Session IV: The ocean domain

11:40 - 12:00 Introduction and Chair: Patrizio Mariani, DTU, Denmark

12:00 - 12:35 The bottom-up view of marine ecosystems, M. Ribera d'Alcalà, Stazione Zoologica Anton Dohrn, Italy,

12:35-13:15 Panel Discussion Session III & IV

December 2-4, 2020

Musing on the concept of good environmental status

Ocean complexity

Patrizio Mariani

The ocean domain

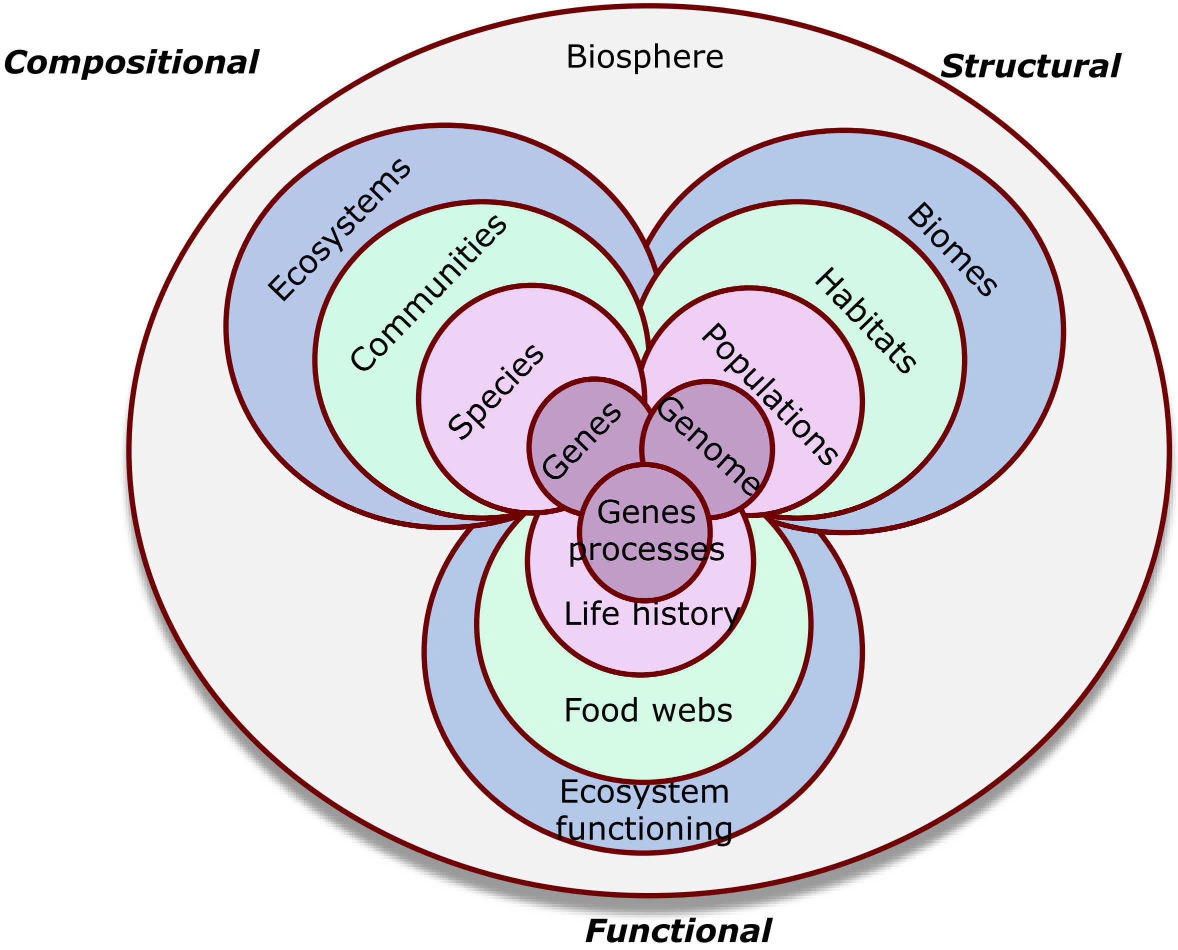
Day 1: we have seen how complex system theory can help to identify methods - and avoid misinterpretations - for identification of patterns in ecosystem dynamics and for an effective data analyses

Day 2:

Session III: examples of complex system organizations and dynamics have been provided from human society and terrestrial ecosystems.

Session IV: The ocean domain session will explore some of those elements showing how marine ecosystems are organised in terms of their **structure, composition, functions** as well as how specific drivers can change the dynamic equilibria around which they fluctuate

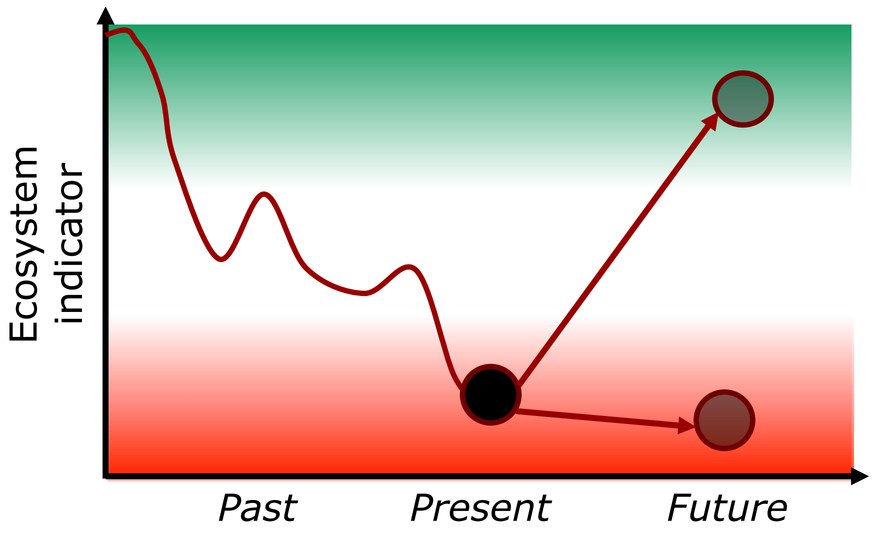
Biodiversity in the Earth System



Noss 1989

Ecosystem status

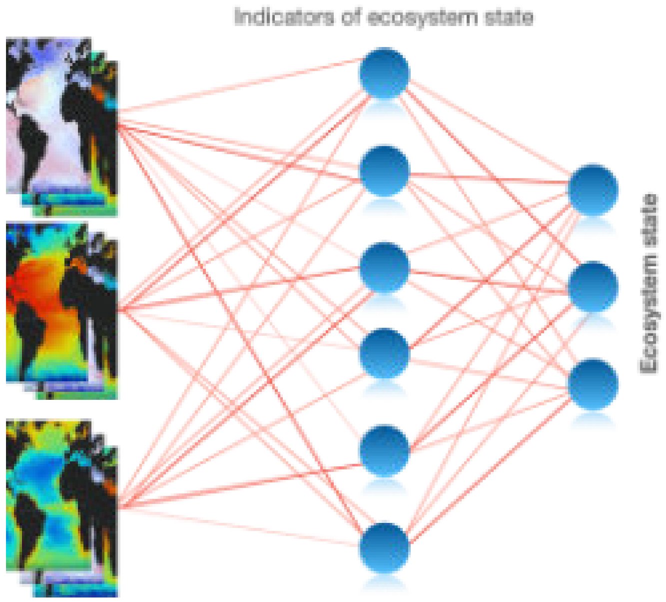
Time series analyses can provide methods to analyse specific indicators to identify trends and thresholds in the dynamic of ecosystem state



But the analyses has to be done acorss multiple indicators and pressures

We had recent revolutions in numerical analyses (fast computing) and data collection (big data)

Methods based on ANN have been suggested

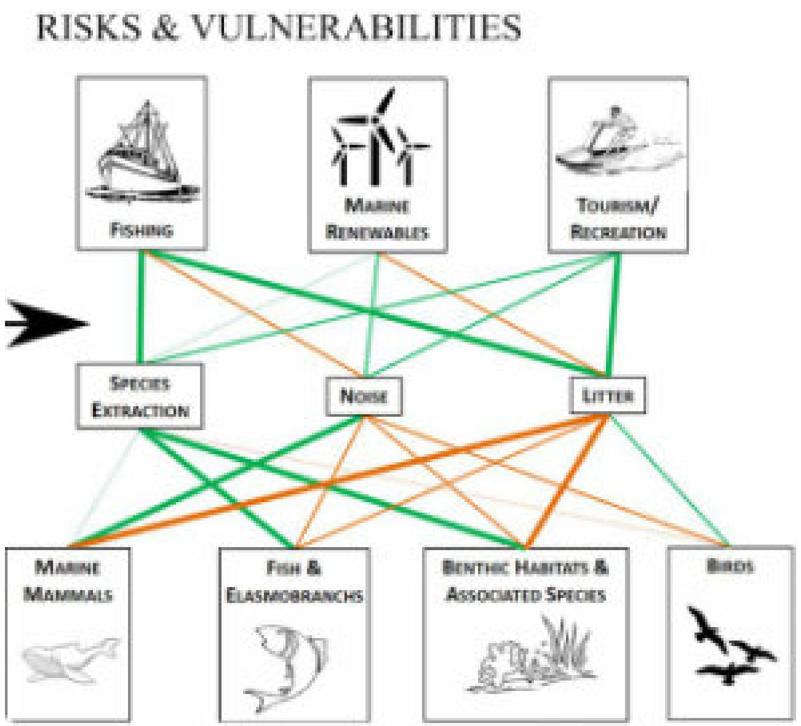


Integrated ecosystem assessment

Provide the links between human activites pressures and ecosystem components (and services)

Provide risk assessment and idetify componenets that are most at risk

IEAs can guide a systemic assessment of marine ecosystems and also indicate which knowledge we need to develop and which data we have to collect

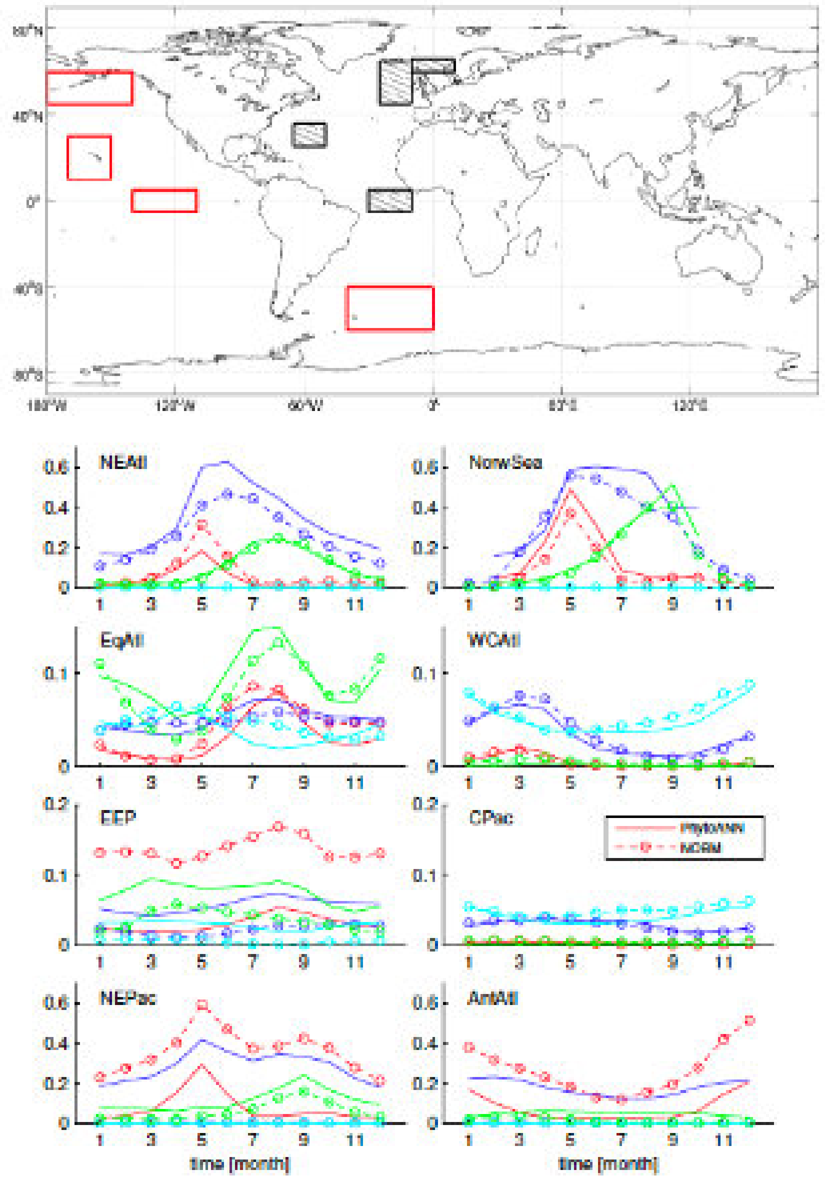


Source: David Reid

Ecosystem modelling

Artificial neural network methods can combine remote sensing and results from ecosystem modelling to generate new, ecologically-consistent estimates of phytoplankton functional types distribution in a wide range of biogeographic conditions

The ANN is able to interpret the complex and nonlinear interactions between phytoplankton groups and the environment, at least to the same extent as the original training model, yet in a fraction of time required to make a dynamic simulation.



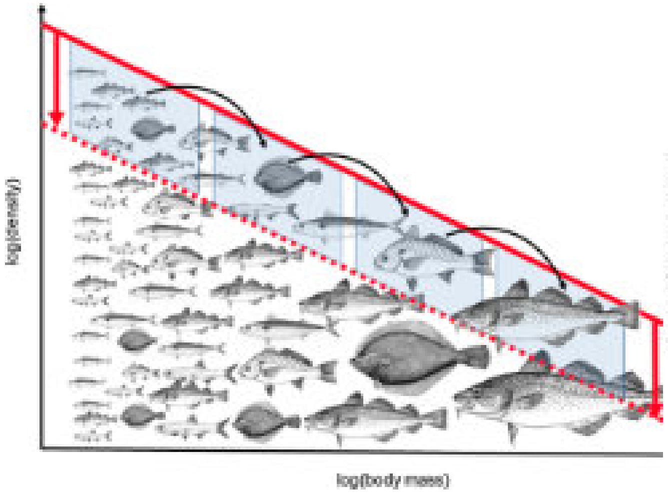
Palacz et al. 2013

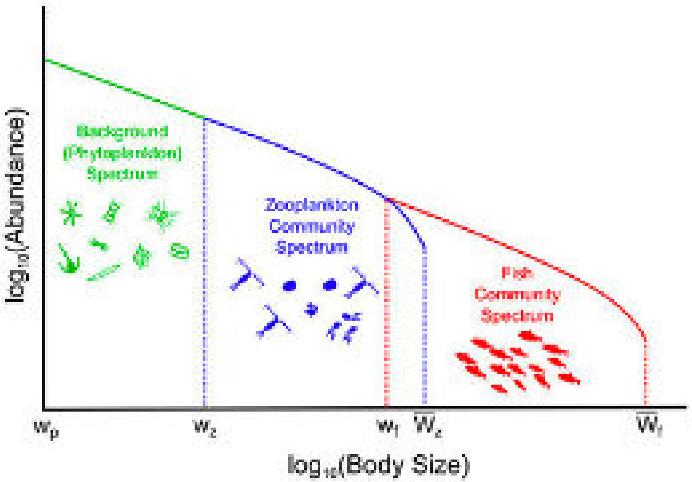
A trait based approach

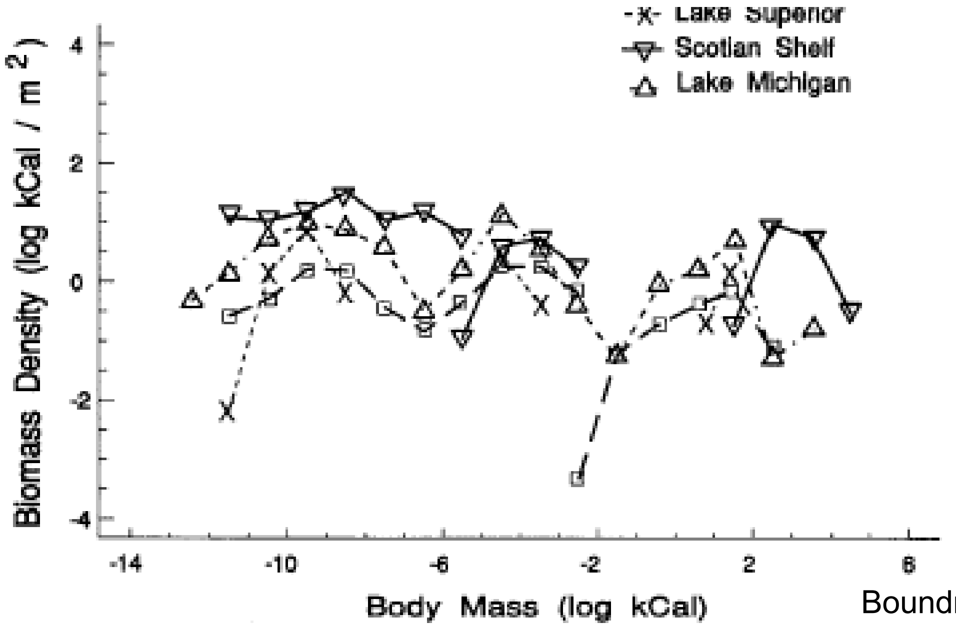
Trait-based ecology is a developing branch of marine ecology.

It describes ecosystems as consisting of individuals rather than species, and characterizes individuals by a few key traits that are interrelated through trade-offs.

Size as a master trait







Boundreau & Dickie 1992

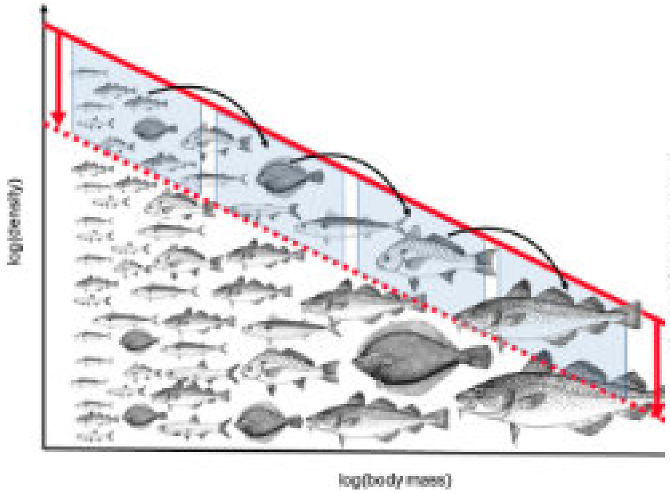
A trait based approach

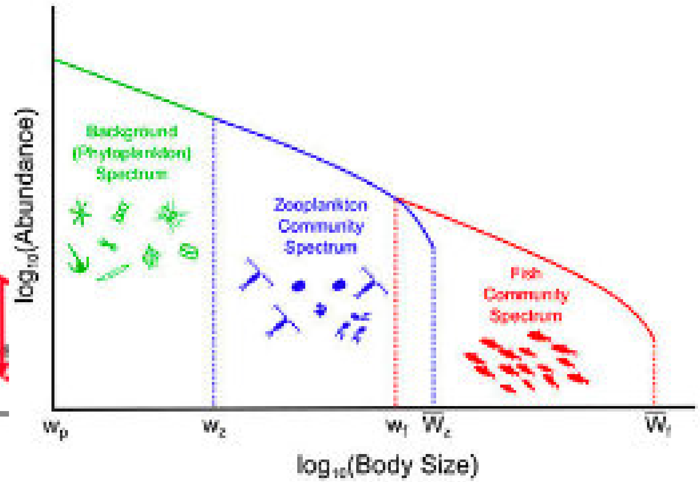
Trait-based ecology is a developing branch of marine ecology.

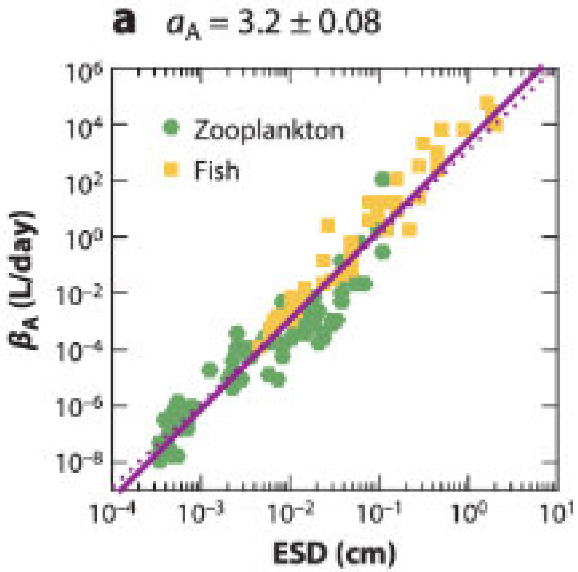
It describes ecosystems as consisting of individuals rather than species, and characterizes individuals by a few key traits that are interrelated through trade-offs.

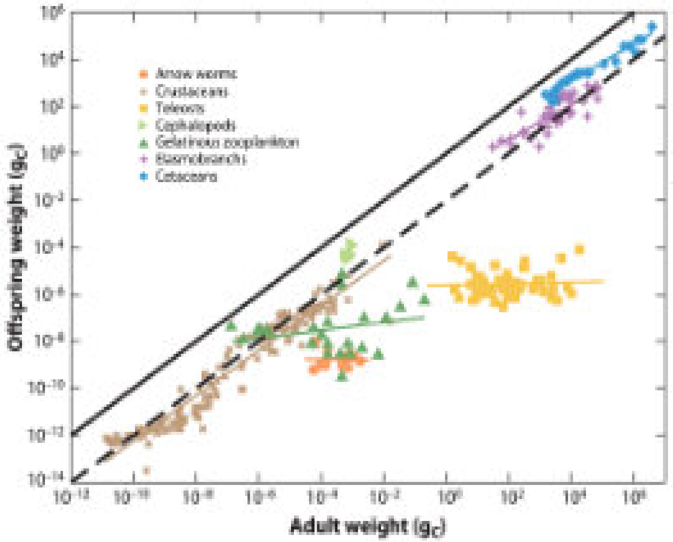
Size as a master trait

The fundamental idea is that the function of an ecosystem is shaped by the traits of individual organisms rather than by which species the organisms belong to.







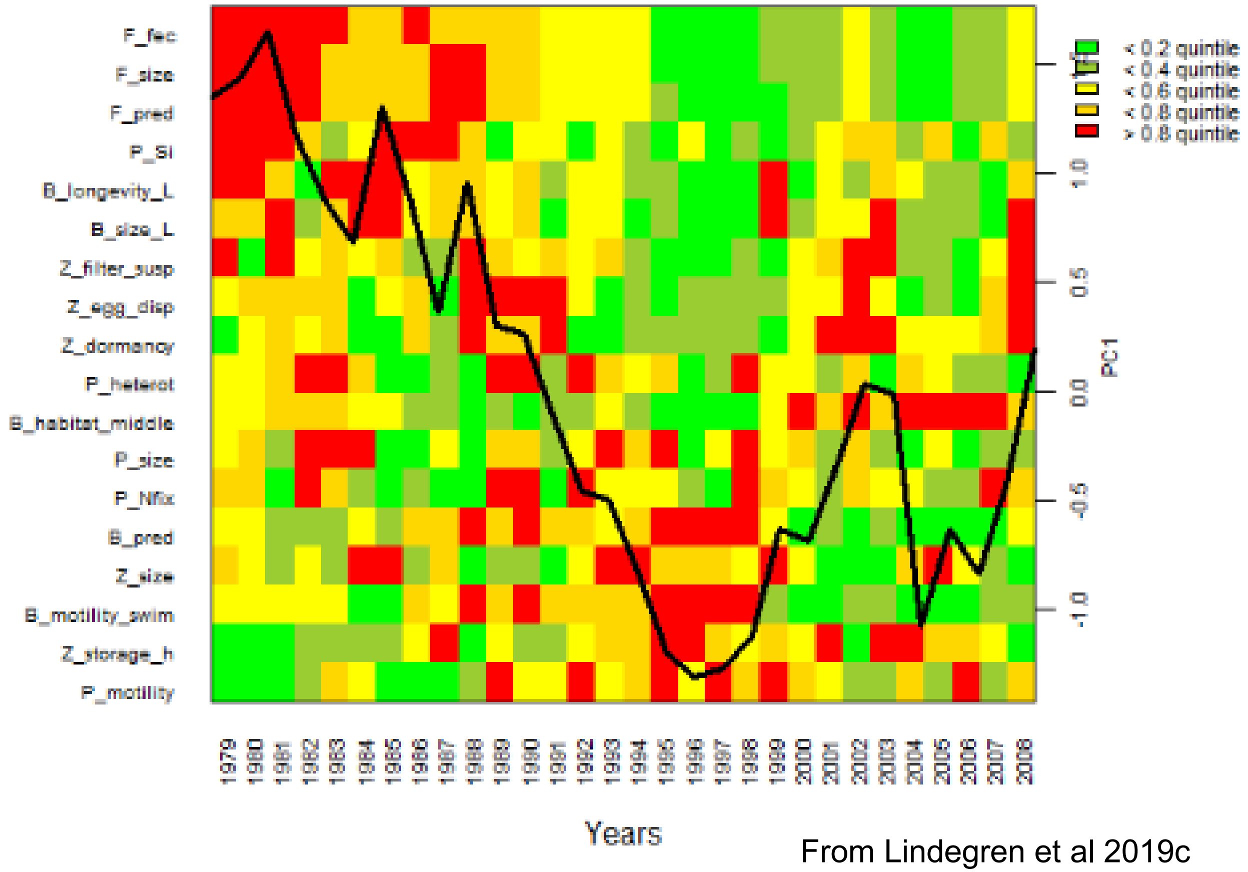


Andersen et al 2018, 2016

Trait based ecosystem assessment

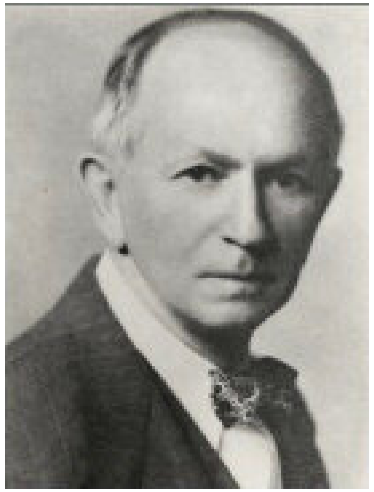
Assessment of long-term changes in the North Sea through community-wide changes in ecological traits across multiple trophic levels

Traits for feeding, reproduction and survival, either separately, or in combination represent various ecological functions and can provide a better understanding of community assembly, ecosystem drivers and functioning



From Lindegren et al 2019c

Population dynamics



Alfred J Lotka 1880 - 1949

Elements of physical biology

Application of physical principles to the study of life

Mainly using a stoichiometry approach

$$\frac{dX_i}{dt} = F_i(X_1, X_2 \; . \; . \; . \; X_n; P, Q) \qquad (1)$$

Predator prey model

$$\frac{dx}{dt} = \alpha x - \beta x y,$$
$$\frac{dy}{dt} = \delta x y - \gamma y,$$

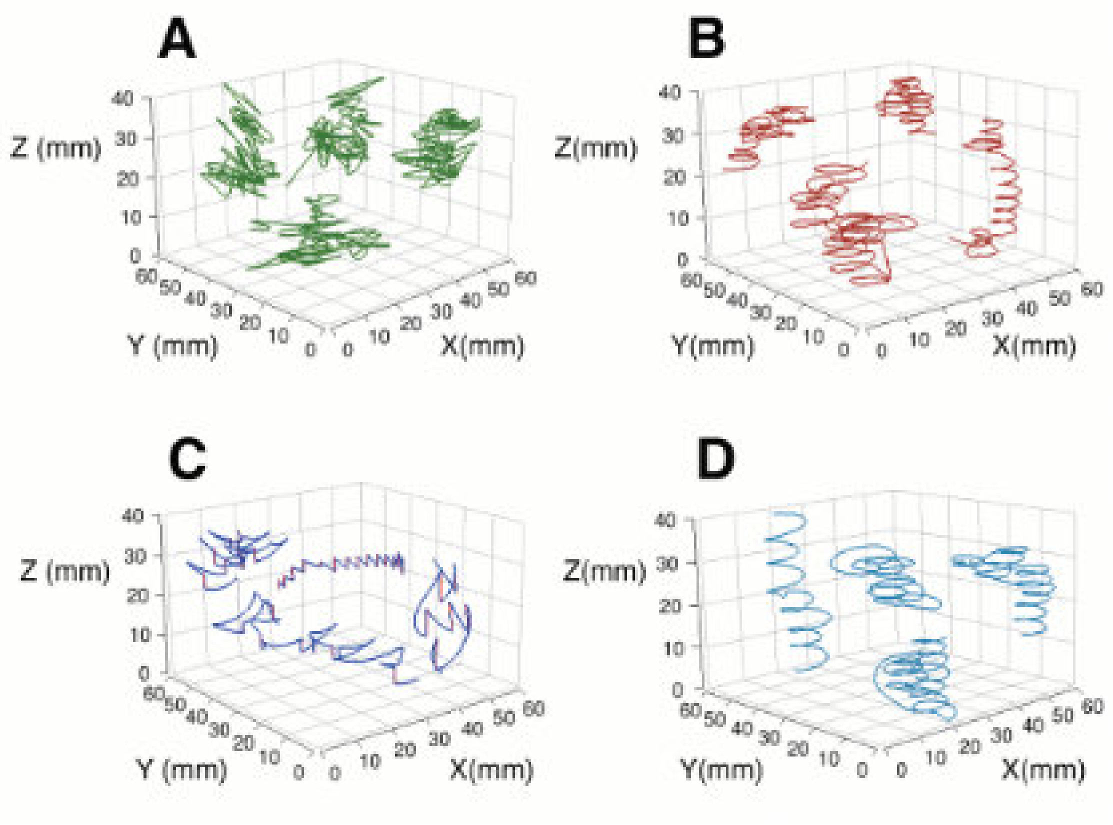
The parameters should descrieb interactions between predator and prey which is often linked to behaviour

Behaviour and dynamics

Optimization and emergence in marine ecosystems

Damping out of chaos

Top down and bottom up dynamical controls

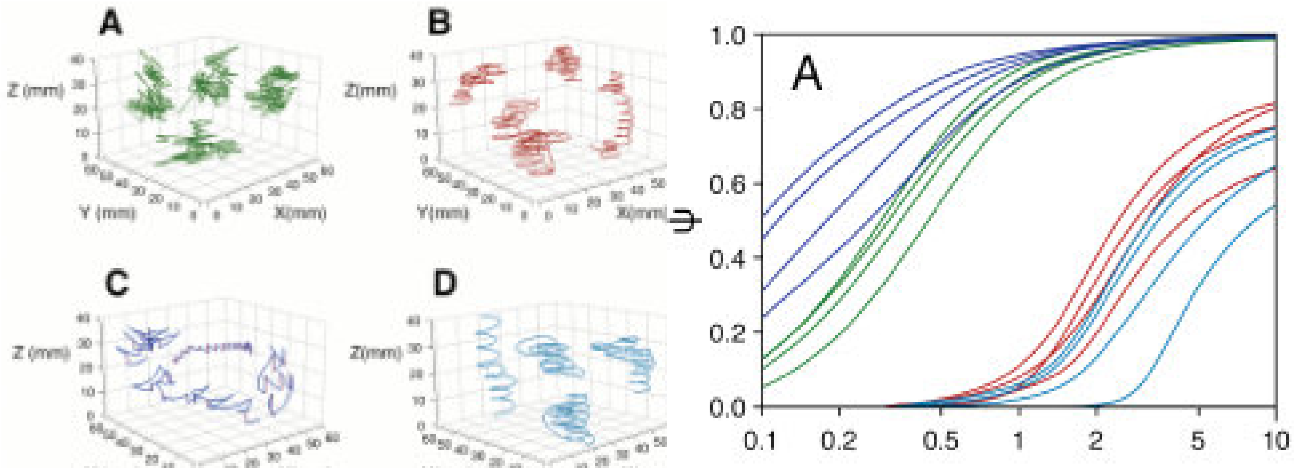


Behaviour and dynamics

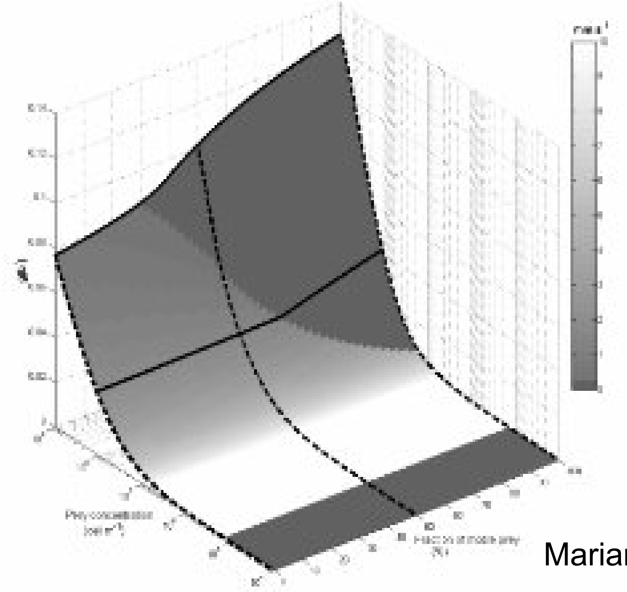
Optimization and emergence in marine ecosystems

Damping out of chaos

Top down and bottom up dynamical controls



Bianco et al 2016



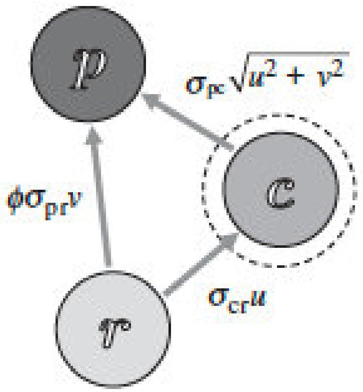
Mariani & Visser 2010

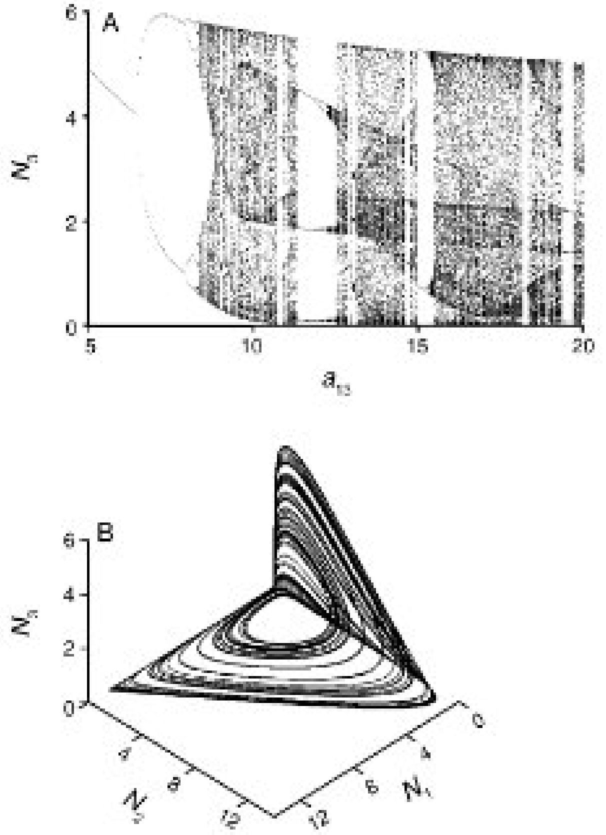
Behaviour and dynamics

Optimization and emergence in marine ecosystems

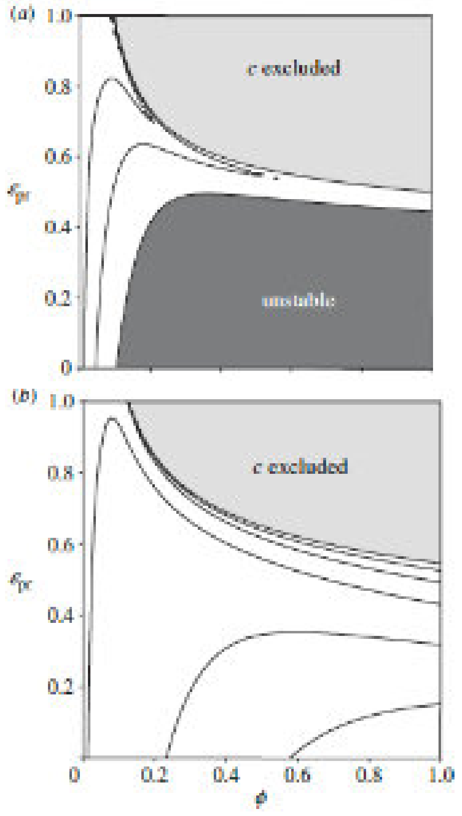
Damping out of chaos

Top down and bottom up dynamical controls





Tanabe and Namba 2005



Visser et al 2012

Sociality and group behaviour

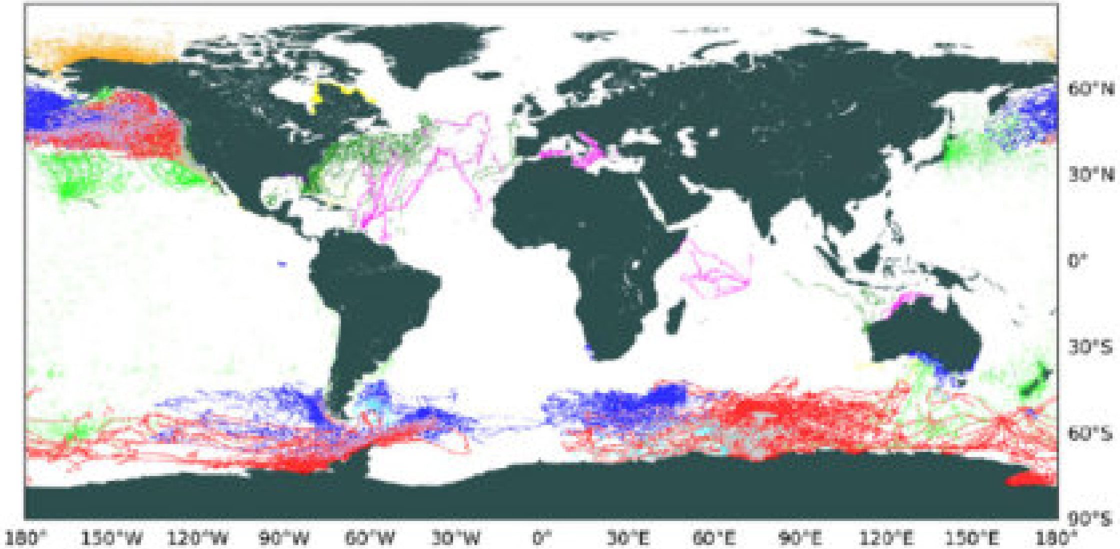
The description of biodiversity patterns is a description of variation.

Quantification of variation requires a determination of scales.

The patterns of species distribution across geographical areas should take into account connectivity across scales and metapopulation structure.

The question is not easy when species move across distant areas. These movements involve not only passive dispersion but also active migrations.

How and why species move across long distant areas is an active area of research which could be considered also as an indicator of ecosystem state.



Sequeiraa et al 2018

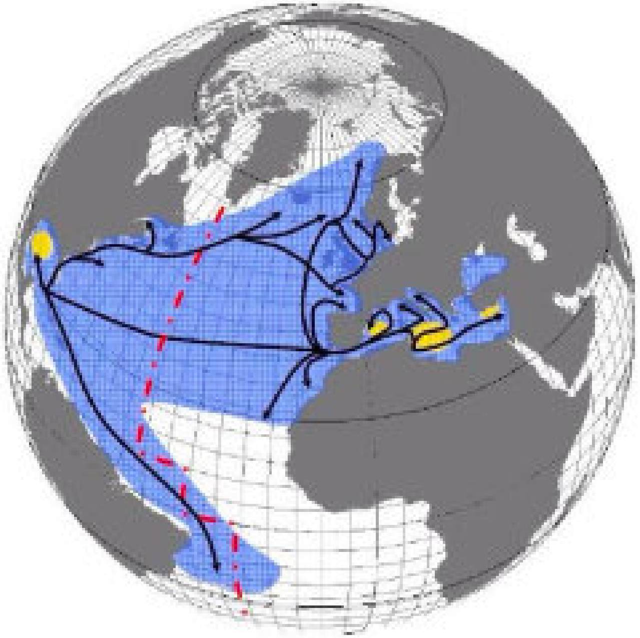
Long distance migrations

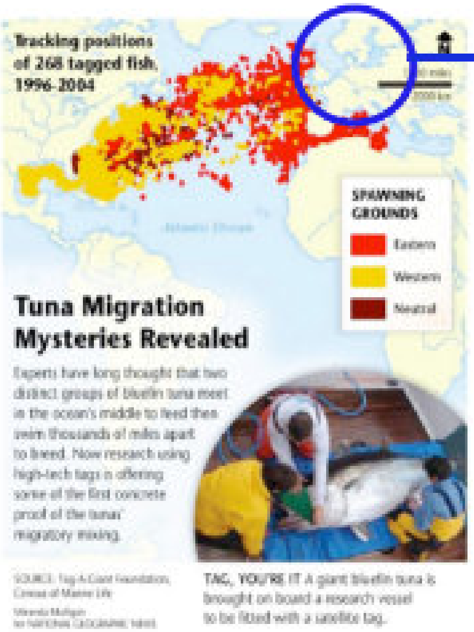
Atlantic bluefin tuna is a large and long lived fish

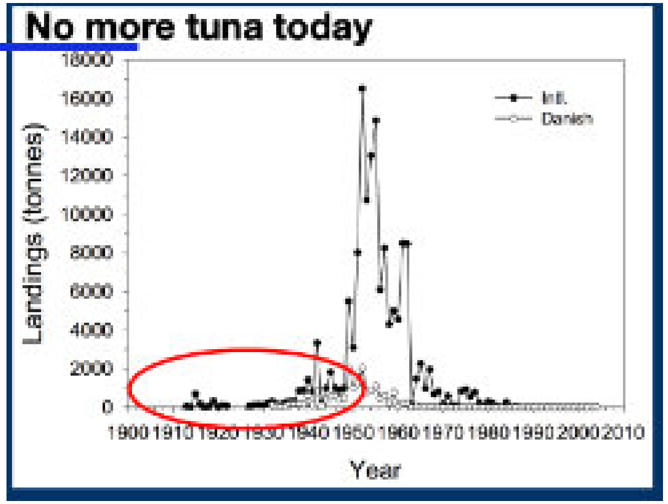
It has range encompassing tropical and polar regions

It is a fast and opportunistic feeder which move in schools and perform long distance migrations from spawning to feeding grounds

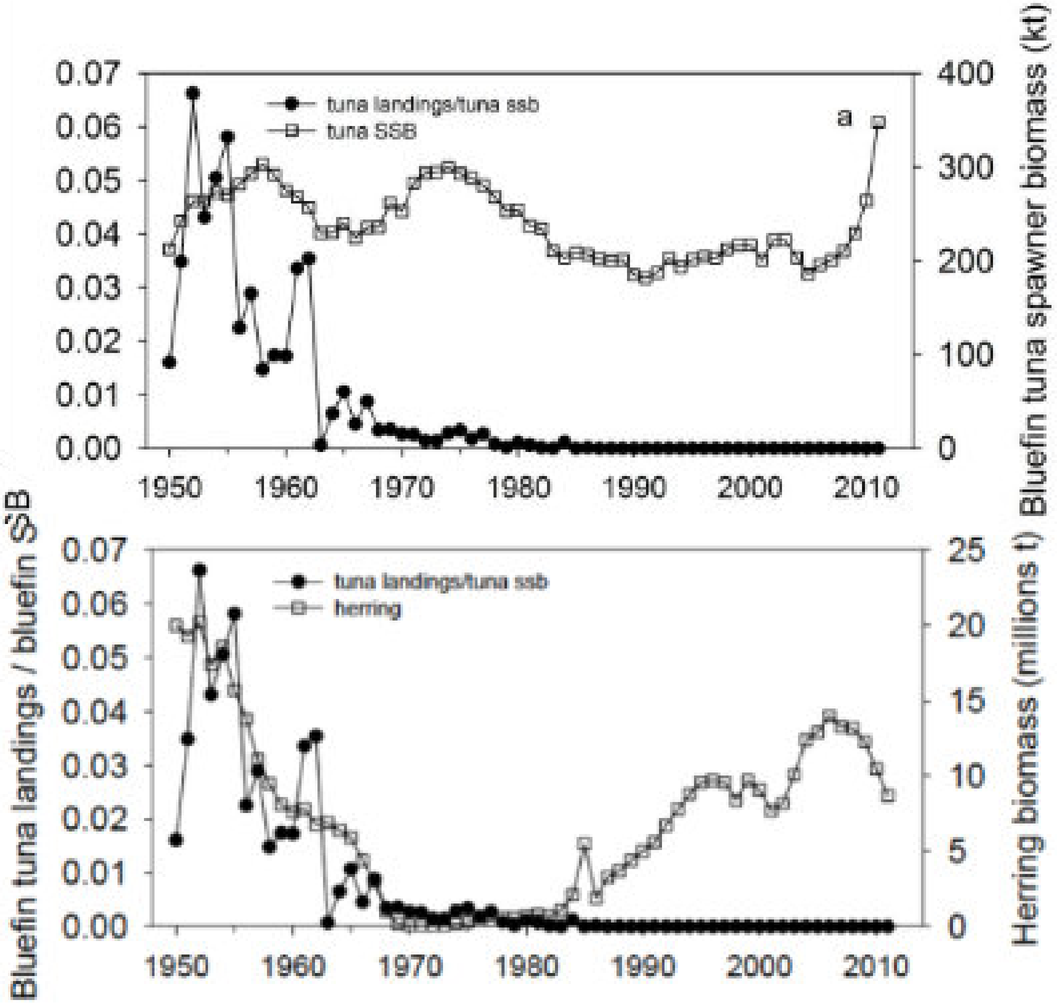
high value fish commodity

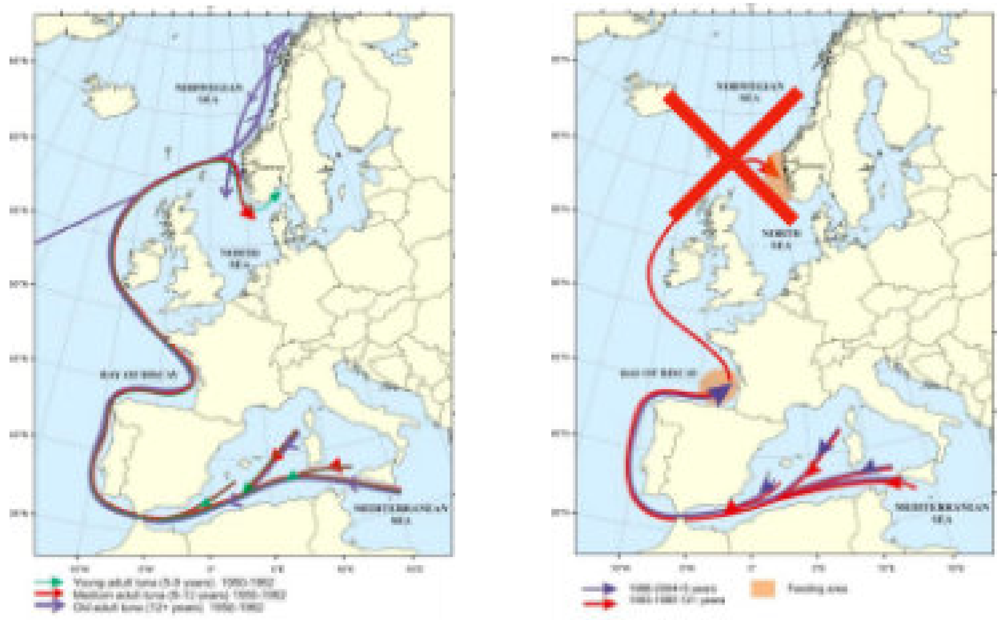






Long distance migrations





How do bluefin tuna retrieve their path?

Where is the information about the migration track stored?

Long distance migrations

We can model migration as a collective memory problem

Each individual is able to interact socially with others in the group and share information

Only a fraction of the individuals posseses information about the right direction to take

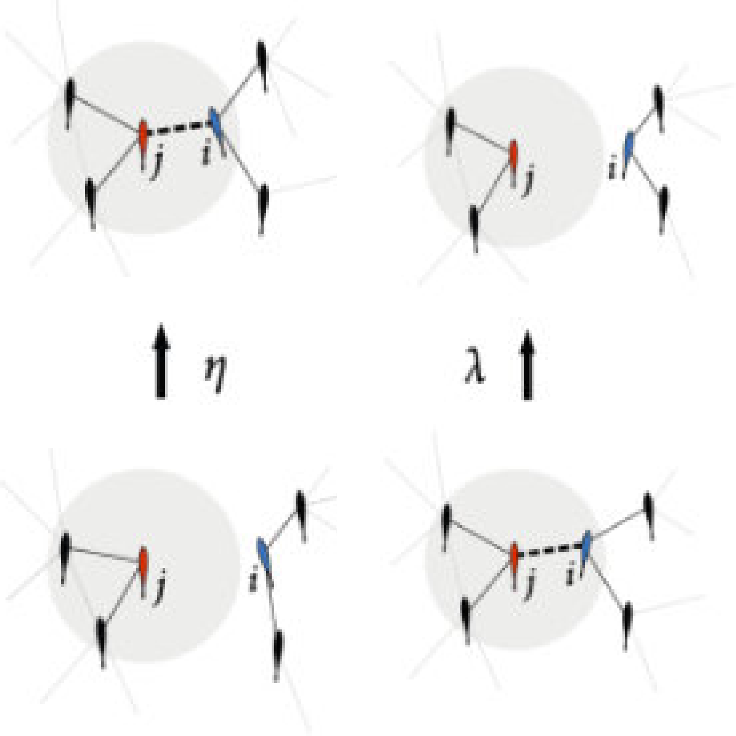
Social interaction may be used by agents to enhance their knowledge about the right direction, and reach consensus

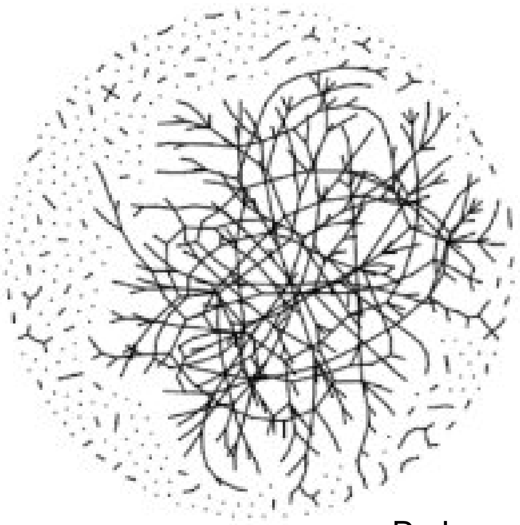
The role of information

A fraction of individual have preference for a direction

h_α measures the strength of the preference that an agent has with respect to destination α

We developed an Adaptive Stochastic Network approach to group formation and migrations in fish

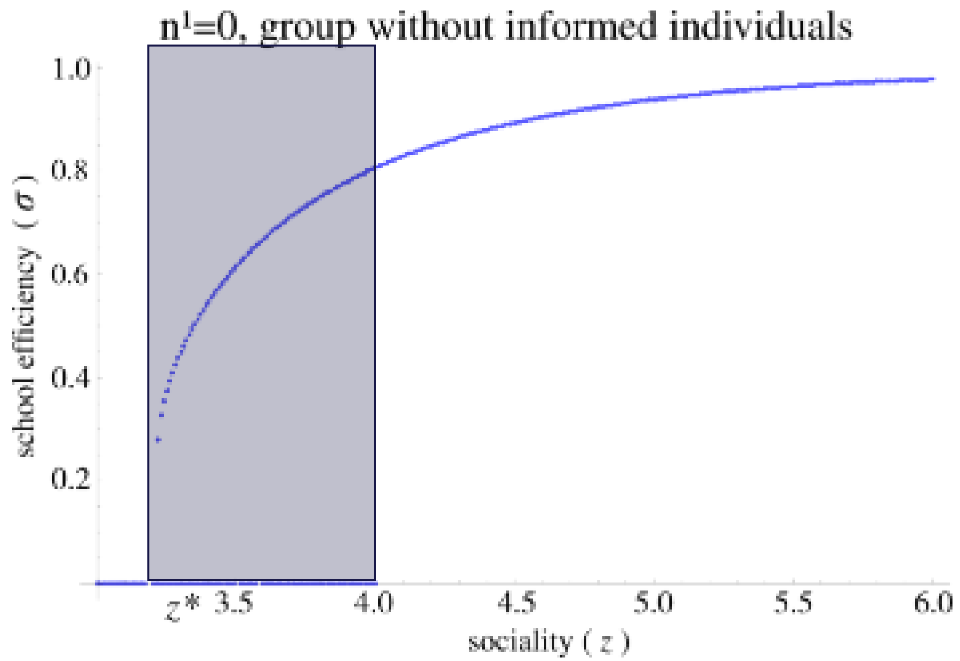




De Luca et al 2016

Long distance migrations

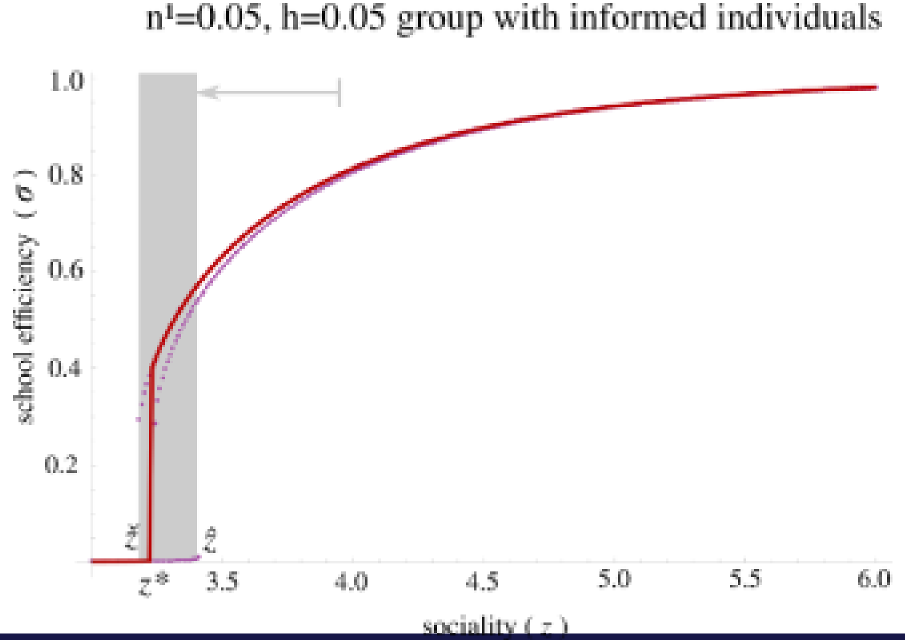
When no information is available in the group, the system reduces to an adaptive network model in which group coordination only depends on the rates at which links are created or destroyed



Information has two main effects on the system:

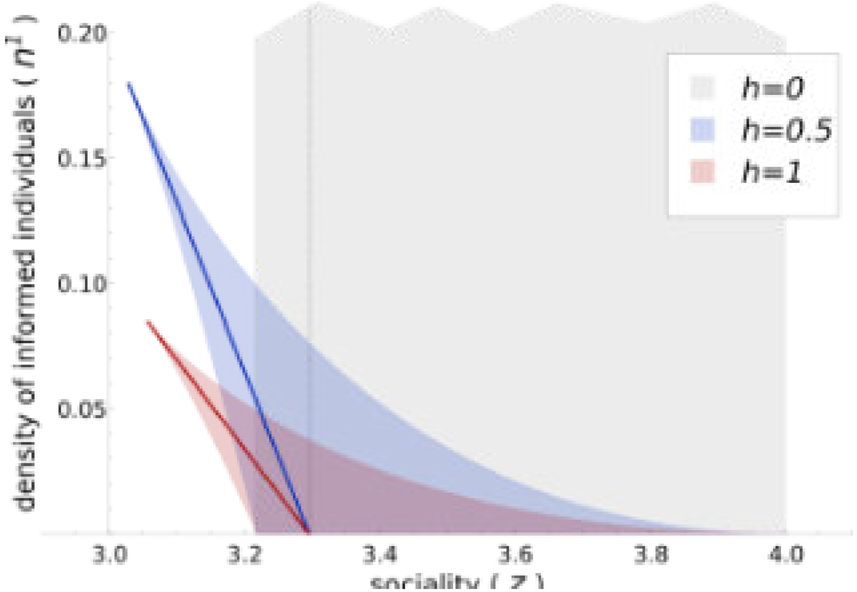
- it breaks the symmetry by selecting the destination with the largest preference

- the coexistence region is reduced

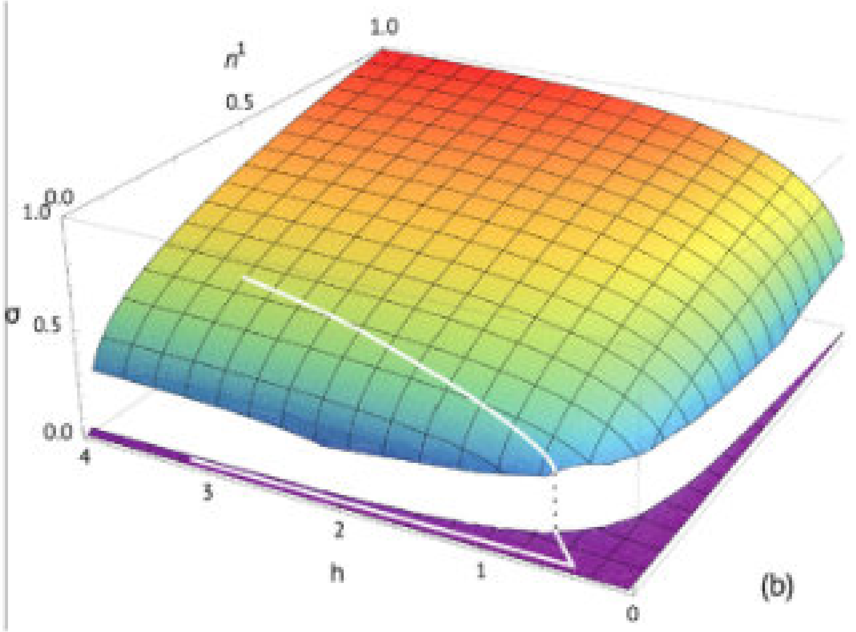


Long distance migrations

As the information density increase or the preference increases group formation is more likely and migration more effective

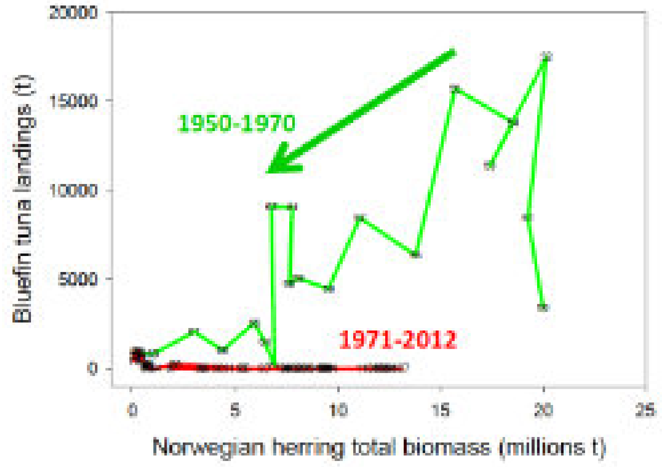


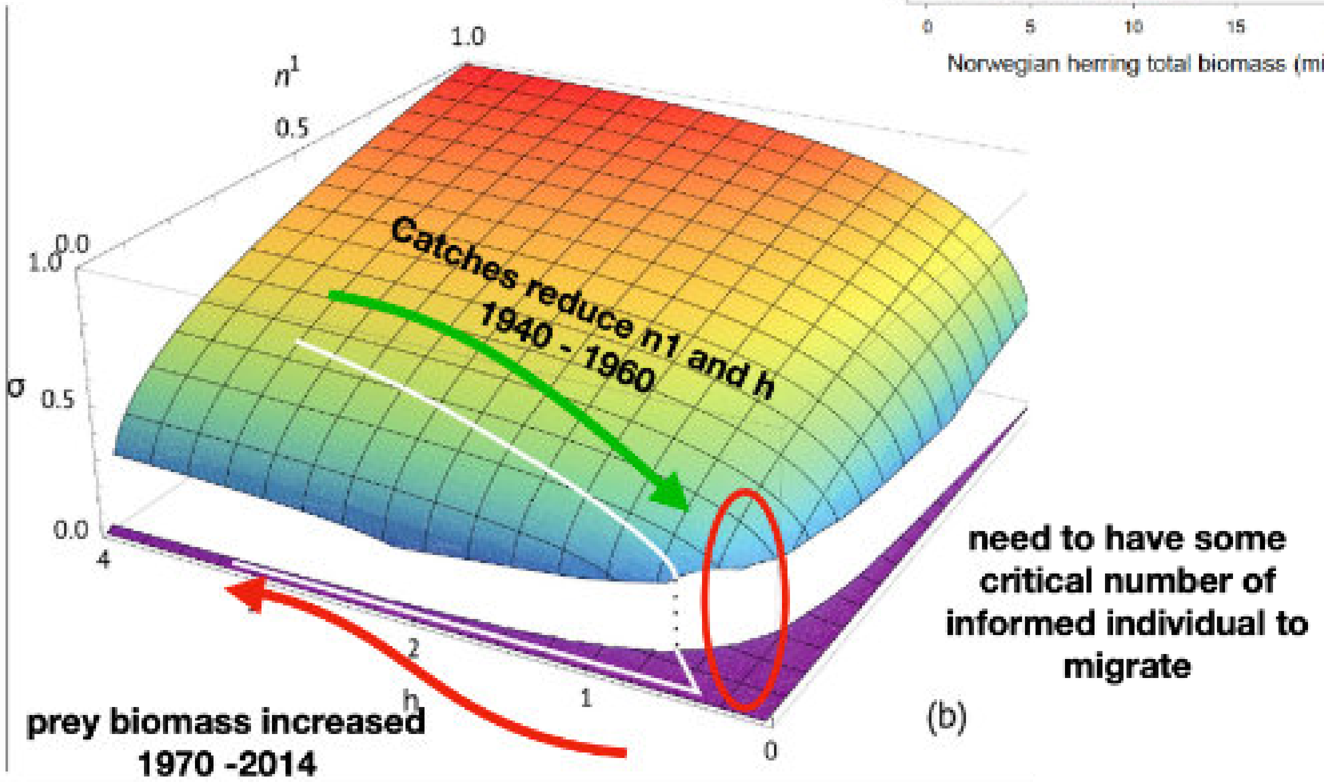
A migration efficiency parameter can be defined and plotted against information density and strength of the preference, displaying a hysteric cycle



Long distance migrations

The dynamics of the model can capture some of the observed patterns in bluefin tuna migrations in the Nordic seas.





Take home message

To achieve the good environmental status the biodiversity is a master descriptor that has effects all across the function and structure and thus the services of marine ecosystems

The description of biodiversity patterns is a description of variation. Quantification of variation requires a determination of scales

Essential functions and structural properties can be captured by describing ecosystems in terms of the life history traits of the underlying species

The role of behaviour is fundamental to establish the proper interactions across marine organisms

Move towards an integrated ecosystem assessment at regional scales to detect knowledge and data gaps

Decision under deep uncertainties

We know ecosystems are difficult, maybe chaotic,
maybe non deterministic, non at equilibrium, evolving

And we rely on them for our life on Earth

We need to take decisions under deep uncertainties

Take home message

Azaele session:

What is healty ecosystem: how can we say that is like human health or someother criteria is needed

Are the 7 descriptors of the MSFD enough

The state of the ecosystem is more than the sum of its components (interactions and emergence, e.g. flocks)

How to link patterns and processes and mechanisms (very difficult, actually impossible)

Do we really need a theory? We have big data to do that. Do not look for models collect data plug in a black box and that is it….. Cannot be true

Science is build up of facts, as a house is with stones - but a collection of facts is not more a scicen than a heap of stones is a house (Poincaré)

Vulpiani:

Understanding the dynamics of complex system (statistical mechanics). Chaos, inductive approach, multiscale factors,… vedi la parte di cambio di scala in fisica e meteorology

Amos:

Forest complex because high degree of structural and functional diversity (structure and functionality are related)

FACTS: in a forest you have a size spectra (abundance) with slope -2, height and volume scales with factor 3, they use crown radius as equivalent spherical radius in ocean, the size of trees change with latitudes (in the procis more spherical than temperate), metabolism (B) scaling Mass^2/3 or ¾ (Kleiber's law)

From facts to scaling approach (should come before any model). Plants evaportransport water which is also the metabolism of the plant.

From single plats to community level: we can use optimization principle : tree crowns occupy as much space as possible, resources are limited (tot metabolic rate of the community < resource availability)

How can we detect the effects of pressures? Some of the scaling changes because of disturbances

Forest is a complex ecosystem yet the scaling of single individuals can be understood and from there we can go to the communities. How to scale it to animals ? We do not know also because data collection is difficullt since they move

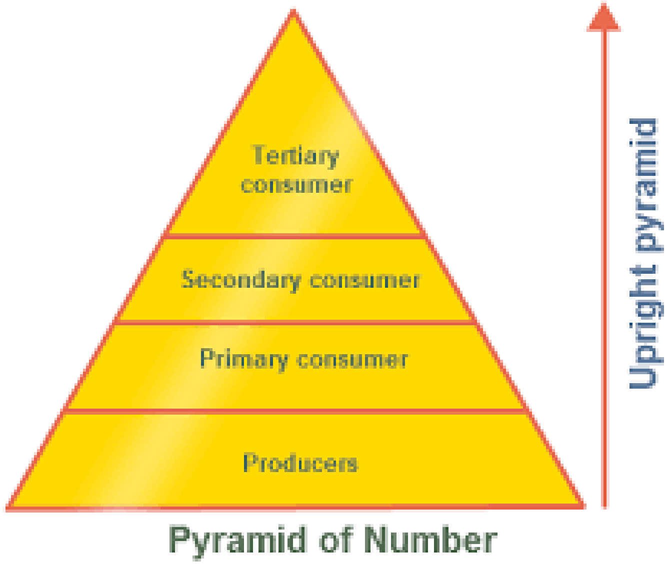
The Bottom-up view of pelagic marine ecosystems

Maurizio Ribera d'Alcalà

Stazione Zoologica Anton Dohrn

Background

In 1927 **Charles Elton** introduced the concept of the '*pyramid of numbers*' based on the observations of two facts:
"...(a) smaller animals are preyed upon usually by larger animals, and (b) small animals can increase faster than large ones, and so are able to support the latter..."

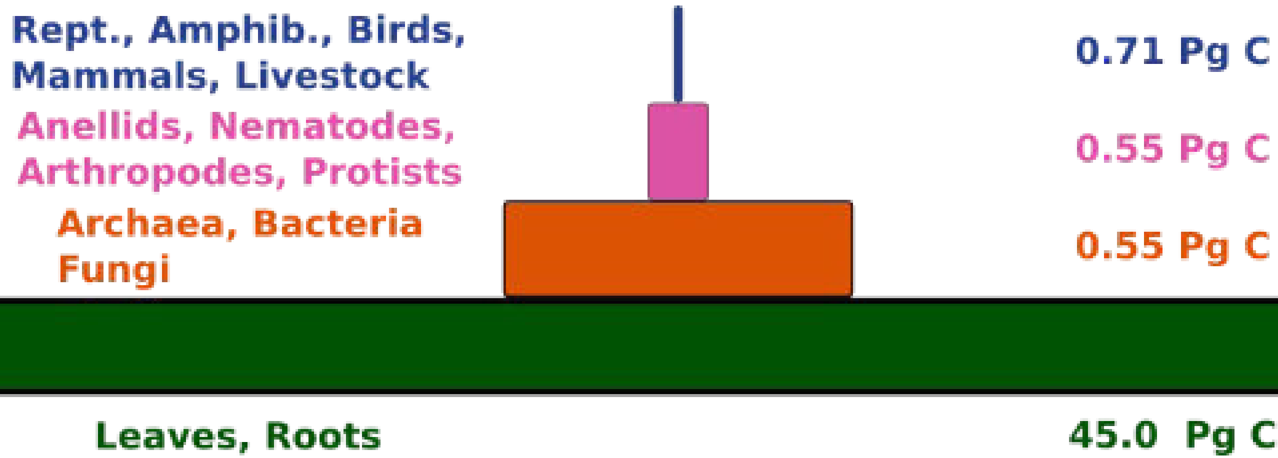


Since Elton pyramids are an intuitive representation of the structure of a food web.

Canonical pyramids

There are also other pyramids than the Eltonian ‘pyramid of numbers’

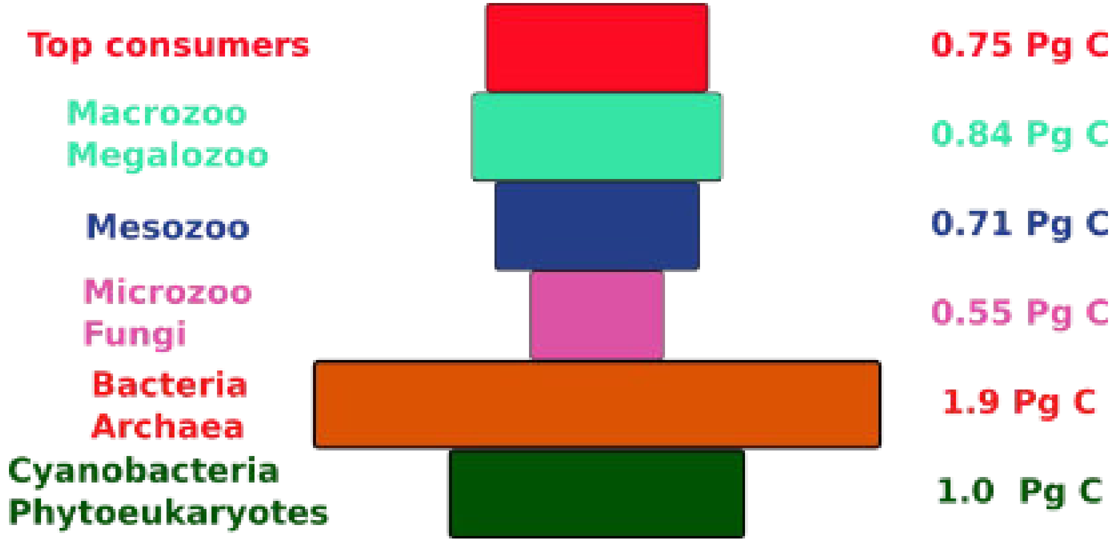
Below is a ‘biomass’ pyramid for terrestrial ecosystems including ‘above the ground’ and ‘soil’ communities based on the most updated estimate of biomass on the Earth (Bar-on et al., 2018)



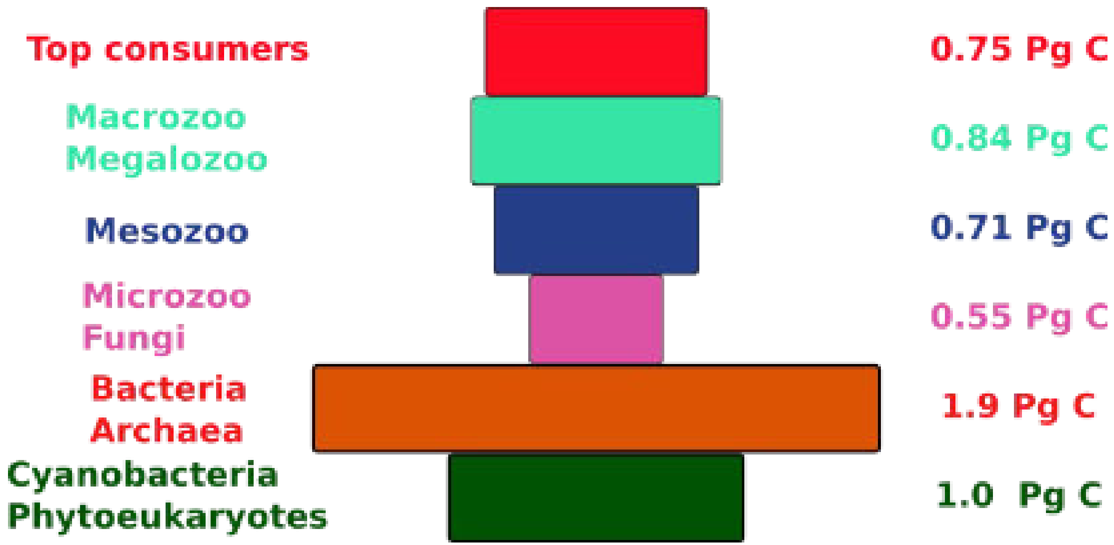
The distribution of groups on the layers is subjective but the main pattern would be the same

Alternative pyramids

The same exercise with a marine pelagic food web, with all the *caveats* of subjective choices on the repartition of groups among layers gives a strikingly different pattern (Bar-on et al., 2018)



Pelagic pyramids



Some groups, for example jellies or molluscs have been divided among levels, but the pyramid:

1. is no more bottom-heavy, but slightly top-heavy or even
2. it has two more layers.

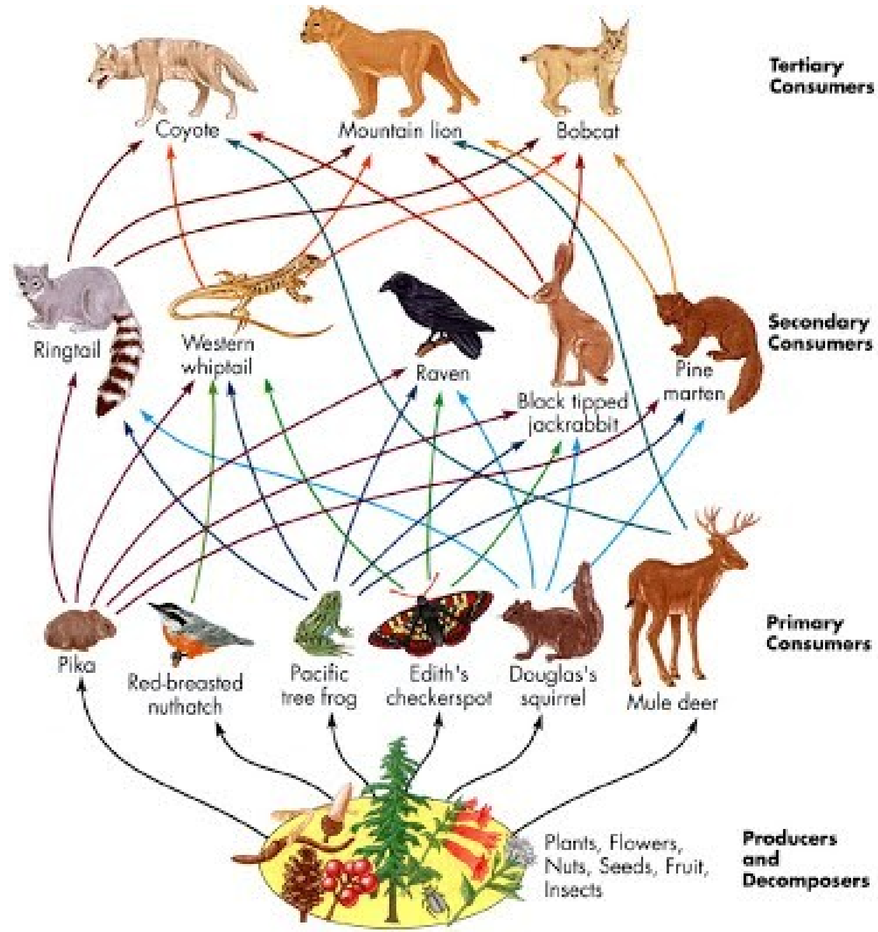
(Number of layers is a bit arbitrary but aquatic environments have more layers)

Graphs

A more detailed, mechanistic representation of what is embedded in pyramid are Graphs

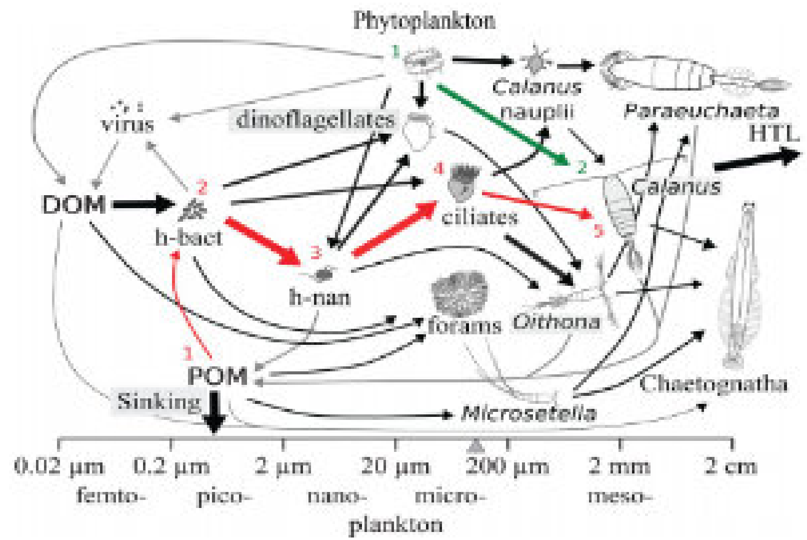
The above ground terrestrial food web graph has a clear physiognomy.

Even with the black box of detritus reworking *switches* are dominantly within the same layer



Pelagic graphs

Just zooming on previous levels 1 to 4 (the plankton) graphs are much more entangled

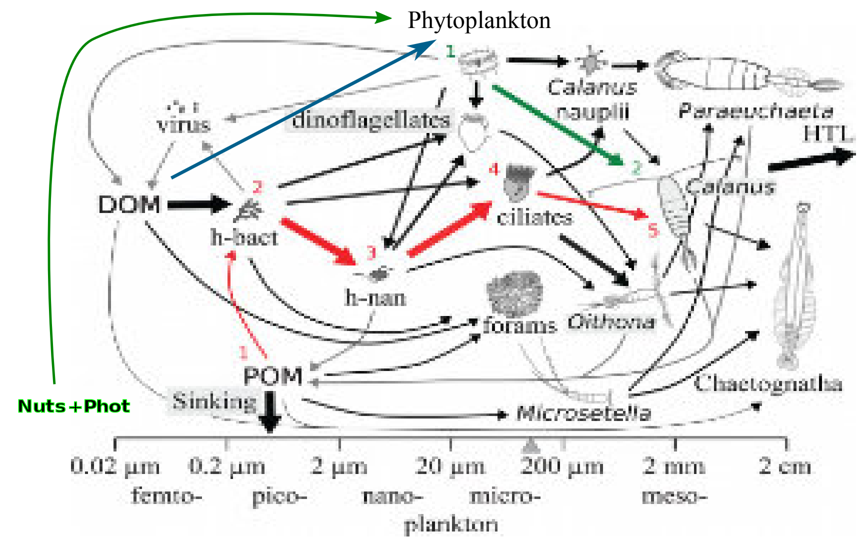


Pelagic graphs

Just zooming on previous levels 1 to 4 (the plankton) graphs are much more entangled

Parasites are not highlighted, as in the terrestrial web

Mixotrophy is the newcomer which may work even without primary concurrent production



Pyramids and food web dynamics

A pyramid has is a compact representation of a food web structure, i.e., of a graph or of a network

Pyramids and food web dynamics

A pyramid has is a compact representation of a food web structure, i.e., of a graph or of a network

It is the steady state solution of fluxes among organisms that are stocked in abundance or biomass

Pyramids and food web dynamics

A pyramid has is a compact representation of a food web structure, i.e., of a graph or of a network

It is the steady state solution of fluxes among organisms that are stocked in abundance or biomass

Therefore there should be a link between matter transfer, pathways of transfer and bioenergetic constraints of transfers, i.e., the network and the pyramid

Pyramids and food web dynamics

A pyramid has is a compact representation of a food web structure, i.e., of a graph or of a network

It is the steady state solution of fluxes among organisms that are stocked in abundance or biomass

Therefore there should be a link between matter transfer, pathways of transfer and bioenergetic constraints of transfers, i.e., the network and the pyramid

Review

Cell PRESS

Ecosystem ecology: size-based constraints on the pyramids of life

Rowan Trebilco[1], Julia K. Baum[2], Anne K. Salomon[3], and Nicholas K. Dulvy[1]

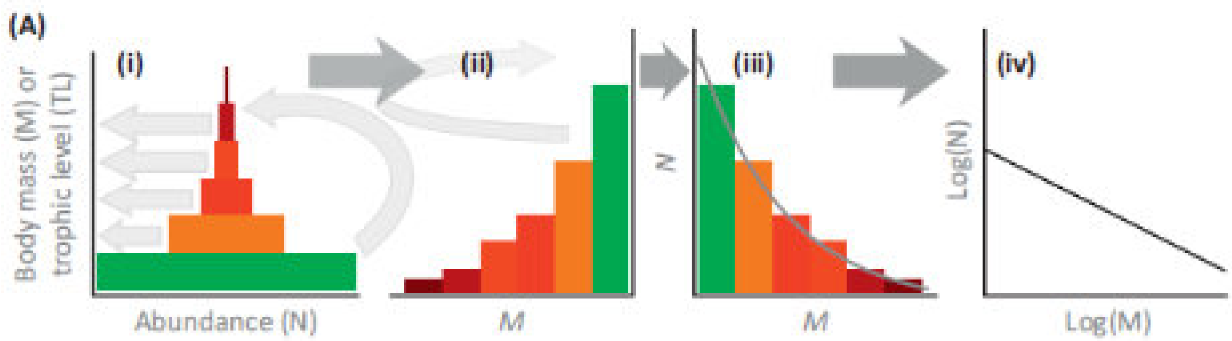
Pyramids and food web dynamics

Assuming one-directional fluxes within the pyramid, matter flow depends on the mechanism by which components of the level above exploit the level below (Predator-Prey Mass ratio - PPMR) and the efficiency of this transfer (Transfer efficiency- TE).

Pyramids and food web dynamics

Assuming one-directional fluxes within the pyramid, matter flow depends on the mechanism by which components of the level above exploit the level below (Predator-Prey Mass ratio - PPMR) and the efficiency of this transfer (Transfer efficiency- TE).

The introduction of PPMR links to size spectra, another possible descriptor of of pyramids or of community structure



Bottom-heavy vs. top-heavy pyramids

The introduction of PPMR links to size spectra, another possible descriptor of of pyramids or of community structure

PPMR depends on size and relative biomasses, with size strongly constraining the metabolism

Bottom-heavy vs. top-heavy pyramids

The introduction of PPMR links to size spectra, another possible descriptor of of pyramids or of community structure

PPMR depends on size and relative biomasses, with size strongly constraining the metabolism

Considering TE and Metabolic requirements and PPMR of organims in several communities. the conclusion by Triblinco and colleagues is that:

The observed pseudo-pyramid in pelagic system must rely on:

High TEs and/or PPMR

However the latter must rely on a sufficient supply from the lower level which implies a high turnover rate of the level below.

May top-heavy or even pyramids exist?

Different scenarios were explored

Conclusion: top-heavy pyramids are unlikely and may depend on problems of sampling or being dealing with subdyzed systems.

This has been a debated issue. Is ocean autotrophic or heterotrophic?

review article

Respiration in the open ocean

Paul A. del Giorgio*† & Carlos M. Duarte†‡

The question is still, to some extent, open but most data (e.g., oxygen release) suggest that the ocean is a self-sustaining system (autotrophic)

Exploring the mechanisms

Which are the implications of a moderate standing stock of autotrophic biomass in respect to the stock of consumers and and the higher number of layers?

Can we mechanistically reproduce that structure?

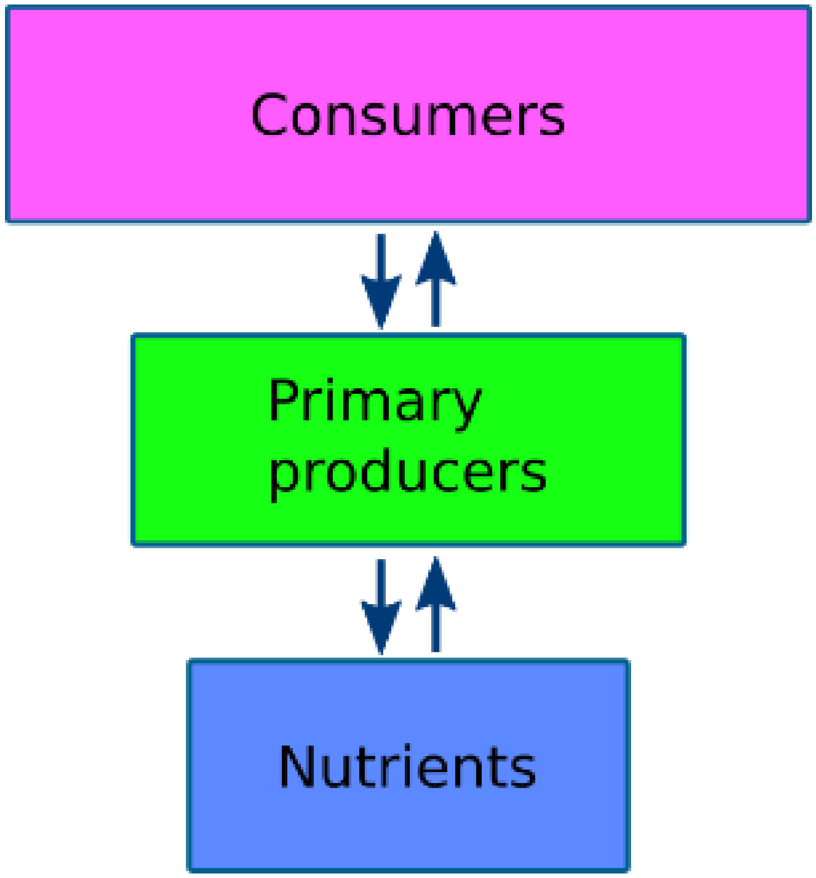
$$\frac{dN}{dt} = cP(egh - P_r) + m(N_0 - N)$$

$$\frac{dP}{dt} = P(P_r - gh - \frac{v}{L} - m)$$

$$\frac{dh}{dt} = h(gP - r_h - fC)$$

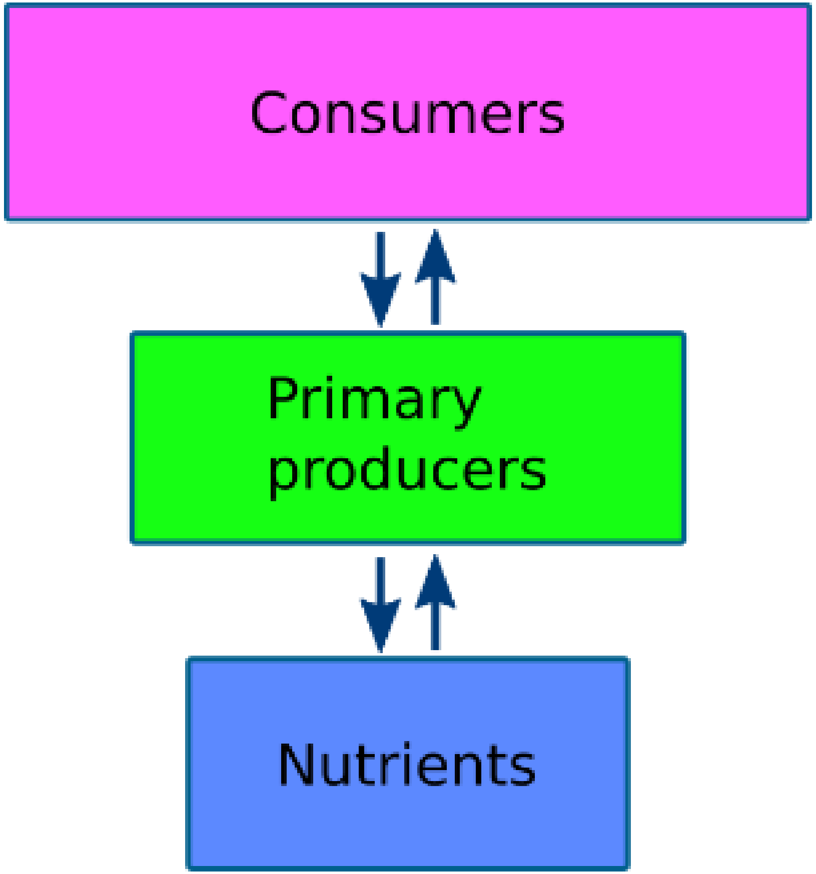
Above are the equations of one of the Gordon Riley formulations which are still the roots of most biogeochemical models used today

A more intuitive representation



The size of the boxes depends on the ratios between the rates within the boxes which also constrained by the exchange rates among the boxes

A more intuitive representation

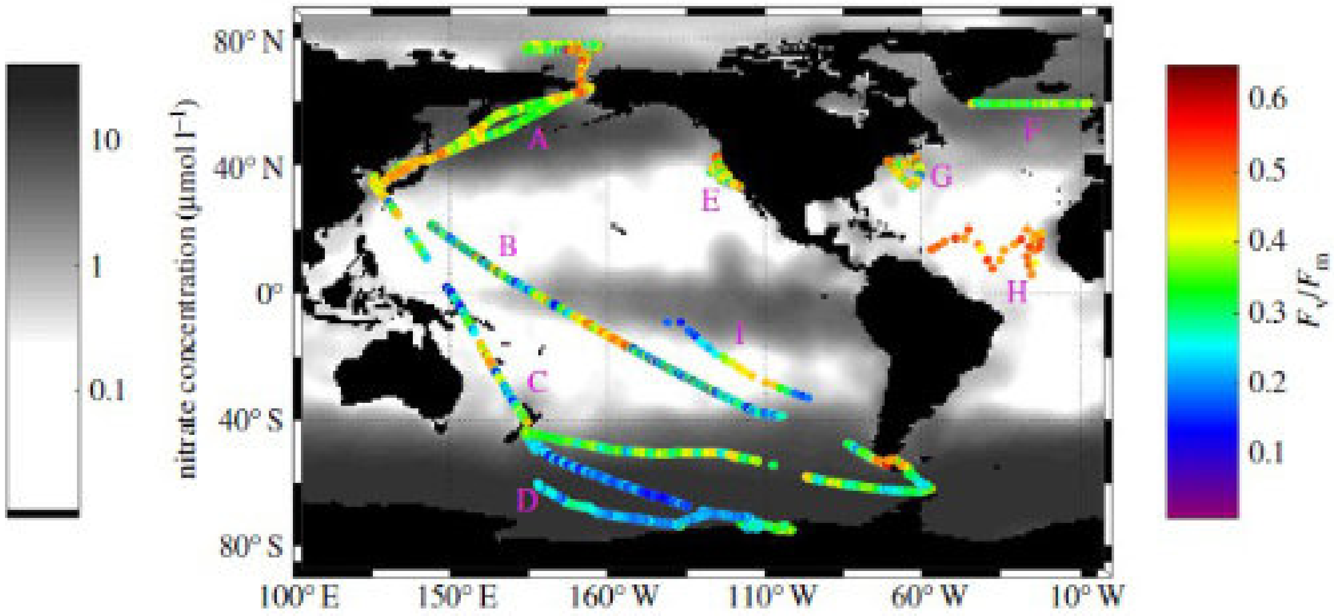


The size of the boxes depends on the ratios between the rates within the boxes which also constrained by the exchange rates among the boxes

In this simple version the larger upper box relies on a fast turnover of the low box

This is the paradigm of all ocean biogeochemical models which present a “**bottom-up view of the marine pelagic ecosystem**”

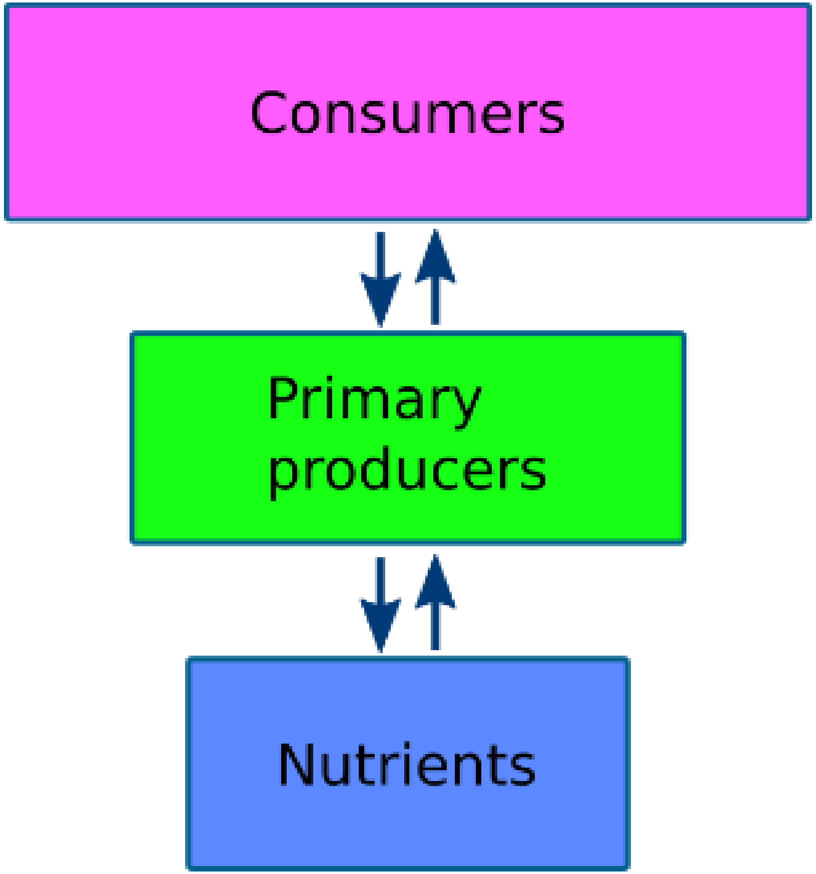
A clue for a bottom-up control



Phytoplankton do not perform at the optimal level

Falkowski et al., 2018

Non linear responses



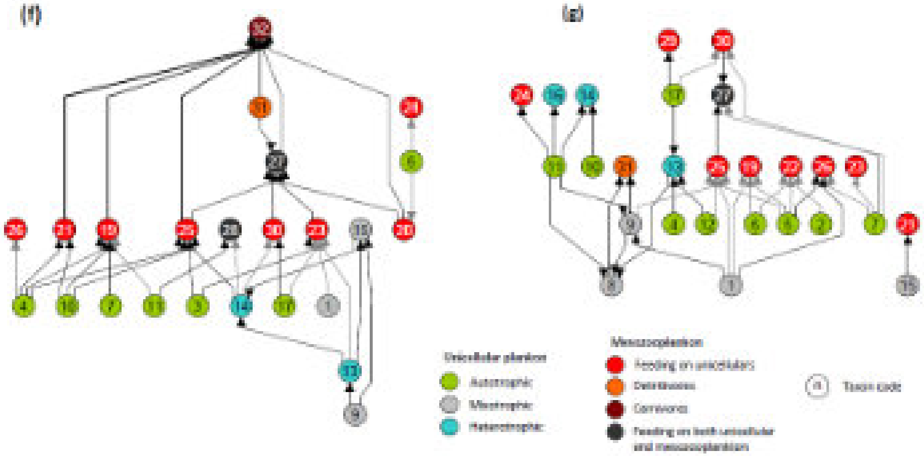
Increasing the size of the 'nutrients' box with constant arrow size the other two boxes should increase proportionally with no dramatic increase of the green box.

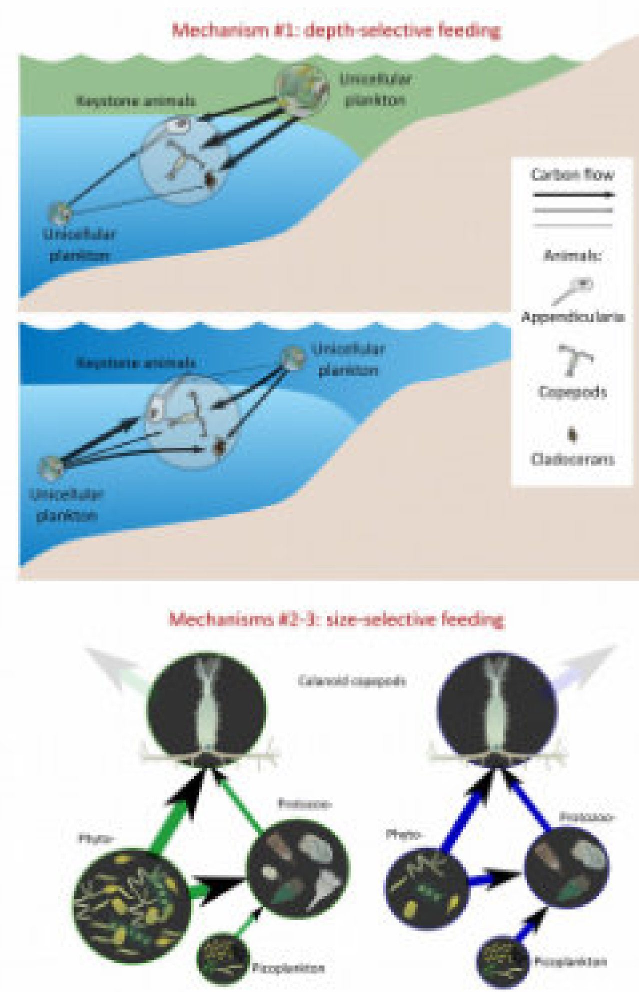
In fact we observe two opposite responses:

1. a critical enlargement green box we term **eutrophication**

2. a rearrangement of the network via compensating mechanisms that changes the 'arrow size'

Network plasticity

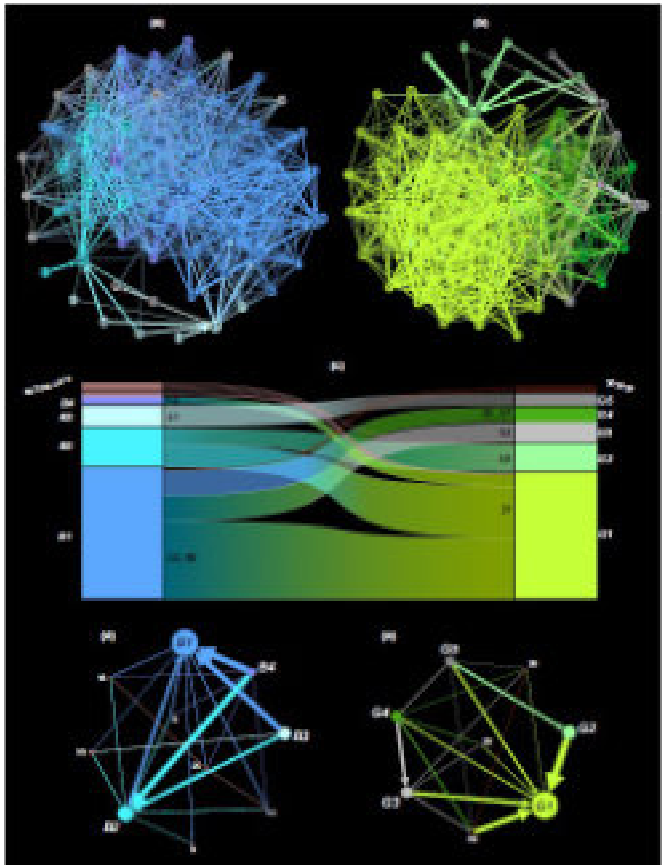


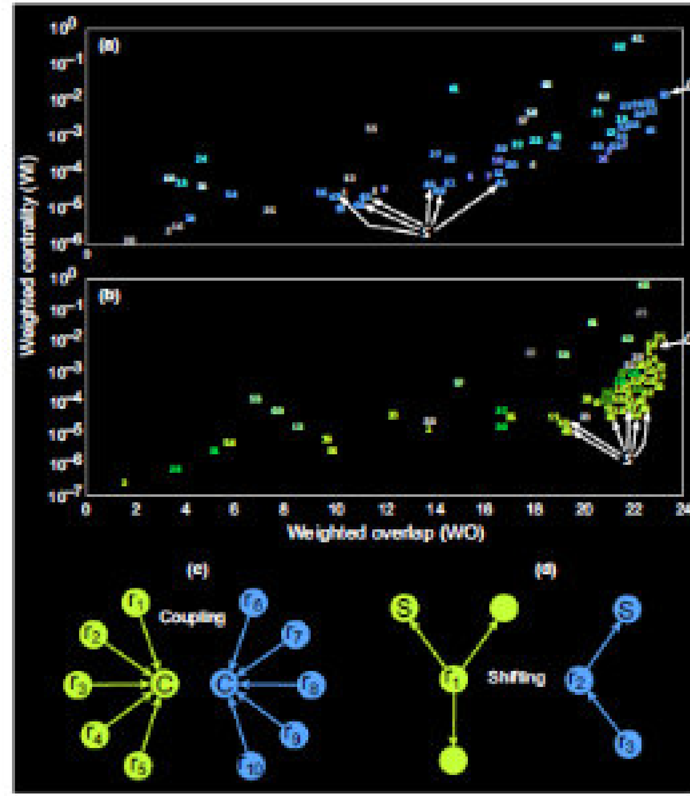


The latter (rearrangement) maybe taken as a response of a resilient (still healthy) system

D'Alelio et al., 2016

Developing metrics

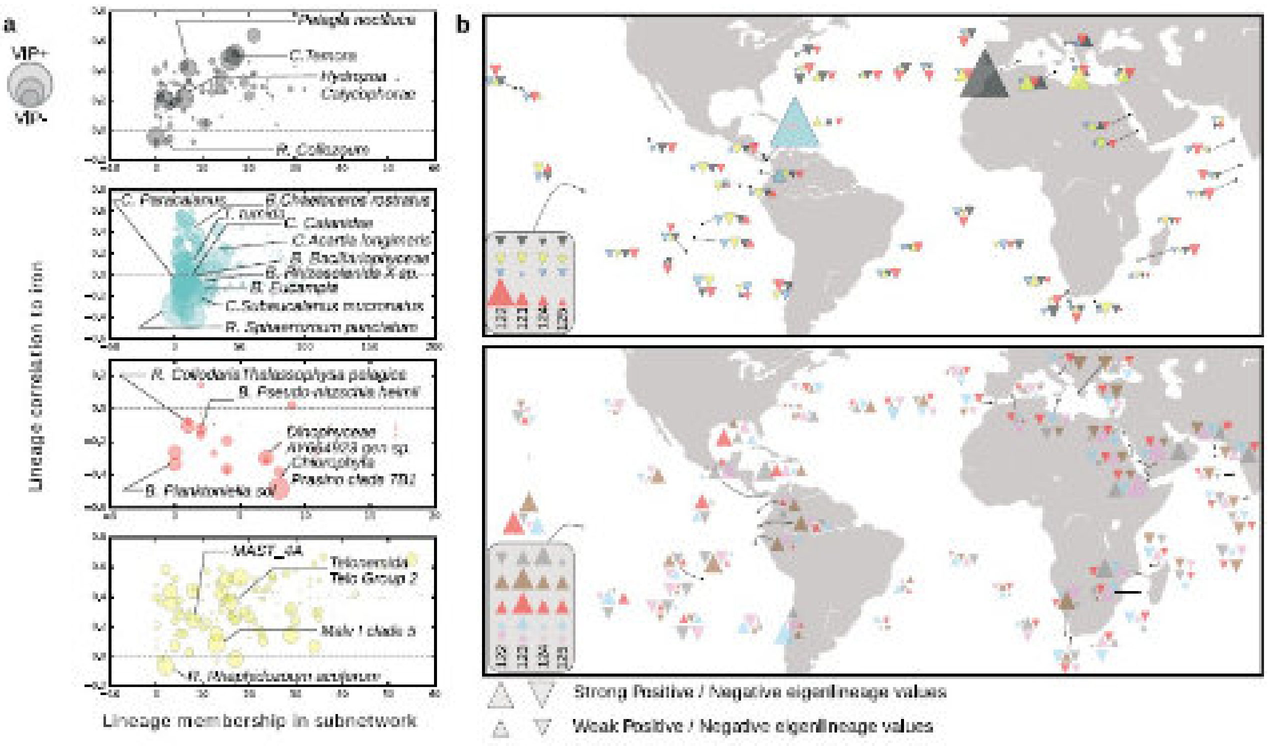




Network theory allows for quantifying the change via network indexes

D’Alelio et al., 2019

Community response to fertilization

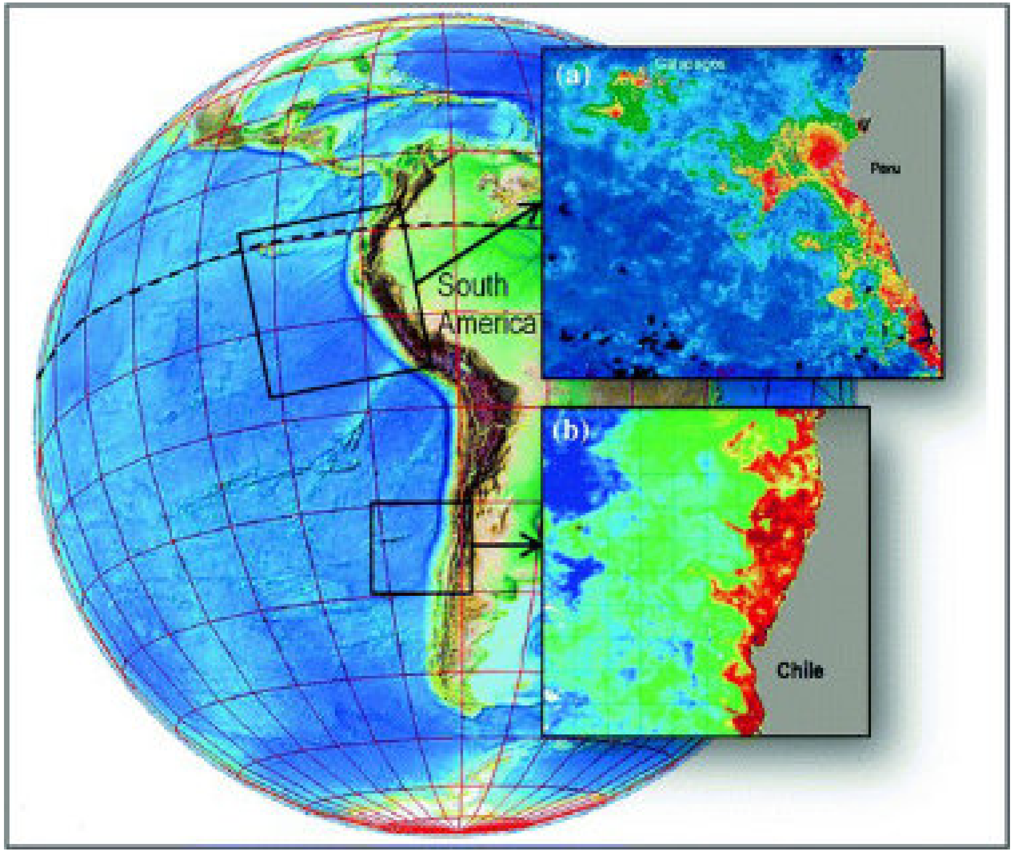


Under changes in (micro)nutrient fluxes diffent 'modules' of the community respond in a coordinated but different way

Caputi et al., 2019

JPI OCEANS

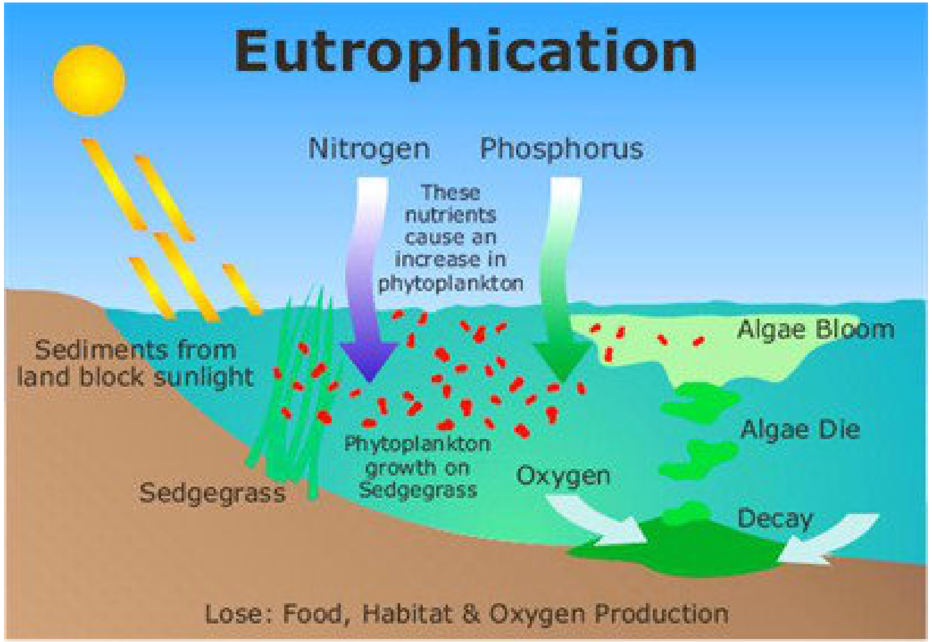
‘Physiological’ response to intense fertilization



In specific region of the ocean nutrient fluxes are comparable to those in stressed coastal areas but the community is more capable to spread the flux among the ‘boxes’

Kampf & Chapman, 2016

‘Stressed’ response to fertilization: Eutrophication

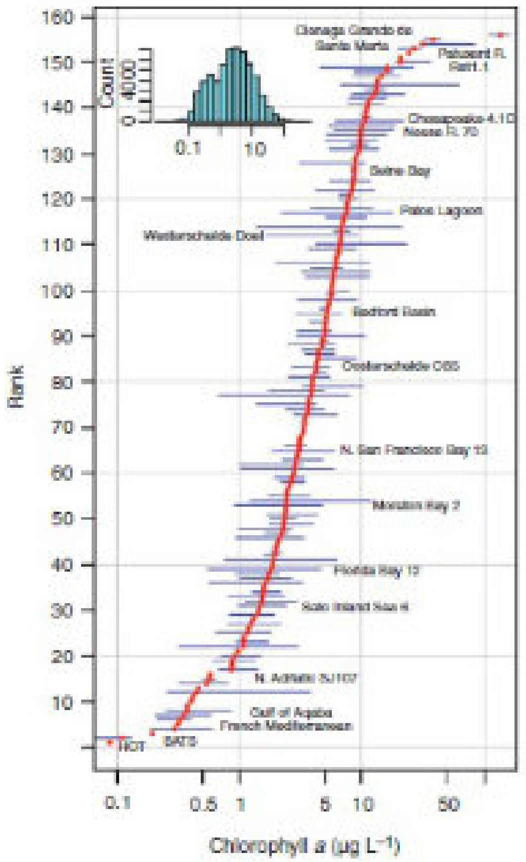


https://onlinesciencenotes.com/eutrophication-causes-effects-and-controlling-measures/

“Eutrophication means the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients”

Ferreira et al., 2011

What is the threshold between eutrophic and eutrophied?



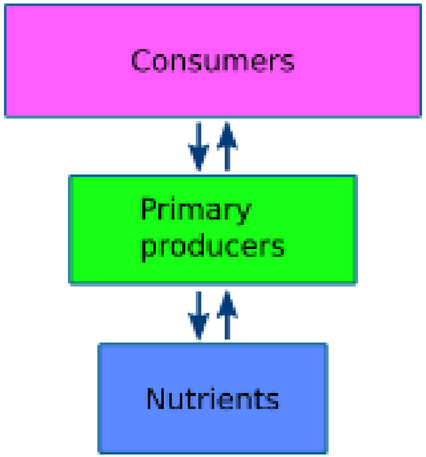
Cloern & Jassby, 2008

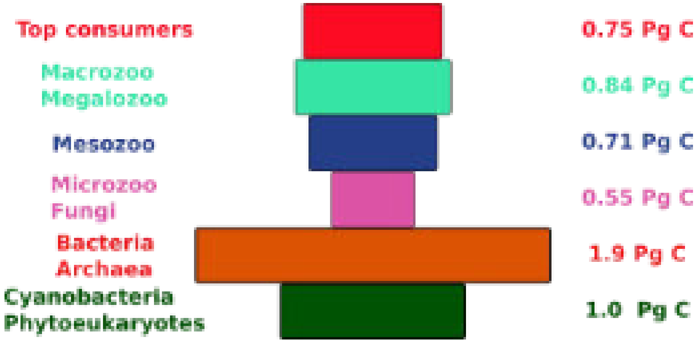
Productivity ranges

Upwelling systems up to 2000 g C $m^{-2}y^{-1}$

Eastern Mediterranean 50 g C $m^{-2}y^{-1}$

Back to boxes an pyramids





Since metabolic scaling, PPMR and TE drive the repartition among boxes, eutrophication is either due to:

- A specific food web is not (yet) suited to properly metabolize the increase of resources

- the time scale is not long enough to exploit their plasticity

This highlights that we assess ex-post

We do not invest in prediction

Contrasting views on fertilization

https://en.wikipedia.org/wiki/Neolithic_Revolution

https://sites.psu.edu/safeearth/2016/03/15/the-downfall-of-chemical-fertilizers/

Neolithic agriculture was based on a background stock of basic elements in the soil, on selection of organisms with high TE and low transfer upward, and periodic replenishment of resources in the soil.

Modern agriculture is based on blocking the upward transfer in the food web to favor the very top utilizer, and to chemical supply of the basic elements to the soil.

Terrestrial eutrophication is a common practice

Contrasting views on fertilization

https://en.wikipedia.org/wiki/Neolithic_Revolution

https://sites.psu.edu/safeearth/2016/03/15/the-downfall-of-chemical-fertilizers/

With marine eutrophication we do not exploit the harvest the unexploited harvest is hampering other harvests.

Ecosystem approach in MSFD can be interpreted as a anthropogenic biased approach

It may seem a trivial to highlight that industrial revolution has been possible because of ancient, very dramatic eutrophication events, with a clear unbalance within marine food webs.

The deep roots of eutrophication

Worrying of and blaming eutrophication is a first order response.

Eutrophication refects a mismatch between the location of fluxes (anthopogenically determined) and the structure of the receiving community.

The latter is a key knowedge gap, which rightly leads us to apply a precautionary principle.

This is a wise decision but conflicts with the, possibly temporary, need of mobilizing more and more resources.

A better knowledge of the ecosystem functioning and an aware design of where and when dispose the excess of material would change the scenario.

Expanding the ecosystem approach

Biota has evolved an unbelievable amount of self-regulating mechanisms to cope with often harsh environmental variations.

Among those also the possibility of shaping the environment to make it better suited for their survival, i.e, niche construction.

Man is by far the most successful species in this respect. Earth is becoming more and more the niche constructed by ourselves.

However, this is not a linear, progessive process.

Environmental management and governance

As competition among species may direct niche construction, likewise competition among economic interests may direct the process of niche construction whose outcome is to destroy other sides of our niche.

We make efforts to map our niche on ecosystem services.

Eutrophication is just the manifestation of a conflict and might be overcome by investing more on the knowledge of pelagic marine food web and ‘governing’ our impact.

THANK YOU

Maurizio Ribera d’Alcalà