Who is controlling whom in marine ecosystems?

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Institut de recherche pour le développement

Seal-bird-fish Interaction in the Benguela ecosystem

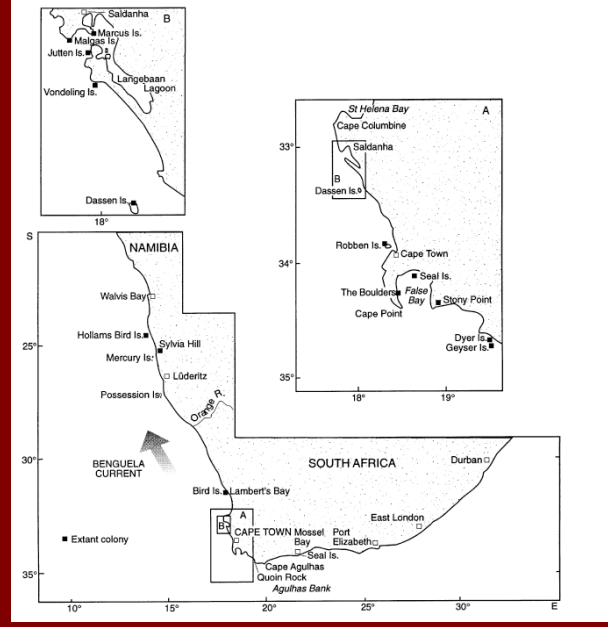
(Cury et al. 2000; David, Cury et al. Biol. Cons. 2003)

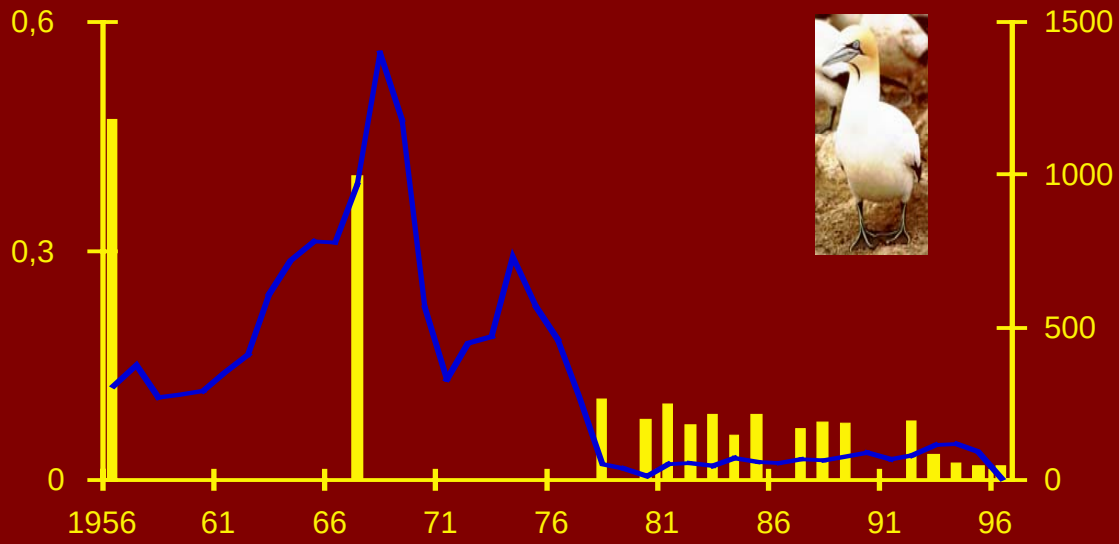
Seals are killing protected marine birds populations

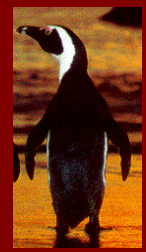
Predation process

Pelagics are controlling marine birds populations

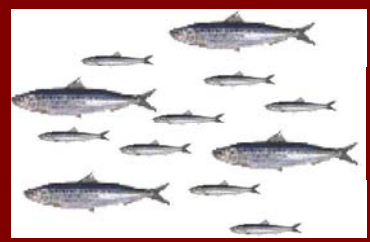
Predation pattern



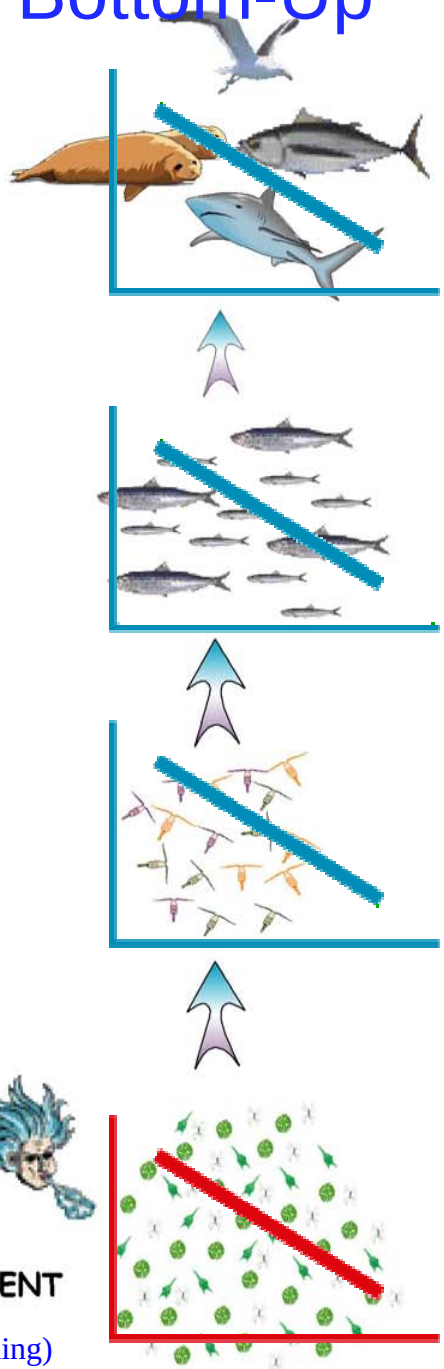




Bottom-up control



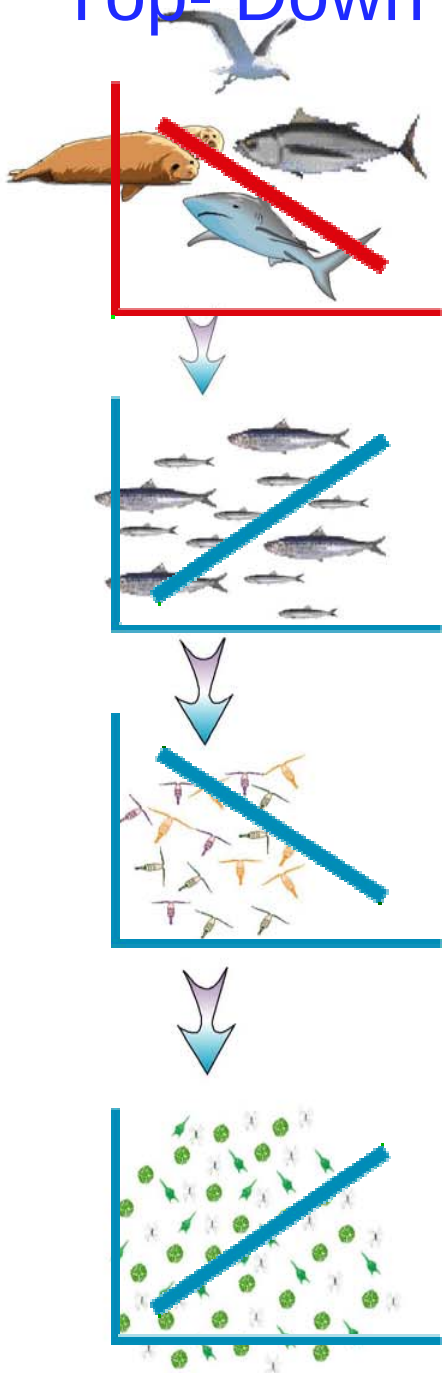
Bottom-Up



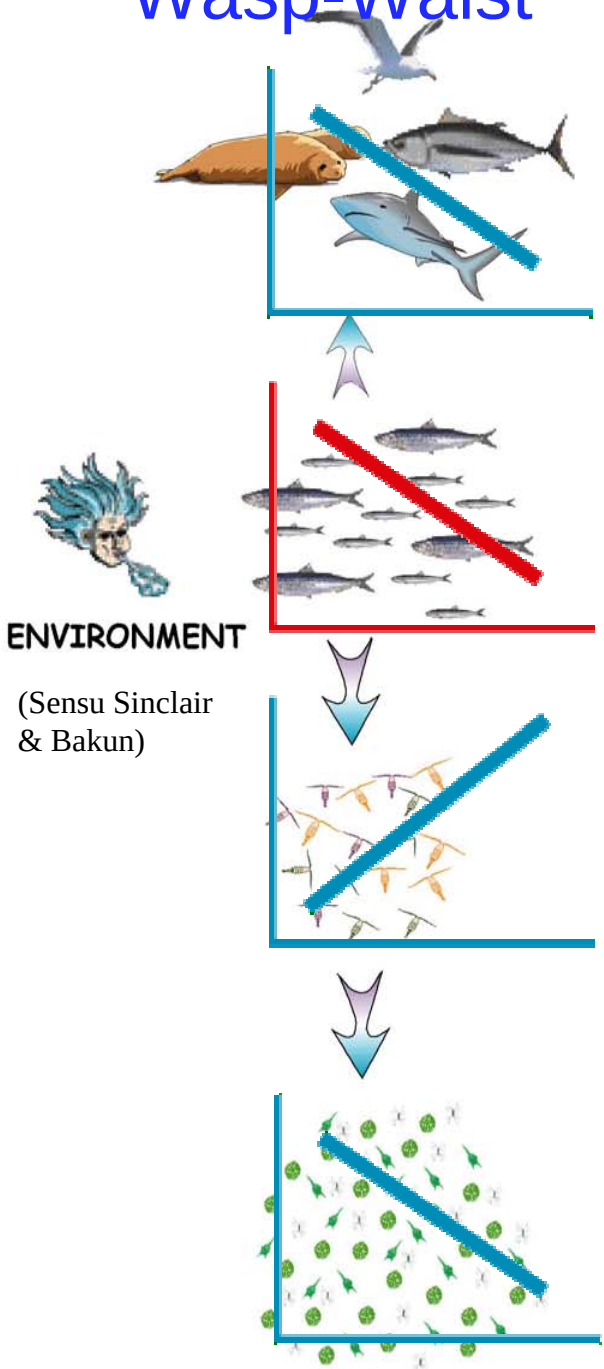
ENVIRONMENT

(Sensu Cushing)

Top- Down



Wasp-Waist



ENVIRONMENT

(Sensu Sinclair & Bakun)

No General Theory can be ascribed to the Functioning of Marine Ecosystems

Our ability to predict ecosystem trajectories is limited

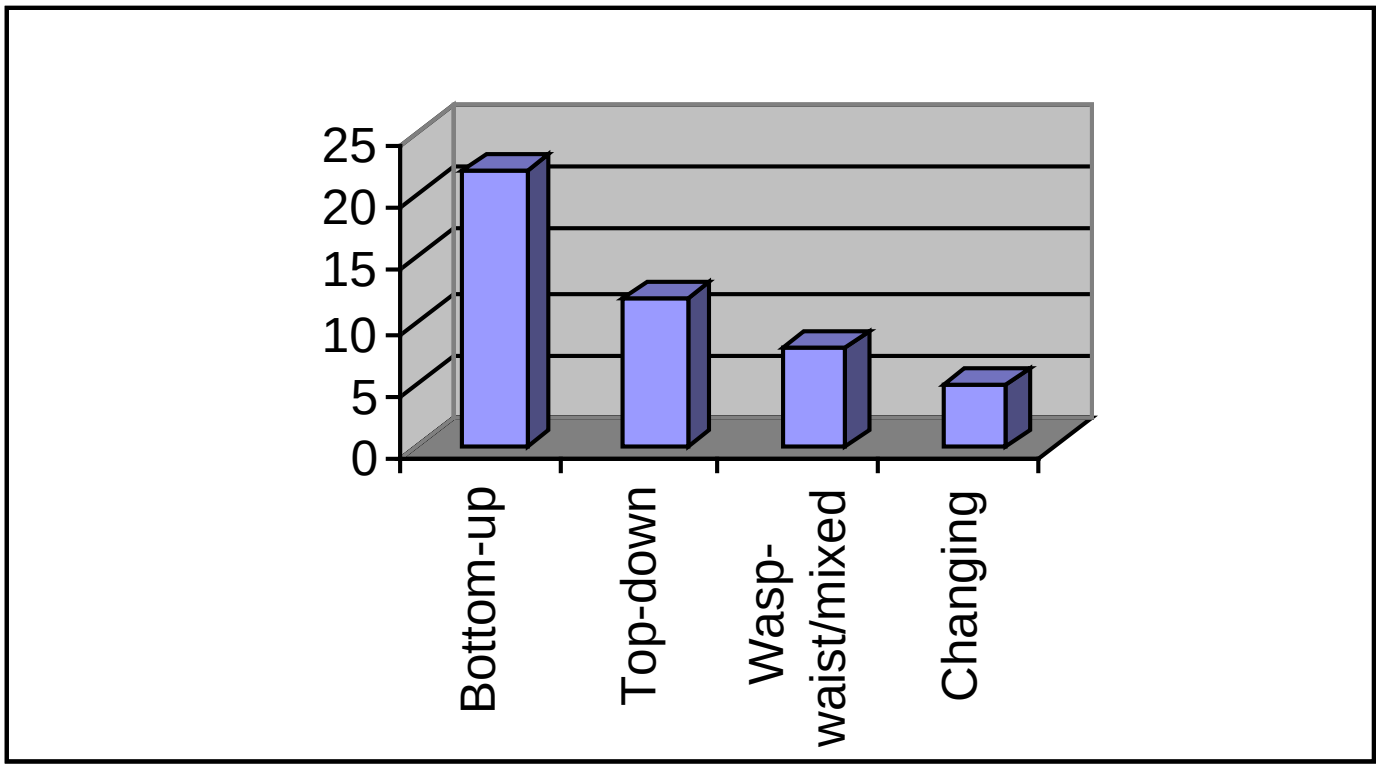
Tentative generalisations can be proposed for selected components of marine ecosystems

- Control by the environment (bottom-up control) predominates
- Control by predators (top-down control) plays a role in dampening ecosystem-level fluctuations
- Wasp-waist control is most probable in upwelling systems

Published examples of controls in marine ecosystems

(Cury, Shannon, Shin et al. 2005)

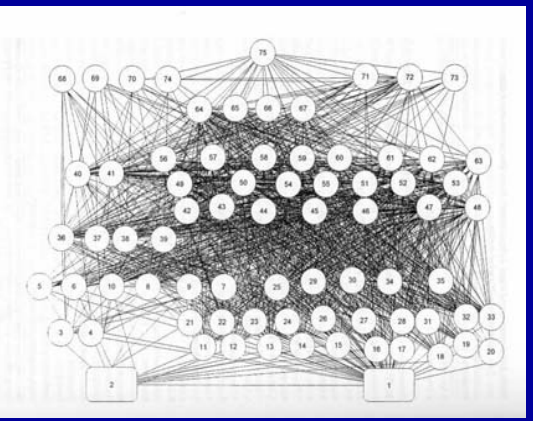
(with a fish component - mostly published after 1995)

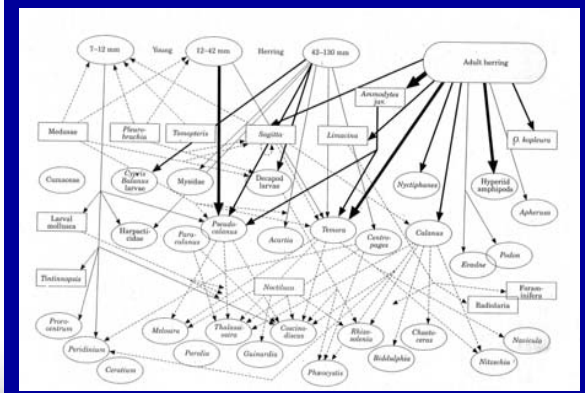


Ecosystems Models

processes ⇢ *patterns*

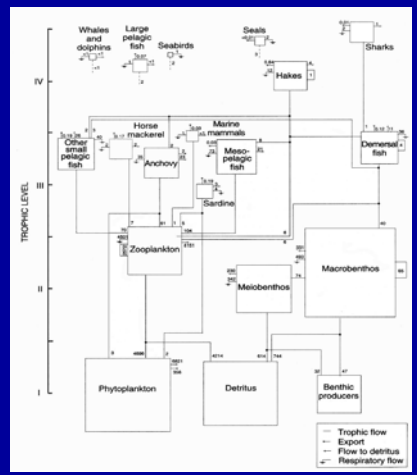
Complex and multiple Interactions

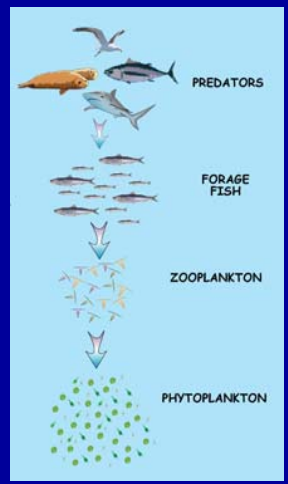




Food-Webs with preferential trophic interactions

Trophic levels





Food-Chain

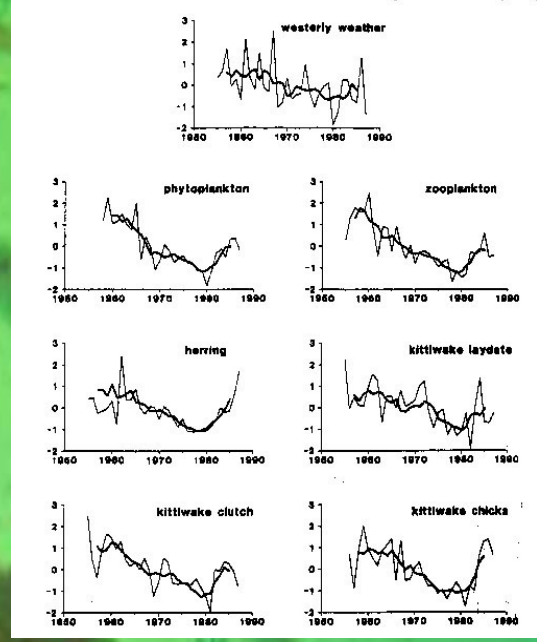
Who is controlling whom in marine ecosystems?

- Patterns & Controls
- Processes & Controls
- Towards Integrated Studies

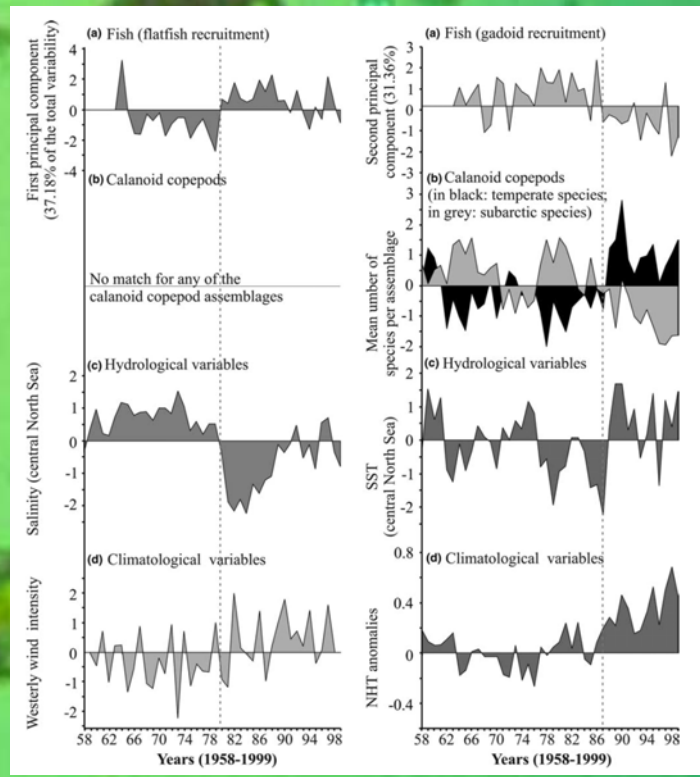
Patterns & Controls

Bottom-up Control

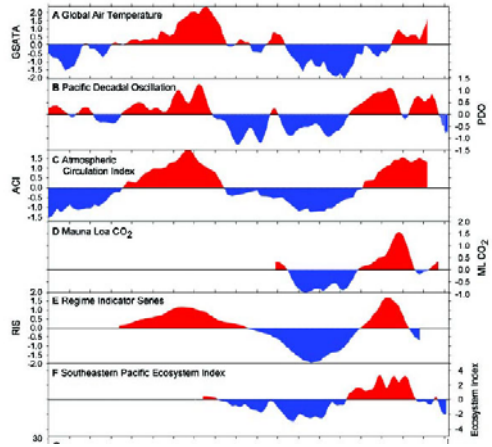
Parallel long-term trends across four marine trophic levels and weather in the North Sea
(Aebischer et al 1990)



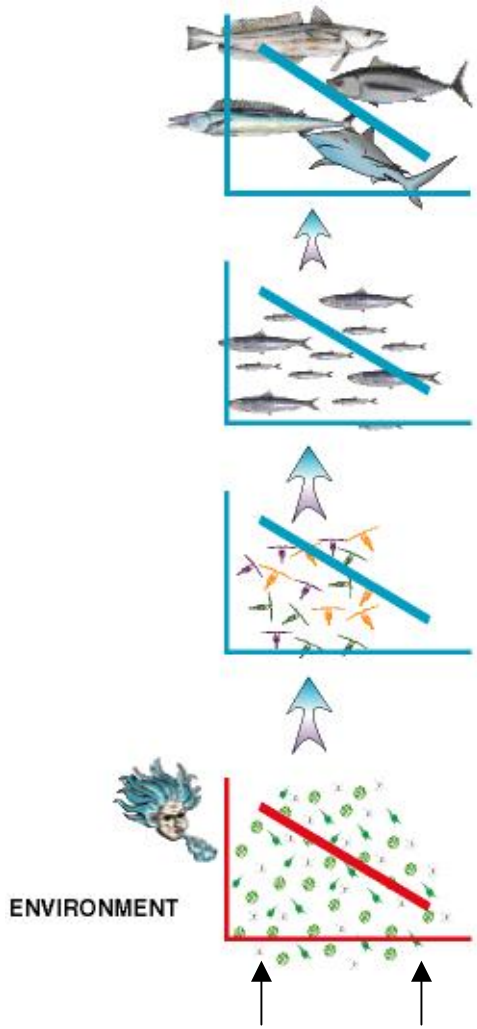
Long-term changes in the North Sea
(Beaugrand 2004)



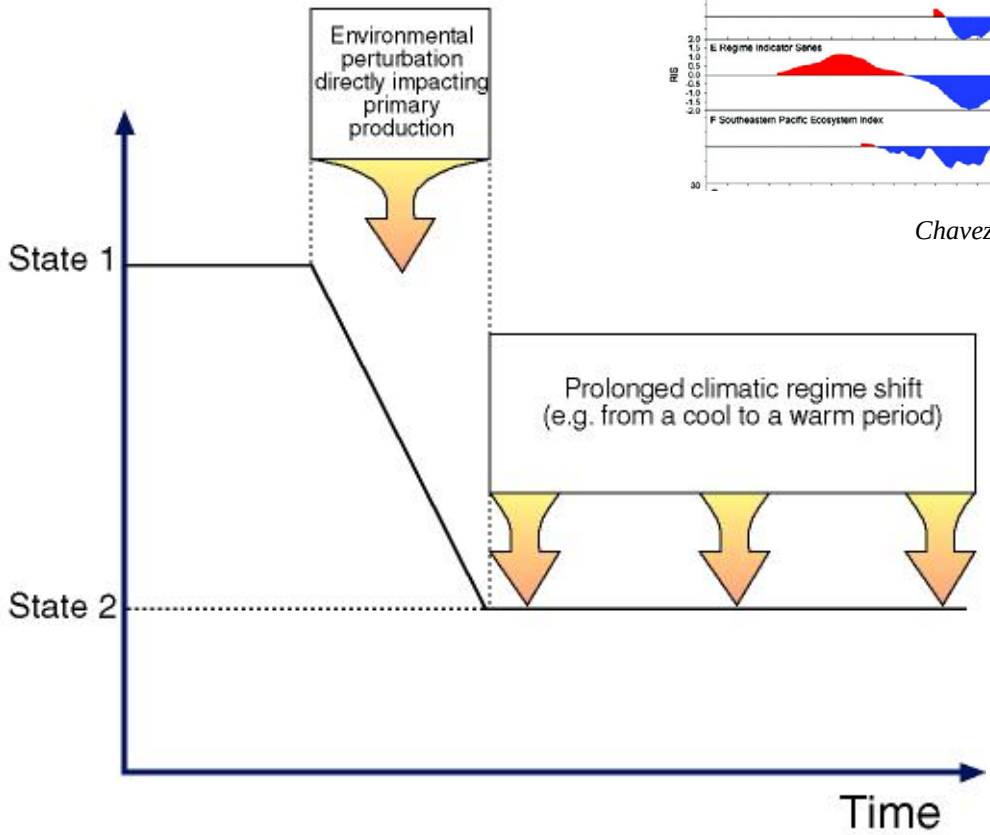
Regime Shift & Bottom-up Control

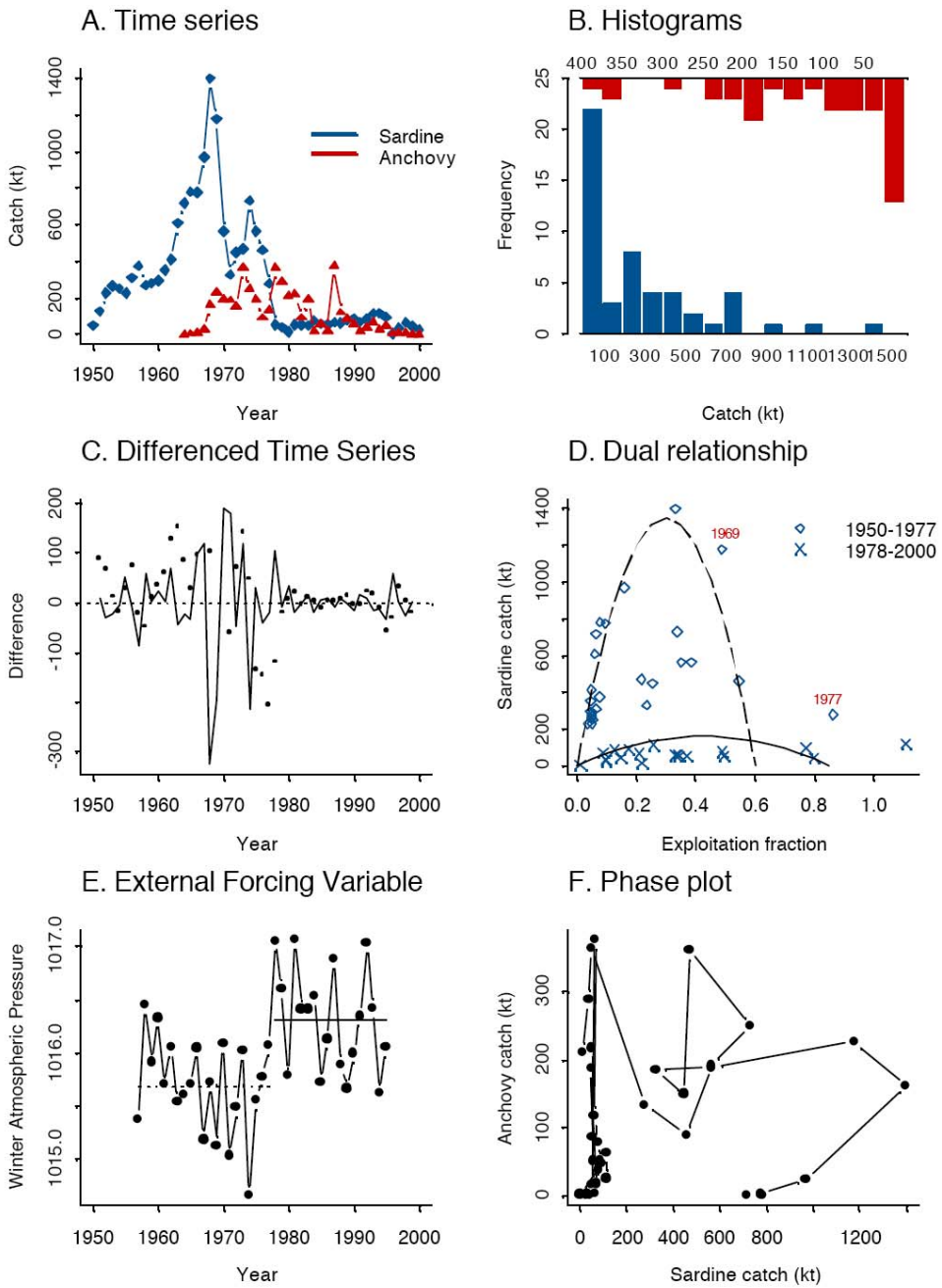


Chavez et al 2003



State 1 State 2



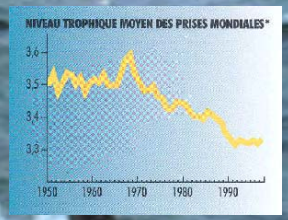


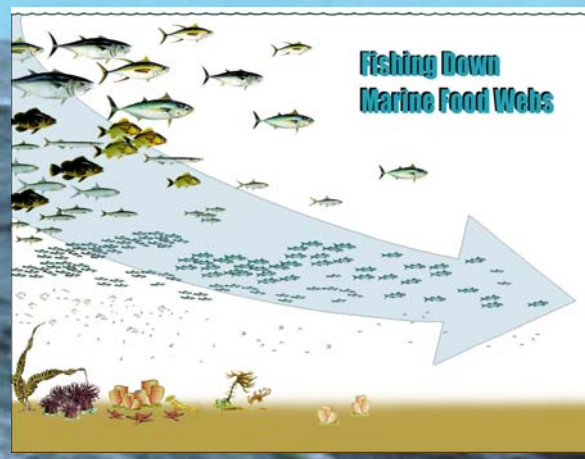
Northern Benguela: Empirical identification of a regime shift

(Collie et al. 2004)

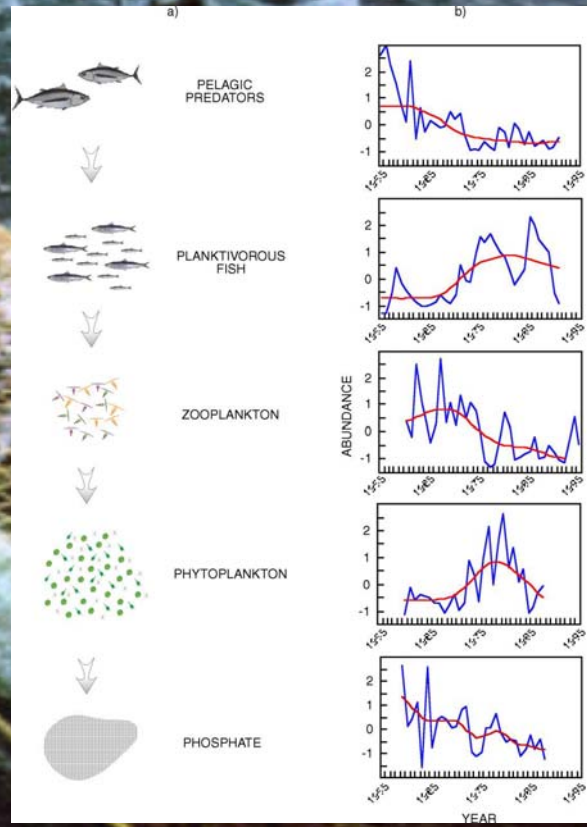
Top-Down Control

Fishing-down marine food-webs
(Pauly et al. , 2002)

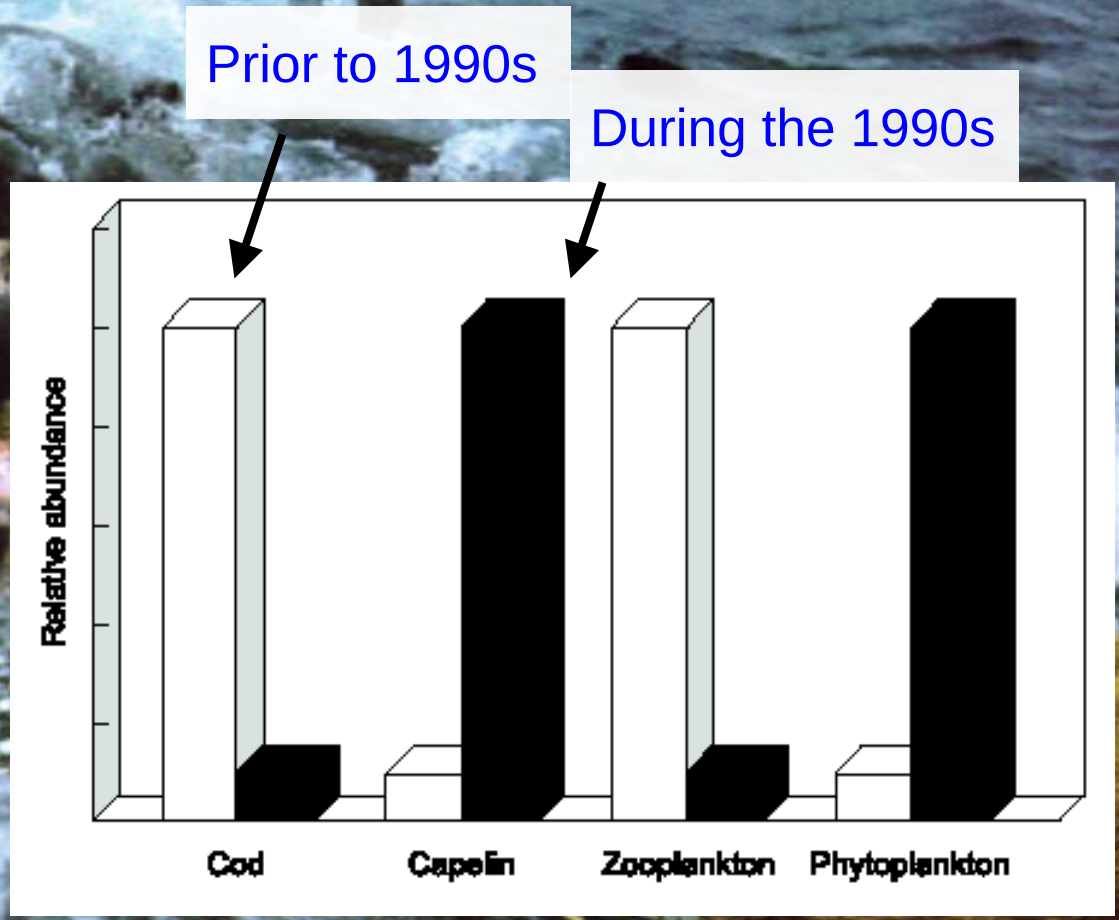




Inverse trends across consecutive trophic levels reveals a trophic cascade in the Black Sea
(Daskalov, 2002)

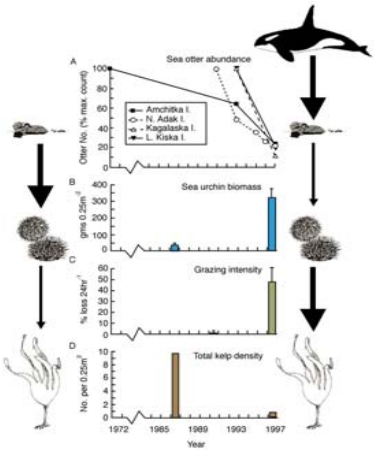


Top-Down Control

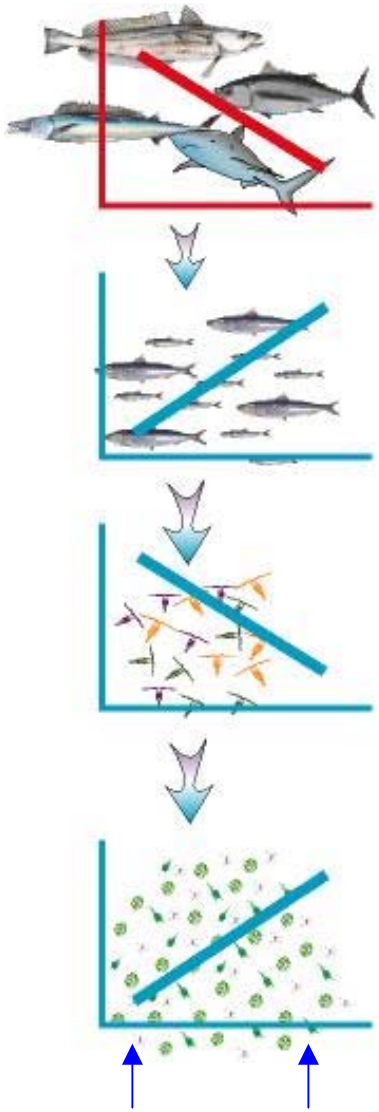


Trophic cascade in the Northwest Atlantic Newfoundland
(Carscadden et al. 2001)

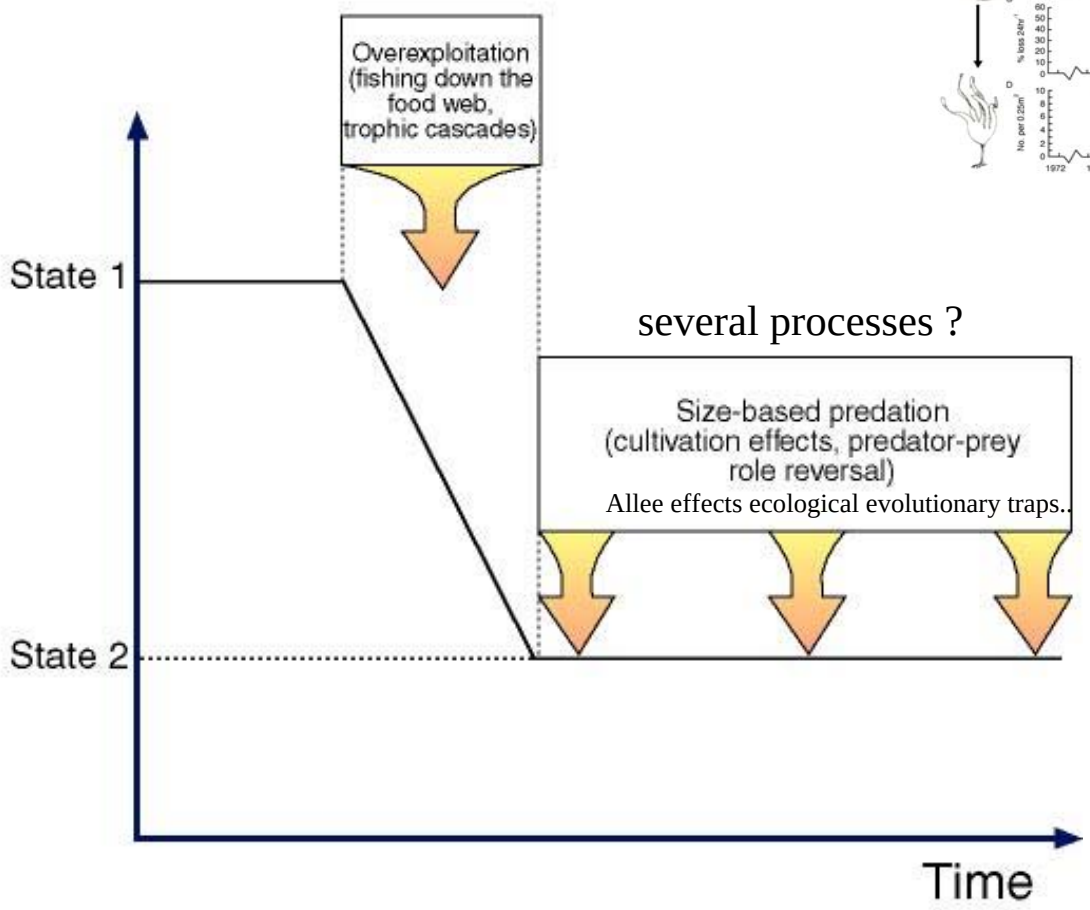
Regime Shift & Top-down Control



Estes et al. 1998



State 1 State 2



several processes ?

Size-based predation
(cultivation effects, predator-prey
role reversal)

Allee effects ecological evolutionary traps..

Top-Down Control

- Several examples of cascading effects and Regime shifts induced by fishing down the food-web?

Shifts from demersal fish dominated to pelagic fish dominated ecosystem (or short-lived species such as shrimps, crabs, squids or octopus) have been documented in the Atlantic, the Baltic, the Canary current, the Northwest Atlantic…(Cury, Shannon, Shin, et al. 2005)

Shifts from fish-dominated to jellyfish-dominated ecosystems have been observed in the Bering Sea, the Black Sea, the Gulf of Mexico, the western Mediterranean Sea, Tokyo Bay and off Namibia (Parsons & Lalli 2002)…

Patterns & Controls

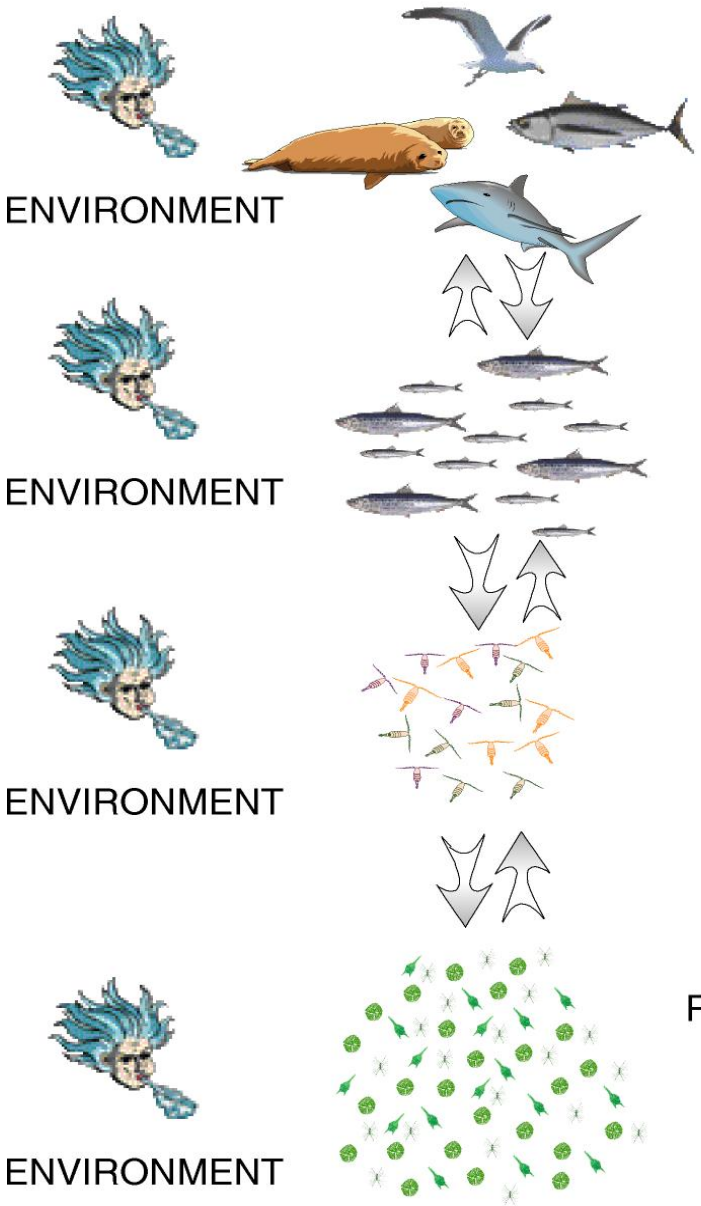
Strong controls exist in marine ecosystems between selected components of the environment

- What are the underlying mechanisms?
- What processes are involved, the speed at which they act, their potential reversibility?
- What are the effects on the other components of the ecosystem?
- Role of controls to initiate and sustain regime shifts?

Processes & Controls

a)

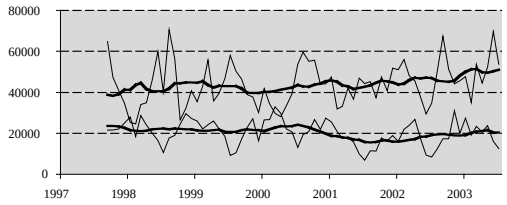
b)



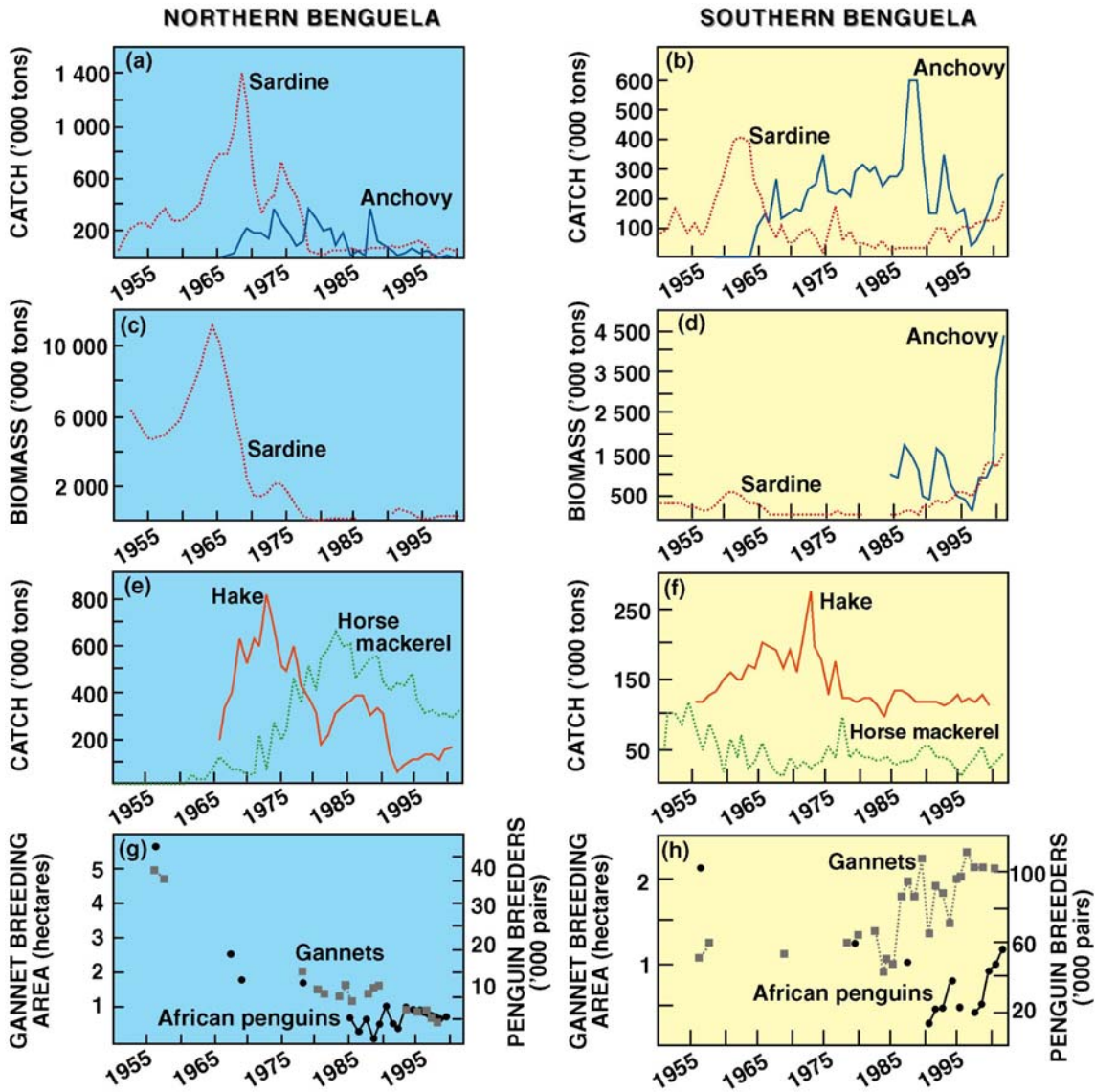
MIXED CONTROL

Benguela: Complex Ecosystem dynamics?

- Several trajectories are not predicted by simple controls
- Top-down versus bottom-up controls are not considered simultaneously
- Why drastic changes of major components can be observed under relatively stable productivity?
- Why sardine and anchovy collapsed and do not recover in the northern Benguela?
- Why top-predators abundance is controlled by their prey?



Chla integrated biomass index
Demarcq 2004



Dynamics of controls: Processes involved

- Ecological processes (predation, competition, evolutionary traps….)
- Spatial and temporal constraints
- Behaviour (e.g. habits, preferences, changing migrations…)

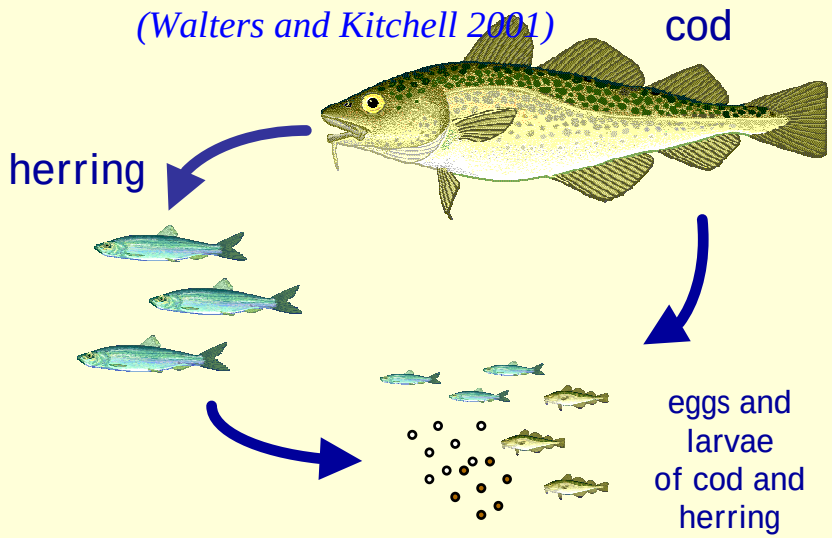
1. Predation:

Size structured trophic interactions

Cultivation effect

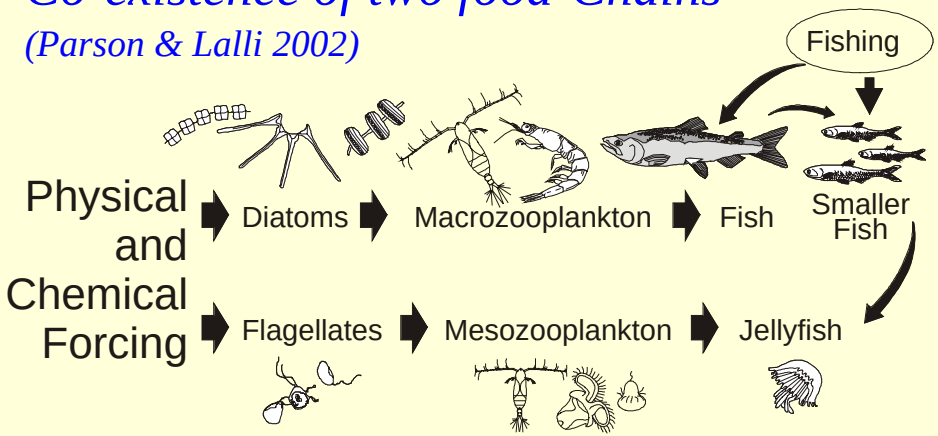
Community based predation

(Walters and Kitchell 2001)



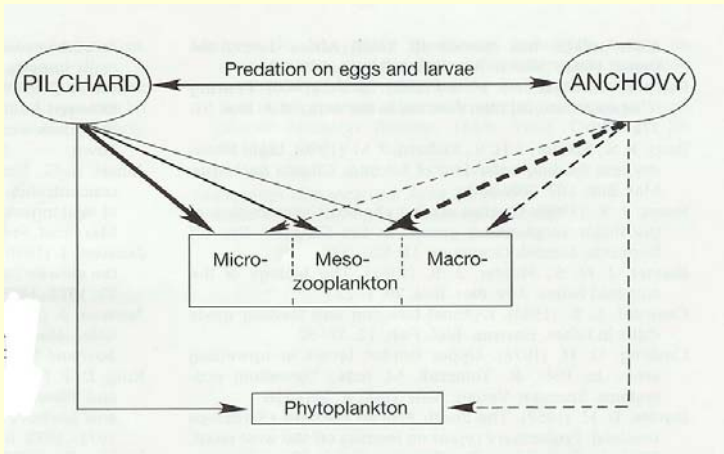
Co-existence of two food-Chains

(Parson & Lalli 2002)



Size or quality food preferences

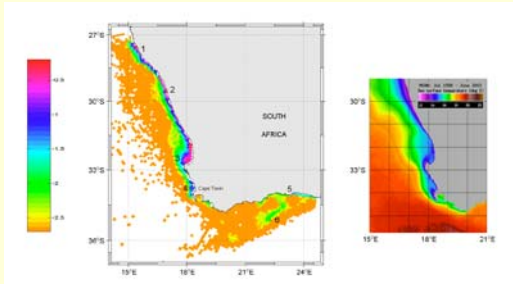
(Van der Lingen 2004)



2. Spatial Constraints

To integrate mesoscale environmental processes in recruitment studies

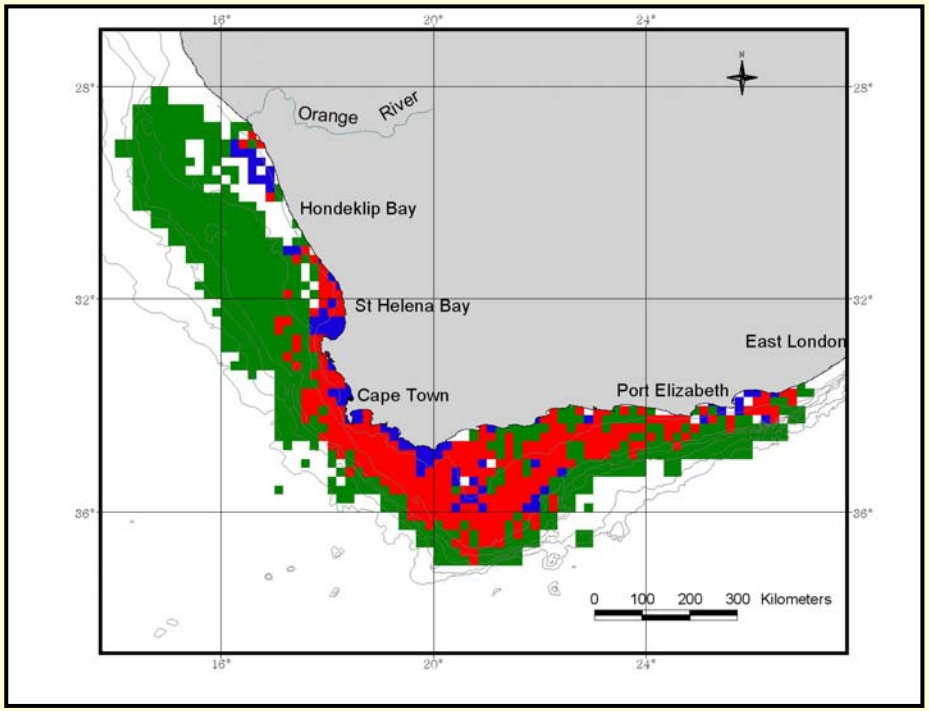
(Bakun 1996, Sinclair et al. 2001; Lett et al. press)

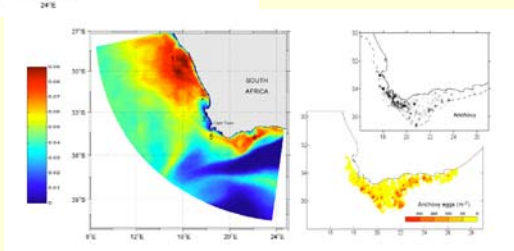


production

Spatial interactions
between a predator and its prey

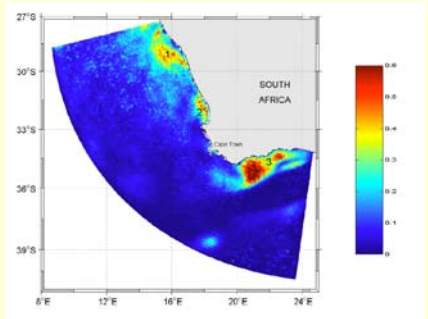
(Drapeau & Freon 2004)





concentration

retention



Hake only

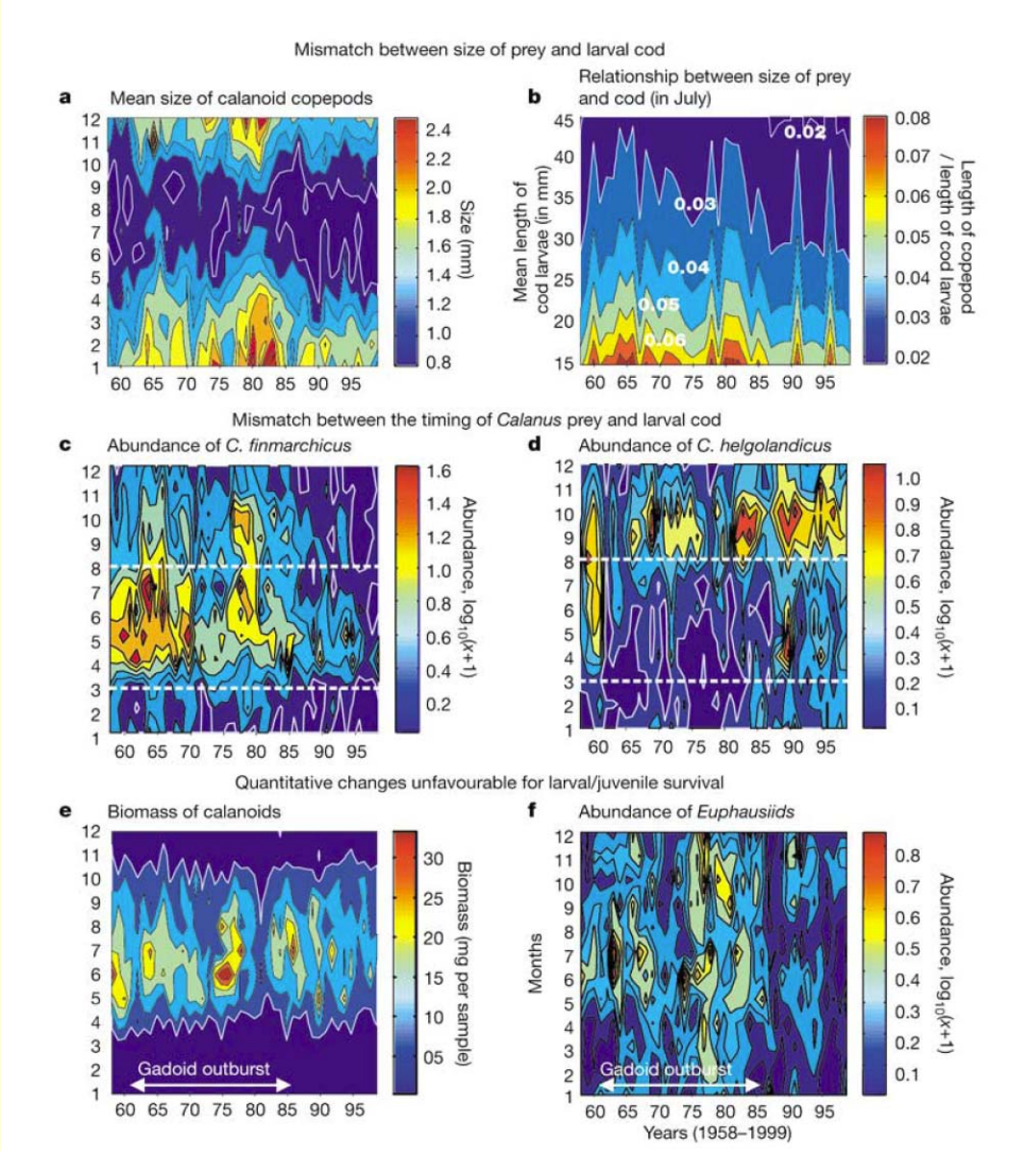
Pilchard only

Hake & Pilchard

Quantification of the triad using 3D hydrodynamical model

4. Temporal constraints

Temporal match-mismatch between cod & calanus
(Beaugrand 2003)

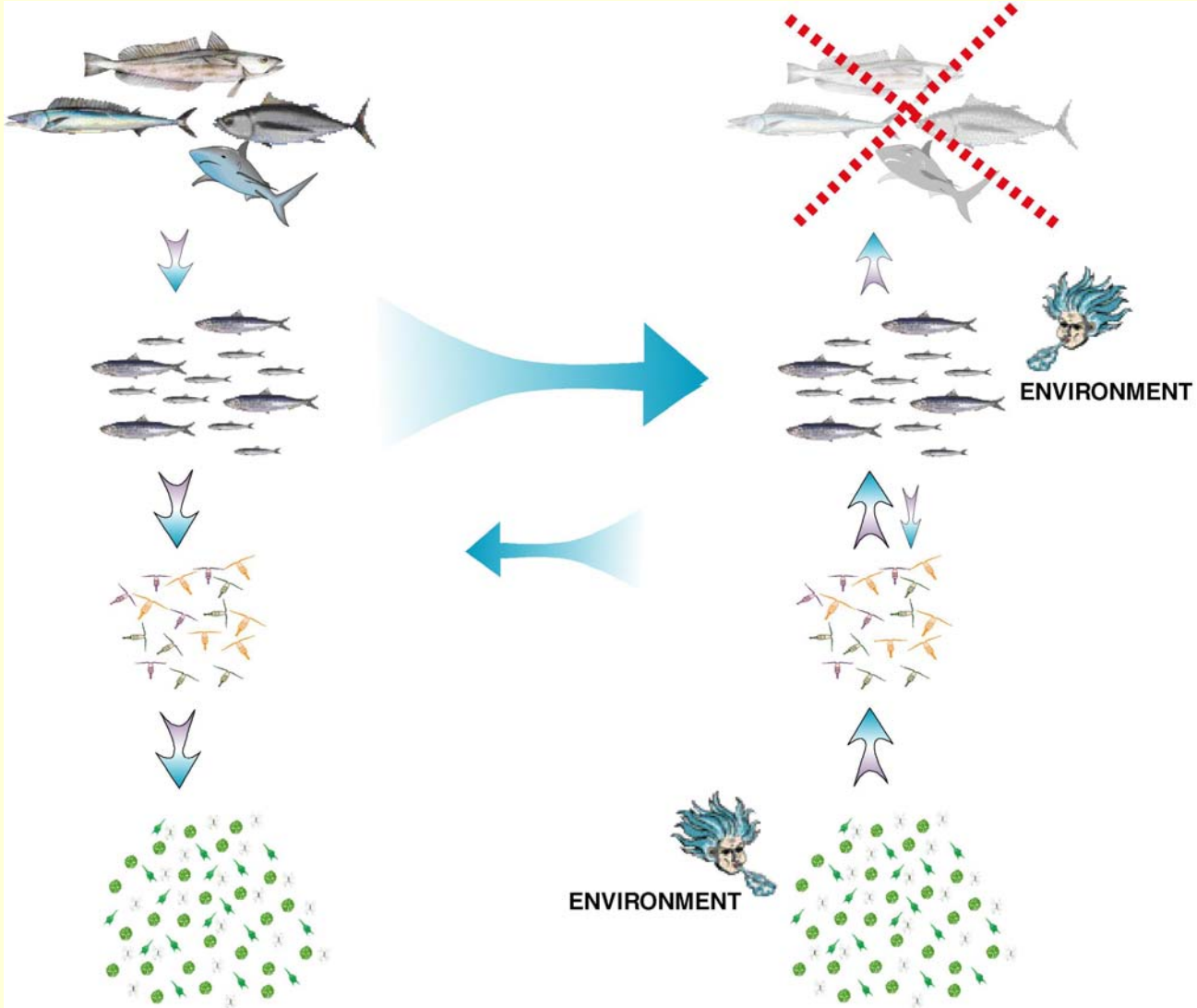


Linking Patterns & Processes

Fishing down marine food-webs and global climatic change

Fisheries affect ecosystems in a way that they become more sensitive to environmental

changes?

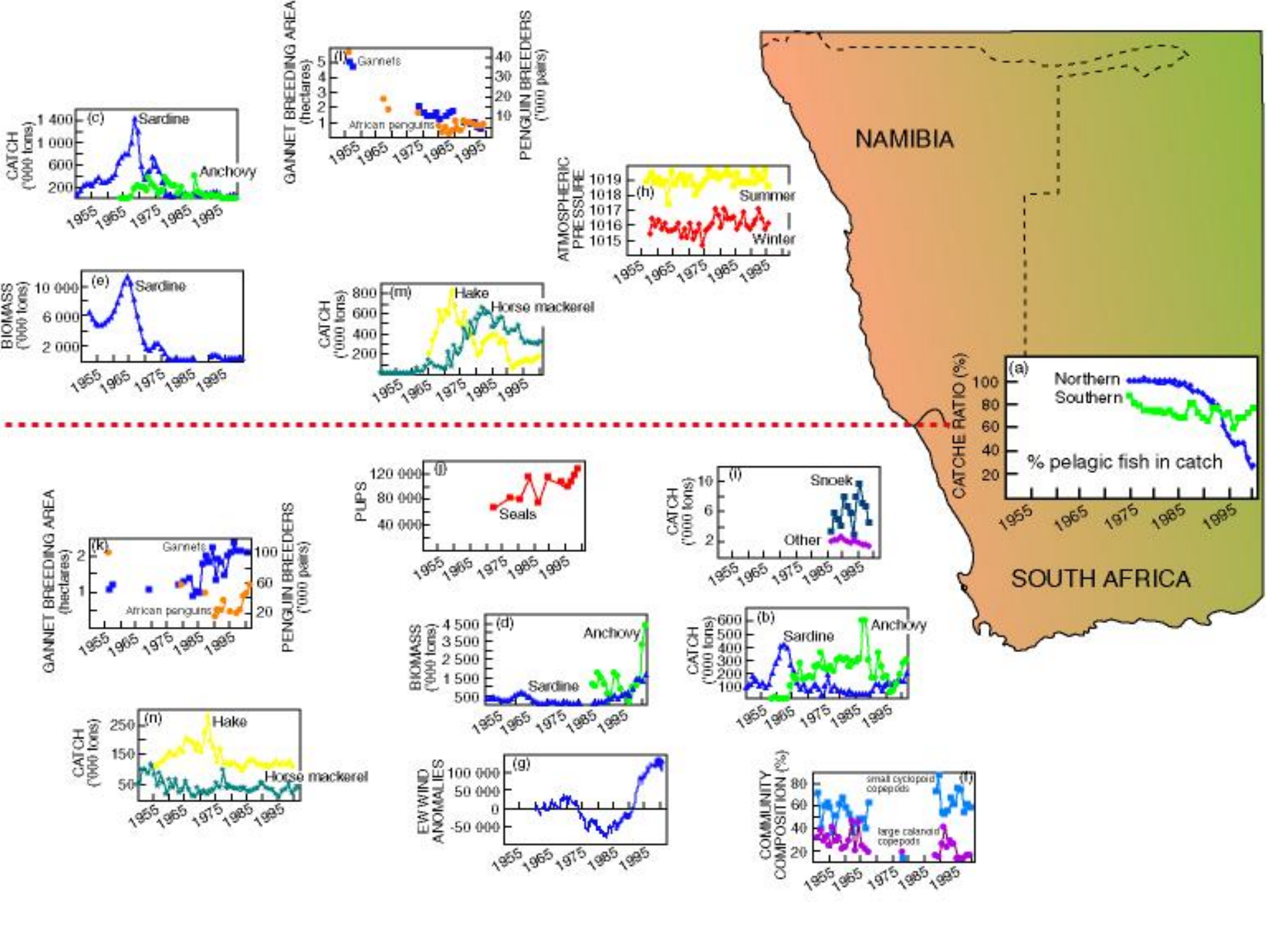


Key Scientific Issues

- Quantifying controls (top-down, bottom-up & wasp waist) and integrate them into ecosystem models
- Controls & regime shifts (not only bottom-up!)
- Controls & recruitment studies (Cushing versus - Sinclair/Bakun)
- Indicators to quantify controls for EAF (bottom-up effects on food-webs)
- Towards a possible generalization of controls (towards an ‘ecology of ecosystems’?)

Studying controls

- For ecological understanding (e.g. Regime shifts)
- For improving models, hypotheses and predictions (e.g. Lokta-Volterra, functional responses, foraging arena, …)
- For EAF and management (tuning ecological interactions, reconciling conservation and exploitation)


NAMIBIA
SOUTH AFRICA
(a)
Northern
Southern
% pelagic fish in catch
CATCHE RATIO (%)
(b)
Sardine
Anchovy
CATCH ('000 tons)
(c)
Sardine
Anchovy
CATCH ('000 tons)
(d)
Anchovy
Sardine
BIOMASS ('000 tons)
(e)
Sardine
BIOMASS ('000 tons)
(f)
small cyclopoid copepods
large calanoid copepods
COMMUNITY COMPOSITION (%)
(g)
EW WIND ANOMALIES
(h)
Summer
Winter
ATMOSPHERIC PRESSURE
(i)
Gannets
African penguins
GANNET BREEDING AREA (hectares)
PENGUIN BREEDERS ('000 pairs)
(j)
Seals
PUPS
(k)
Gannets
African penguins
GANNET BREEDING AREA (hectares)
PENGUIN BREEDERS ('000 pairs)
(l)
Snoek
Other
CATCH ('000 tons)
(m)
Hake
Horse mackerel
CATCH ('000 tons)
(n)
Hake
Horse mackerel
CATCH ('000 tons)
1955
1965
1975
1985
1995

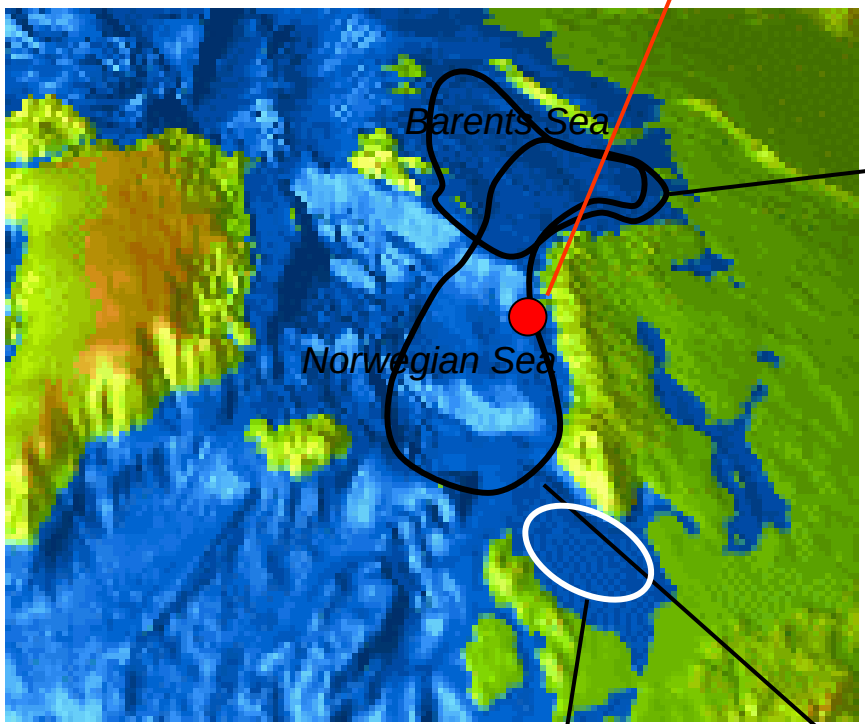
Mapping study areas and species & Quantifying controls

(Hjermann et al. 2004, Stenseth 2003, 2004)

Puffin (*Fratercula arctica*)

Norwegian Sea

Barents Sea



Atlantic cod
(*Gadus morhua*)

Norwegian spring-spawning herring
(*Clupea harengus*)

Capelin
(*Mallotus villosus*)

Calanus

Atlantic cod
(*Gadus morhua*)

$$\log(N^1_t) = a_1 + (1\text{-}b_1)\cdot\log(N^{mat}_{t-2}) - c_1\cdot(harv_{aut,t-2}+harv_{wint,t-1})/BM_{t-2} - d_1\cdot\log(cod_{t-1}{}^{\alpha}\cdot BM_{t-1}{}^{\beta}) - e_1\cdot herr_{t-1}$$

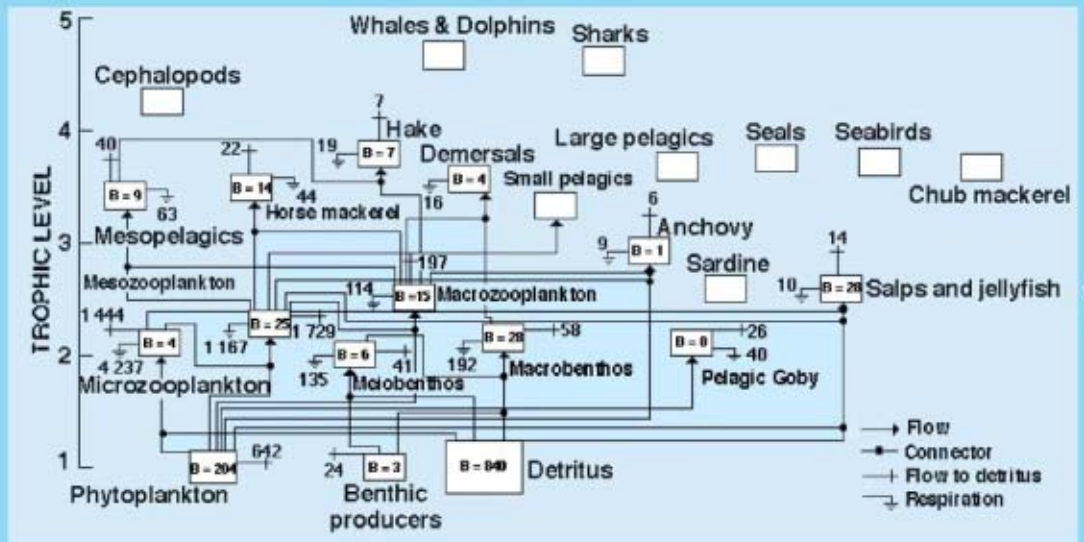
$$\log(N^2_t) = a_2 + (1\text{-}b_2)\cdot\log(N^1_{t-1}) - c_2\cdot harv_{aut,t-1}/BM_{t-1} - d_2\cdot\log(cod_t{}^{\alpha}\cdot BM^{immat}_{t-1}{}^{\beta}) - e_2\cdot herr_t$$

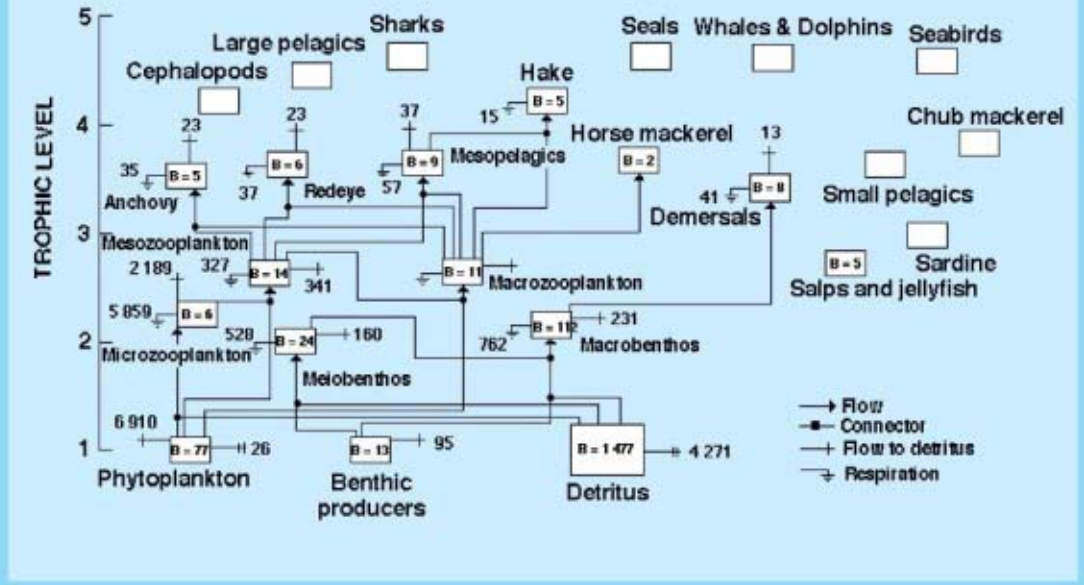
$$\log(N^3_t) = a_3 + (1\text{-}b_3)\cdot\log(N^2_{t-1} - N^{2,mat}_{t-1}) - c_3\cdot harv_{aut,t-1}/BM_{t-1} - d_3\cdot\log(cod_t{}^{\alpha}\cdot BM^{immat}_{t-1}{}^{\beta}) - e_3\cdot herr_t$$

$$\log(N^4_t) = a_4 + (1\text{-}b_4)\cdot\log(N^3_{t-1} - N^{3,mat}_{t-1}) - c_4\cdot harv_{aut,t-1}/BM_{t-1} - d_4\cdot\log(cod_t{}^{\alpha}\cdot BM^{immat}_{t-1}{}^{\beta}) - e_4\cdot herr_t,$$

Develop ecosystem models

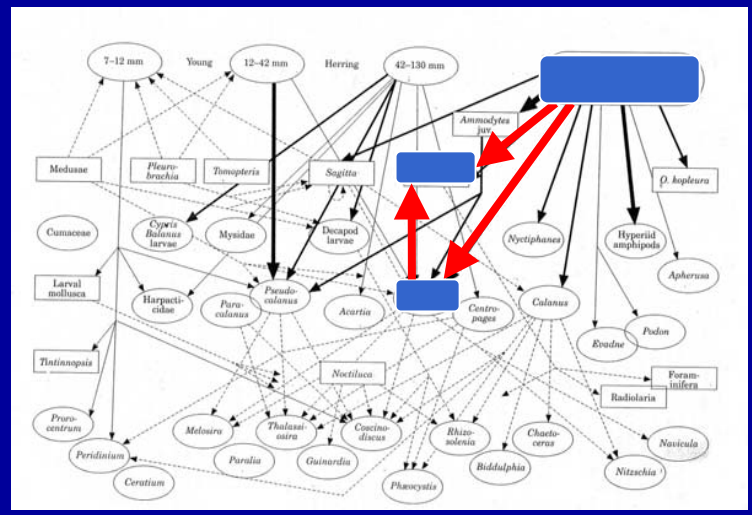
Northern versus Southern Benguela (Shannon & Roux)





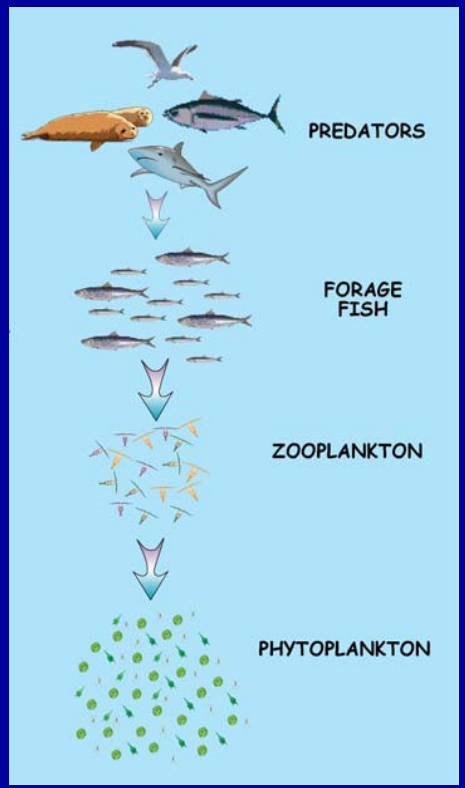
5. From food-chain to ecosystems models: controls and food web dynamics

Processes



How a strongly structured sub-system can affect the overwhole dynamics of a food-web?

Patterns



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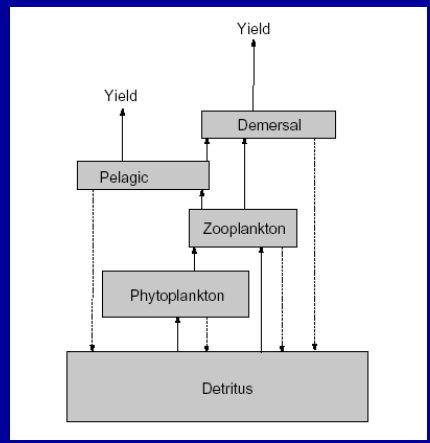

How to simplify a complex system?

Quantifying Controls and their importance for ecosystem dynamics

- Field & behavioural studies:
  - Experiments and manipulations of ecosystems, e.g. in lakes (Carpenter 2004) and coastal domain
  - Quantify processes that are supposed to be key for controls (such as predation: stomach content, Isotopic studies…)
- Retrospective Studies:
  - Meta Analysis (Myers and Worms 2003, Richardson and Schoeman 2004)
  - Empirical studies (Cury et al. 2000, Daskalov 2002)
  - Multivariate Time series analysis considering both environmental variables and predator/competitor interactions (Stenseth et al. 2004)
  - Spatial Studies (GIS) and indicators of interactions (Drapeau and Fréon 2004)
- Ecosystem models:
  - Forward models and simulations: EwE (foraging arena-Walters et al. 2002), Osmose (predation-Shin and Cury 2002), dynamic trophic cascade (Herendeen 2004)
  - Inverse models & reconstructions of ecosystem flows (Vezina et al. 2004)

Controls & Prediction
Advocacy for ‘connecting’ studies

- To develop multidisciplinary framework to study controls in marine ecosystems
- Integrate processes (behavioural, ecological, spatial…) into ecosystem models and general framework to study ecosystem dynamics
- To explore changing controls and their effects on fish populations dynamics and regime shifts (i.e. to integrate processes and patterns in ecosystem end-to end type models and information systems)

Ecologists have been analysing ecological interactions in two different and most often exclusive ways using reductionist or holistic approaches

As stated by Elton (1927), a combination of the two methods would be the best procedure