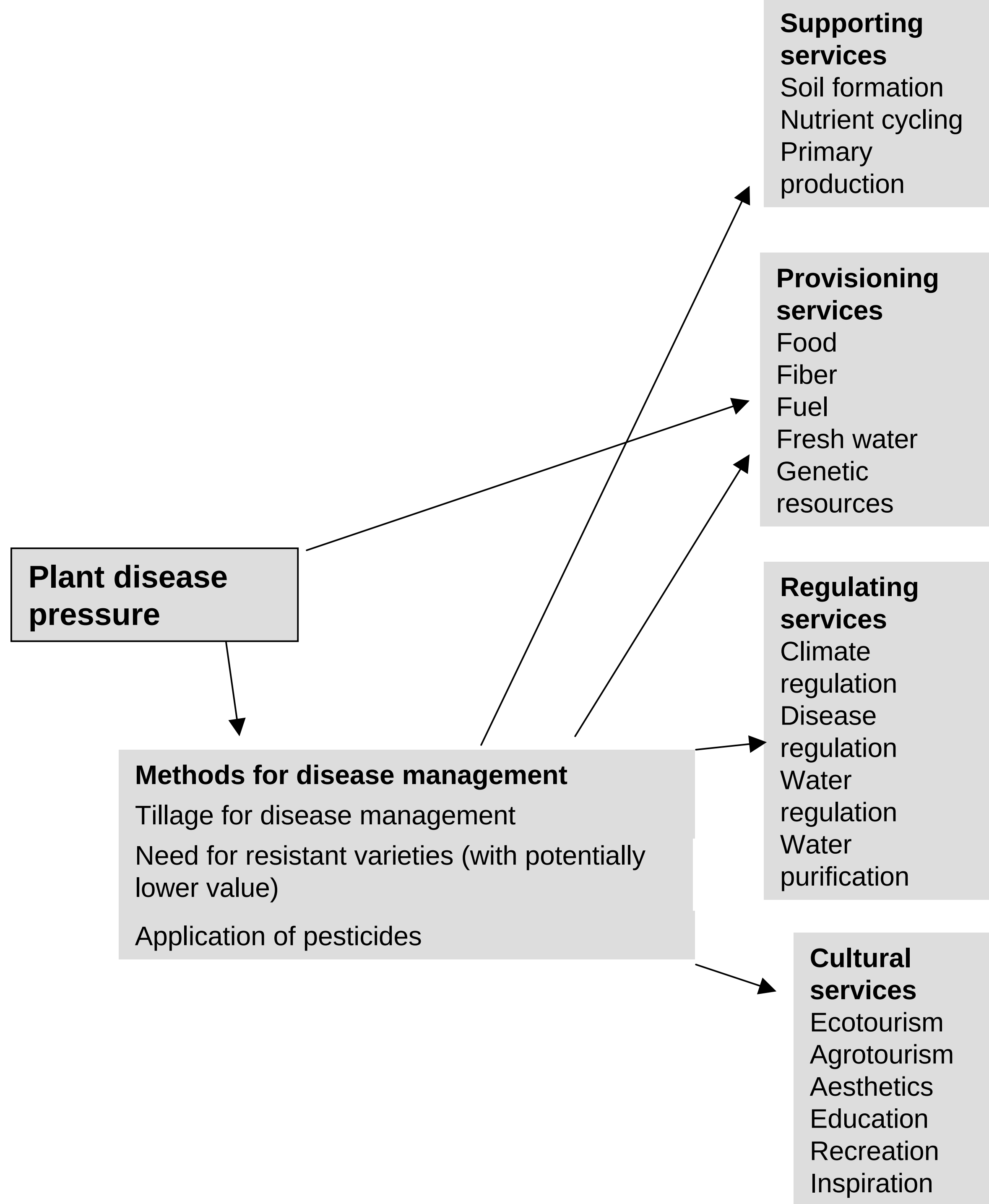
Regulating services
Climate regulation
Disease regulation
Water regulation
Water purification

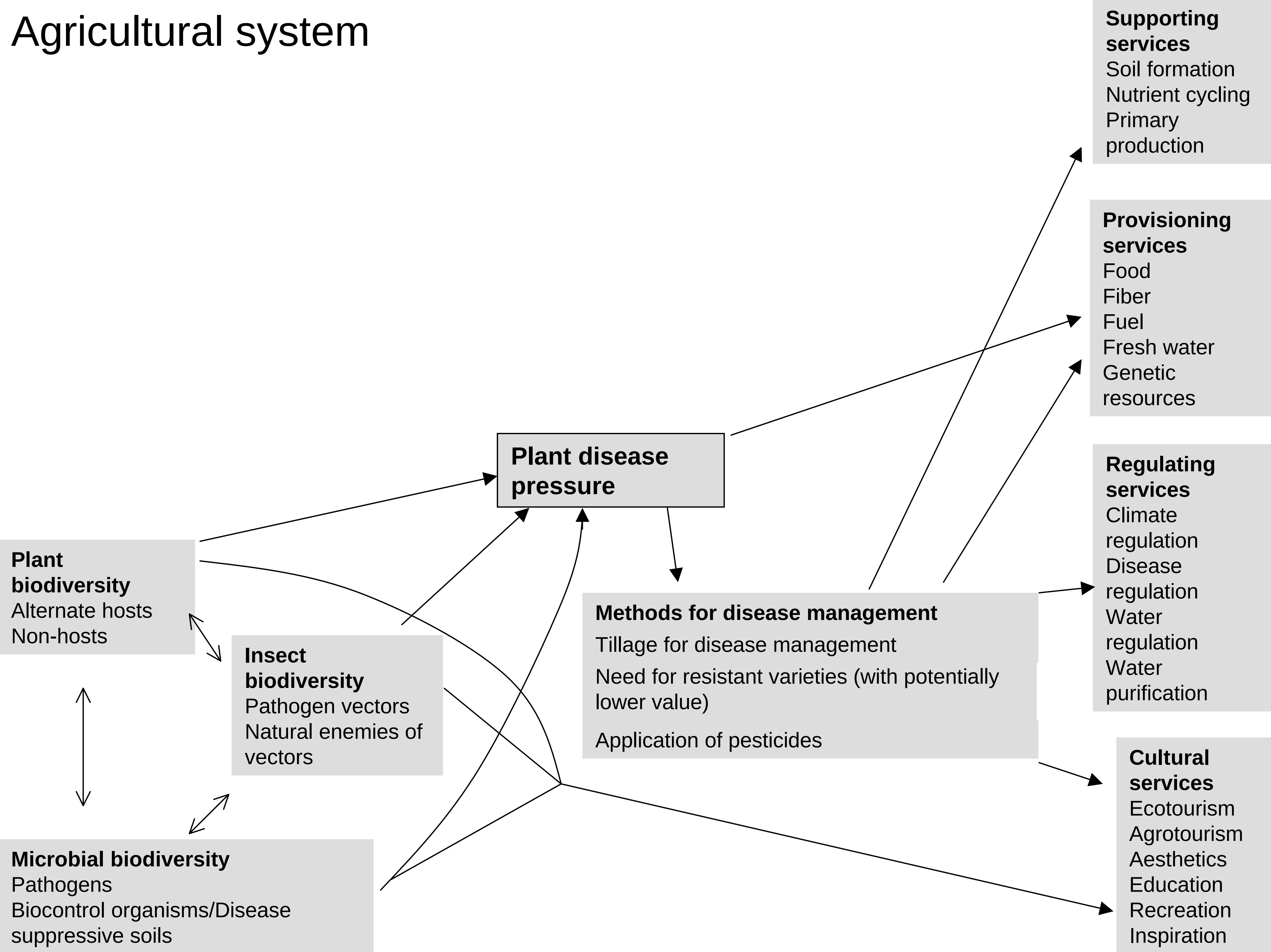
Cultural services
Ecotourism
Agrotourism
Aesthetics
Education
Recreation
Inspiration

Agricultural system



Agricultural system




Agricultural system
Supporting services
Soil formation
Nutrient cycling
Primary production
Provisioning services
Food
Fiber
Fuel
Fresh water
Genetic resources
Plant disease pressure
Regulating services
Climate regulation
Disease regulation
Water regulation
Water purification
Plant biodiversity
Alternate hosts
Non-hosts
Methods for disease management
Tillage for disease management
Need for resistant varieties (with potentially lower value)
Application of pesticides
Insect biodiversity
Pathogen vectors
Natural enemies of vectors
Cultural services
Ecotourism
Agrotourism
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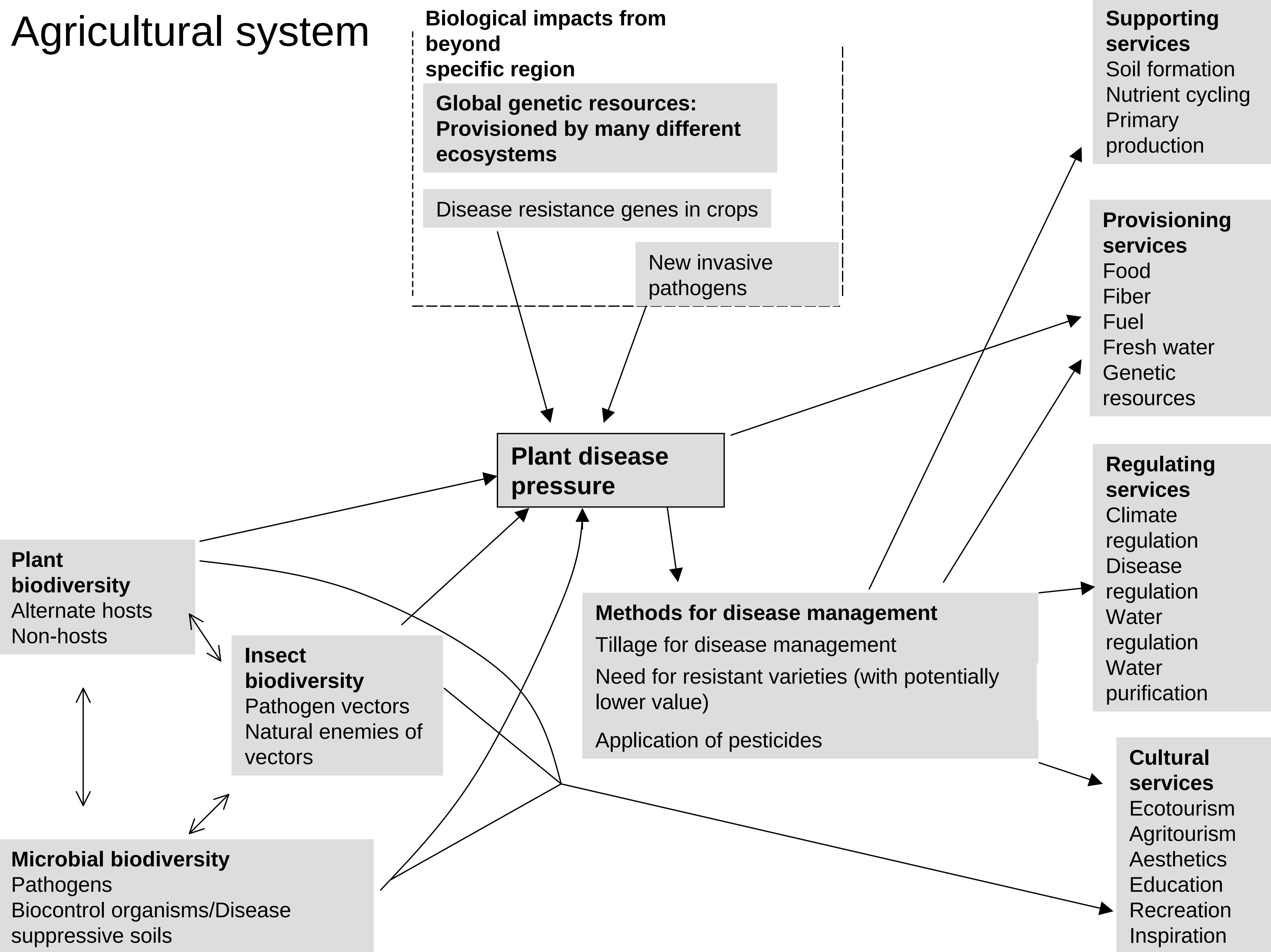
Education
Recreation
Inspiration
Microbial biodiversity
Pathogens
Biocontrol organisms/Disease suppressive soils


Agricultural system
Biological impacts from beyond specific region
Global genetic resources: Provisioned by many different ecosystems
Disease resistance genes in crops
New invasive pathogens
Plant disease pressure
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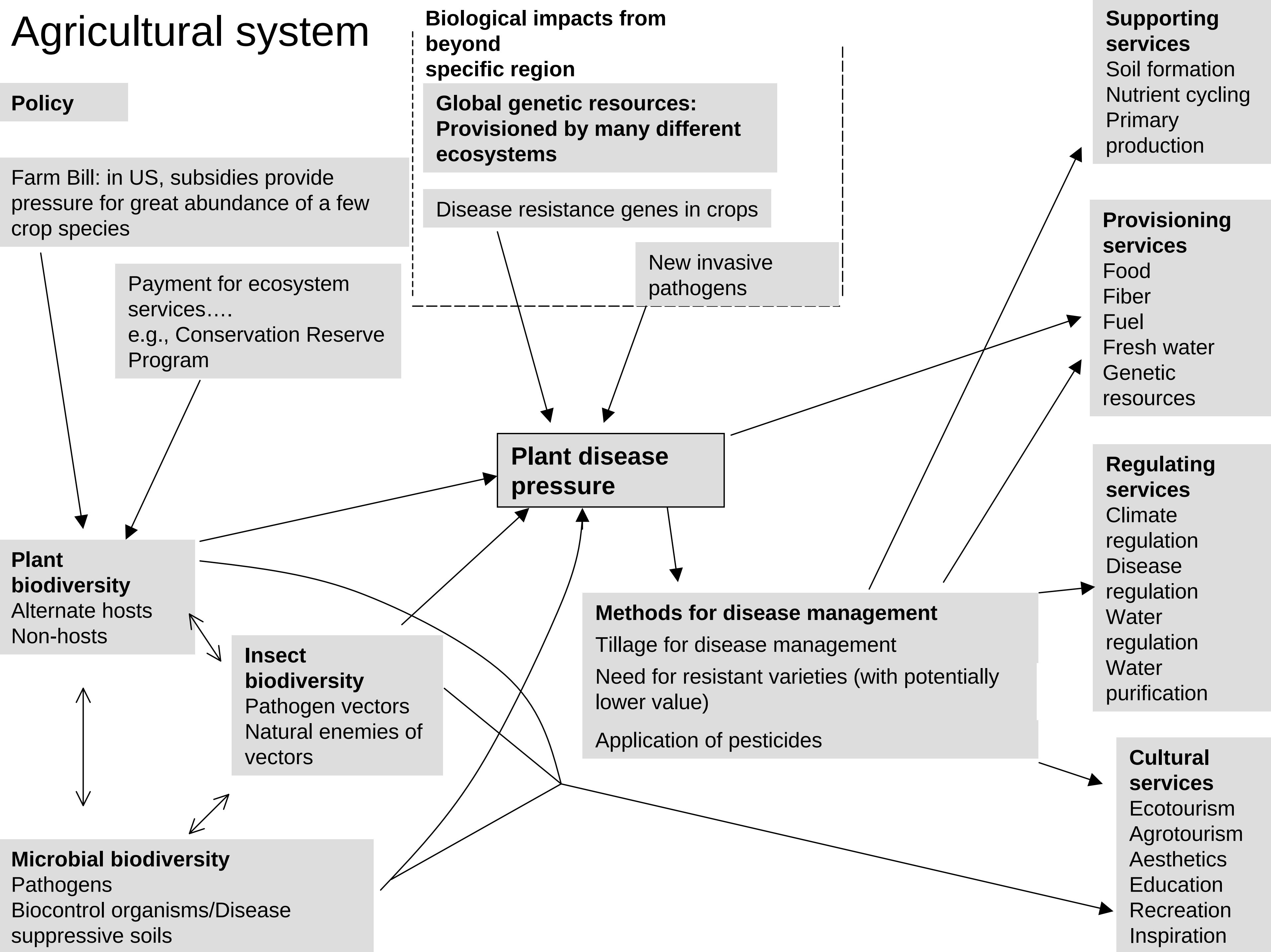
Agricultural system
Policy
Farm Bill: in US, subsidies provide pressure for great abundance of a few crop species
Payment for ecosystem services….
e.g., Conservation Reserve Program
Biological impacts from beyond specific region
Global genetic resources: Provisioned by many different ecosystems
Disease resistance genes in crops
New invasive pathogens
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Rubi Raymundo

Adam Sparks

Tom Gordon