Plant health threats to agriculture from globalisation and climate change

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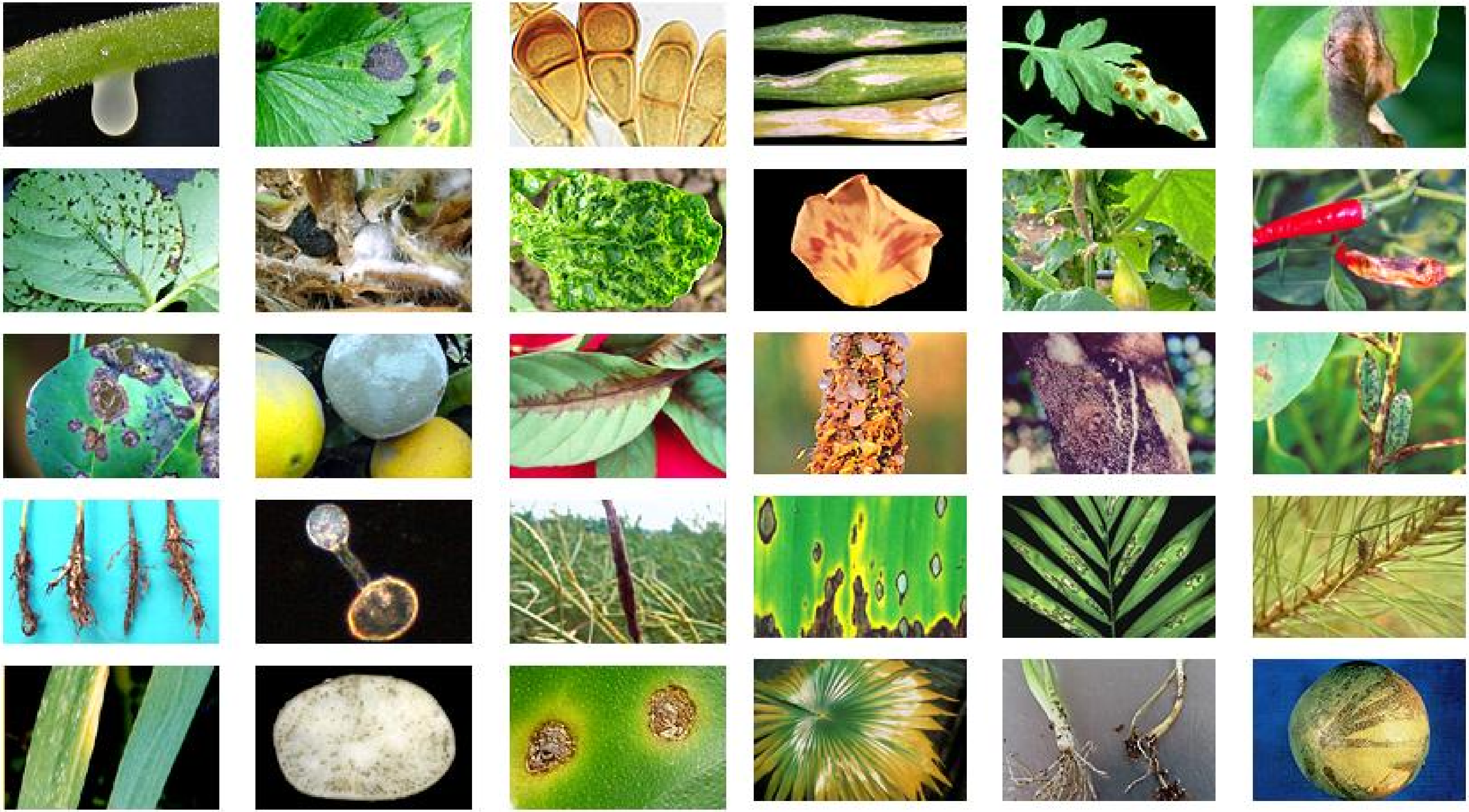
Brussels, February 2010

Photo: O. Holdenrieder

Biodiversity of plant pathogens



Photos: American Phytopathological Society, www.apsnet.org - Online Resources

Ozone, SO_2 and acid rain

''Depending on the particular pollutant/host/pathogen interaction, there may be either an increase, decrease, or no change in disease development''

Coakley (1995) ***Canadian Journal of Plant Pathology***

Fungal pathogens

Environmental change, especially when combined with pathogen and host introductions, may result in unprecedented effects

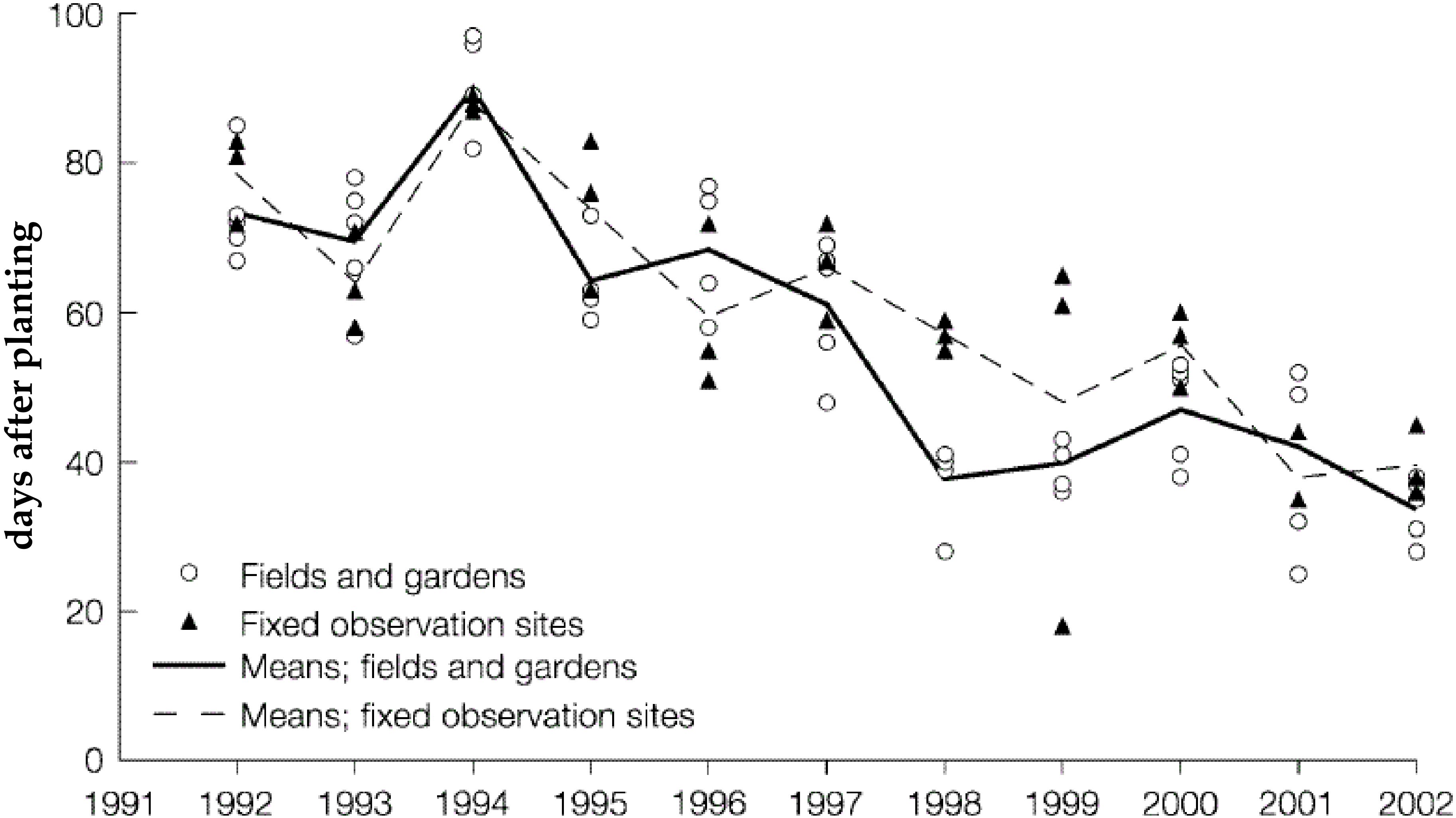
Lonsdale & Gibbs (1995) ***Cambridge Univ. Press***

CO2, O3 and UVB

''We know very little about the actual impacts of climate change factors on disease epidemiology''

Manning & Tiedemann (1995) ***Environmental Pollution***

Early observations of potato late blight (*Phytophthora infestans*) in Finland



From: Hannukkala et al. (2007) *Plant Pathology*

Genetic diversity and climate change in the tropics

As ''many effects of climate change may be similar to the effects of habitat alteration and fragmentation, protected areas and buffer zones should be enlarged, with an emphasis on connectivity''

Bawa & Dayanandan (1998) ***Climatic Change***

Plant disease management

Climate change will "add another layer of complexity and uncertainty onto a system that is already exceedingly difficult to manage on a sustainable basis"

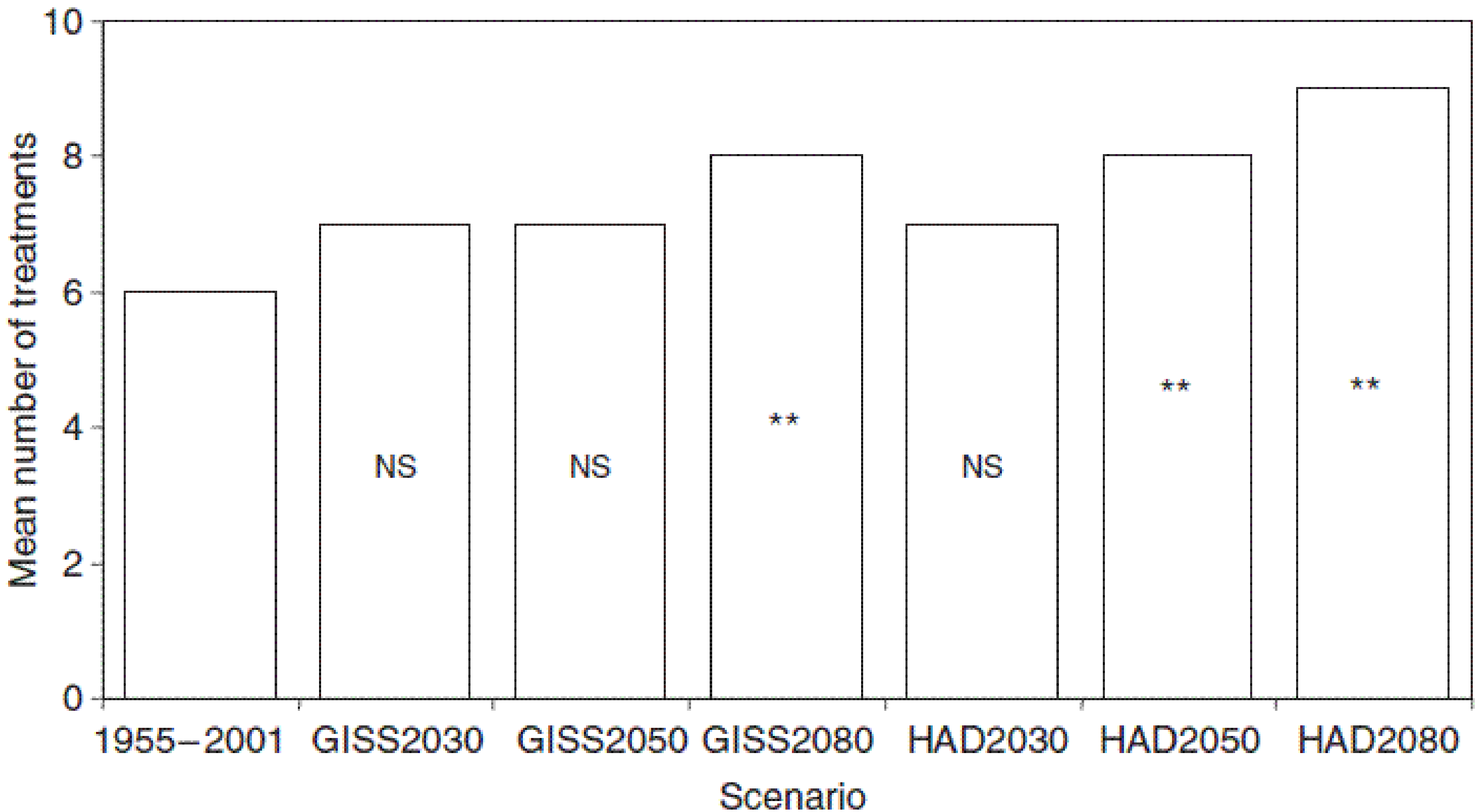
Coakley et al. (1999) ***Annual Review of Phytopathology***

Herbivores and pathogens

"Climate change tends to produce a mismatch between trees and their environment, which can increase their vulnerability''

Ayres & Lombardero (2000) ***Science of the Total Environment***

Climate change and grape downy mildew in Italy



From: Salinari et al. (2006) ***Global Change Biology***

Plant epidemiology

"Impact of climate change will be felt in three areas: in losses from plant diseases, in the efficacy of disease management strategies and in the geographical distribution of plant diseases"

Chakraborty et al. (2000)
Environmental Pollution

Symbiotic and antagonistic organisms

"It is probable that current disturbance patterns […] will be altered and that new problems will arise more frequently in future"

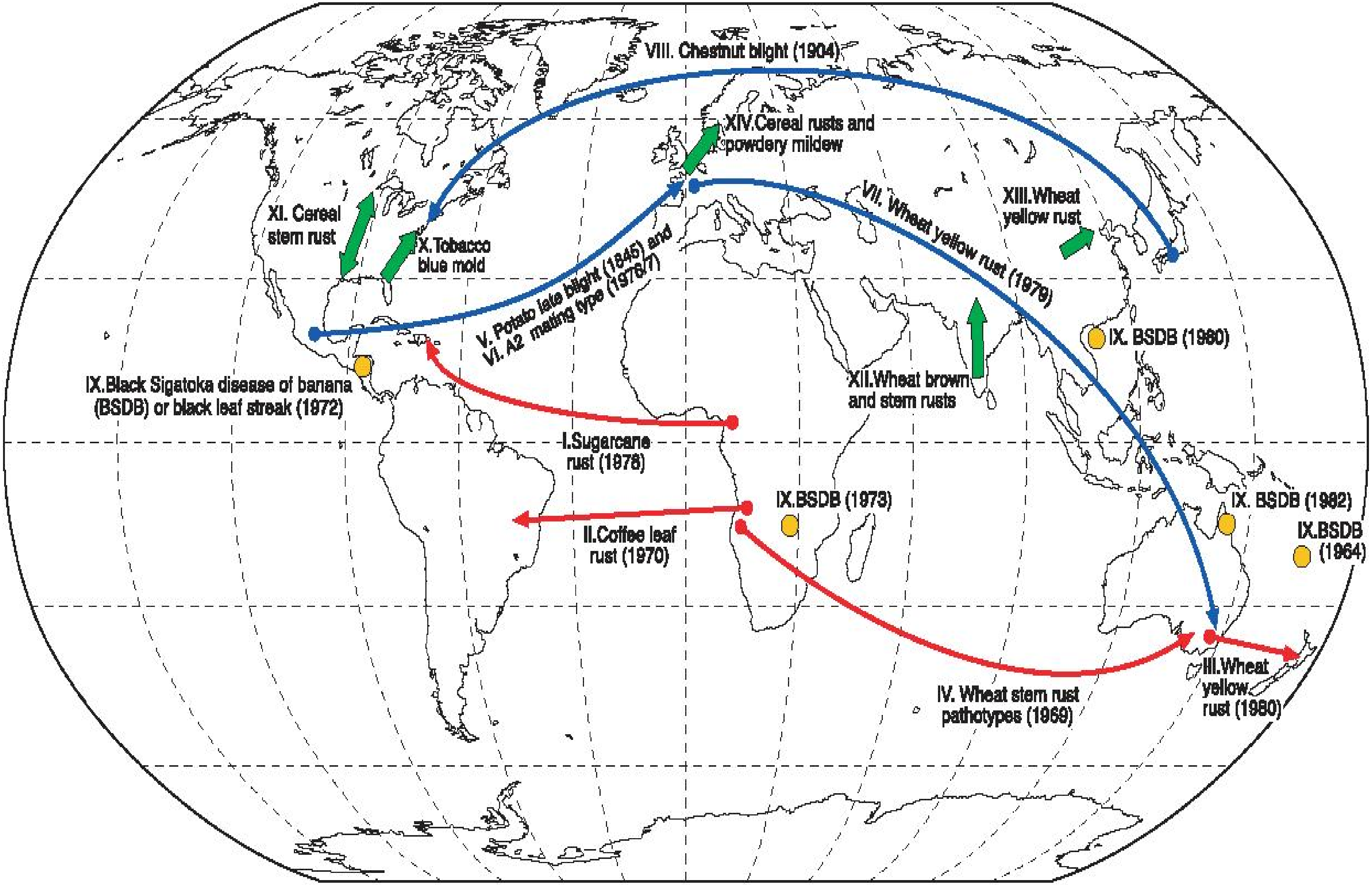
Marçais et al. (2000)
Revue Forestière Française

Plant health

"Climate change and air pollution may interact with and sometimes exacerbate the dynamics of insect and disease outbreaks"

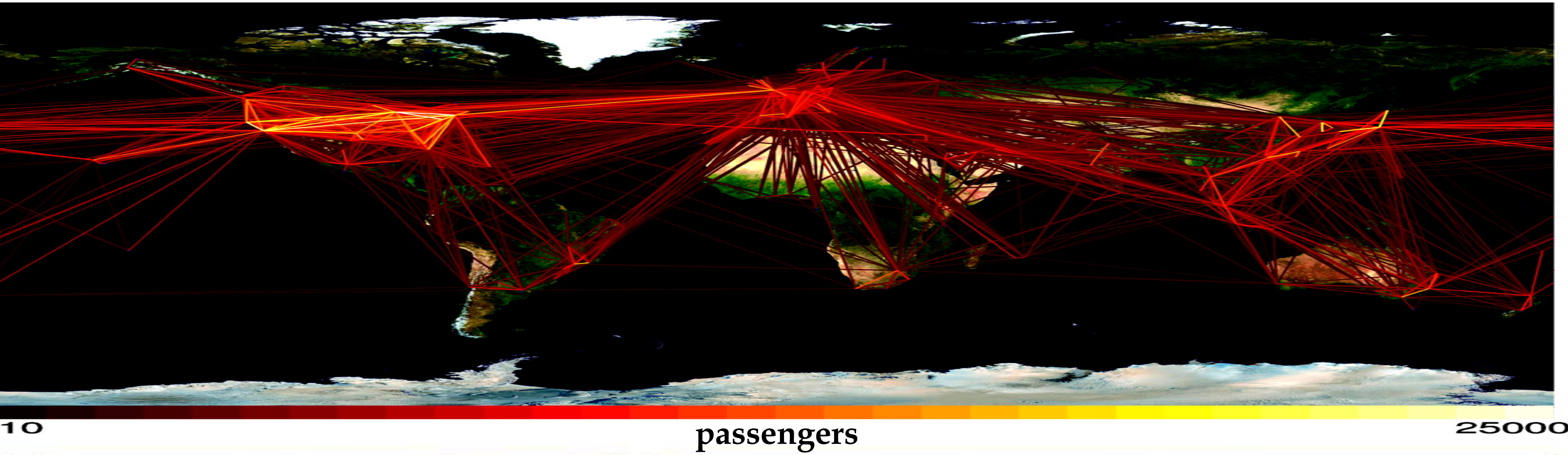
Mistretta (2002)
Journal of Forestry

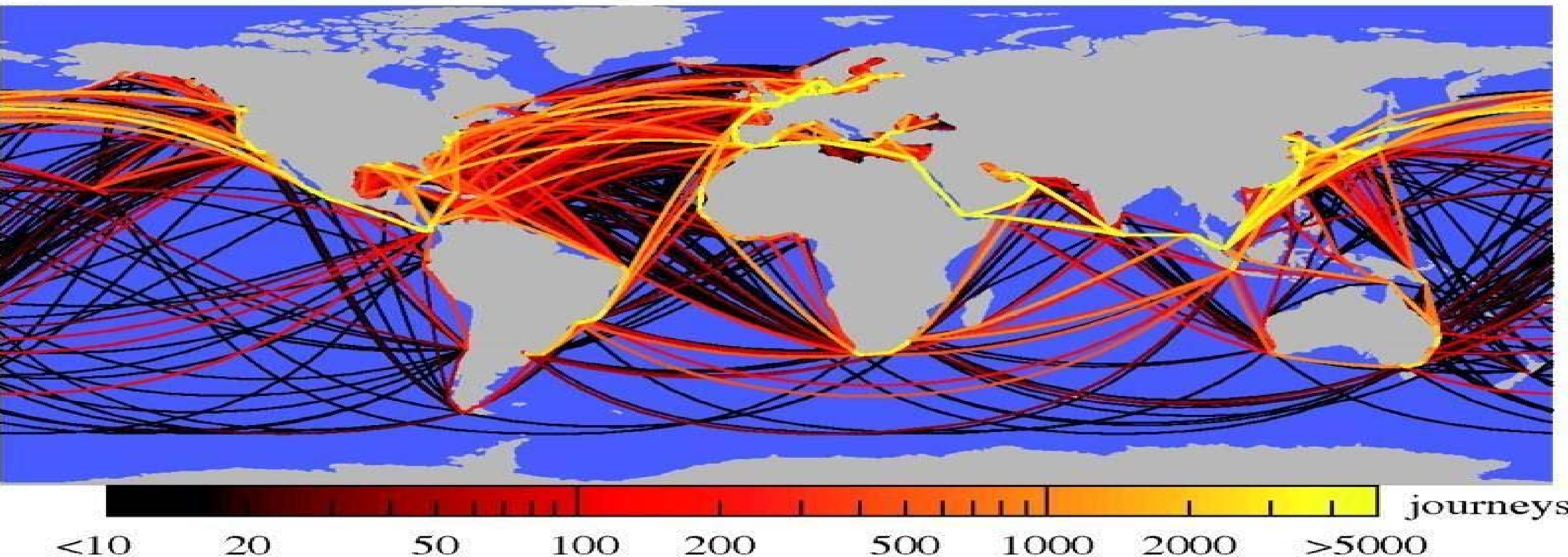
Examples of invasions of plant pathogens



From Brown & Hovmøller (2002) *Science*

Plant movements in a globalized world

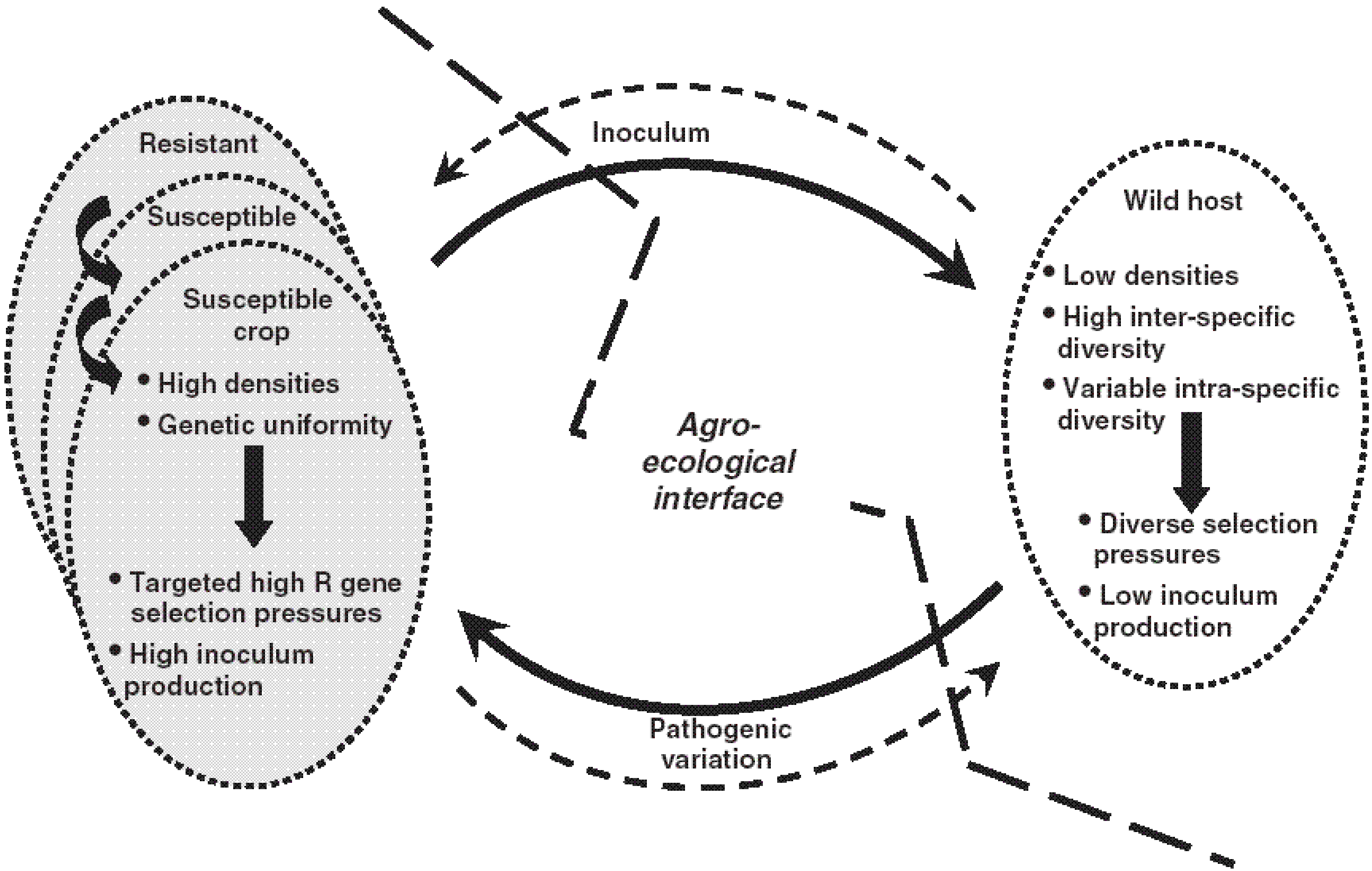




From: Hufnagel et al. (2005) *PNAS* (air) & Kaluza et al. (2010) *Interface* (sea)

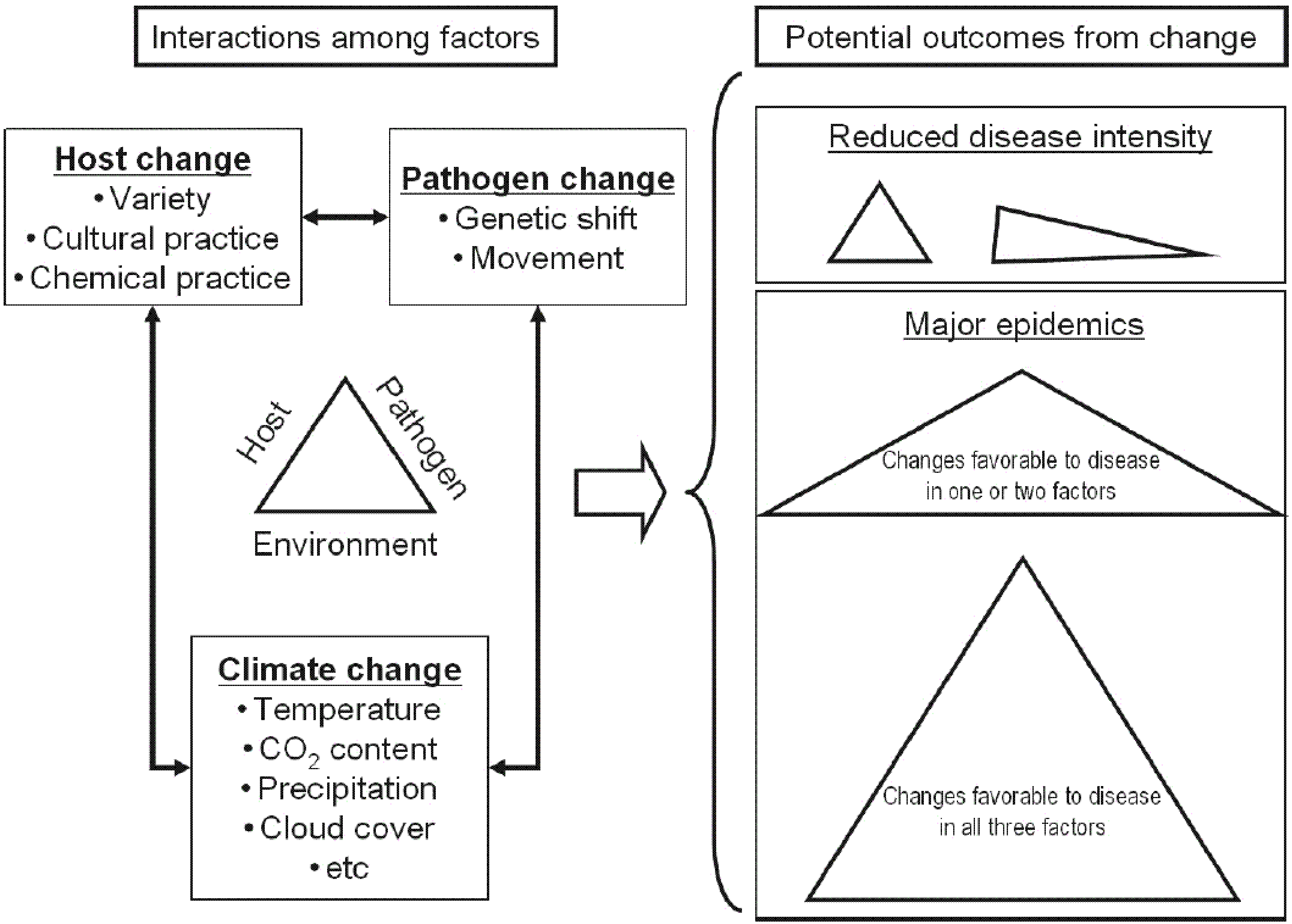
CO2, ozone and temperature	**Ecological impacts of CO2 enrichment**	**Insect outbreaks in North America**
"A major effect of climate warming in the temperate zone could be a change in winter survival of insect pests"	There is a need for "much more realistic experimental conditions and larger-scale test units, which permit biotic interactions across taxa and trophic levels to occur while simulating our CO2 future"	"Climate change and air pollution may interact with and sometimes exacerbate the dynamics of insect and disease outbreaks"
Fuhrer (2003) *Agriculture, Ecosystems & Environment*	**Körner (2003)** *Philosophical Transactions of the Royal Society London A*	**Logan et al. (2003)** *Frontiers in the Ecology and the Environment*

Pathogen evolution in agro-ecosystems



Burdon & Thrall (2008) ***Evolutionary Applications***

Climate change and the disease triangle



Garrett et al. (2009) In: ***Climate Change: Observed Impacts on Planet Earth***

Emerging plant diseases

“The underlying cause of most emerging plant diseases is the anthropogenic introduction of parasites, although severe weather events are also important”

Anderson et al. (2004) *Trends in Ecology & Evolution*

Model prediction

“The use of climate-change fingerprints has been limited because time series containing disease variables collected in a standardized manner are unavailable for most plant pathogens”

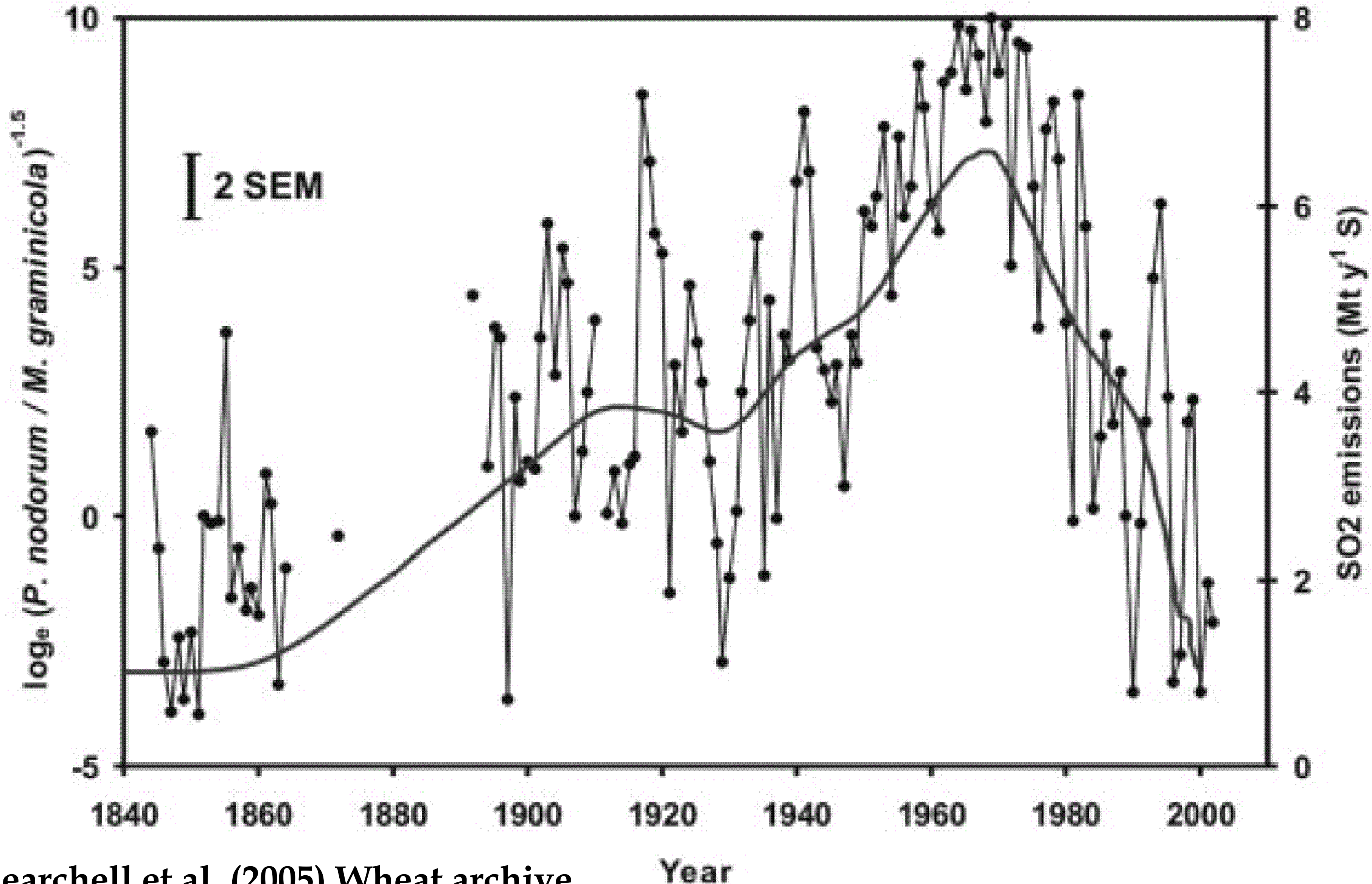
Scherm (2004) ***Canadian Journal of Plant Pathology***

Mitigation strategies

“Improving our understanding of how land use alters resistance or susceptibility to invasion and impacts of pollutants” is a key research need

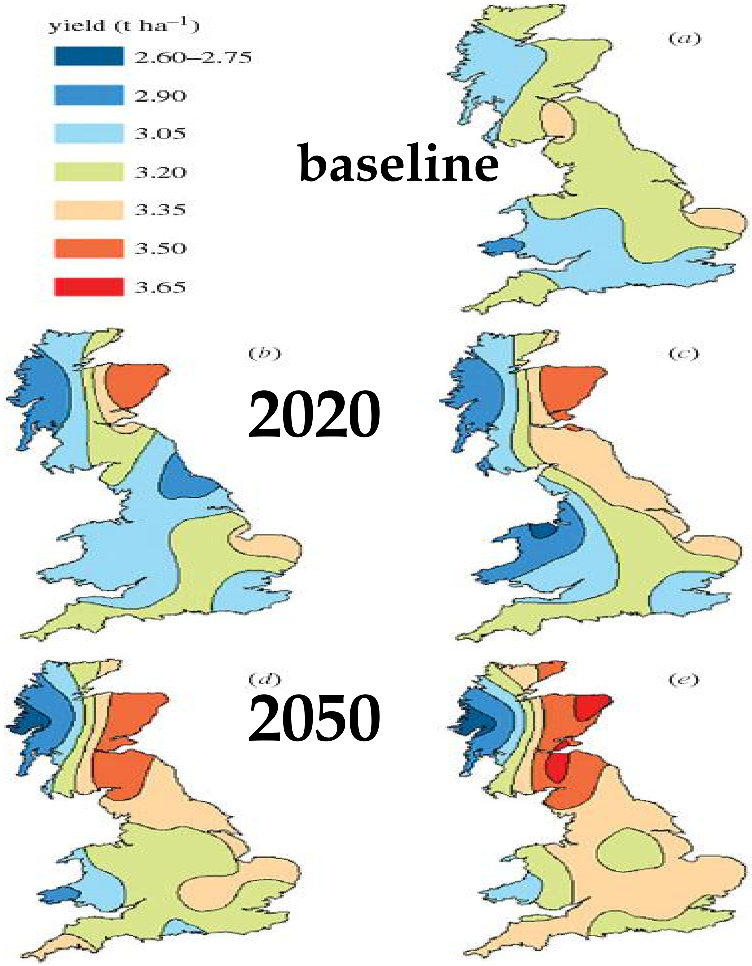
Dale et al. (2005) *Ecological Applications*

The importance of long-term datasets

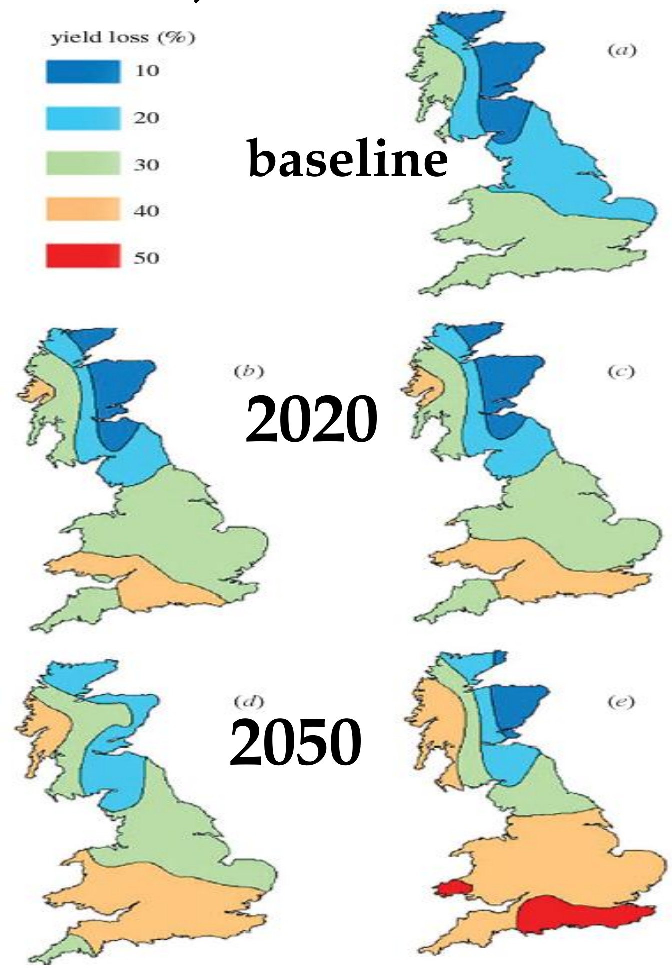


Bearchell et al. (2005) Wheat archive links long-term fungal pathogen population dynamics to air pollution. ***PNAS***

Predicted climate change effects on phoma stem canker (*Leptosphaeria maculans*) on oilseed rape



Yield



Yield loss

From Butterworth et al. (2010) ***Journal of the Royal Society Interface***

Disease in plant communities

Enhanced dispersal and climate change will increase the impacts of pathogens on plant community structure and on ecosystem function

Burdon et al. (2006)
Annual Review of Phytopathology

Agriculture and forestry in Switzerland

"Long-term adaptive strategies in agriculture and silviculture, investments for prevention, and new insurance concepts seem necessary"

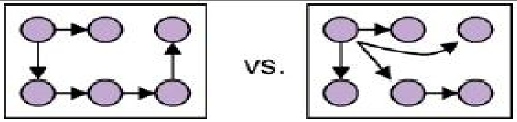
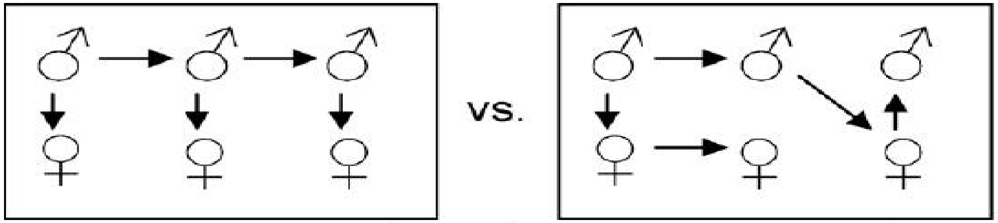
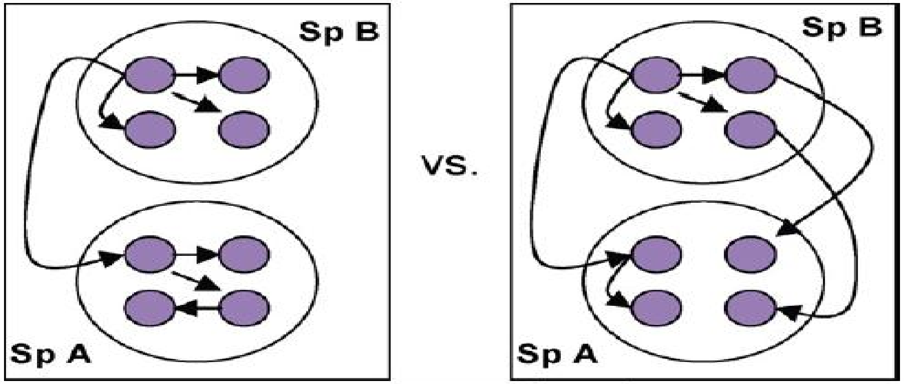
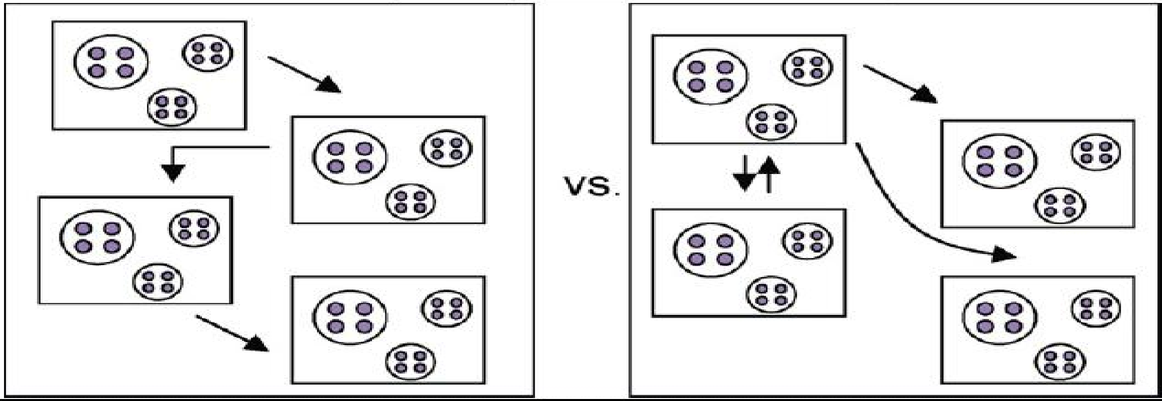
Fuhrer et al. (2006)
Climatic Change

Genomes to ecosystems

There is a "challenge in the scaling up from individual infection probabilities to epidemics and broader impacts"

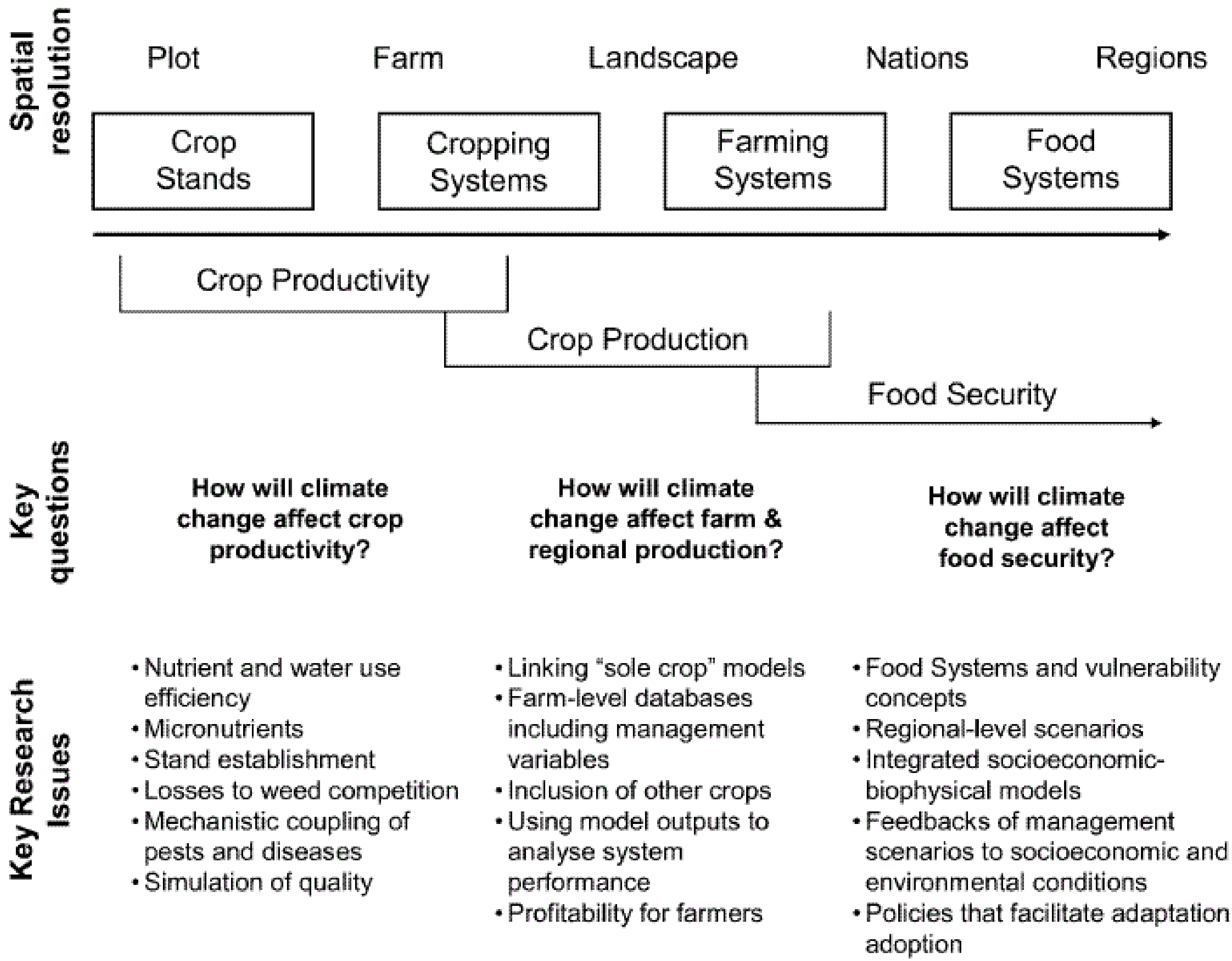
Garrett et al. (2006)
Annual Review of Phytopathology

Questions addressed in (plant) epidemiology

Scale of analysis	Questions	Examples
Between individual hosts	Who infects whom? Which individuals contribute most to transmission? Are there heterogeneities in transmission?	
Between groups of individuals (e.g. sex or age classes)	Are there sex biases in transmission? Are certain age classes more important for disease spread?	
Between host populations or species	What is the relative rate of within- versus between-species transmission? Which populations act as sources or sinks of infection? Which populations or species are reservoirs of infection?	
Between geographic locations[a]	What are the geographic pathways of transmission? Where do new diseases originate?	

From Archie et al. (2008) *Trends in Ecology & Evolution*

Spatial scale, agriculture, and climate change



From Ingram et al. (2008) ***Agriculture, Ecosystems & Environment***

Increase of [CO_2] and phenology

"The increase in atmospheric [CO_2] is a key driver of changes in temperature and precipitation, but could also alter phenology directly."

Cleland et al. (2007)
Trends Ecology & Evolution

Insurance hypothesis

"Heterogeneous […] communities could insure against climate-change related pressures"

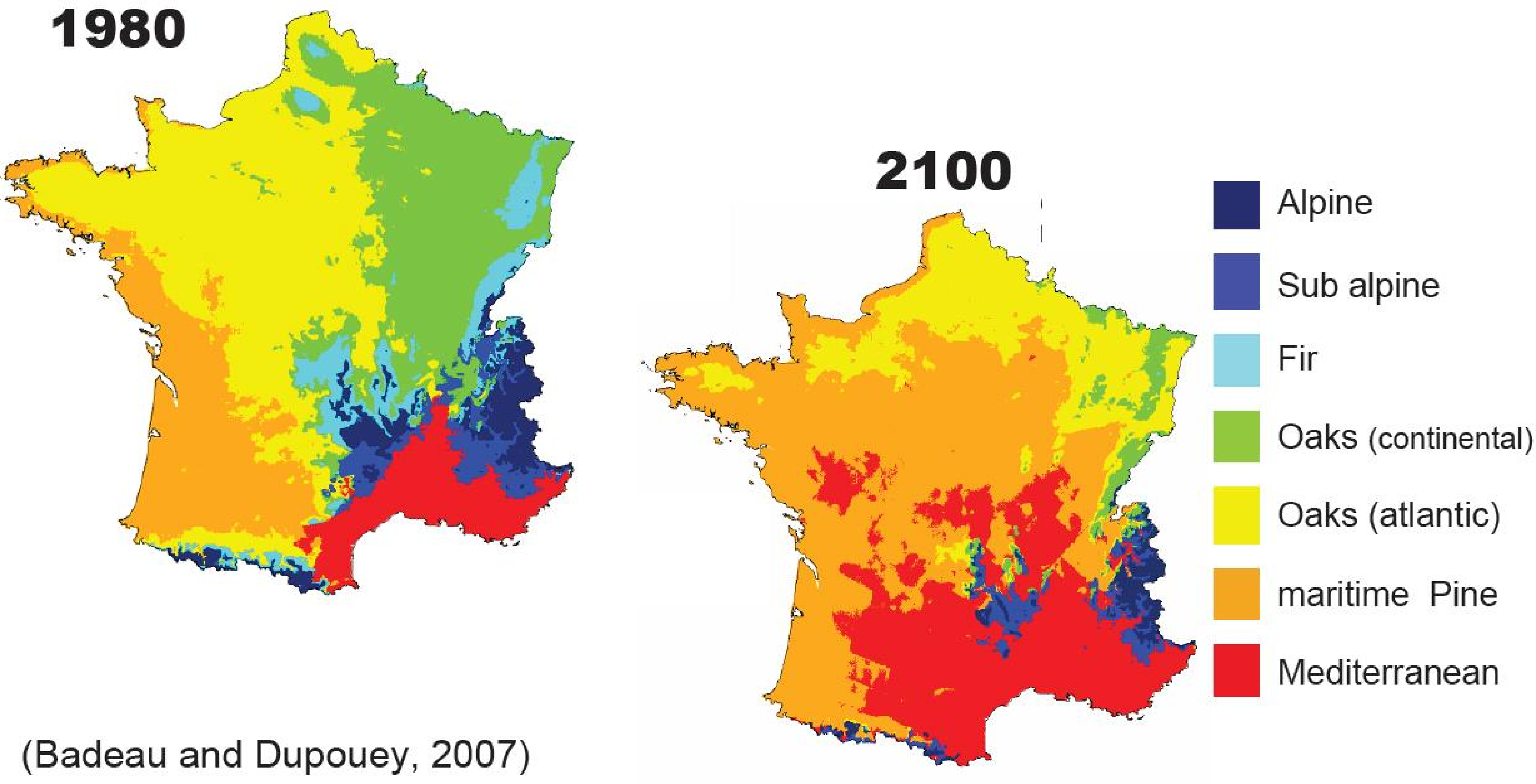
Bodin & Wiman (2007)
Forest Ecology & Management

Plant distribution shifts

"The changes in climatic conditions [will] result in altered population dynamics of native species and, thus, [in shifts of] their geographic ranges"

Walther et al. (2009)
Trends Ecology & Evolution

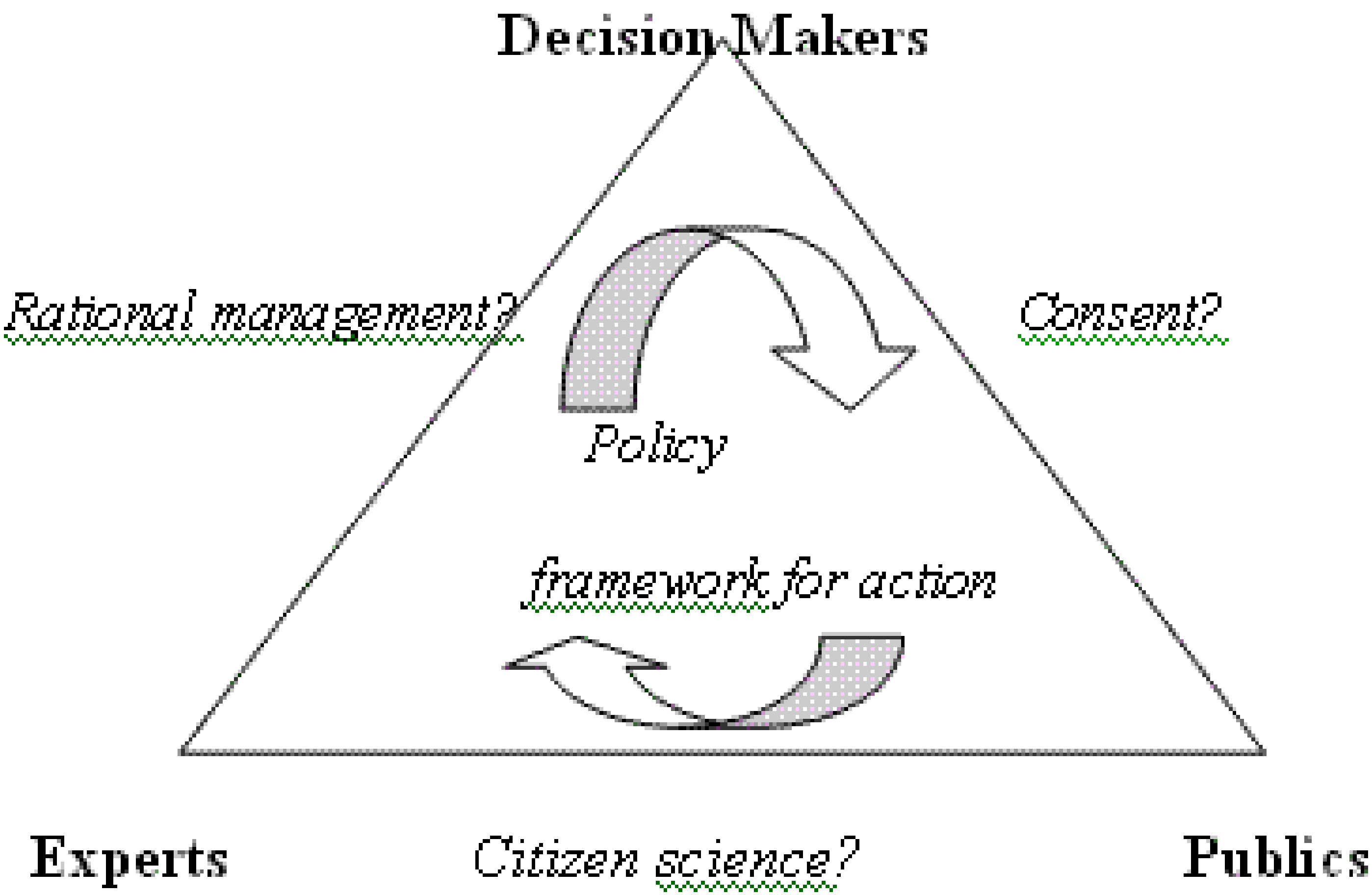
Climate change and plant distribution shifts



From: Denis Loustau (2006) Climate change impacts on extensively managed forest: a modelling approach, *Wilton Park Conference*

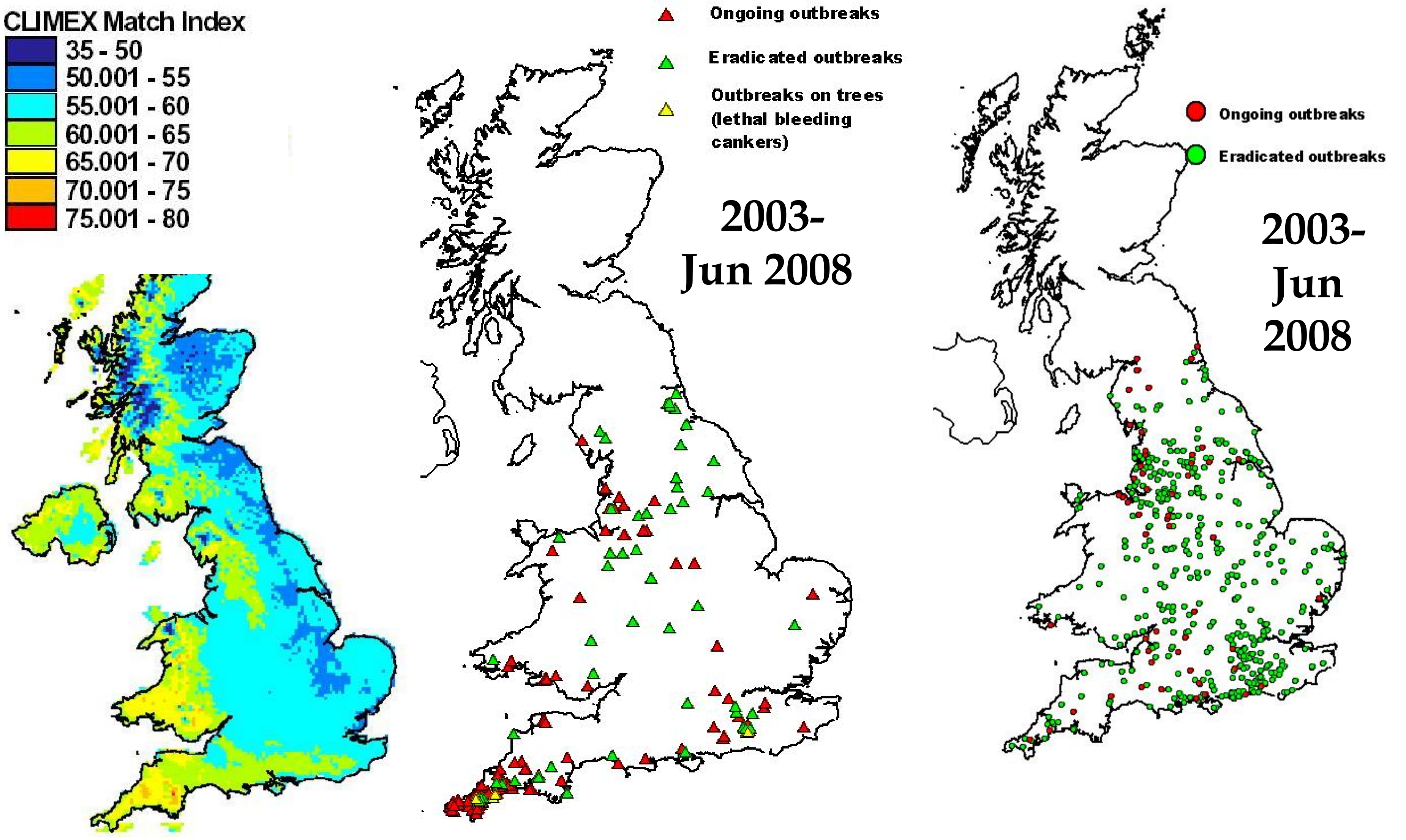
Simulations	Sustainability and global change	Management strategies
''The predicted warming would be favourable to most of the studied species, especially those for which winter survival is a limiting factor linked to low temperatures''	''Some specific pollutant problems remain and will intensify; climate change has become an environmental issue of overwhelming importance''	The overall utility of the management strategies [in the presence of climate change should be] compared under the priority settings of different stakeholder groups''
Desprez-Loustau et al. (2007) ***Canadian Journal of Plant Pathology***	**Freer-Smith (2007)** ***Journal of Sustainable Forestry***	**Furstenau et al. (2007)** ***European Journal of Forest Research***

Climate change and stakeholder engagement



MacLeod et al. (2010) ***Food Security***

Phytophthora ramorum in England & Wales (2003-2006)

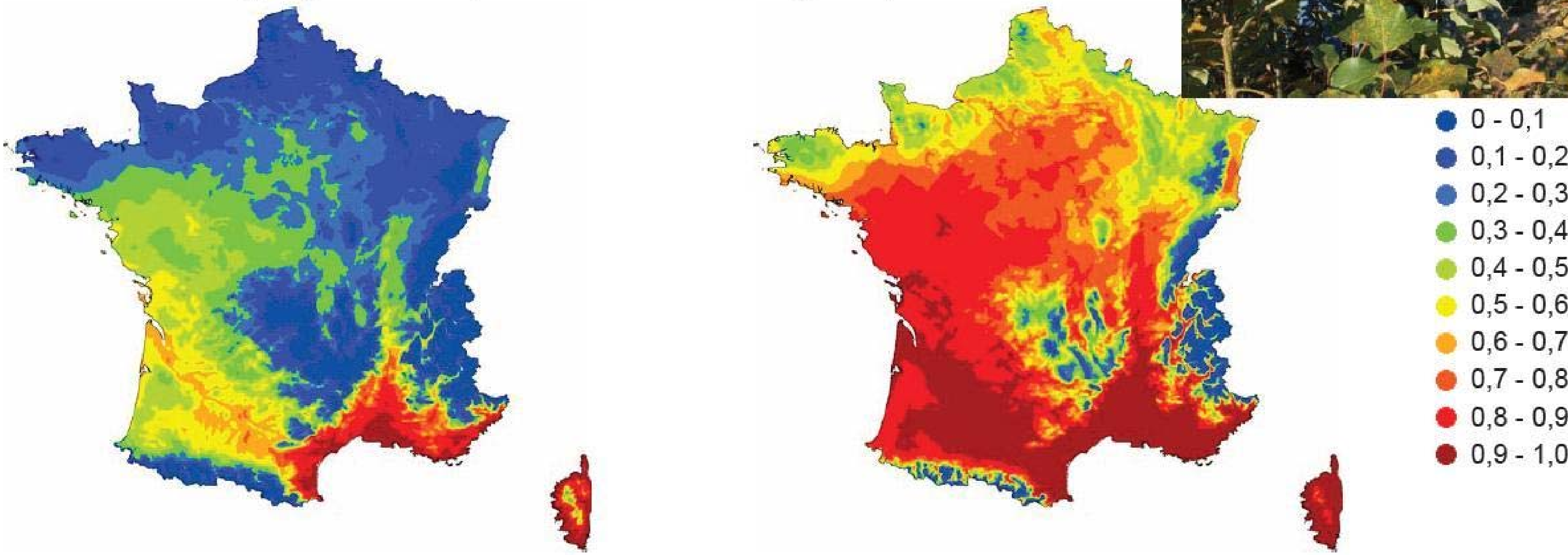


Climatic match courtesy of Richard Baker, CSL, UK

Outbreak maps courtesy of David Slawson, PHSI, DEFRA, UK

Climate change effects on tree pathogens: simulations

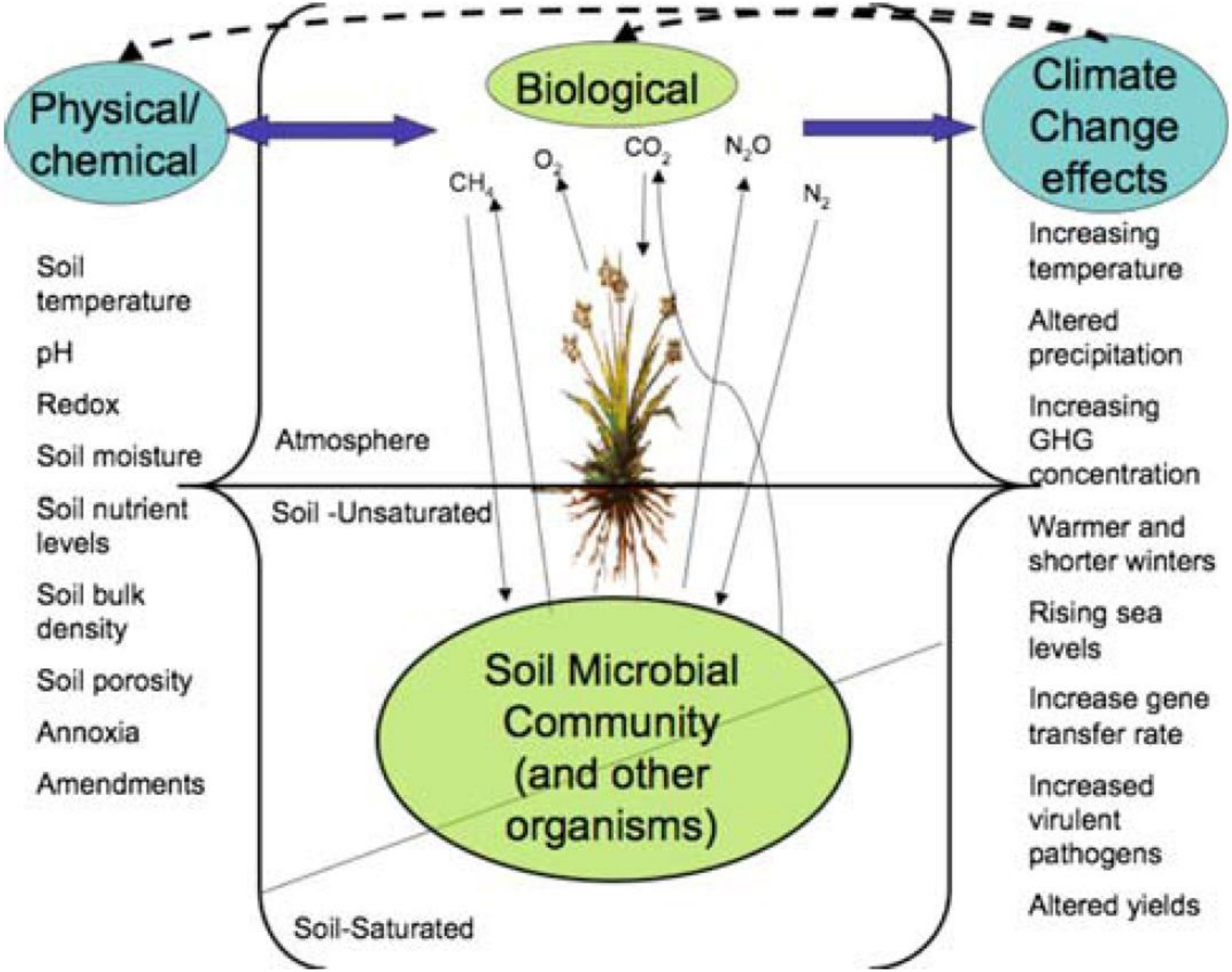
M. allii-populina (leaf rust on Poplar)



1969-1998 2069-2098

Denis Loustau (2006) Climate change impacts on extensively managed forest: a modelling approach, Wilton Park Conference

Climate change, soil microbes and plant health



French et al. (2009) *World Journal of Microbiology and Biotechnology*

Biosecurity	**Sustainability**	**Adaptive management**
"There is a broad consensus that biosecurity problems are getting worse owing to globalization, and specifically owing to growing trade, travel, transportation and tourism, the 'four Ts' "	"Disease management […] has to rely on an anticipatory and preventive approach, based on risk analysis"	"We encourage flexible approaches that promote reversible and incremental steps, and that favour ongoing learning and capacity to modify direction as situations change"
Waage & Mumford (2008) ***Philosophical Transactions of the Royal Society***	**Loustau et al. (2007) In:** ***Forestry and Climate Change***	**Millar et al. (2007)** ***Ecological Applications***

Invasive fungal pathogens are a subset of invasive fungal species

Table 1. Representation of fungi in available databases of alien (invasive) species[a]

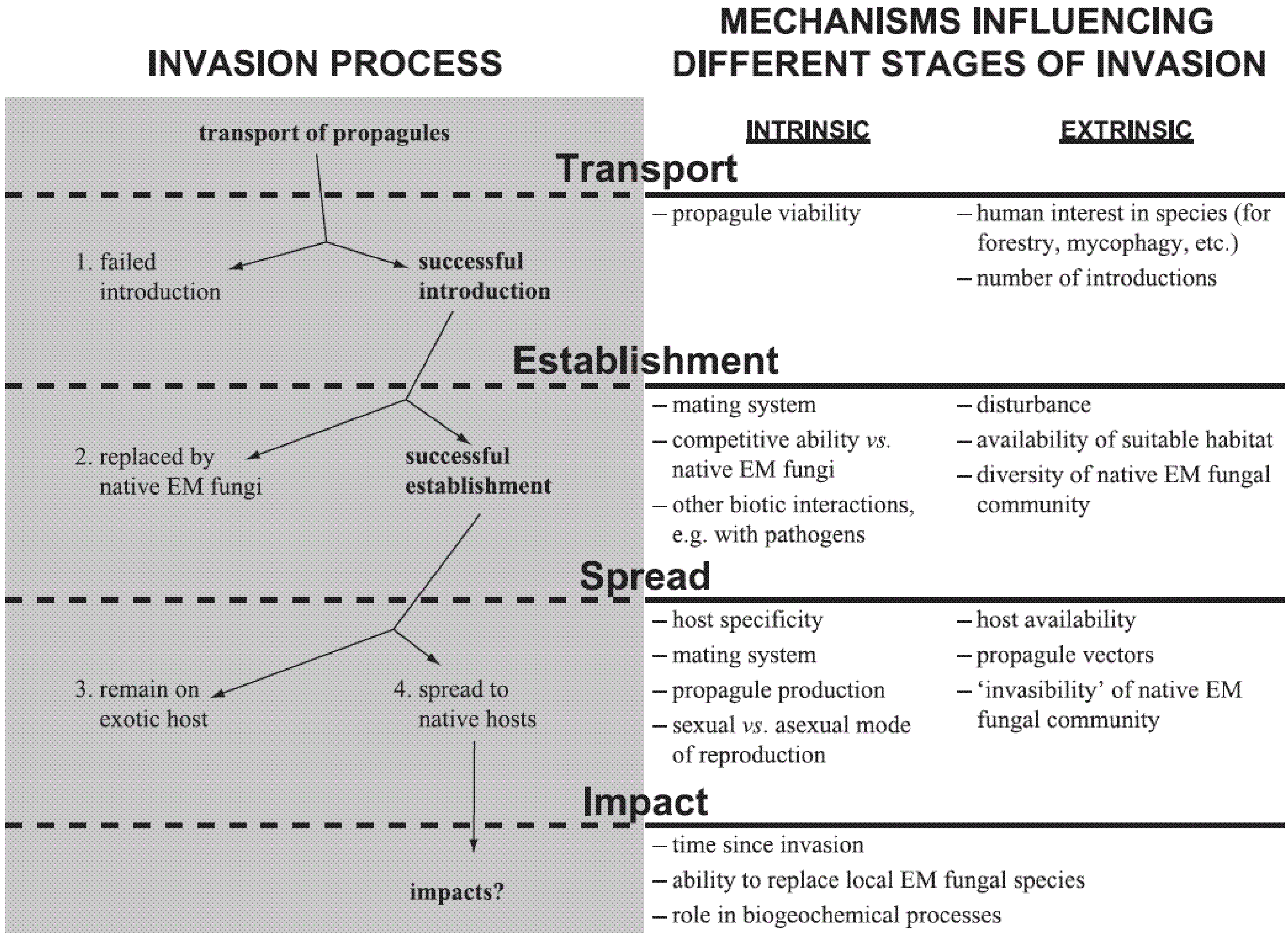
Region	List	Fungi	Vascular plants	Vertebrates	Insects	Others	Total	Source
Austria	Neobiota (invasive)	83 (6)	1110 (17)	>500 Animalia (6)		11	1704 (29)	[84]
England	Non-native species	198	1854	109	339	222	2722	[85]
India	Invasive species (in progress)	5	40	59			104	http://www.ncbi.org.in/invasive/search/index.html
Latvia	Alien species	7	629	44	99 (invertebrates)	2	781	http://lv.invasive.info/
Lithuania	Invasive species	98	520	26	8	17	669	http://www.ku.lt/lisd/
Nordic–Baltic Europe	Alien species	98	3321	442	1245	397	5503	http://sns.dk/nobanis/
Poland	Alien species	81	282	78	38	132	611	http://www.iop.krakow.pl/ias/
Switzerland	Alien species (invasive)	?[b] (6)	362 (48)	40 (20)	311 (16)	87 (17)	800 (107)	[86]
USA	Invasive species	38	427	11	160	44	680	http://www.invasive.org
World	Global invasive species (worst)	9 (5)	142 (35)	73 (30)	42 (14)	53 (16)	319 (100)	http://www.issg.org/database/welcome/

[a]When fungi are included; several other databases without fungi.

[b]Only alien species threatening biodiversity were listed for fungi. It was considered impossible to list all neomycetes.

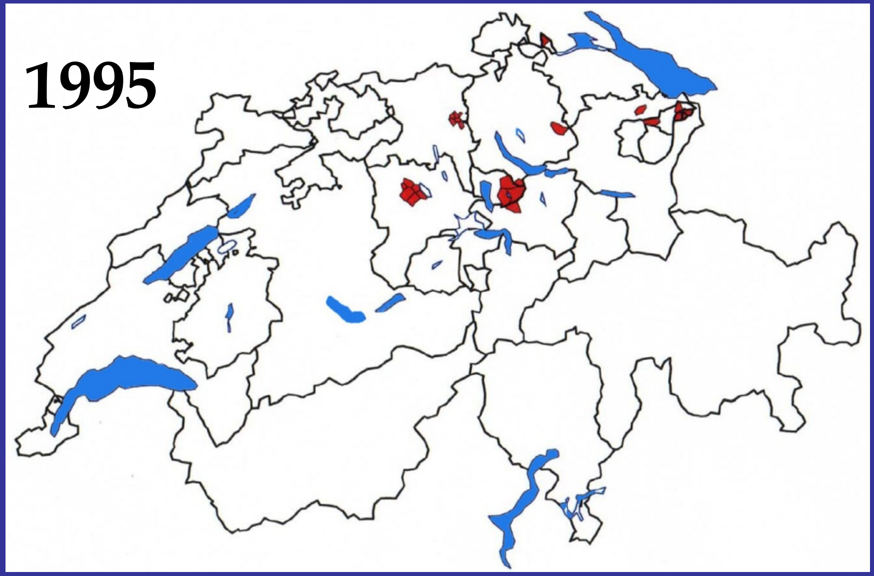
From Desprez-Loustau et al. (2007) ***Trends in Ecology & Evolution***

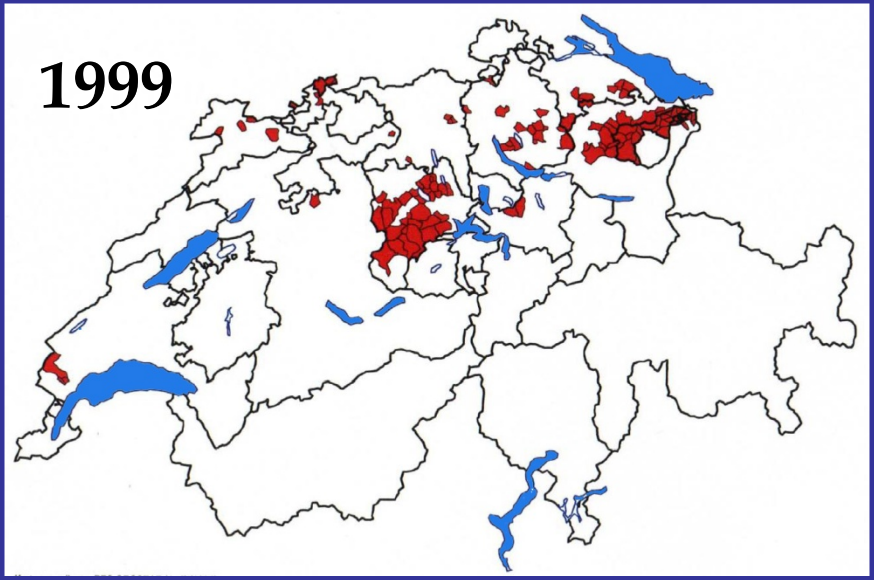
Invasion biology of ectomycorrhizal species

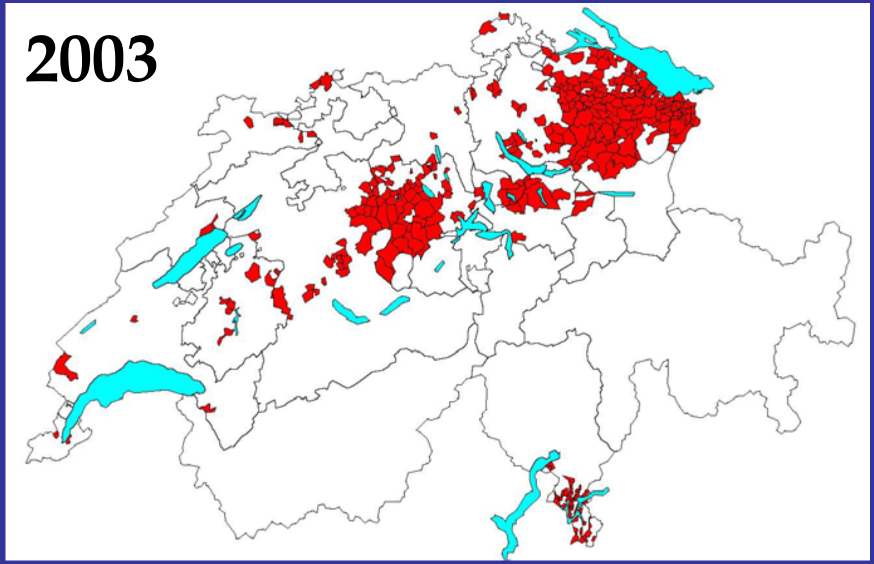


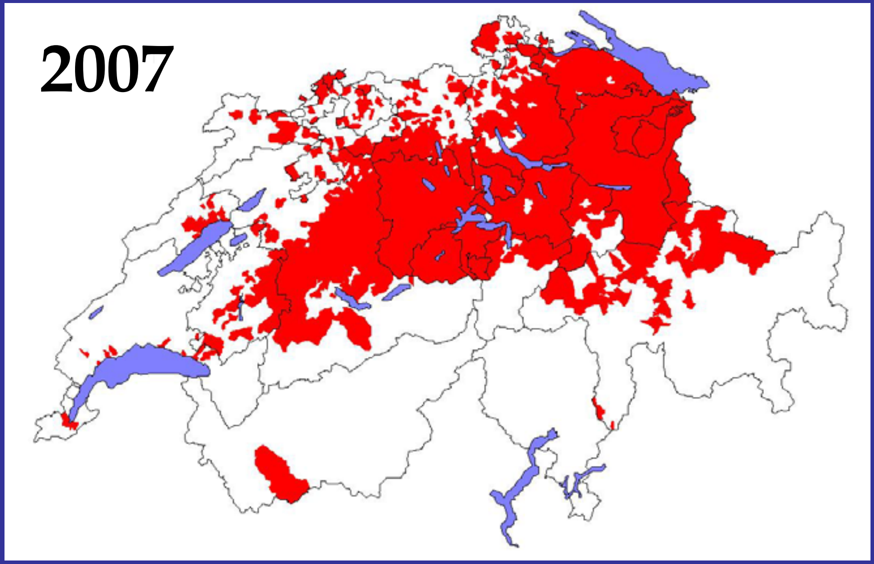
From Vellinga et al. (2009) *New Phytologist*

Fire blight epidemic development in Switzerland





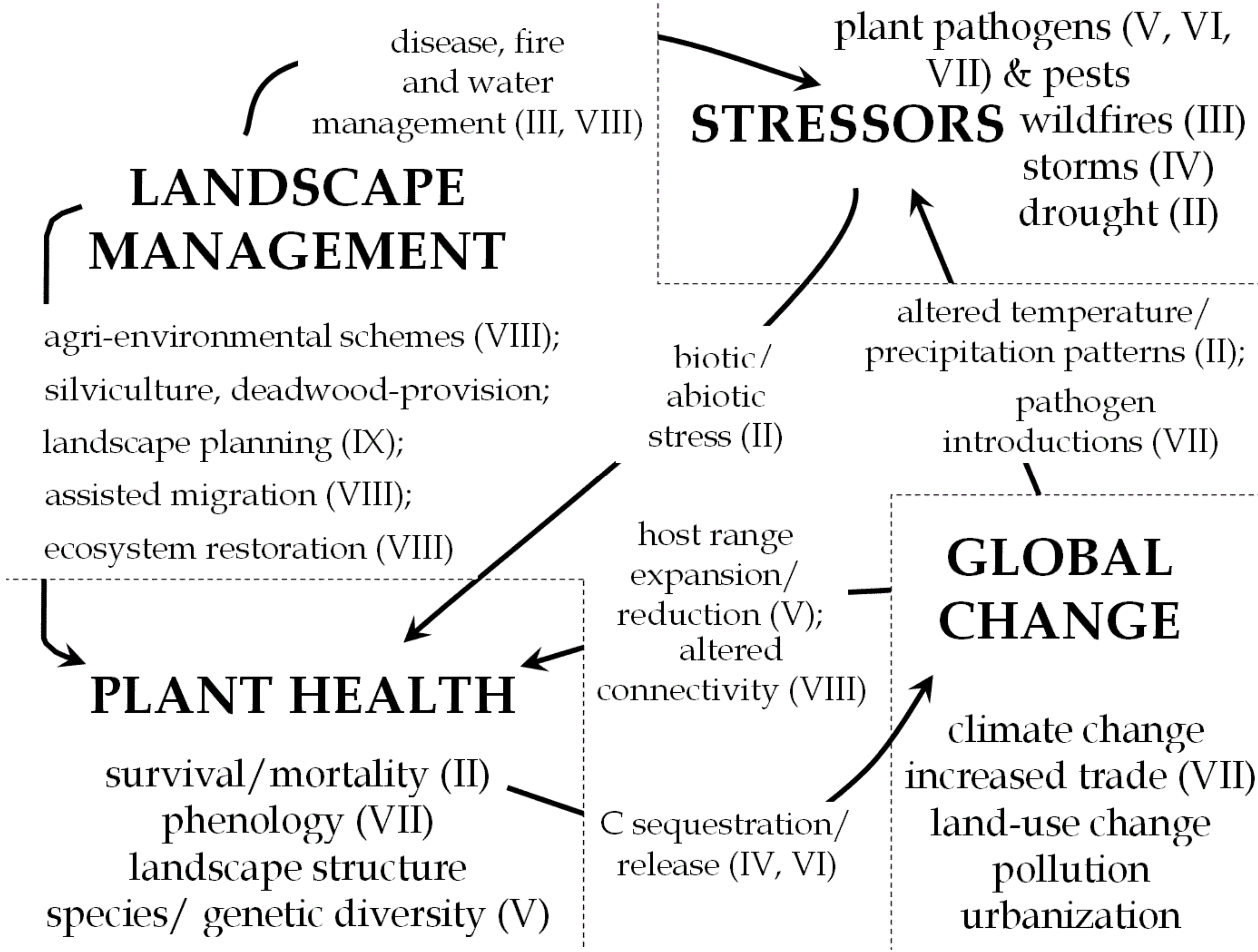




From: Holdenrieder et al. (2008) ICPP, Turin, Italy

Long-term data sets	**Plant pathogens in Europe**	**Interspecific interactions**
There is a need for "more awareness of investigations relating to climate change and diseases of plants, animals and humans in the three scientific communities"	"Pathogens with evolutionary potential for greater damage should be identified to estimate the magnitude of the threat and to prepare for changing conditions"	"The greatest single challenge will be to determine how biotic and abiotic context alters the direction and magnitude of global change effects on biotic interactions"
Jeger & Pautasso (2008) *New Phytologist*	**La Porta et al. (2008)** *Canadian Journal of Forest Research*	**Tylianakis et al. (2008)** *Ecology Letters*

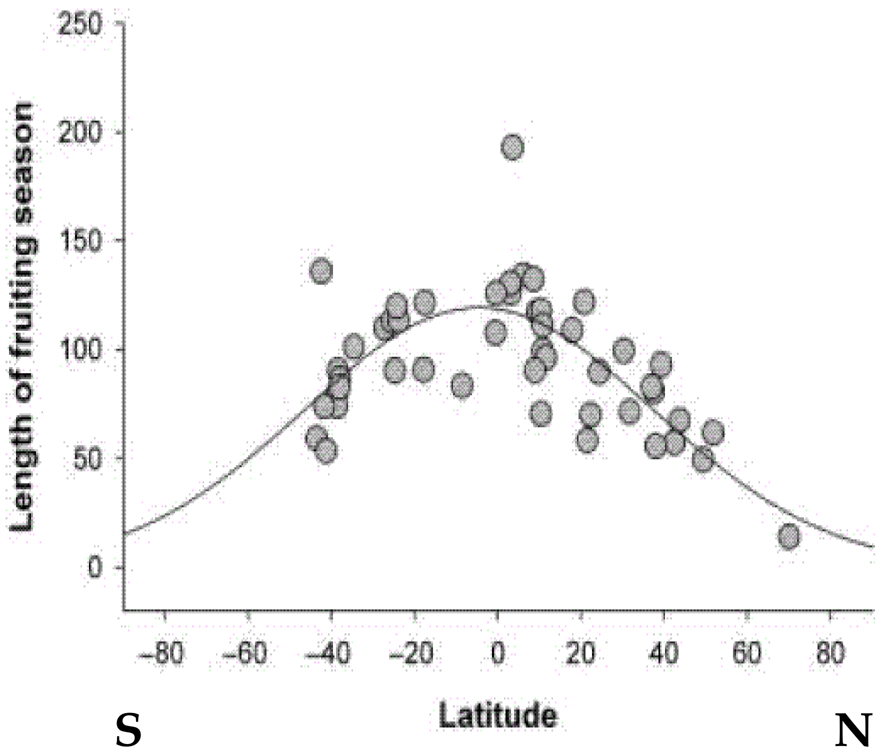
Plant Health, Global Change and Landscape Management

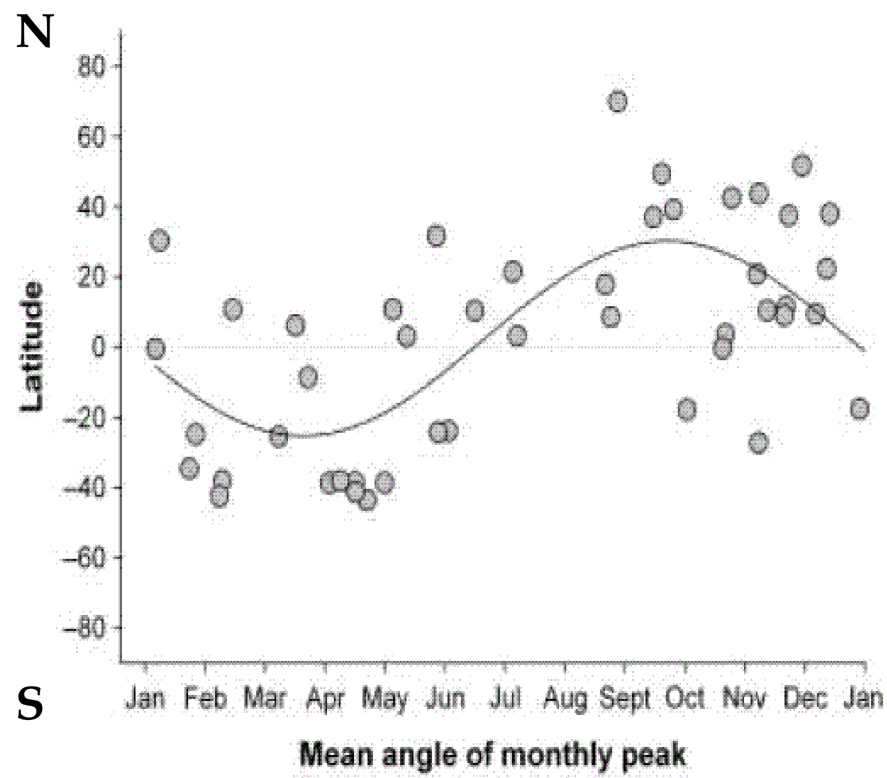


Pautasso et al. (2010) *Biological Reviews*

Preparing for changes in plant diseases	Climate change, plant pathogens and food security	Plant disease control and climate change mitigation
"One fairly secure prediction is that climate change will increase the rate at which unpleasant surprises appear"	"The ability to include realistic impacts of pests and diseases in future climates has a direct link to considerations of food security"	''There are also benefits from controlling plant diseases in terms of decreased GHG per tonne of crop produced''
Shaw (2009) ***Plant Protection Science***	**Gregory et al. (2009)** ***Journal of Experimental Botany***	**Mahmuti et al. (2009)** ***International Journal of Agricultural Sustainability***

Global patterns in fruiting seasons (season length vs. peak)





From Ting et al. (2008) *Global Ecology & Biogeography*

Global production of eight major crops and estimated losses by crop and region (1988-90)

Crop	Actual Crop Production (billions of US$)	US$ (billions) Losses due to			
		Pathogens	Insects	Weeds	Total
Rice	106.4	33.0	45.4	34.2	112.5
Wheat	64.6	14.0	10.5	14.0	38.5
Barley	13.7	1.9	1.7	2.0	5.7
Maize	44.0	7.8	10.4	9.3	27.4
Potatoes	35.1	9.8	9.6	5.3	24.8
Soybeans	24.2	3.2	3.7	4.7	11.6
Cotton	25.7	4.3	6.3	4.9	15.5
Coffee	11.4	2.8	2.8	2.0	7.6
Region					
Africa	13.3	4.1	4.4	4.3	12.8
N. America	50.5	7.1	7.5	8.4	22.9
Latin America	30.7	7.1	7.6	7.0	21.7
Asia	162.9	43.8	57.6	43.8	145.2
Europe	42.6	5.8	6.1	4.9	16.8
Former Soviet Union	31.9	8.2	7.0	6.7	22.1
Oceania	3.3	0.8	0.6	0.5	1.9

Rosenzweig et al. (2001) *Global Change & Human Health*

Pathogen/pest crop damage due to extreme weather

Floods and heavy rains

- Increased moisture benefits epidemics and prevalence of leaf fungal pathogens.
  - Rice leaf blight caused great famine in Bengal (1942), 2 million people died.
  - Wheat stripe rust outbreak in major production regions of China contributed to the 1960s famine.
  - Fungal epidemics in corn, soybean, alfalfa, and wheat (U.S. Midwest, 1993).
  - Mycotoxin (produced by *Fusariun spp.*) reached a record high (U.S. Great Plains, 1993); mycotoxin increases are related to high humidity during harvest (East Africa and South America, 1990s).
  - Humid summers drive epidemics of gray leaf spot of maize (Iowa and Illinois, 1996).
- Water induced soil transport increases dissemination of soilborne pathogens to non-infected areas.
  - Outbreaks of soybean sudden death syndrome in the north central U.S. (1993).
- Continuous soil saturation causes long-term problems related to rot development and increased damage by pathogens.
  - In maize, crazy top and common smut

Drought

- Water stress diminishes plant vigor and alters C/N lowering plant resistance to nematodes, and insects.
  Attack by fungal pathogens of stems and roots are favored by weakened plant conditions.
  Dry and warm conditions promote growth of insect vector populations, increasing viral epidemics.
  - Outbreak of soybean cyst nematode correlated to drought conditions in north central U.S. (1990).
  - Summer locust outbreak correlated to drought in Mexico (1999).
  - Increased incidence of *Aspergillus flavus* (producer of aflatoxin) in southern U.S. (1977 and 1983).

Rosenzweig et al. (2001) ***Global Change & Human Health***

Potential benefits of global change for plant health?

Increase of both CO2 and temperature

"The predicted negative effects of CO2 elevation on herbivores are likely to be mitigated by temperature increase"

Zvereva & Kozlov (2006) ***Global Change Biology***

Plant disease risk

"Since invasive pathogens have the potential to exacerbate the effects of climate change, policies to reduce the spread of exotic pathogens will be important"

Garrett (2008) In: ***Global Climate Change and Extreme Weather Events***

Biological control

"There is practically no information on the impacts of climate change on plant disease biological control"

Ghini et al. (2008) ***Scientia Agricola***

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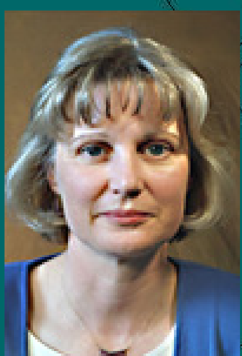

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Jennifer Parke, Oregon State Univ.

Some Implications for Landscape Management

(0) Reduce emissions of greenhouse gases;

(1) Reconsider what is alien and native in a changing climate;

(2) Consider assisted migration (but with risk assessment);

(3) Focus on rare, peripheral/endangered habitats;

(4) Enhance the diversity within ecosystems;

(5) Preserve genetic diversity as an insurance policy;

(6) Be flexible, so as to be able to learn from monitoring;

(7) Adjust protected area networks to evolving species distributions;

(8) Keep track of/alleviate local human impacts on pathosystems;

(9) Improve awareness of climate/global change;

(10) Use landscape management as a tool to sequester carbon.

modified from Pautasso et al. (2010) ***Biological Reviews***