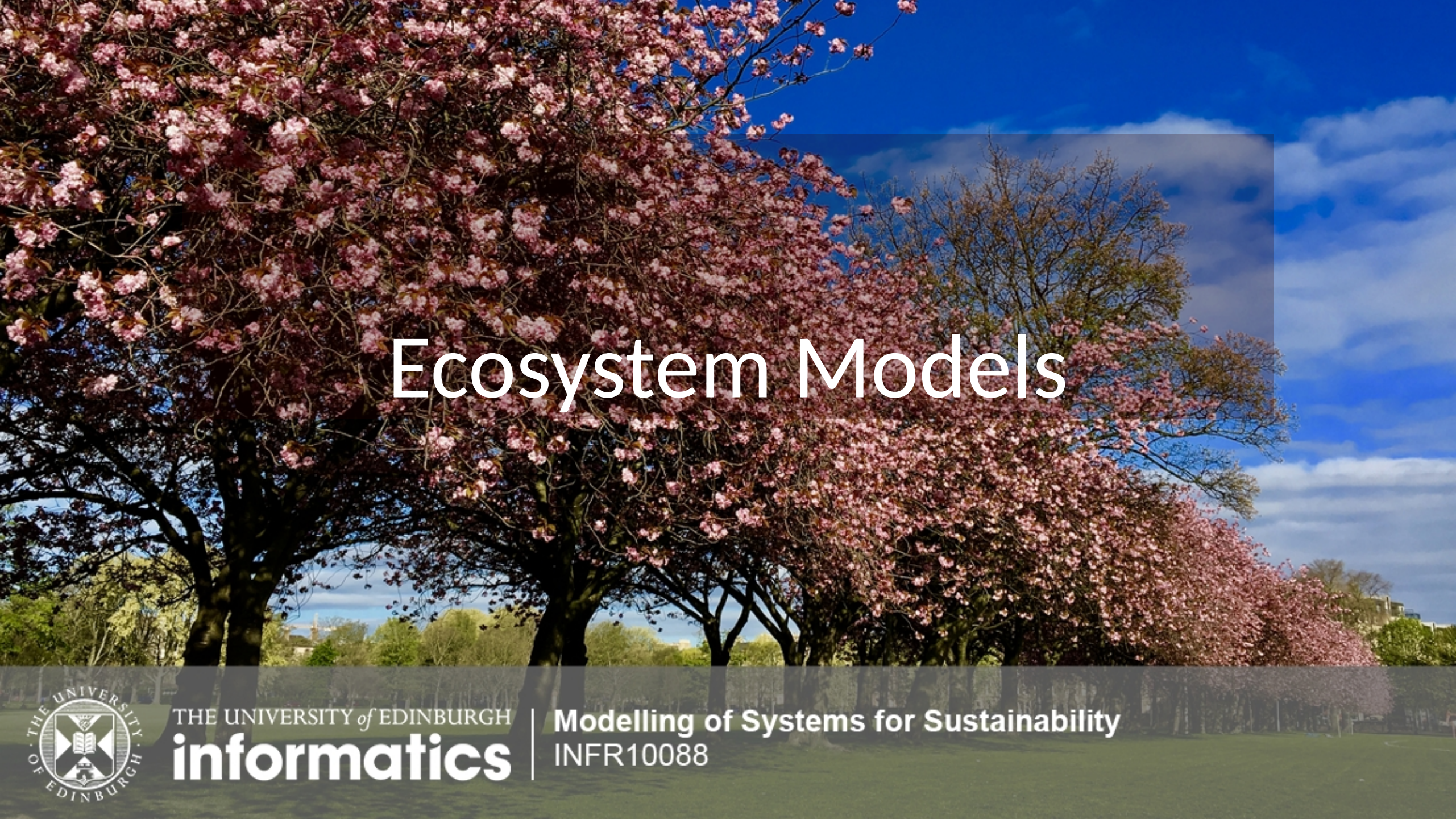


Ecosystem Models

THE UNIVERSITY of EDINBURGH
informatics

Modelling of Systems for Sustainability
INFR10088

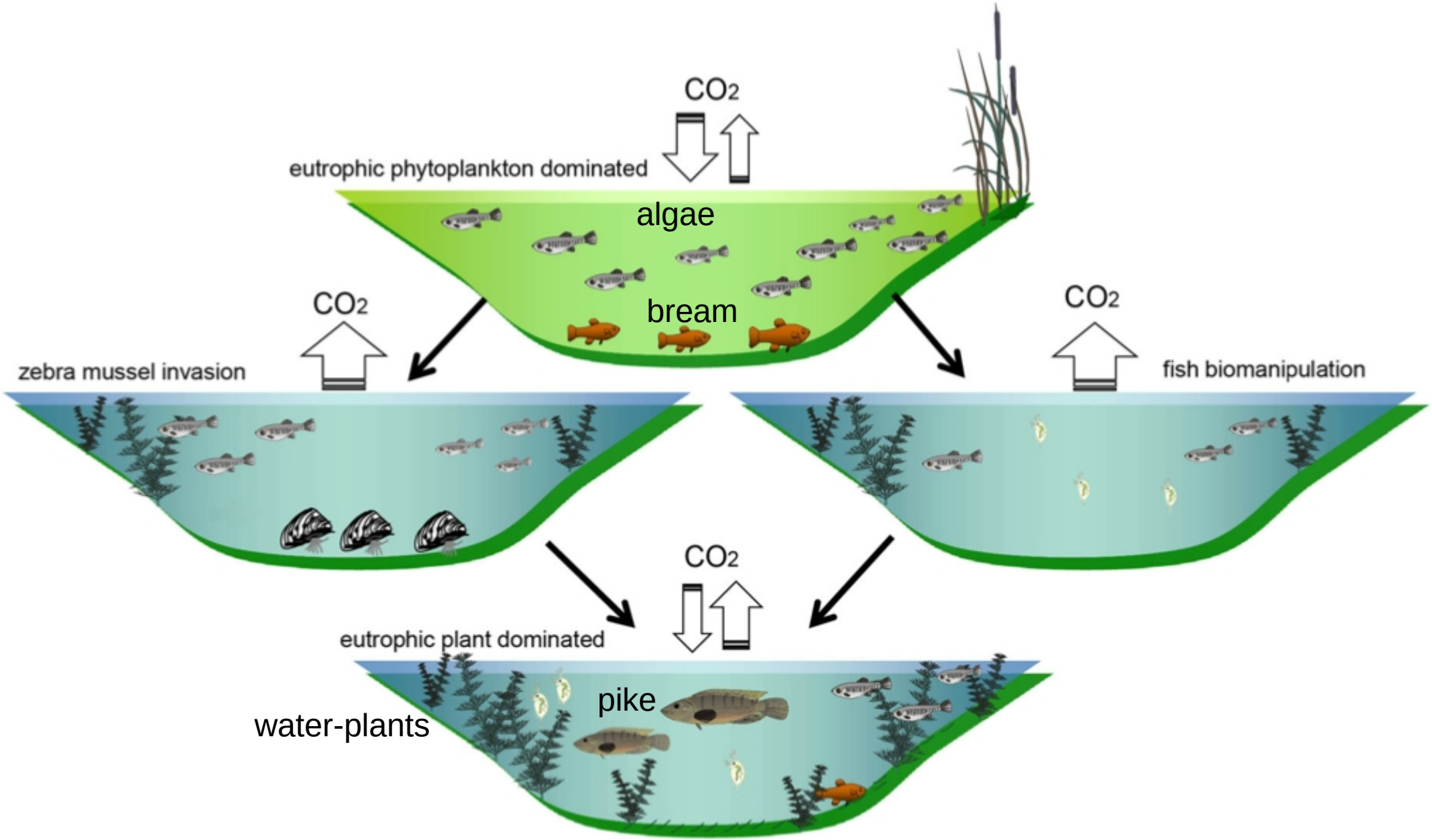
Outline

- Lake ecosystem model and tipping points
  - Stable states, regime shift
  - Phase diagrams revisited
  - Some other examples in ecosystems
  - Agent based, system dynamics and hybrid models
- If time, model of land use change in Mongolia

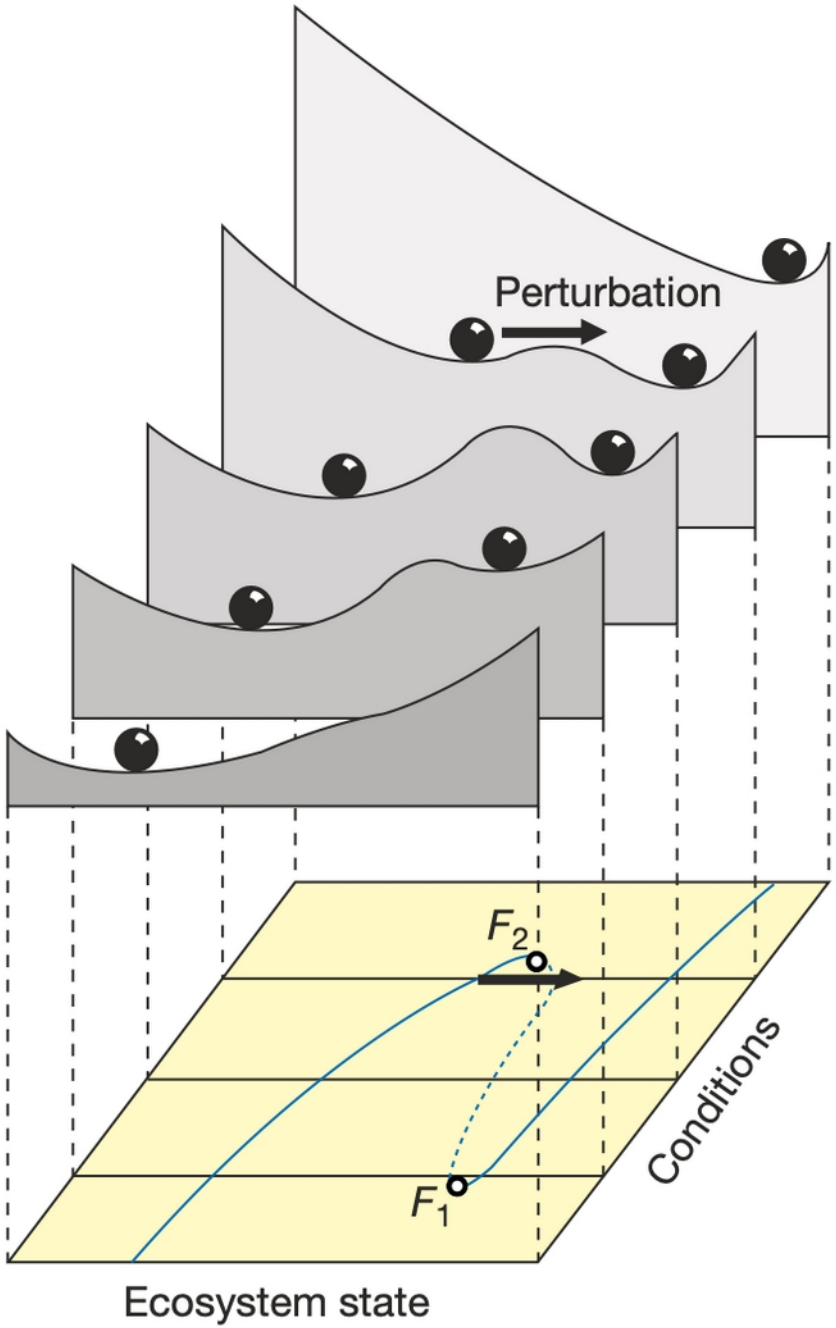
Clear and Turbid lakes

Photo: Stephen R. Carpenter

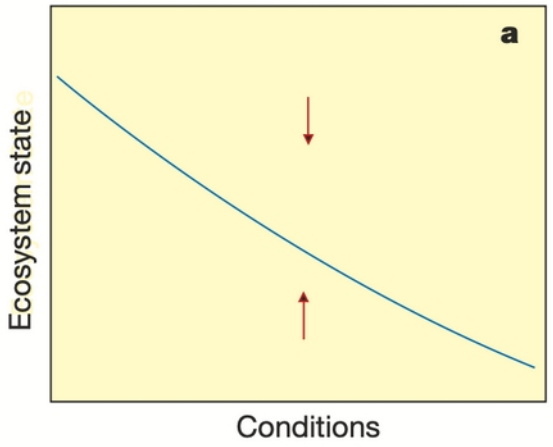
- Shallow lakes exist in one of two states:
  - Transparent water, high lake vegetation, low nutrients, diverse fish
  - Turbid water, low lake vegetation, high nutrients, algal blooms, bottom-feeding fish.
- Both states stable under the same environmental conditions.
- Adding lots of nutrients to a clear lake can cause switch to turbid
- Reducing nutrients a lot can cause switch from turbid to clear
- Example of a tipping point / bifurcation / phase change

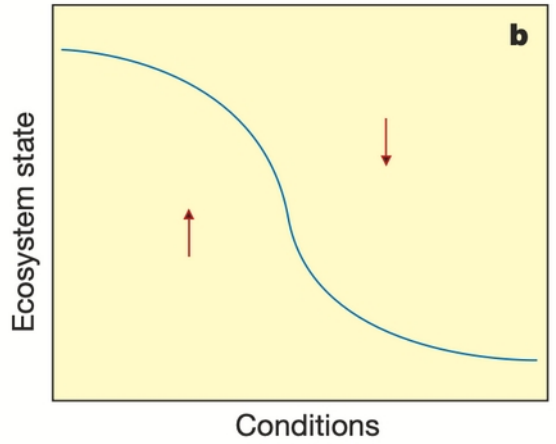


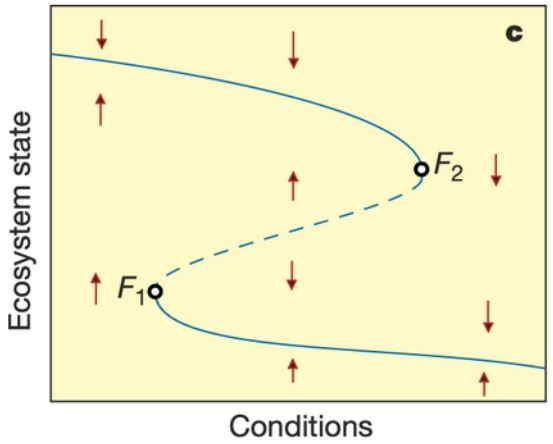
Graphic from Jeppeson *et al*, *Hydrobiologica*, 2016

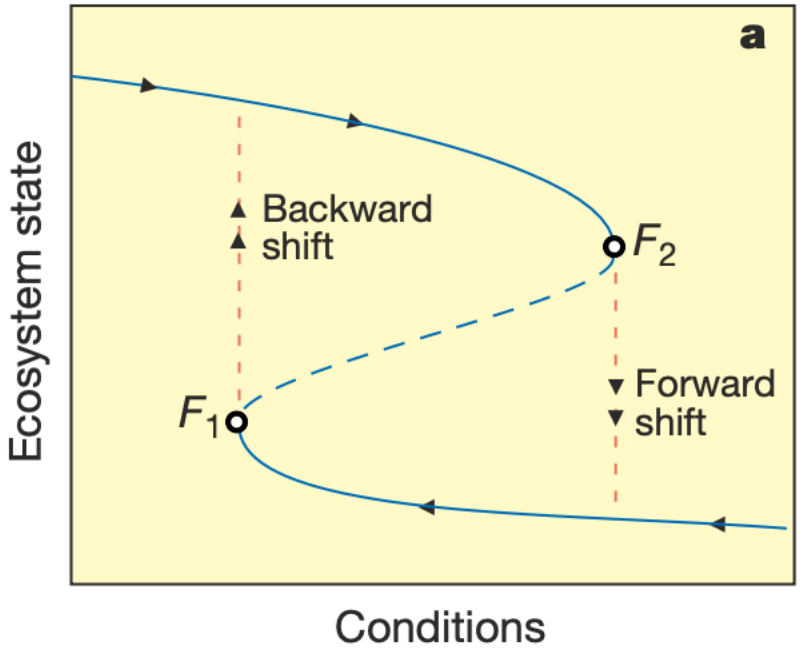


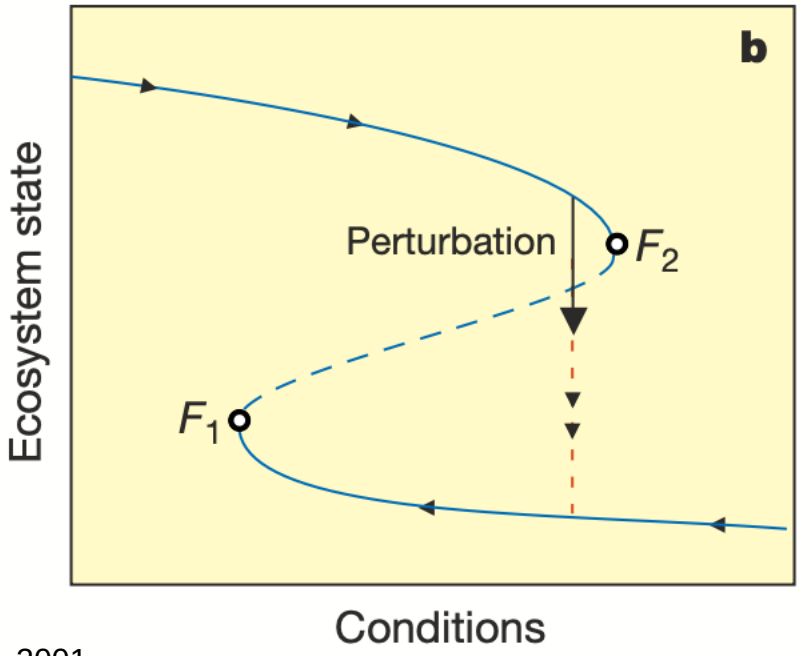
From Scheffer *et al*, *Nature*, 2001



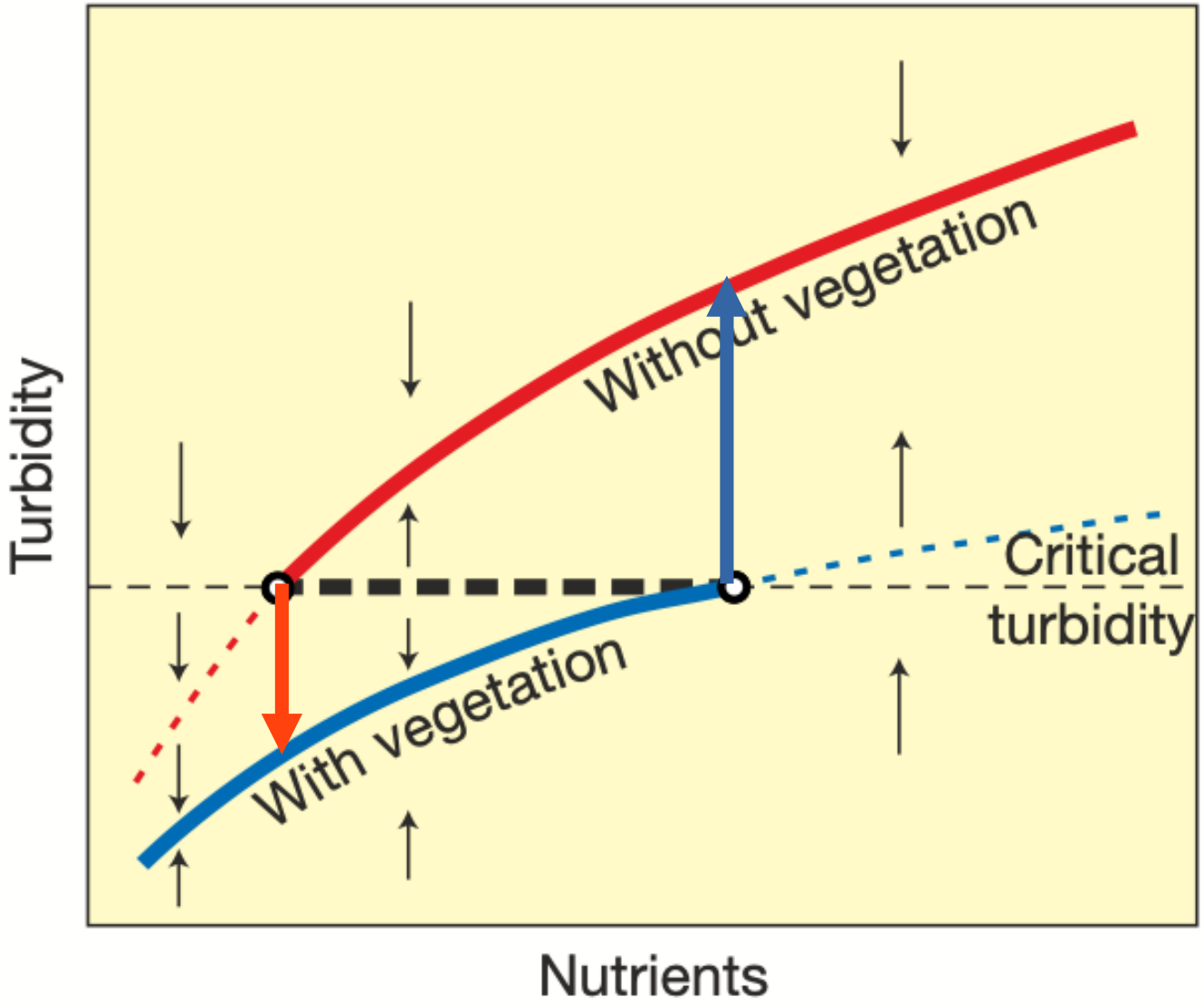








From Scheffer *et al*, *Nature*, 2001



From Scheffer *et al*, *Nature*, 2001

Veluwemeer (Lake Veluwe)

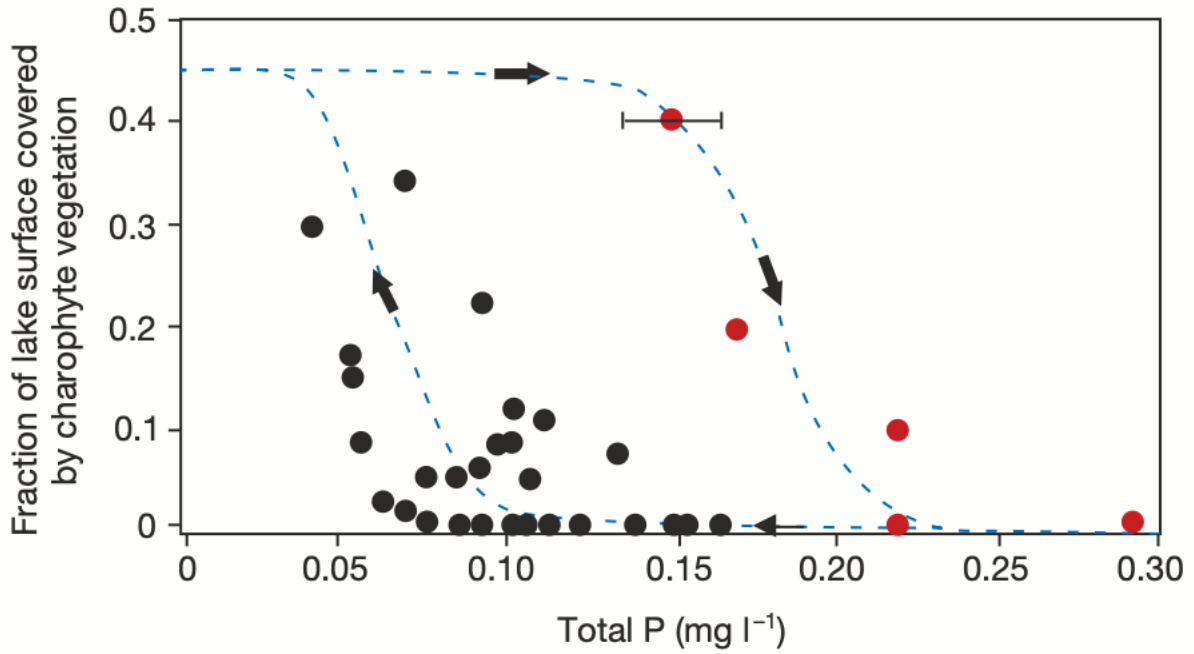


Figure 4 Hysteresis in the response of charophyte vegetation in the shallow Lake Veluwe to increase and subsequent decrease of the phosphorus concentration. Red dots represent years of the forward switch in the late 1960s and early 1970s. Black dots show the effect of gradual reduction of the nutrient loading leading eventually to the backward switch in the 1990s. From ref. 59.

From Scheffer *et al*, *Nature*, 2001

Sahara Desertificiation

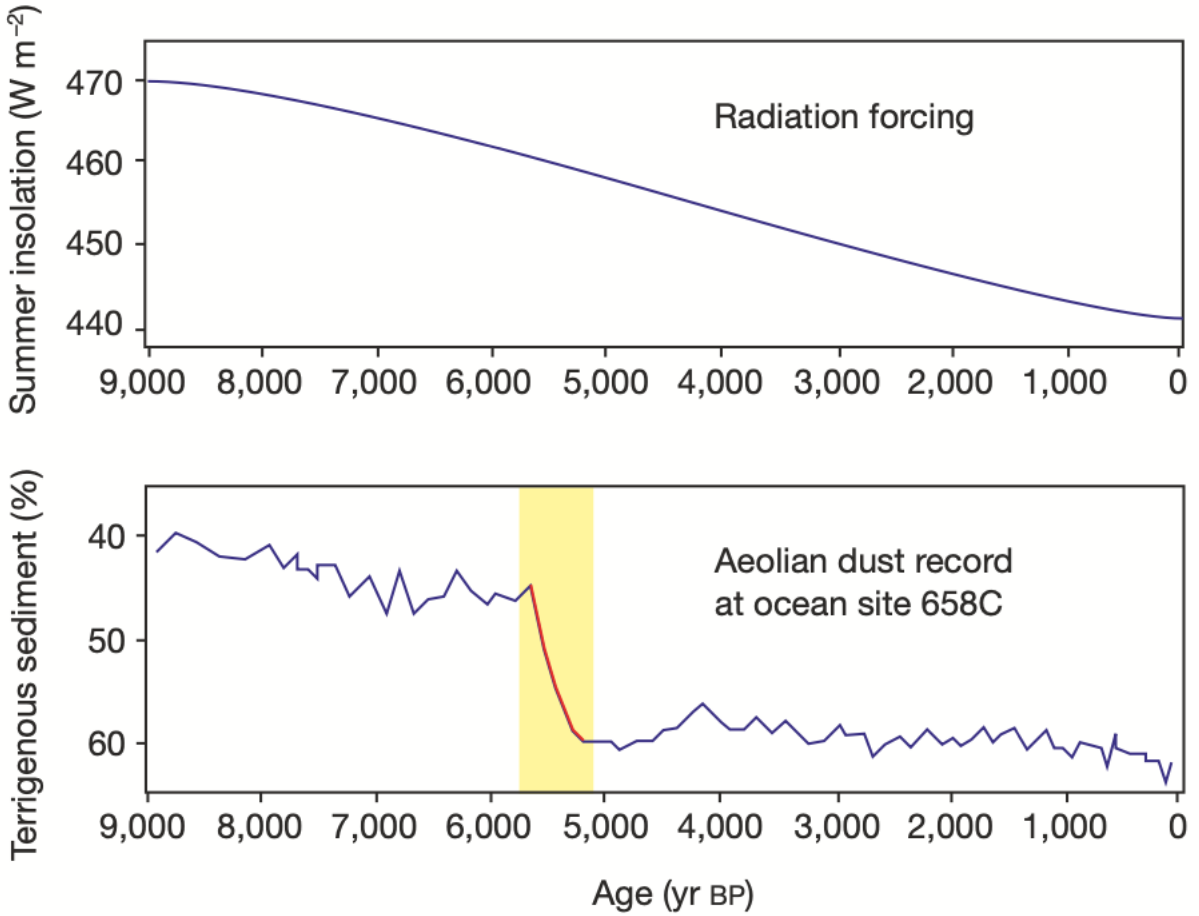


Figure 6 Over the past 9,000 years, average Northern Hemisphere summer insolation (upper panel) has varied gradually owing to subtle variation in the Earth's orbit. About 5,000 years before present (yr BP), this change in solar radiation triggered an abrupt shift in climate and vegetation cover over the Sahara, as reflected in the contribution of terrigenous (land-eroded) dust to oceanic sediment at a sample site near the African coast (lower panel). Modified from ref. 61.

From Scheffer *et al*, *Nature*, 2001

Pacific Ocean

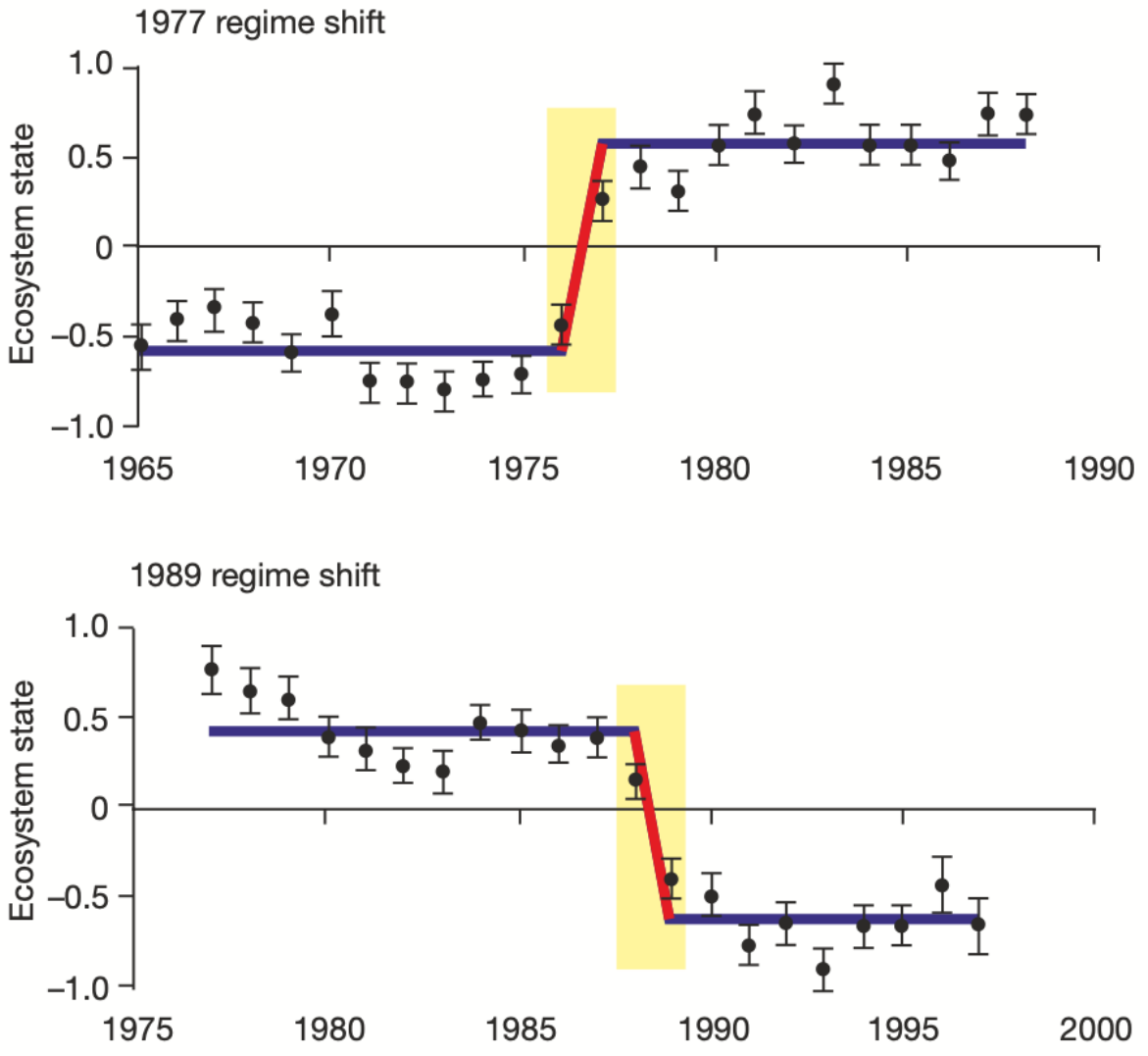


Figure 7 Distinct state shifts occurred in the Pacific Ocean ecosystem around 1977 and 1989. The compound indices of ecosystem state are obtained by averaging 31 climatic and 69 biological normalized time series. Modified from ref. 41.

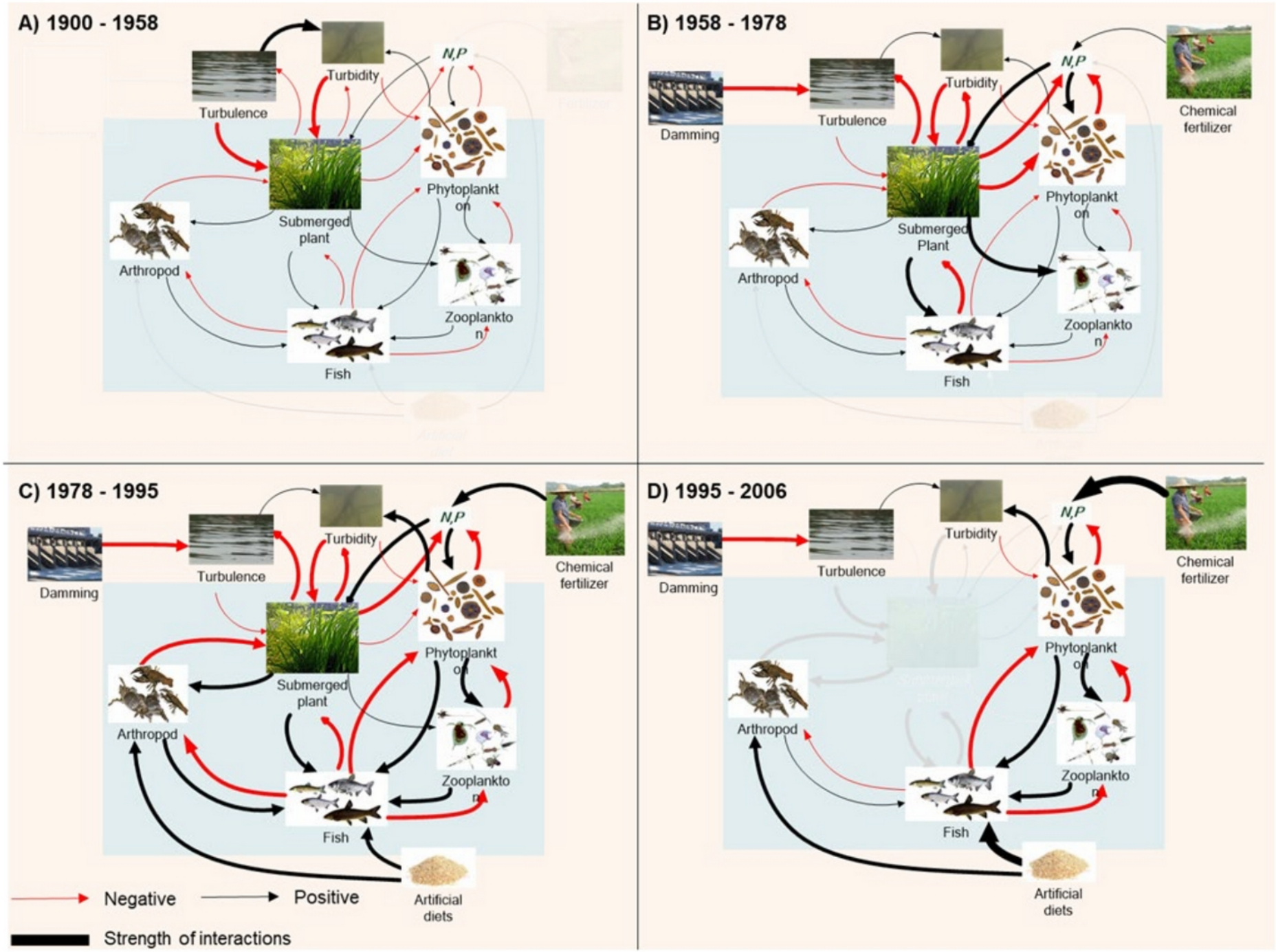
From Scheffer *et al*, *Nature*, 2001

Modelling Lake Ecosystems

- *Regime Shifts in Shallow Lakes*: *palaeoecological and agent-based model approaches*, Yanjie Zhao, 2022, PhD dissertation, Faculty of Environmental and Life Sciences Geography and Environment Science, University of Southampton
- *Combining system dynamics and agent-based modeling to analyze social-ecological interactions—an example from modeling restoration of a shallow lake*, Romina Martin & Maja Schlüter, 2015, *Frontiers in Environmental Science*

Taibai Lake

Yangtze River System



Model Structure

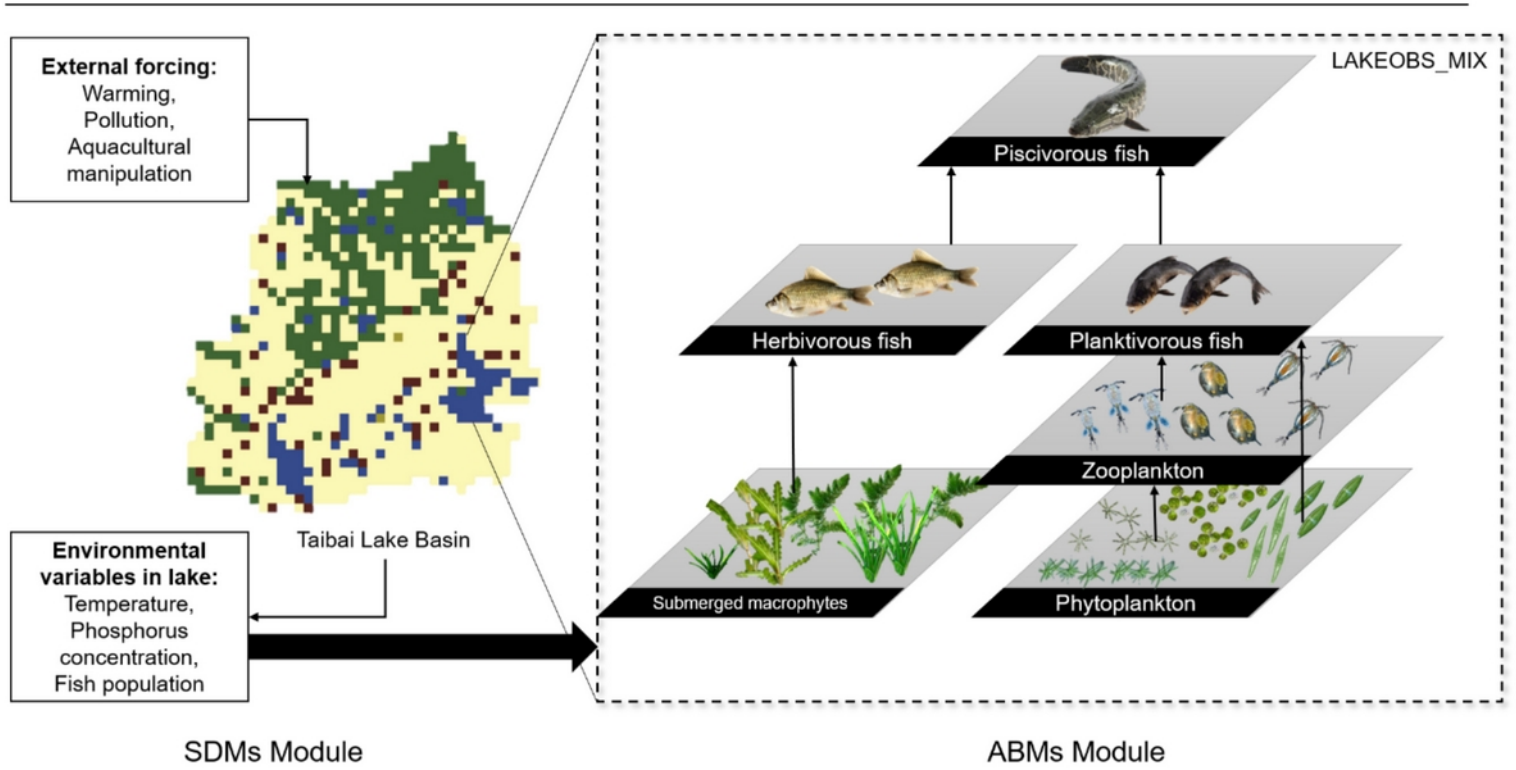


Figure 4-1: Conceptual diagram of the components and interactions in the LAKEOBS_MIX integrated model

Influence Diagram

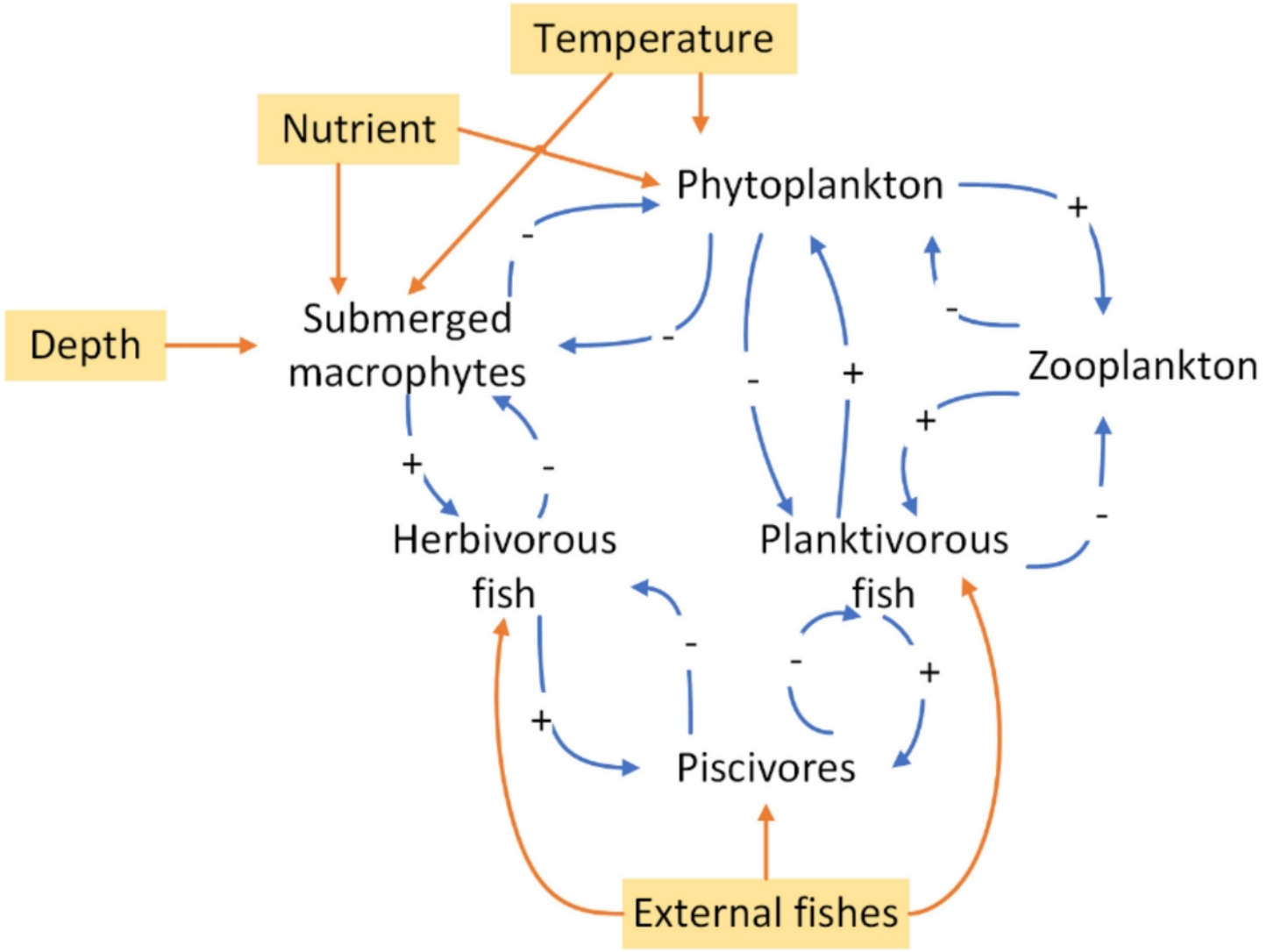
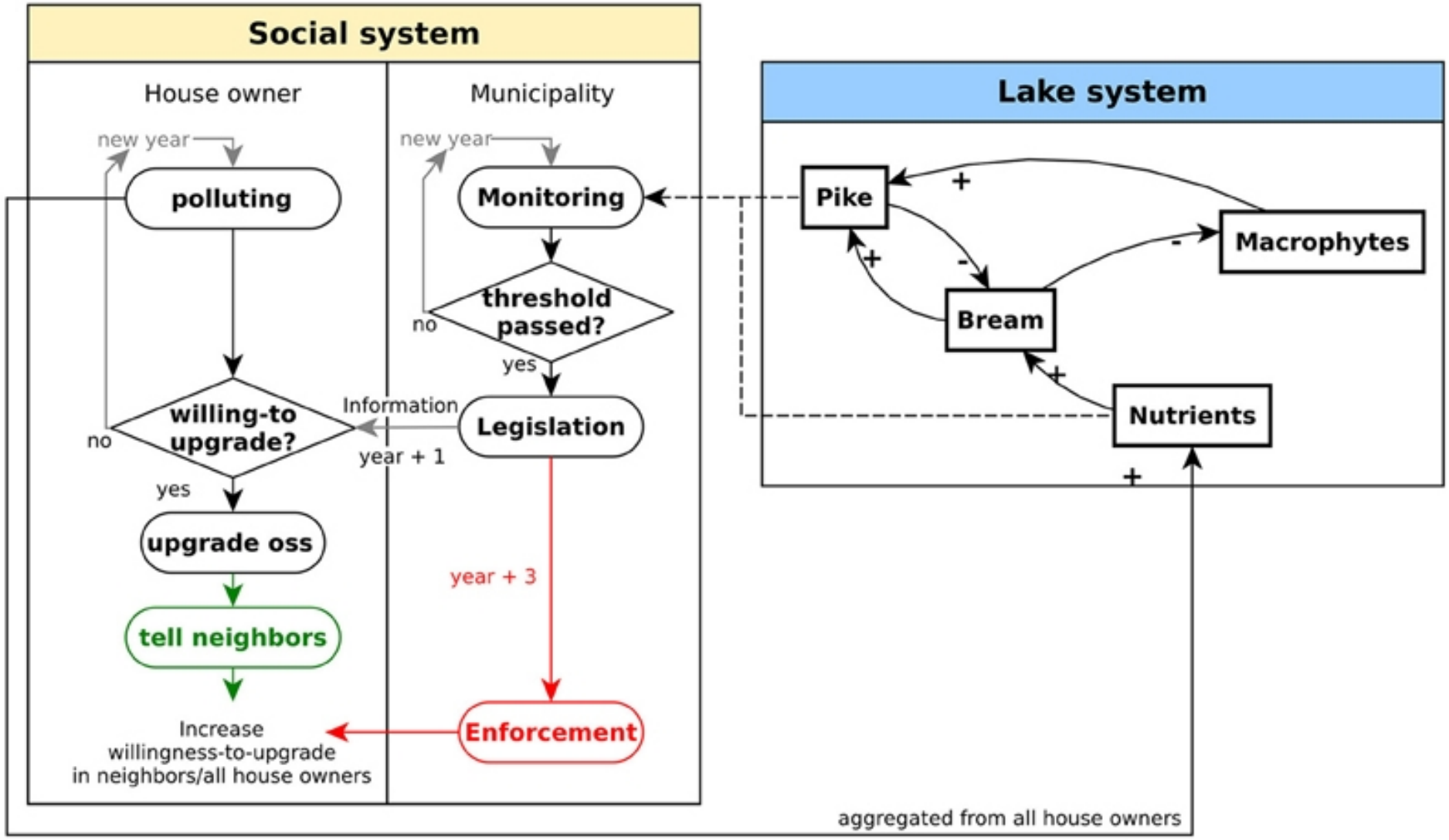


Figure 4-2: A schematic diagram of feedback loops and drivers in the model. The yellow rectangles highlight external drivers which affect the biotic communities in orange arrows. Blue arrows show general positive or negative interactions in the biome with the signal "+" or "-" respectively.

LIMNOSES hybrid AB+SD model



From R. Martin & M. Schlüter, *Frontiers in Environmental Science,* 2015

LIMNOSES Bifurcation Diagram

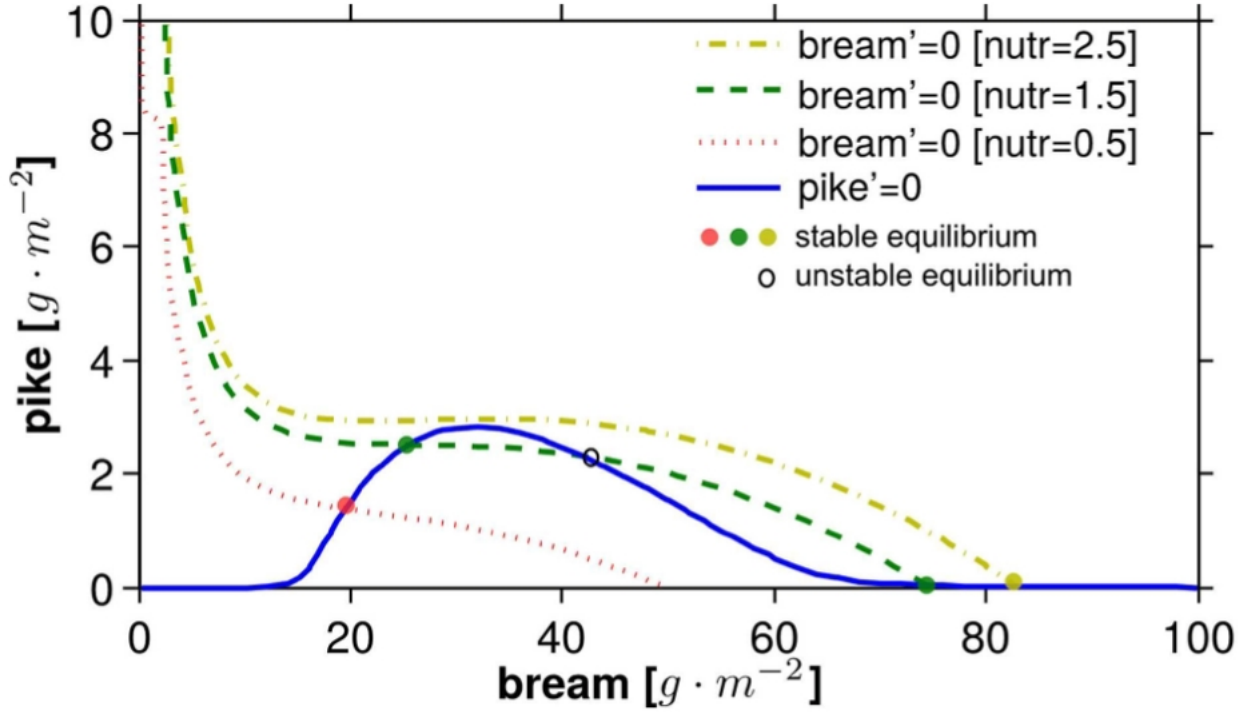
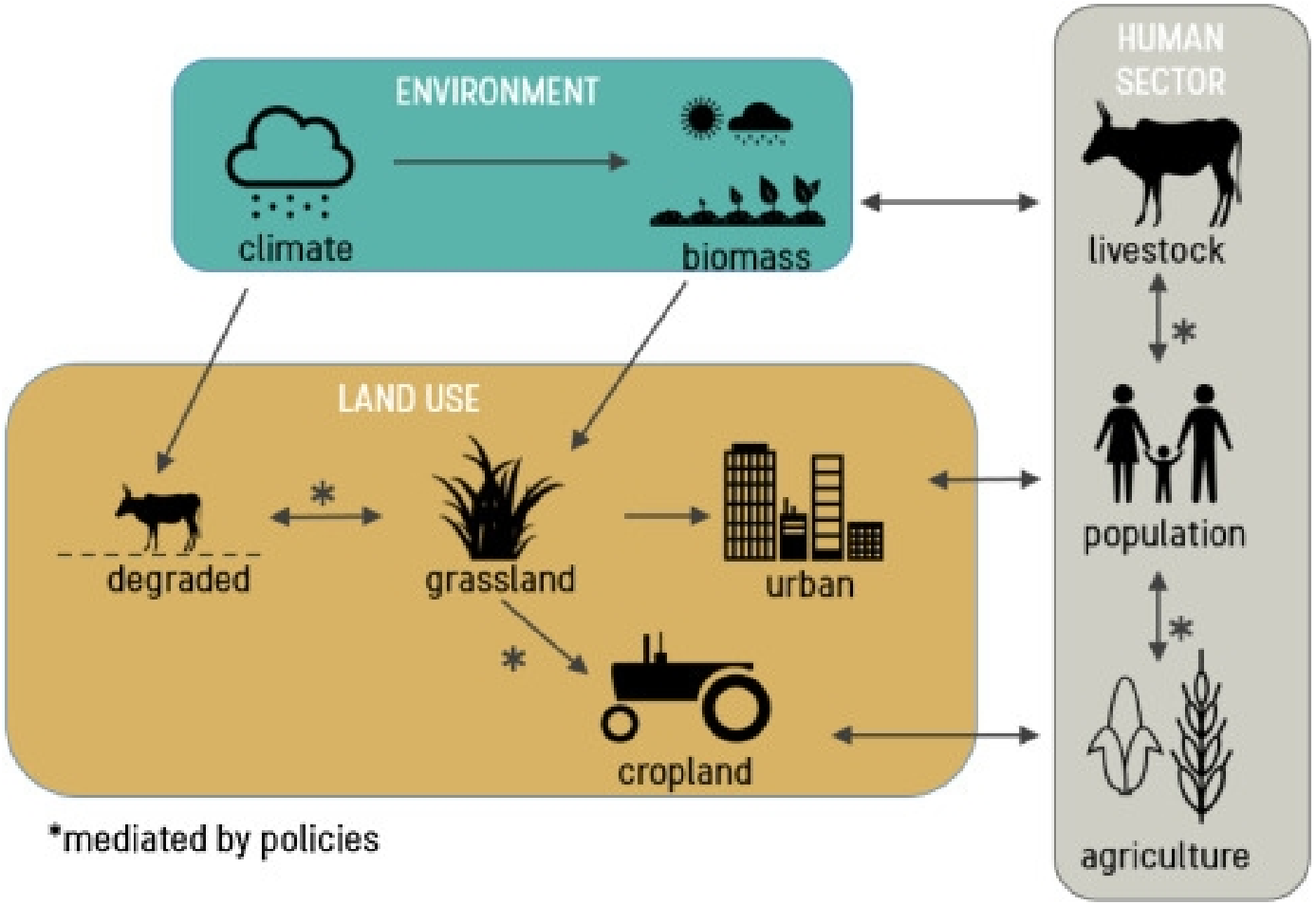


FIGURE 4 | State-space diagram showing zero-isoclines for bream and pike with different stable states depending on the nutrient level that influences the position of the zero-isocline for bream. The zero-isocline for pike is unaffected by the nutrient level. Reimplementation is based on the model developed by Scheffer (1989).

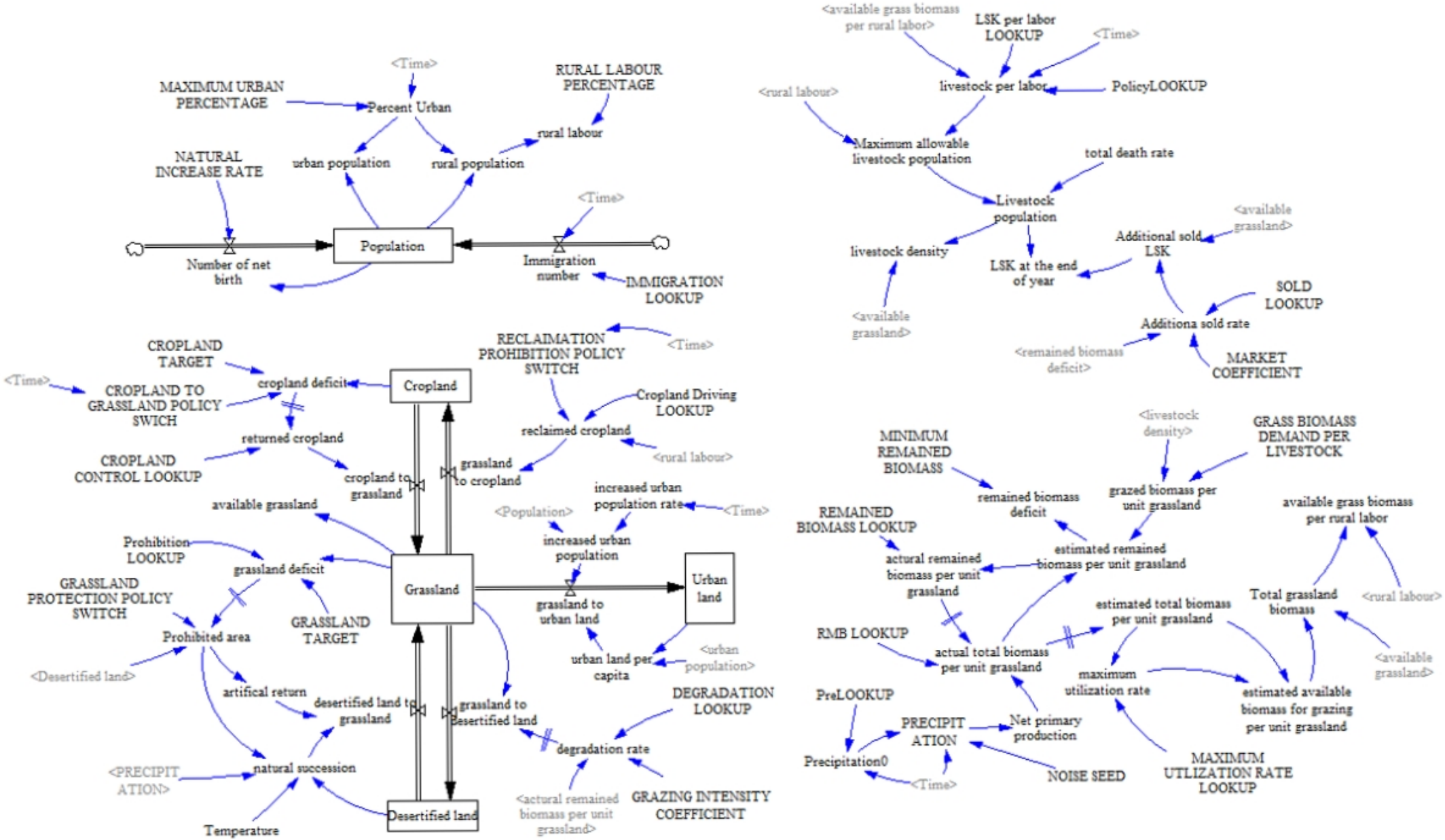
Mongolia Land Use

Allington et al, Environmental Science and Policy, 2017

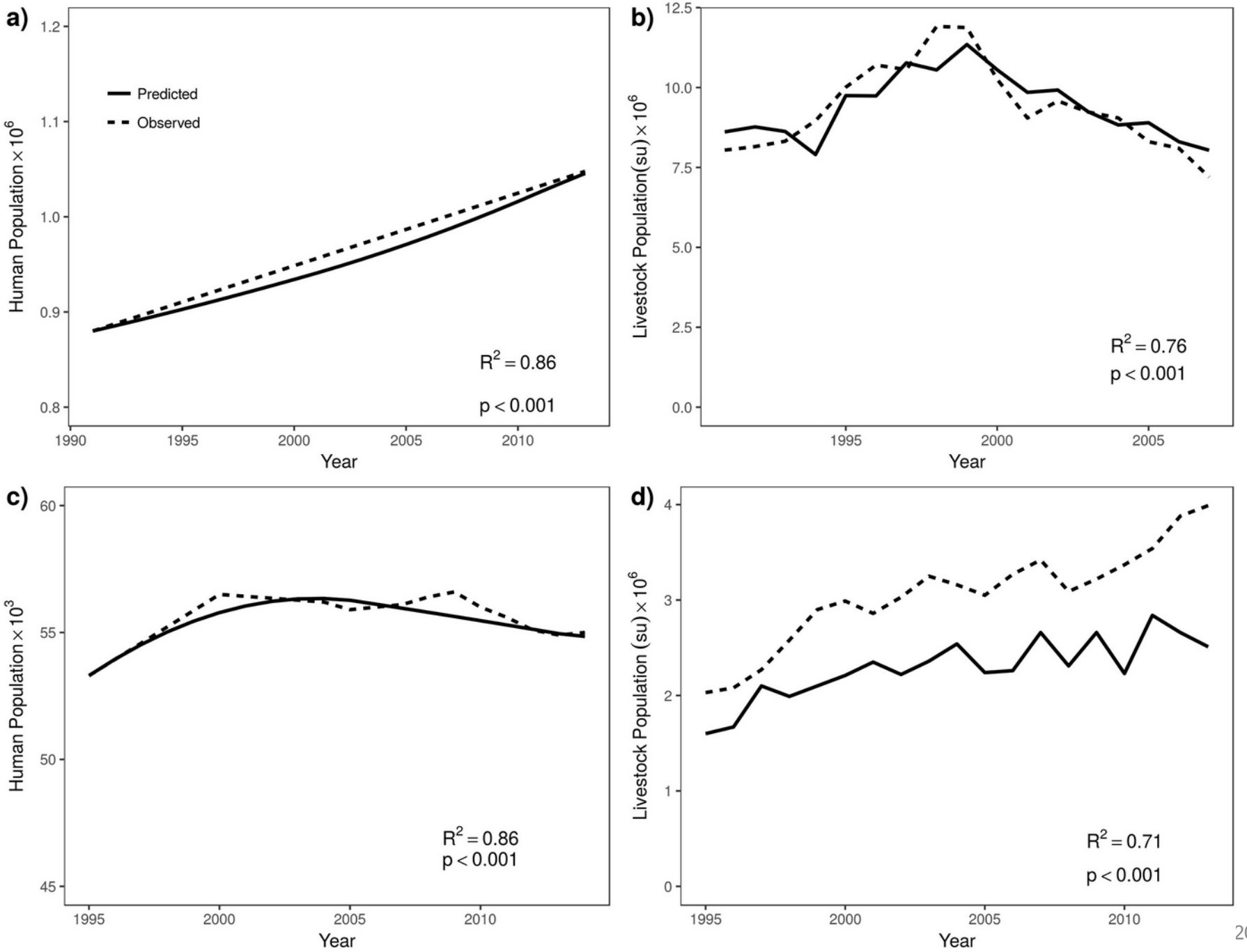
Model Structure



Potential Fig. S1: Model structures a) Xilingol



Validation


a)
Predicted
Observed
Human Population × 10^6
1.2
1.1
1.0
0.9
0.8
1990
1995
2000
2005
2010
Year
R^2 = 0.86
p < 0.001
b)
Livestock Population(su) × 10^6
12.5
10.0
7.5
5.0
2.5
0.0
1995
2000
2005
Year
R^2 = 0.76
p < 0.001
c)
Human Population × 10^3
60
55
50
45
1995
2000
2005
2010
Year
R^2 = 0.86
p < 0.001
d)
Livestock Population (su) × 10^6
4
3
2
1
0
1995
2000
2005
2010
Year
R^2 = 0.71
p < 0.001

Summary

- Revisited tipping points with examples in ecosystems
- Lake ecosystem models – agent based and system dynamics
- Land use change
- Next time: focus on social system models