Economic management and thresholds in ecosystems

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The material in this keynote presentation has been published in the following journal articles:

- K.-G. Maler, A. Xepapadeas and A. de Zeeuw, "The economics of shallow lakes", Environmental & Resource Economics, 26, 4, 2003, 603-624.

- A.-S. Crepin, "Using fast and slow processes to manage resources with thresholds", Environmental & Resource Economics, 36, 2, 2007, 191-213.

Textbook fishery models

- Logistic growth
- Maximal sustainable yield
- Economics, Gordon-Schaefer
- Optimal management, open access, game
- Dynamic models
- Spatial aspects
- Links with the ecological system?

Acknowledgement

- The Beijer Institute research agenda on complex systems (non-convexities)
- Karl-Goran Maler, Anastasios Xepapadeas, William Brock (economists)
- Steve Carpenter, Marten Scheffer, Terry Hughes (ecologists)
- Anne-Sophie Crepin, Therese Lindahl

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

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

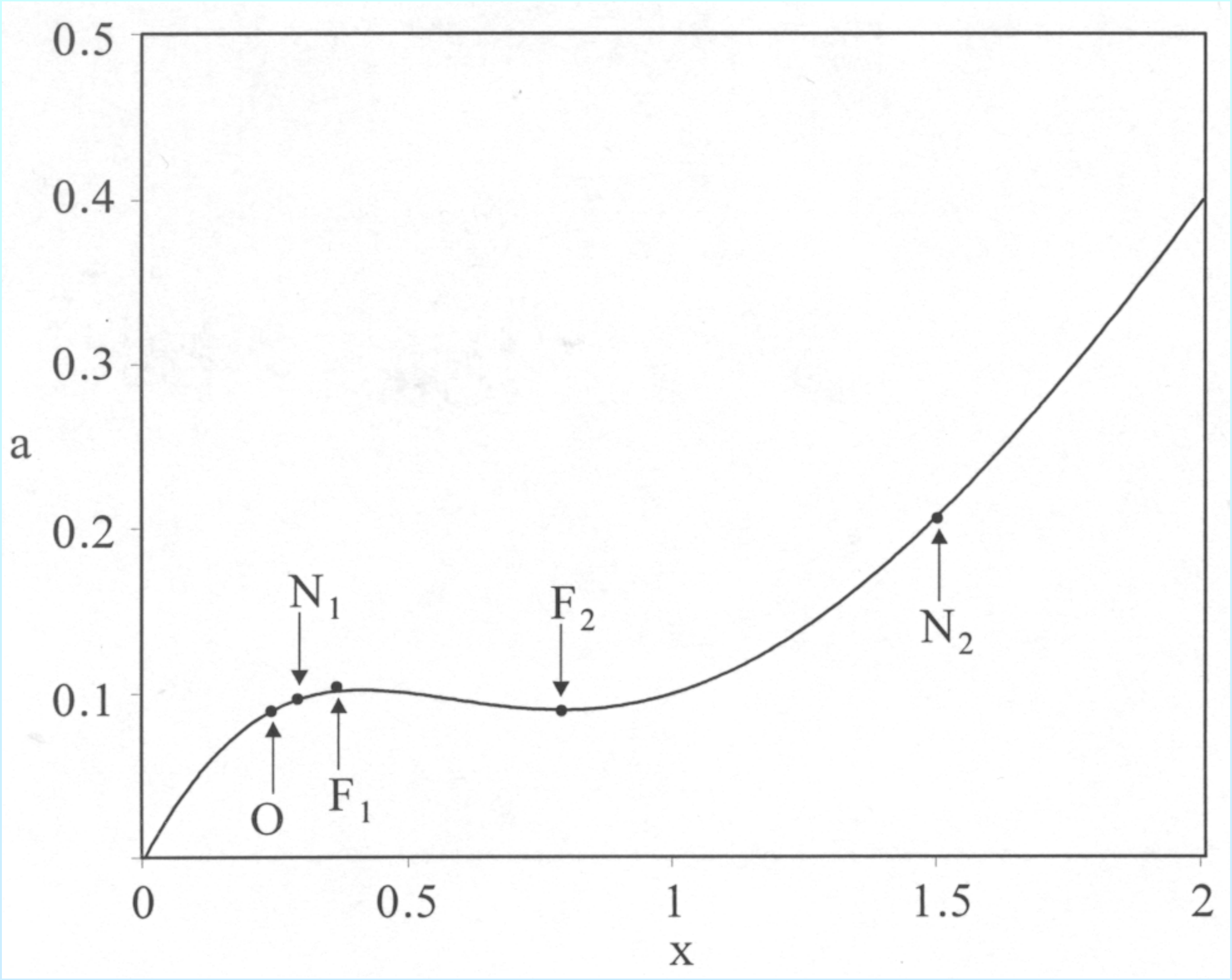
Mathematical structure

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

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

Concepts

- Shallow lake equilibria: steady-states for the stock of phosphorus x, given a certain level of loading a and a type of lake b
- Fast process: adjustment to this steady state
- Slow process: changes in the parameter b ("mud equation")
- Parameter b affects the thresholds



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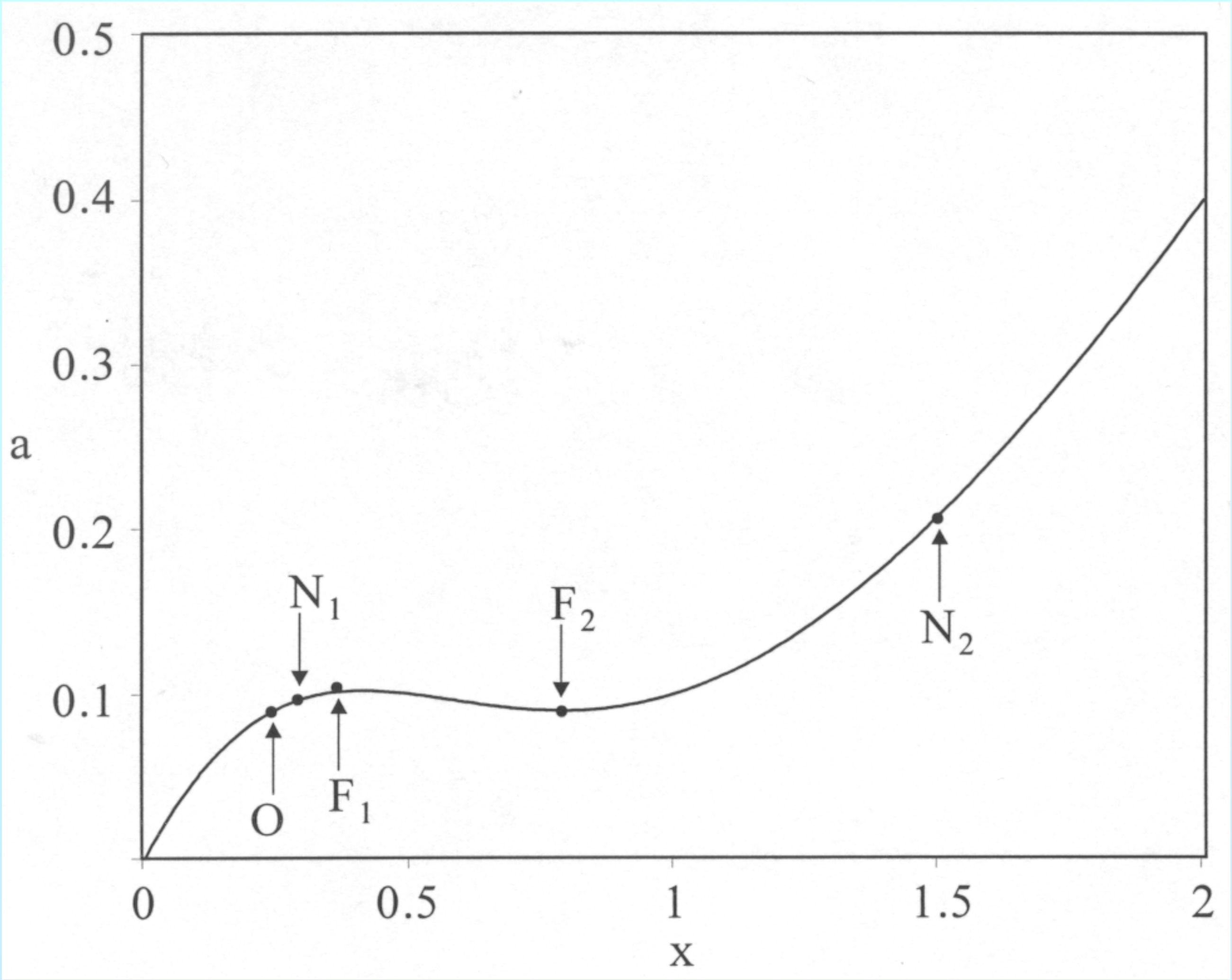
Economics

- 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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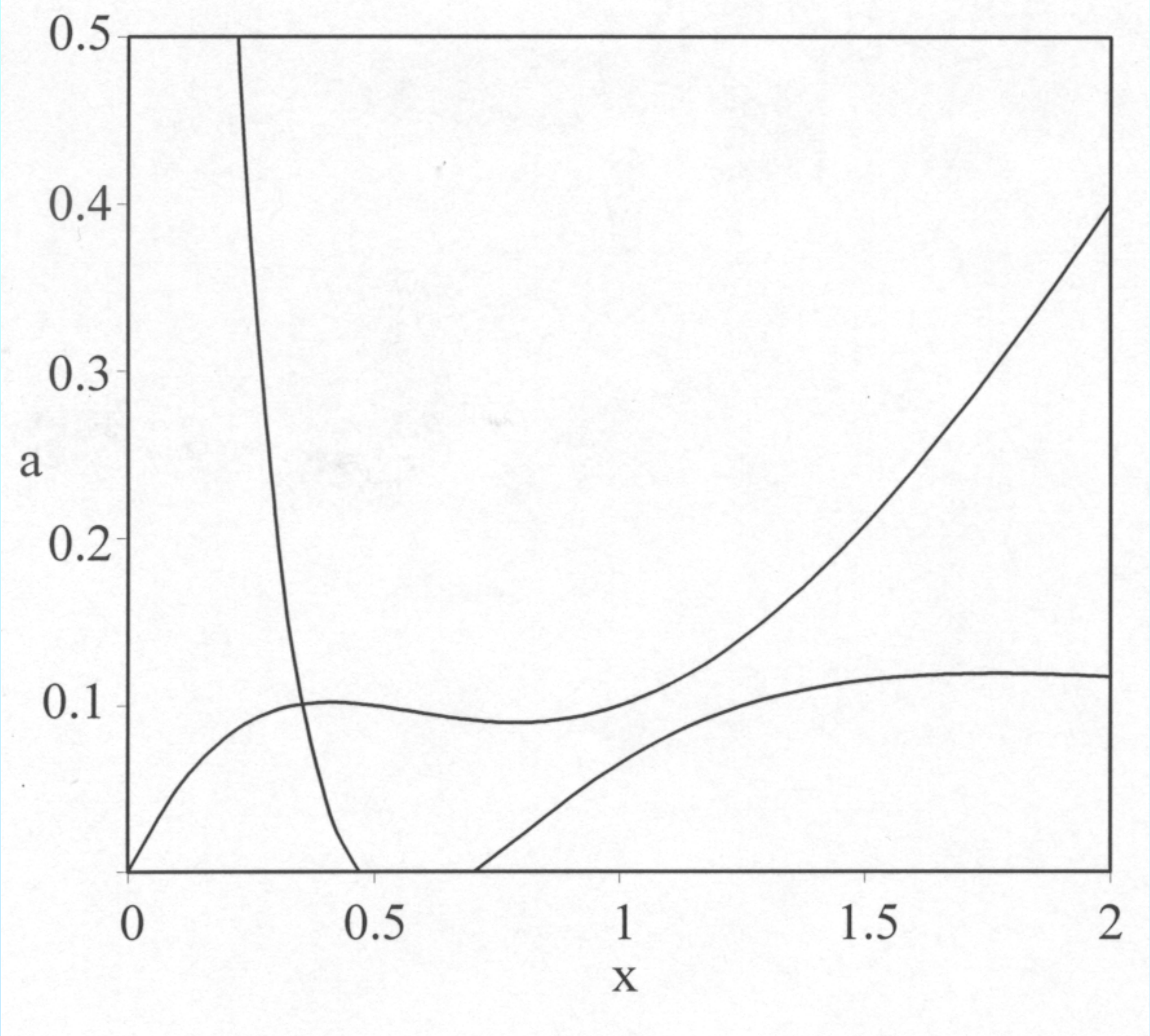
Optimal Management

- 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*

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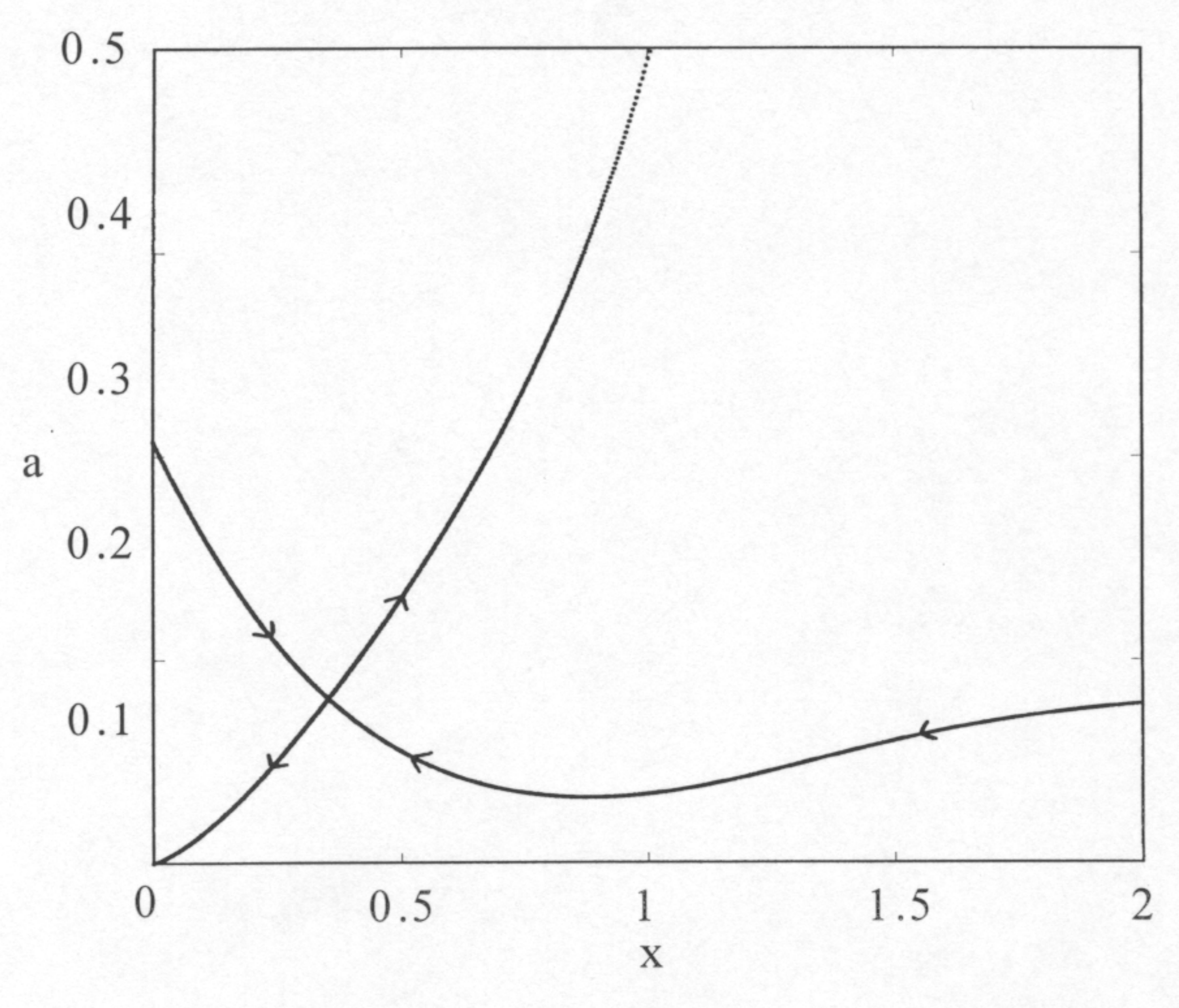
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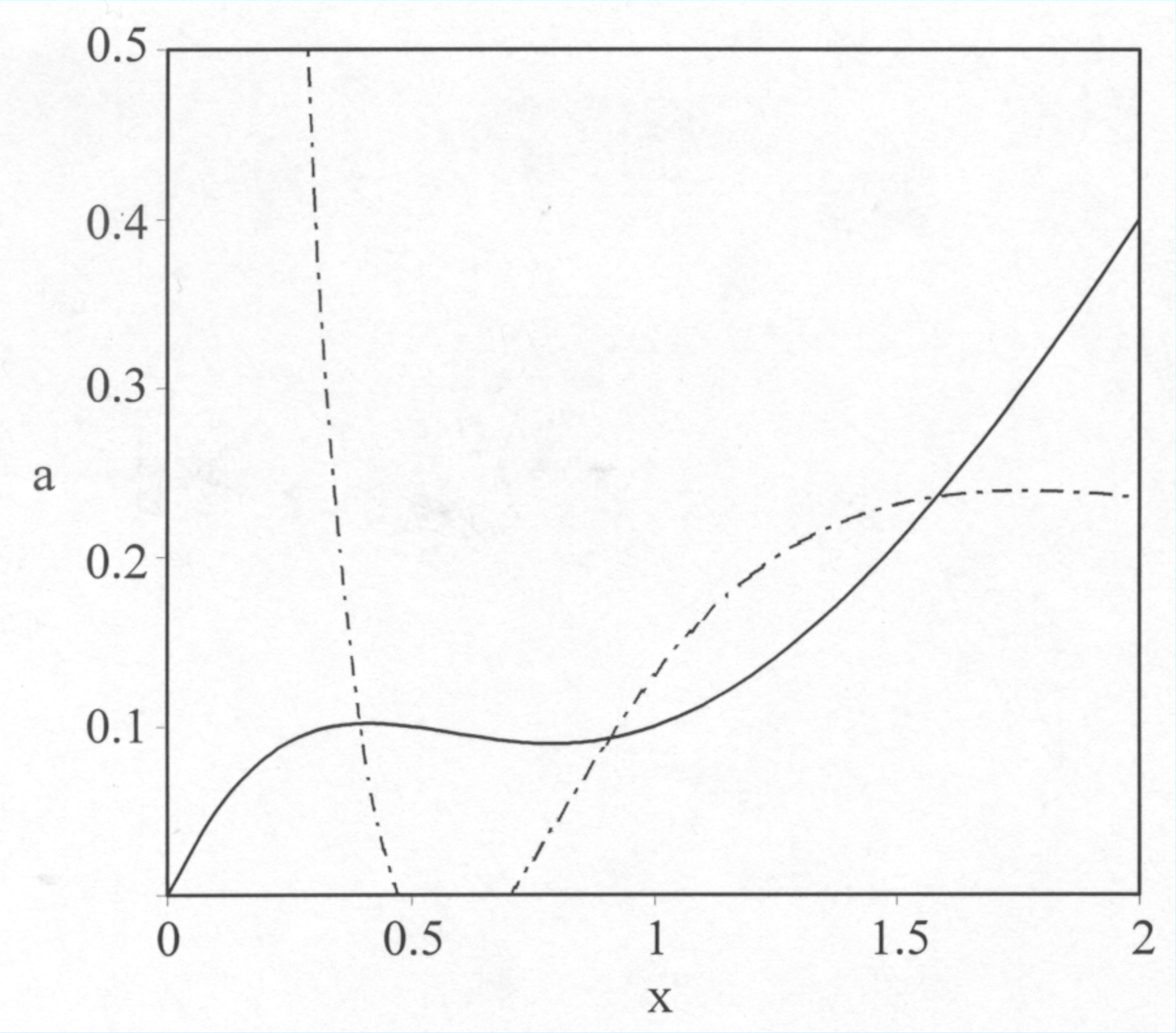
Common property

- *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*)

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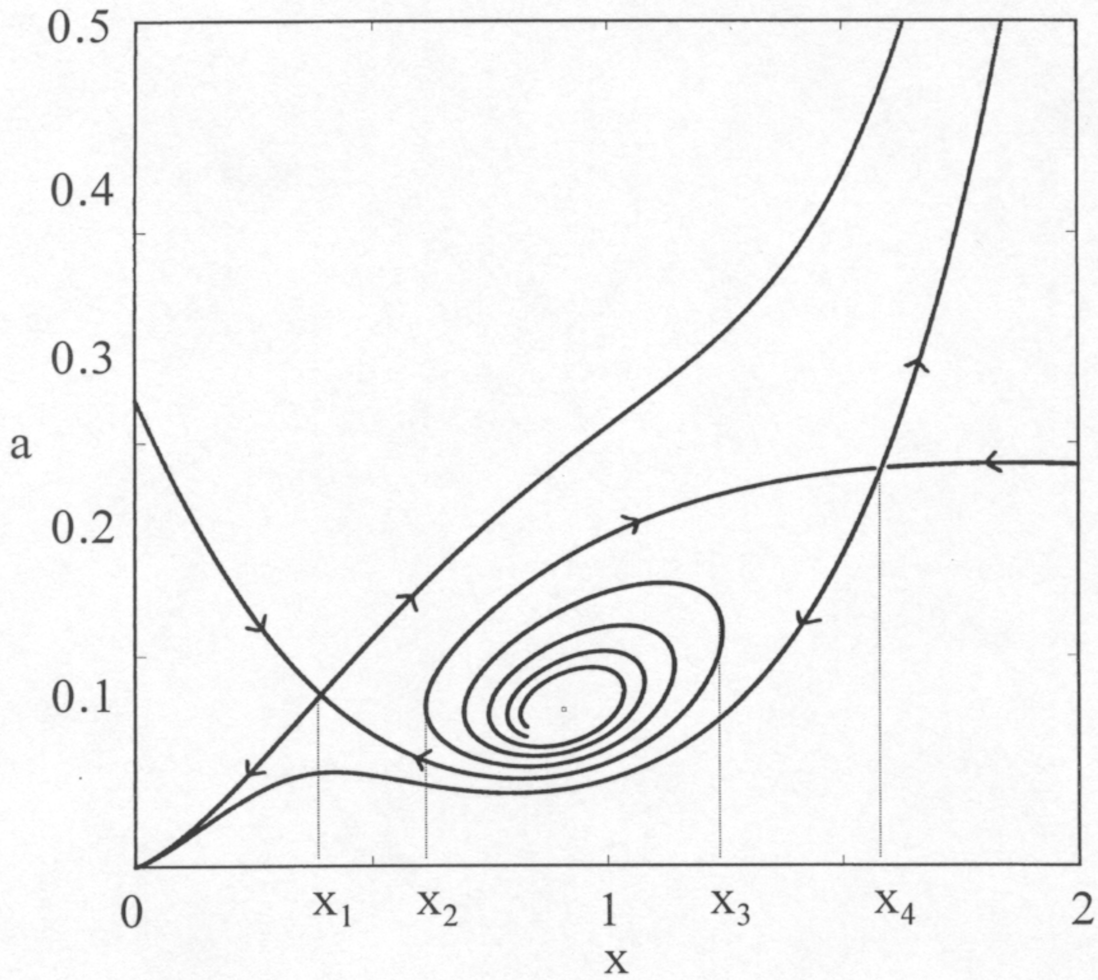

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Other game models

- "Feedback" Nash equilibrium: loadings a_i depend explicitly on the state of the lake x
- Bad steady state does not occur anymore
- However, welfare is still low

$$\rho V(x) = \max[\ln a_i - cx^2 + V_x(x)\dot{x}]$$

Coral reefs (ERE 2007)

- Three major threats:
  - nutrient loadings
  - changes in the food web (overfishing)
  - bleaching (climate change)
- Thresholds
- Coral dominated state
- Algae dominated state

Model

- Fast processes: herbivores and algae
- Slow process: adjustments in coral
- Herbivores:
  - typical fish model
  - carrying capacity depends on algae
  - non-linear predation term (“Holling type III”) that depends on coral (shelter)

Model

- Algae:
  - depends positively on nutrients
  - depends negatively on herbivores
- Coral:
  - depends negatively on algae
- Human actions: fishing and pollution
  - possible flips to an algae dominated state

Results

- Fishing and pollution may induce large costs because of hysteresis/ irreversibility
- Fishing enlarges algae dominated domain of attraction, and coral deteriorates (slowly): lower resilience
- Optimal fishing w.r.t. fishery model may be far from optimal because of the thresholds

Policy

- Understanding of complex systems
- Combination of instruments affecting fishing, pollution and climate change: balancing resilience w.r.t. all threats
- Adaptive management
  - only if experimentation is possible
- Precautionary principle?

Other applications

- Grasslands
  - grass dominated state or woody vegetation dominated state (or even dry desert)
  - via animal stock that depends on grass and that is controlled by human action
  - common property issue
- Climate change?, financial crisis?

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