Managing Ecosystems

Aart de Zeeuw
Tilburg Sustainability Center
Tilburg University, the Netherlands

Textbook bio-economic model

- Fishery
  - species oriented
  - logistic growth; MSY versus economics
  - optimal management, games, open access
  - dynamics, spatial aspects
- Links with the ecological system?
  - management in case of possible bad states
  - resilience (under uncertainty)

Acknowledgement

- Beijer Institute of Ecological Economics (Stockholm) research agenda on complex systems (non-convexities)
- Karl-Goran Mäler, Anastasios Xepapadeas, William Brock, Steve Polasky (economists)
- Steve Carpenter, Marten Scheffer, Terry Hughes, Carl Folke (ecologists)

The Shallow Lake (ERE 2003)

- Phosphorus loadings from agriculture
- Hysteresis, irreversibility
- Oligotrophic states: high level of ecosystem services
- Eutrophic states: low level
- Bifurcations, domains of attraction
- Resilience

Basic model

- System of non-linear differential equations
- Essential dynamics
  - P: phosphorus in algae; L: input of phosphorus
  - s: rate of loss; r, m: other parameters

$$\dot{P}(t) = L(t) - sP(t) + r\frac{P^2(t)}{P^2(t) + m^2}$$

Mathematical structure

- Substitute $x = P/m$, $a = L/r$, $b = sm/r$
- Change time scale to rt/m
- Parameters a (control) and b (type of lake)

$$\dot{x}(t) = a(t) - bx(t) + \frac{x^2(t)}{x^2(t)+1}$$

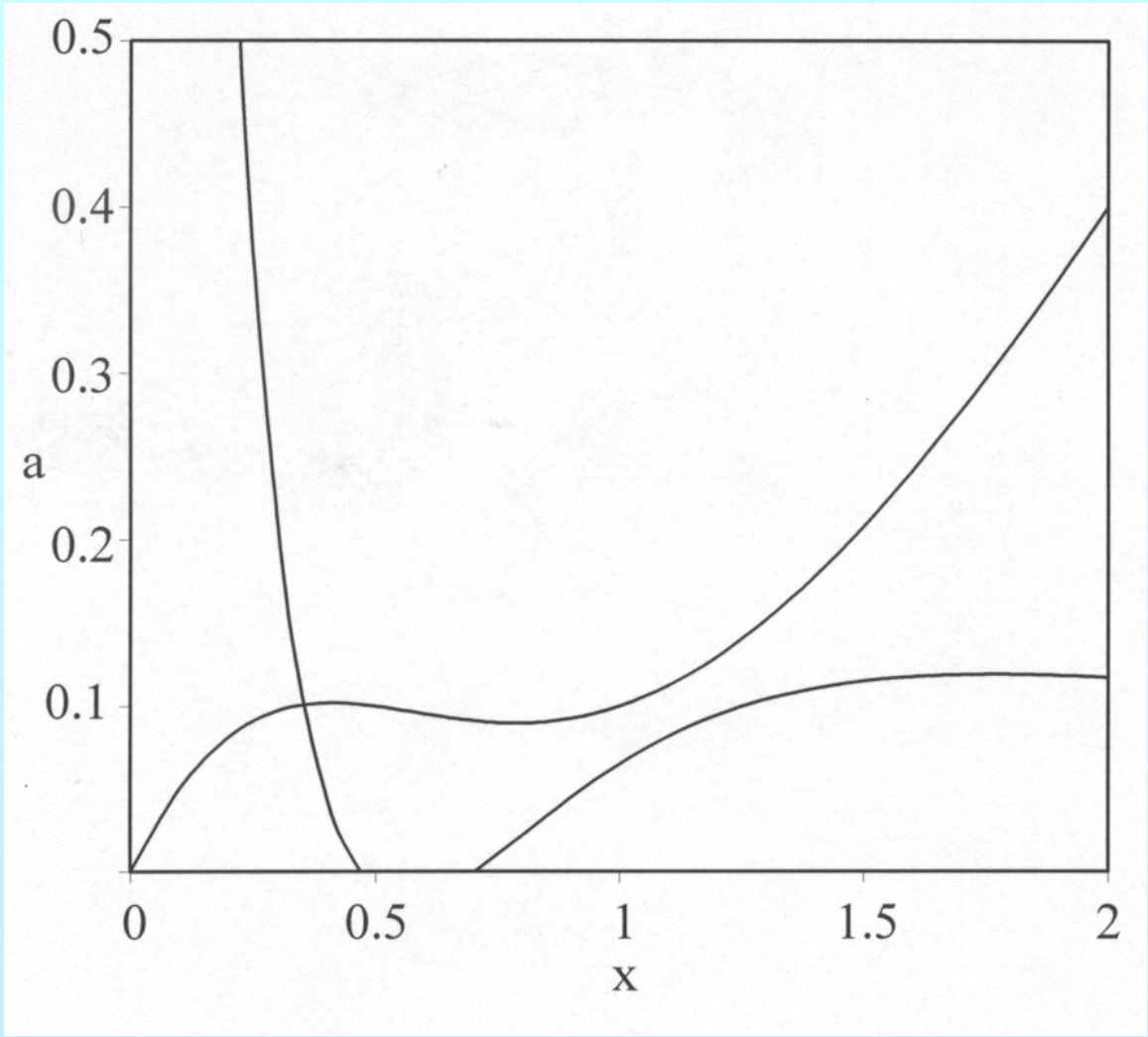
Economics

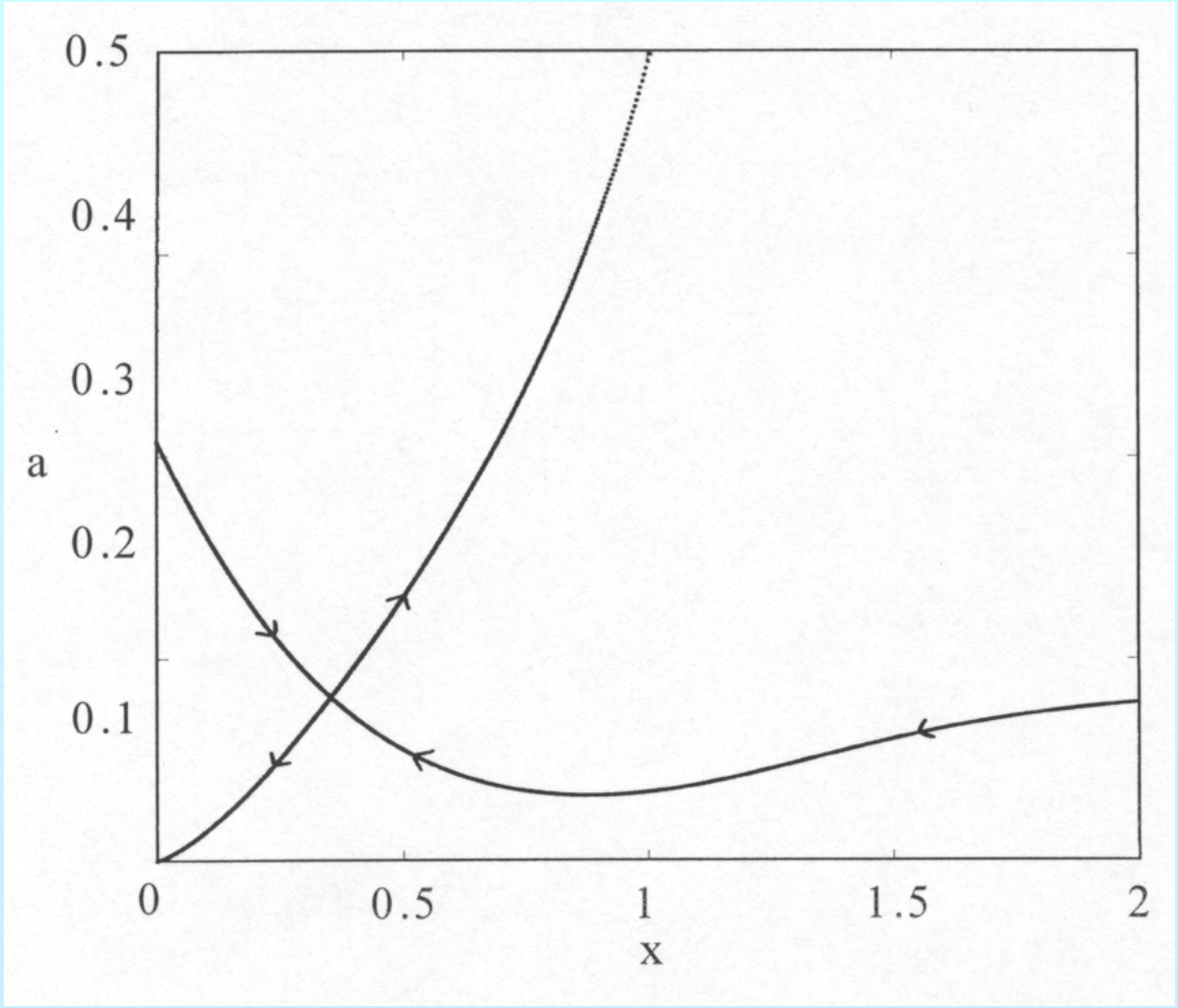
- Trade-off, conflicting services
  - release of phosphorus stems from agricultural activities: value as a waste sink ($ln\ a$)
  - clean lake means benefits for fishermen, drinking water companies, vacationers, etc.: decrease in value of ecological services ($-cx^2$)
- Common property (game approach)
  - N communities sharing the lake

Optimal Management

- Loading *a* is a function of time
- Pontryagin's maximum principle
- Phase diagram with stable manifold *a(x)*
- *b=0.6,c=1,rho=0.03*

$$\max \int_0^{\infty} e^{-\rho t}[\ln a(t) - cx^2(t)]dt$$

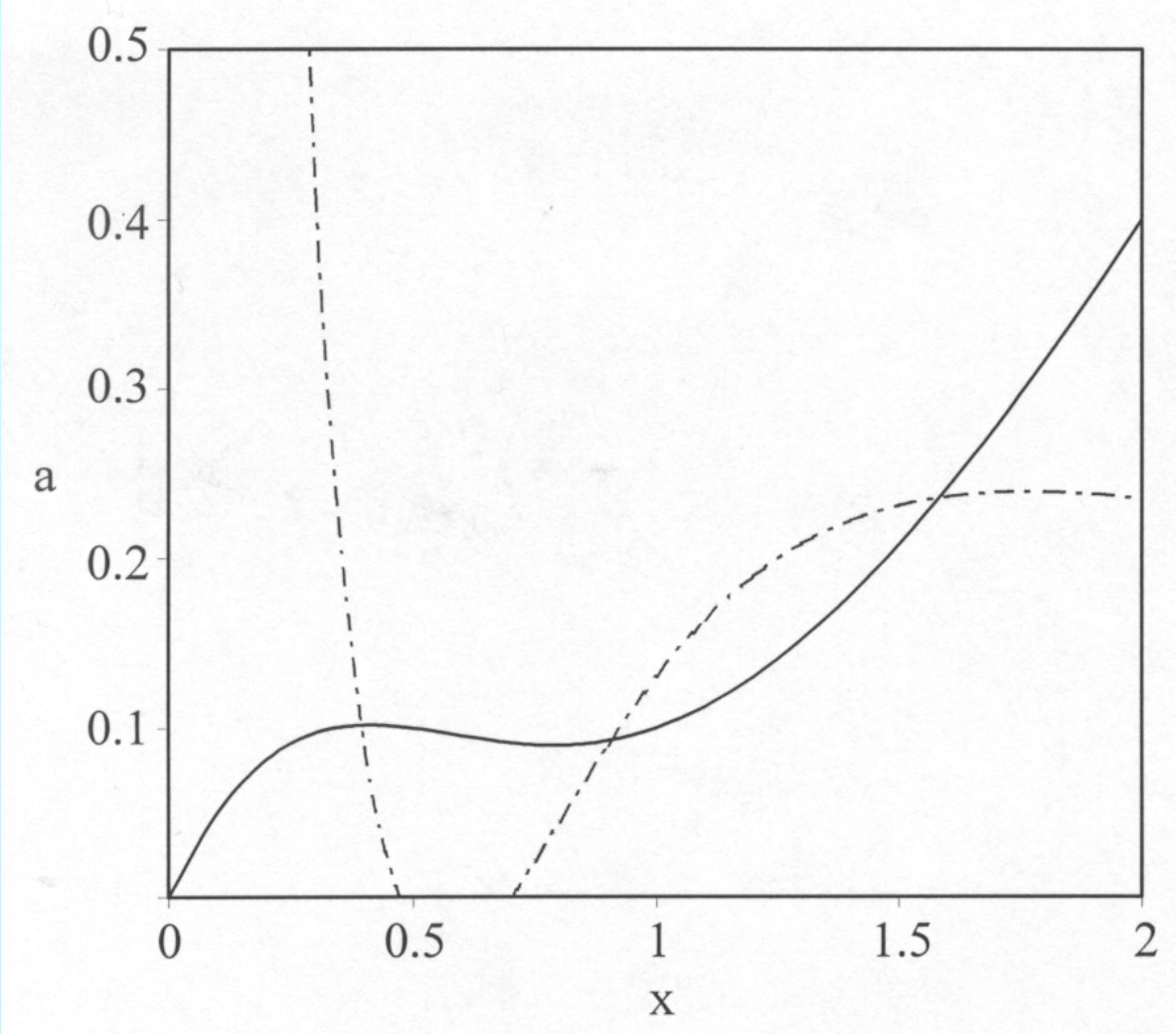

0.5
0.4
0.3
a
0.2
0.1
0
0.5
1
1.5
2
x

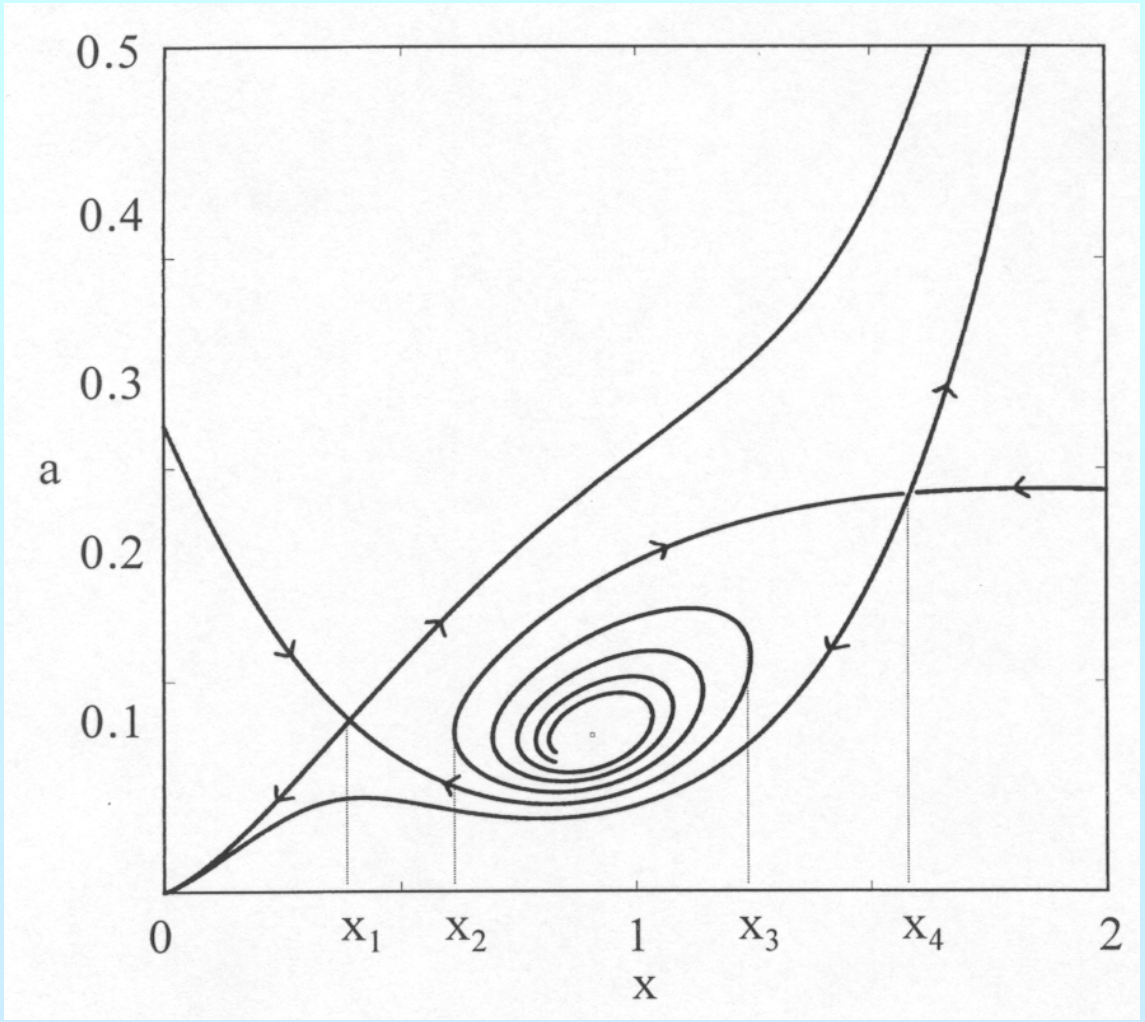

0.5
0.4
0.3
a
0.2
0.1
0
0.5
1
1.5
2
x

Common property

- N communities loading a_i, in total a
- Pontryagin's maximum principle
- Phase diagram with stable manifold $a(x)$
- "Open-loop" Nash equilibrium (N=2)

$$\max \int_0^{\infty} e^{-\rho t}[\ln a_i(t) - cx^2(t)]dt, i = 1,2,..,N$$


0.5
0.4
0.3
a
0.2
0.1
0
0.5
1
1.5
2
x


0.5
0.4
0.3
a
0.2
0.1
0
x_1
x_2
1
x_3
x_4
2
x

Extensions

- Feedback Nash equilibria where control a depends on the state x
  - bad equilibria do not occur
  - welfare still low
- Taxes on a to induce optimal management
  - fixed taxes
  - state-dependent taxes

Coral reefs

- Three major threats:
  - nutrient loadings
  - changes in the food web (overfishing)
  - bleaching (climate change)
- Thresholds: coral/algae dominated states
- “Optimal fishing” becomes sub-optimal
- Anne-Sophie Crépin (ERE 2007)

Other issues

- Grasslands
  - grass/woody vegetation dominated states
  - control is animal stock
  - common property issue
  - A.-S. Crépin, Therese Lindahl (ERE 2009)
- Climate change?
- Financial crisis?

Resilience

- Small shocks do not push the system across the threshold
- “Optimal management” too close to the threshold?
- Where is the threshold?
  - variance indicator?
- Is the threshold changing? (“slow variable”)

Regime shift

- Fishery: logistic growth shifts down
  - e.g., coral reef collapses
- Uncertainty about when this may happen
- If probability is exogenous: business-as-usual
- If probability is endogenous: precautionary
- In case of total fish collapse: higher harvest

Conclusions

- Thresholds and flips between states with very different levels of ecosystem services occur in many ecological systems
- This is very important for studying optimal management and common property issues
- Knowledge in this area is growing but it is still insufficient