Fishing affects more than fish stocks: Overfishing, trophic cascade, regime shifts, biological invasions, and their effects on ecosystem functioning and fisheries

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... In the spring the mackerels and bonitos move to the Pont (Euxin) where they stay during the summer like all other fishes swimming in schools. And they are very numerous ... They go to the Pont for food, because there the food is better and more abundant because of the rivers' water... And they spawn there because there are many suitable places and the rivers' water is good for feeding their larvae ...
Aristotle, Historia Animalium, 384-322 BC

Bluefish. Photo by L. Klissurov © http://www.klissurov.dir.bg g

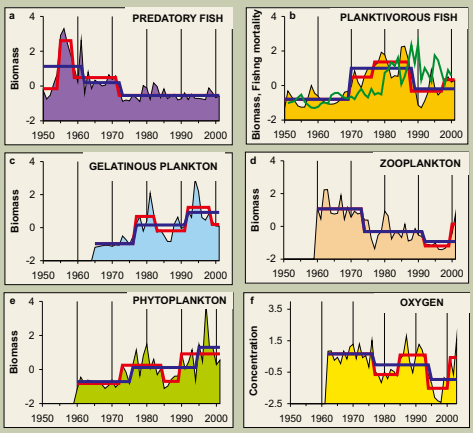
Once described as healthy and dominated by various marine predators, the Black Sea ecosystem had experienced, by the late 20th century, serious anthropogenic impacts

1950 1966	Decimating the dolphin population
~1970	Collapse of bonito and bluefish and disappearance of the mackerel
~1970	Construction of the Iron Gates dams on the river Danube
1970s	Intensive bottom trawling and silt disposal the NW Black Sea
1975-1985	Development of industrial fishery for small pelagic fish
1975-1990	Increase in the nutrient loadings, cultural eutrophication and related effects of bottom hypoxia and hydrogen sulphide production
1975-1985	Increased biomass of the jellyfish *Aurelia aurita*
1975-1980	Collapse of the red algae *Phyllopora* and black mussel populations
1980-1990	Increased plankton blooms accompanied by hypoxia and benthos mortality
~1985	Collapse of the turbot stock
~1988	Invasion of the ctenophore *Mnemiopsis leidyi*
~ 1990	Collapses of most of the commercially exploited fish stocks
1997	Invasion of the ctenophore *Beroe ovata*
2000s	Relative decrease of the nutrient loading
2000s	Relative decrease in *M. leidyi* and partial recovery of sprat and anchovy

Jelly-fish Aurelia aurita swarm. Photo by L. Klissurov © http://www.klissurov.dir.bg

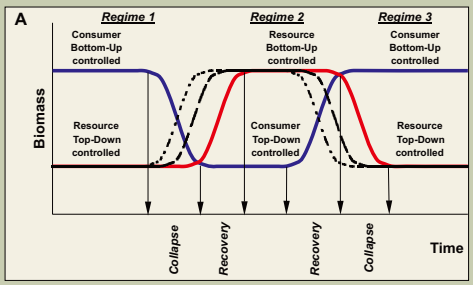
Fishing can trigger ecosystem scale regime shifts

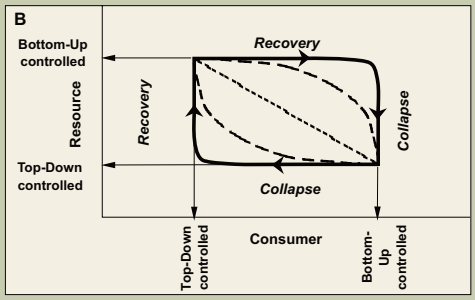
Marine ecosystems exist in internally consistent dynamic states, or regimes. Switches between alternative regimes are called regime shifts and can be driven by both external forcing (climate change, cultural eutrophication, overfishing) and internal perturbations. Alternating top-down and bottom-up controls, trophic cascade, fish stock collapse and recovery and alien invasions may be between the causes and consequences of ecosystem regime shifts



Conceptual model of top-down driven regime shift and recovery

Food webs are controlled alternatively by consumption (top-down control) or by production and availability of resources (bottom-up control). Prey populations are top-down controlled when their biomass productivity is low and/or they are heavily exploited by consumers. They are bottom-up controlled when they are only lightly exploited and/or biomass productivity is high. In such systems, a switch to an alternative regime (i.e. a **regime shift**) can be driven by overexploitation of the consumer population. The return to initial states follows a different path (**hysteresis**) and leads to recovery of consumer biomass, which subsequently suppresses the resource biomass at a lower level.

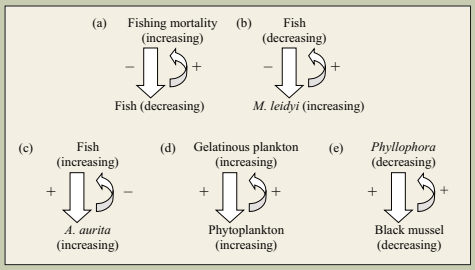




Feedback mechanisms of regime shifts

Structural/functional transformations related to regime shifts often involve positive and negative feedbacks and interactions between fast and slow processes. Feedback effects are positive when leading to amplification of the existing direct effects, and negative when reducing the strength of direct effects.

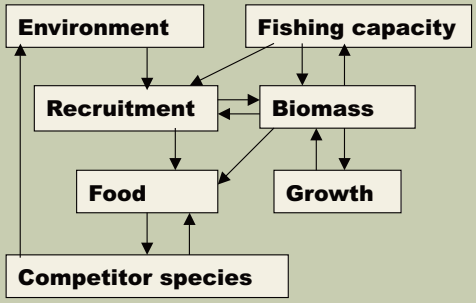
Comb-jelly Mnemiopsis leidyi. Photo by L. Klissurov © http://www.klissurov.dir.bg



Mechanisms of fish stock collapse and recovery

Fish Stock Collapse

1. Decrease in fish productivity related to fluctuating environment, biological interactions
2. Sustained and growing fishing pressure: building fishing capacity and improvement in technology
3. Multi-species effects: food competition, changes in dominance
   Trophic cascade and environmental deterioration

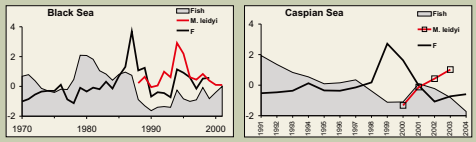


... and Recovery

1. Reduction in fishing fleet capacity and effort
2. Increase in fish production and biomass
3. Normalisation of species interactions: diverse community, abundant food
4. Buffering of trophic cascades and improved environment

Overfishing and intrusion of Invasive species

The settling and outbursts of the invasive *M. leidyi* followed the overfishing of abundant planktivourous fish in the Black and Caspian Seas.



Conclusions and lessons for the Ecosystem Approach to Fisheries management

- Ecosystem regime shifts associated with trophic cascades are detected from analysis of "natural experiments" – top-predator extinction and *M. leidyi* invasion
- Overfishing is recognised as a main driving factor, though associated with other factors such as climate, eutrophication, and alien invasion
- Fishing is a structuring factor affecting not only fish stocks, but the whole ecosystem and can be responsible for a system shift to pathological states
- Recovery of a resilient ecosystem should mean restoring all important components into a new desirable states: reducing the anthropogenic impact, normalizing species interactions, buffering trophic cascades, increasing biodiversity, and improving environmental quality.
- Fisheries are subject to regulation and management that must target recovery of damaged ecosystems into a healthy and resilient state. Partial recovery of only some components is not stable and may drag the system back into an undesirable state

Bottom ecosystem. Photo by L. Klissurov © http://www.klissurov.dir.bg

Black Sea flounder. Photo by L. Klissurov © http://www.klissurov.dir.bg

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