Economic management and thresholds in ecosystems

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


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
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 $a(x)$
- $b=0.6, c=1, \rho=0.03$

$$\max \int_{0}^{\infty} e^{-\rho t} [\ln a(t) - cx^2(t)] dt$$
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 ($N=2$)

$$\max_{0}^{\infty} e^{-\rho t} \left[ \ln a_i(t) - cx^2(t) \right] dt, i = 1,2,.., N$$
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