Biological resources

Growth, uncertainty, and complexity

Rolf Groeneveld

What's so special about biological resources?

- Renewable
- Biological processes
  - Growth
  - Species interactions
  - Interaction with abiotic factors

Program

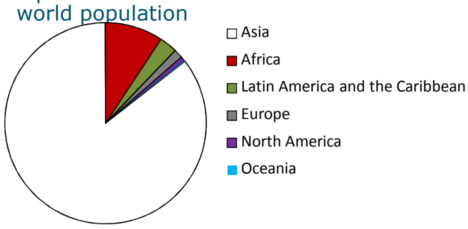
- Today: Fisheries
  - Good example of a biological resource
  - Many problems with overexploitation
  - Representative for other biological resources such as game
- Tomorrow
  - R practical dynamic fisheries models
  - Dynamic programming
- Thursday
  - R practical dynamic programming
  - Complex dynamics in ecosystems

Economic importance of marine resources

- Fish: $93.9 bln in 2008 (FAO, 2010)
  - A 16% increase since 2000
- Aquaculture: $98.4 bln in 2008 (FAO, 2010)
  - A 73% (!) increase since 2000
  - But not all is marine
- Tourism: Estimated at $161 bln in 1995
  - But this is a very shaky figure
- Unregistered uses, especially in poor countries
  - Timber, fuelwood, fish

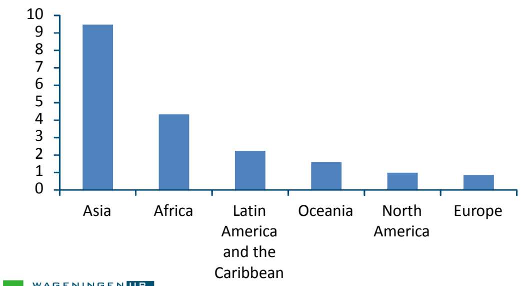
Employment in fisheries

- 44.9 mln people were involved in fisheries or aquaculture in 2008 – that is 0.6% of the total world population

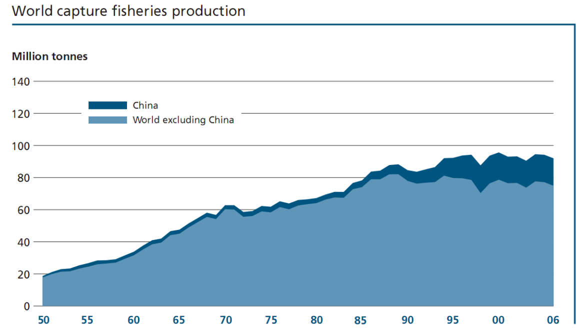


Employment in fisheries

- Employment in fisheries or aquaculture per 1000 people:



FAO, 2008 (1):



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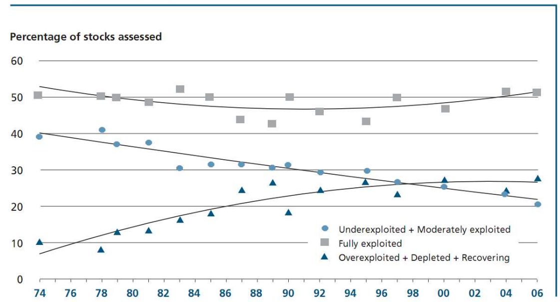
FAO, 2008 (2):



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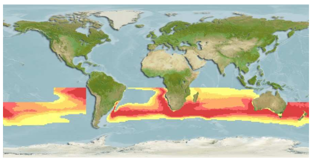
Example: Southern bluefin tuna



- Scientists estimate stock at 10% of original level
- IUCN lists species as critically endangered

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Economics of fisheries: Program

- This morning: 'diagnosis'
  - What is driving overfishing?
  - How do fishers and fish interact?
- This afternoon: 'prognosis'
  - How much should we fish?

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Overfishing in a nutshell

- Open entry/exit
  - All rents dissipate as fishers enter the market
- This is inefficient because
  - We can catch the same amount with less effort
  - Stocks will be larger -> more existence values, less risk of stock collapse

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Dynamic analysis

- Equilibrium
  - What are the steady states in the system?
- Dynamics
  - What happens out of the equilibrium?

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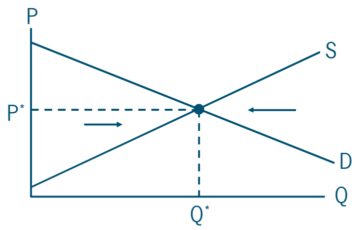
Equilibrium analysis in a market



Dynamic analysis in a fisheries system

- State variables
  - Size of the fish population
  - Size of the fishing fleet
- Changes in states
  - Net growth of the fish stock
  - Entry/exit of fishers

Net growth of the fish population

- The change in stock over time ($\dot{X}$) is equal to:

$$\dot{X} = G(X) - Y(X, E)$$

- Where
  - X denotes stock size
  - G denotes biological growth
  - Y denotes fish harvest
  - E denotes fishing effort

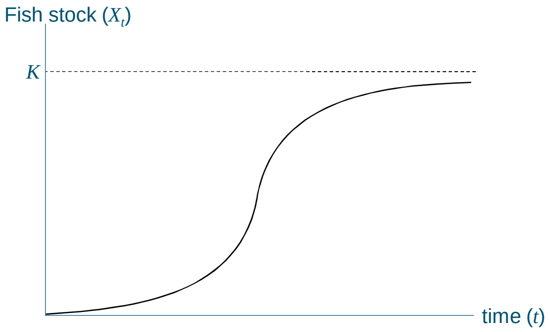
Net growth of the fish population

- Biological growth actually has two sources
  - Recruitment of juveniles
  - Growth of adults
- In the simplest model we lump this together and call it 'biomass':

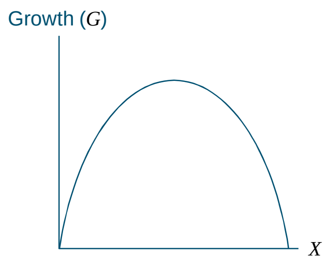
$$G(X) = rX\left(1 - \frac{X}{K}\right)$$

- where
  - r is the 'intrinsic growth rate'
  - K is the 'carrying capacity'

Logistic growth



Fish growth



Net growth of the fleet

- Fishers enter when profits are being made:

$\dot{E} = \delta\pi$

- where π denotes profits:

$\pi = pY(X, E) - cE$

- where fish harvest Y is:

$Y(X, E) = qEX$

- This harvest function assumes a *search fish*
- The alternative is a *schooling fish*
  - Harvest independent of stock

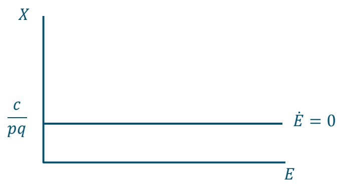
Finding a steady state

- State equations
  - Fish population: $\dot{X} = rX\left(1 - \frac{X}{K}\right) - qEX$
  - Fishing fleet: $\dot{E} = \delta(pqEX - cE)$
- Steady-state conditions
  - Fish population: $\dot{X} = 0$
  - Fishing fleet: $\dot{E} = 0$

Steady-state condition for fishing fleet

- Solve the steady-state condition:

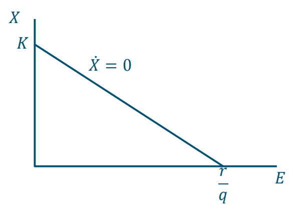
$\dot{E} = 0 \Rightarrow pqEX = cE \Longrightarrow X = \frac{c}{pq}$



Steady-state condition for fish stock

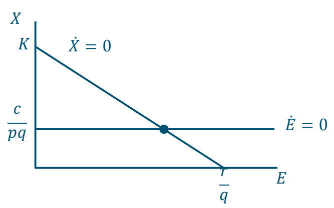
- Solve the steady-state condition:

$\dot{X} = 0 \Longrightarrow rX\left(1 - \frac{X}{K}\right) = qEX \Longrightarrow X = K\left(1 - \frac{q}{r}E\right)$

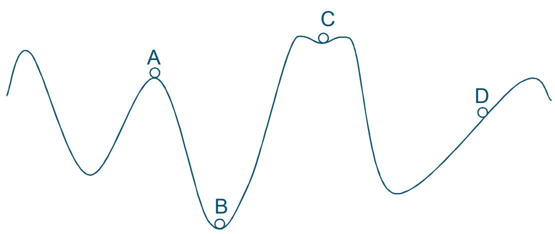


Steady-state in the entire system

- Both state variables are stable in the point where the lines cross:

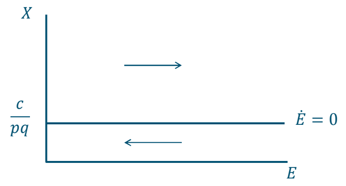


Steady states: stable and unstable



Fishing fleet dynamics

- How does the fishing fleet develop?
  - $X > \frac{c}{pq} \longrightarrow$ fishing fleet grows
  - $X < \frac{c}{pq} \longrightarrow$ fishing fleet shrinks



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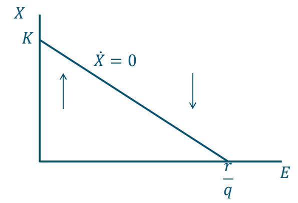
Fish stock dynamics

- How does the fish stock develop?
  - $qEX > rX\left(1-\frac{X}{K}\right) \longrightarrow$ fish stock declines
  - $qEX < rX\left(1-\frac{X}{K}\right) \longrightarrow$ fish stock grows



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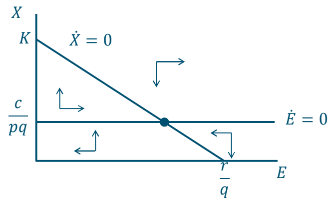
Dynamics in the entire system

- Consider the movement of both state variables:



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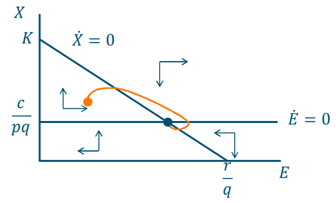
Dynamics in the entire system

- If you start from a given combination of X and E:



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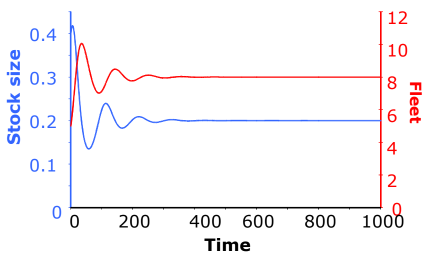
Dynamics in the entire system

- Typical development of stock and fleet over time:



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Dynamics of open-access fishing

- We saw a system with two state variables
  - Fish: biological growth
  - Fishers: free entry/exit
- We identified the steady state
- This steady state is stable
- But is good? Is it bad?
- To answer these questions we need a different approach

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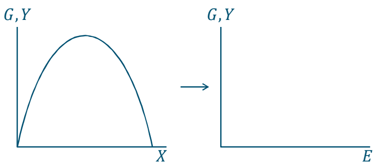
Sustainable yield curve (graphical)

- Relation effort – steady state yield:



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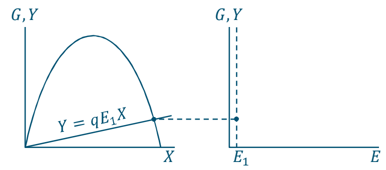
Sustainable yield curve (graphical)

- Consider one effort level (E_1):



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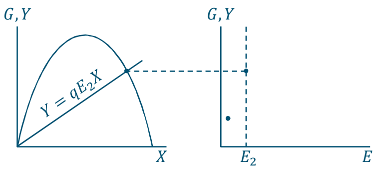
Sustainable yield curve (graphical)

- And another effort level (E_2):



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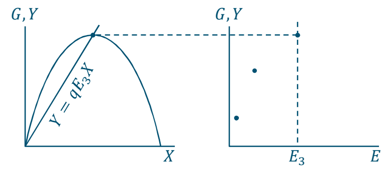
Sustainable yield curve (graphical)

- And another effort level (E_3):



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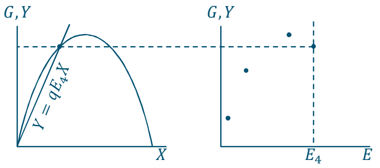
Sustainable yield curve (graphical)

- And another effort level (E_4):



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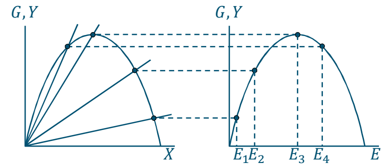
Sustainable yield curve (graphical)

- This way we can trace the effort-yield curve:



- Notice the similarity in shape – don't confuse them!

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Sustainable yield curve (mathematical)

- Steady-state condition fish population:

$$rX\left(1-\frac{X}{K}\right) = qEX \Rightarrow r - \frac{r}{K}X = qE$$

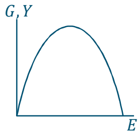
- Yield function:

$$Y = qEX \Rightarrow X = \frac{Y}{qE}$$

- Substitute yield function in steady-state condition:

$$r - \frac{r}{K}\frac{Y}{qE} = qE \Longrightarrow Y = qEK - \frac{K}{r}q^2E^2$$

- So yield is a parabolic function of effort:



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Sustainable revenue curve

- So far we derived sustainable *yield*:

$$Y = qEK - \frac{K}{r}q^2E^2$$

- Assume constant price to get sustainable *revenue:*

$$R = pY = p\left(qEK - \frac{K}{r}q^2E^2\right)$$

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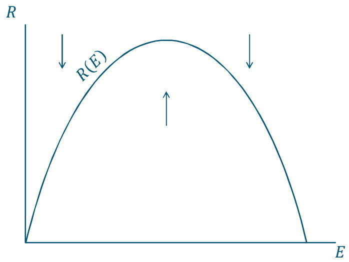
Sustainable revenue curve



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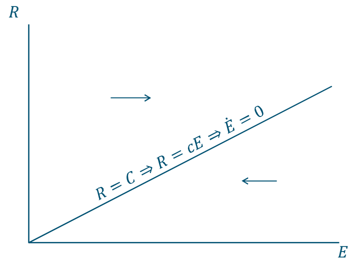
Cost curve



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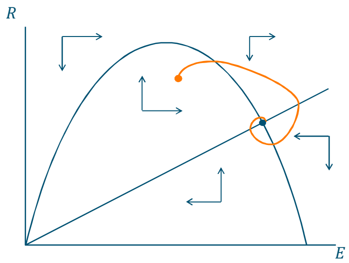
Dynamics of entire system



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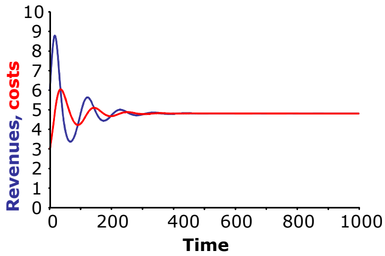
Dynamics in the entire system

- Typical development of costs and revenues over time:



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Summary

- Overfishing
  - Open access -> dissipation of rents
- Dynamics
  - Phase-plane diagram suggests fluctuations towards equilibrium
  - But how heavy they are depends on parameter values
- If this is inefficient, then what is efficient?
  - This afternoon: fisheries objectives
  - Tomorrow: modelling fisheries dynamics in R

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Tomorrow

Optimal fishing

MSY, MEY

Discounting

Optimal control

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