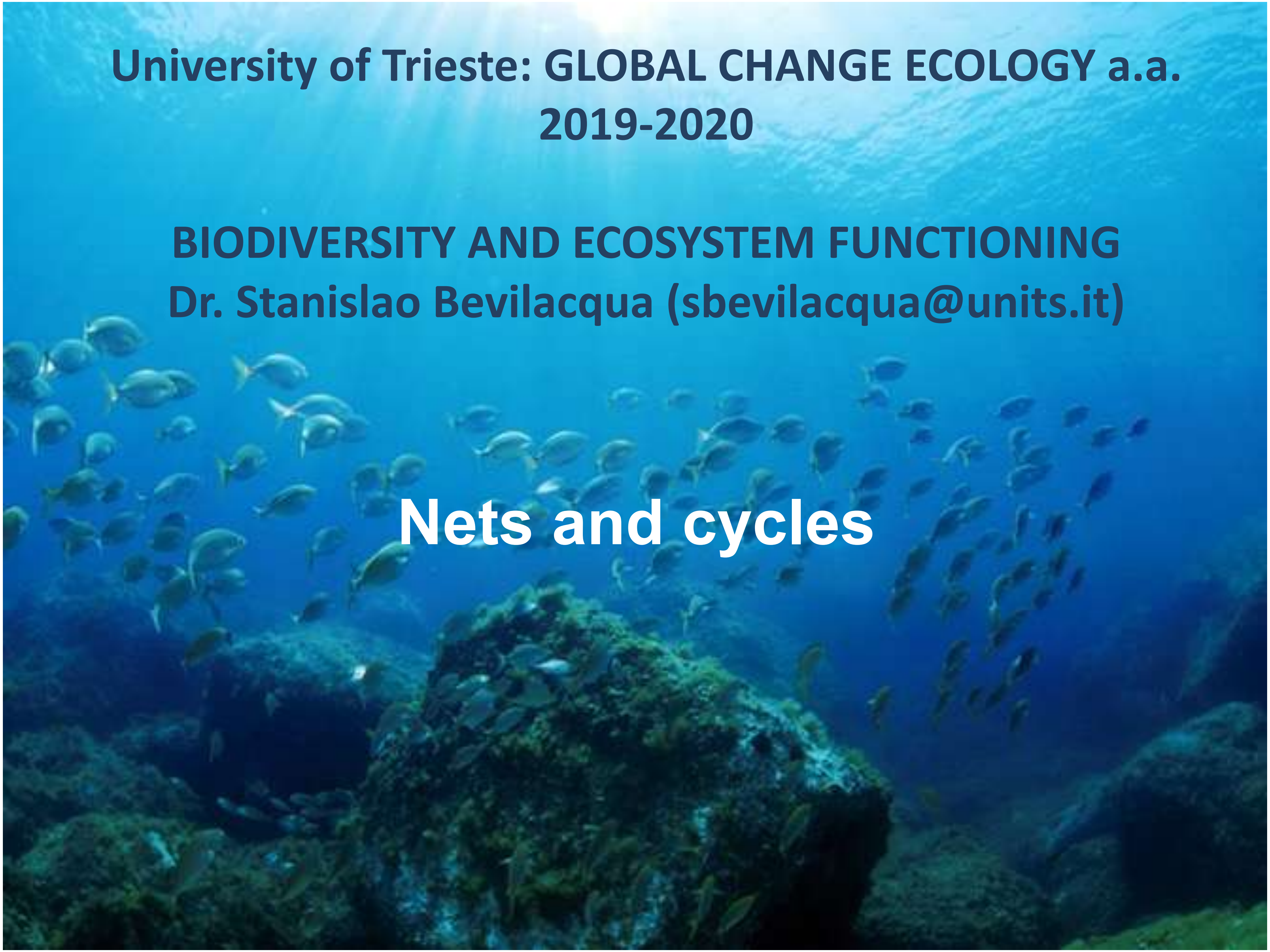
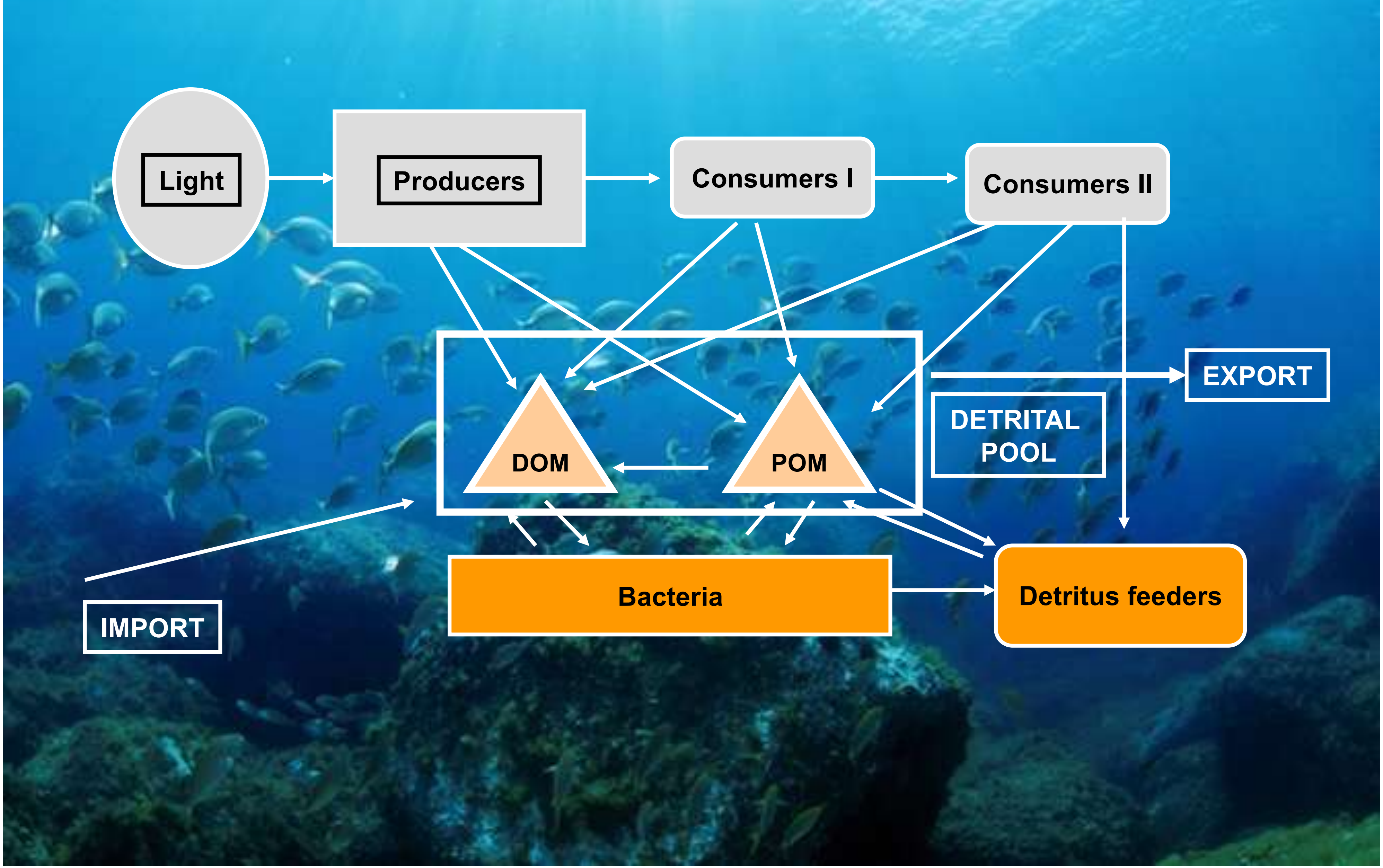

University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2019-2020
BIODIVERSITY AND ECOSYSTEM FUNCTIONING
Dr. Stanislao Bevilacqua (sbevilacqua@units.it)
Nets and cycles

Trophic chains and the importance of detritus

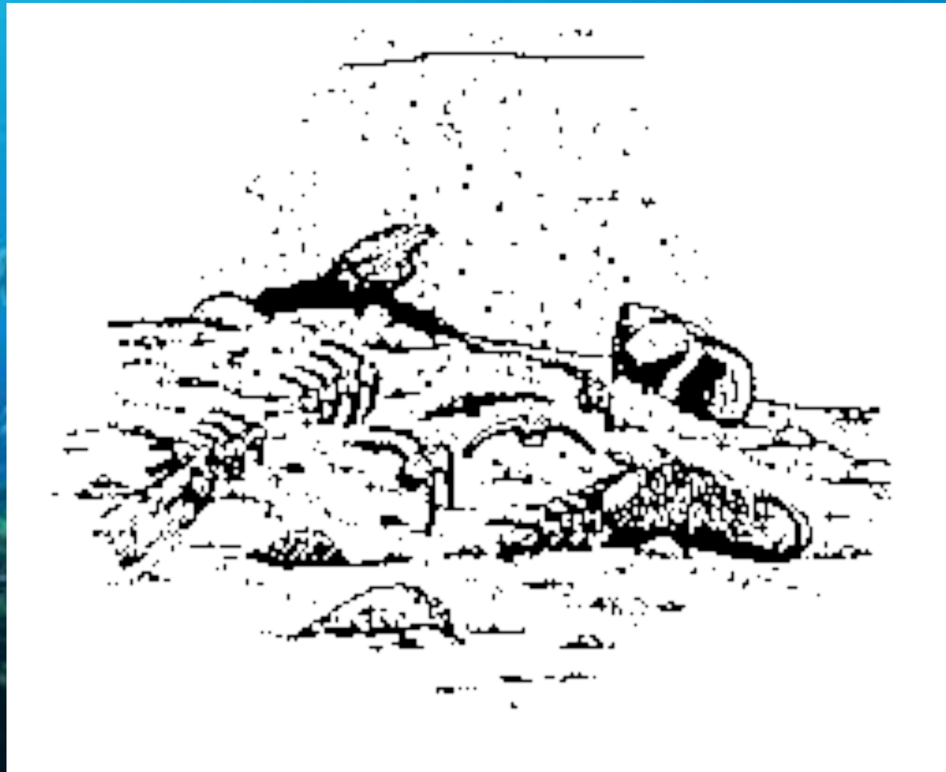
Detritus (90% of primary production)



Detritus

“non-predatory loss of organic carbon from each trophic level or inputs from external sources”
(Wetzel et al.,1972)

So, everything non-living and organic, irrespective of its size, composition and origin



Origin

Terrestrial supply
Small plankton remains
Moults
Fecal pellets

Large animal remains
(fish and mammal carcasses)

Algal and plant debris
(kelp, seagrass, etc.)

Classification of organic matter

1. **Type**:	Living	(Organisms)	10%
	Detritus	(fecal pellets, excretions, etc.)	90%

2. **Size**: DOM (<0.45 µm = detritus+virus+bacteria)
POM (>0.45 µm = detritus+bacteria+ phytoplankton+microzooplankton)

3. **Sources**:	*in situ* production	10-90%
	exogenous	0-90%

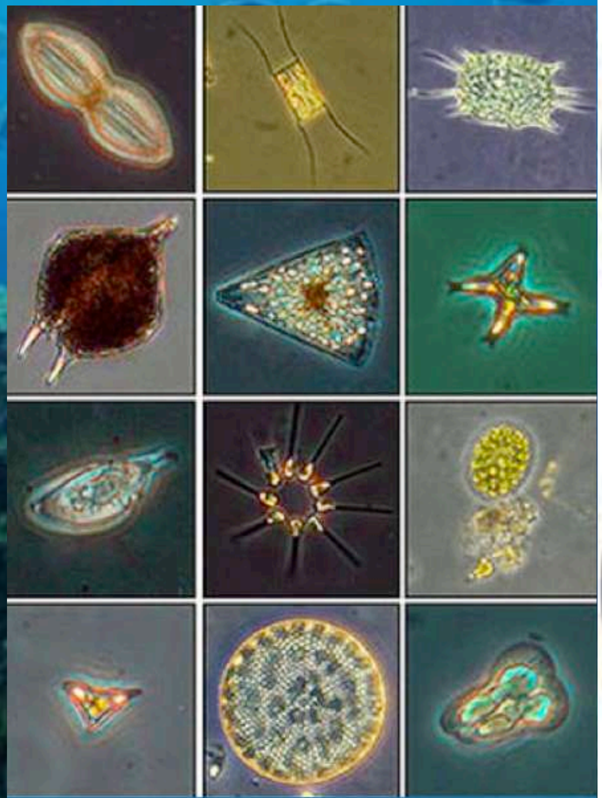
4. **Trophism**:	Bioavailable	1-10%
	Recalcitrant	90-99%

Type

Most of living organic matter in oceans comes from planktonic and benthonic bacteria, protists, phytoplankton, micro-zooplankton and meiofauna

Larger components are negligible in terms of amount and numbers

Microzooplankton are a group of heterotrophic and mixotrophic planktonic organisms between 20 and 200 µm in size. Important contributors to the group are phagotrophic protists such as flagellates, dinoflagellates, ciliates, radiolarians, foraminiferans, etc., and metazoans such as copepod nauplii, rotiferans and meroplanktonic larvae, among others.



Trophism

POM is composed by proteins, carbohydrates and fat acids

DOM is composed by a huge range of substances of molecular weight from very few until >100.000 d, and includes, for instance,

a. virus
b. carbohydrates (glucose, 50-60%)
e. aromatic compound (e.g., phenol, lignin, lipids)
f. amino acids
g. DNA and RNA

DOM pool is largely produced by phytoplankton and decomposition or bacterial and virus action

DOC/POC ratio 10-20:1 in the water column
DOC < 5% del TOC in sediments

Labile organic matter is easily and rapidily available to be remineralized by organisms, whereas recalcitrant organic matter is formed during decomposition and other processes (agglomeration), and is difficult to be degraded by bacteria unless during long periods. Example: CRAM (carboxyl-rich alicyclic molecules) amino-sugars, amino acids, terpenoids, lignin)

BCP, ML, and MCP

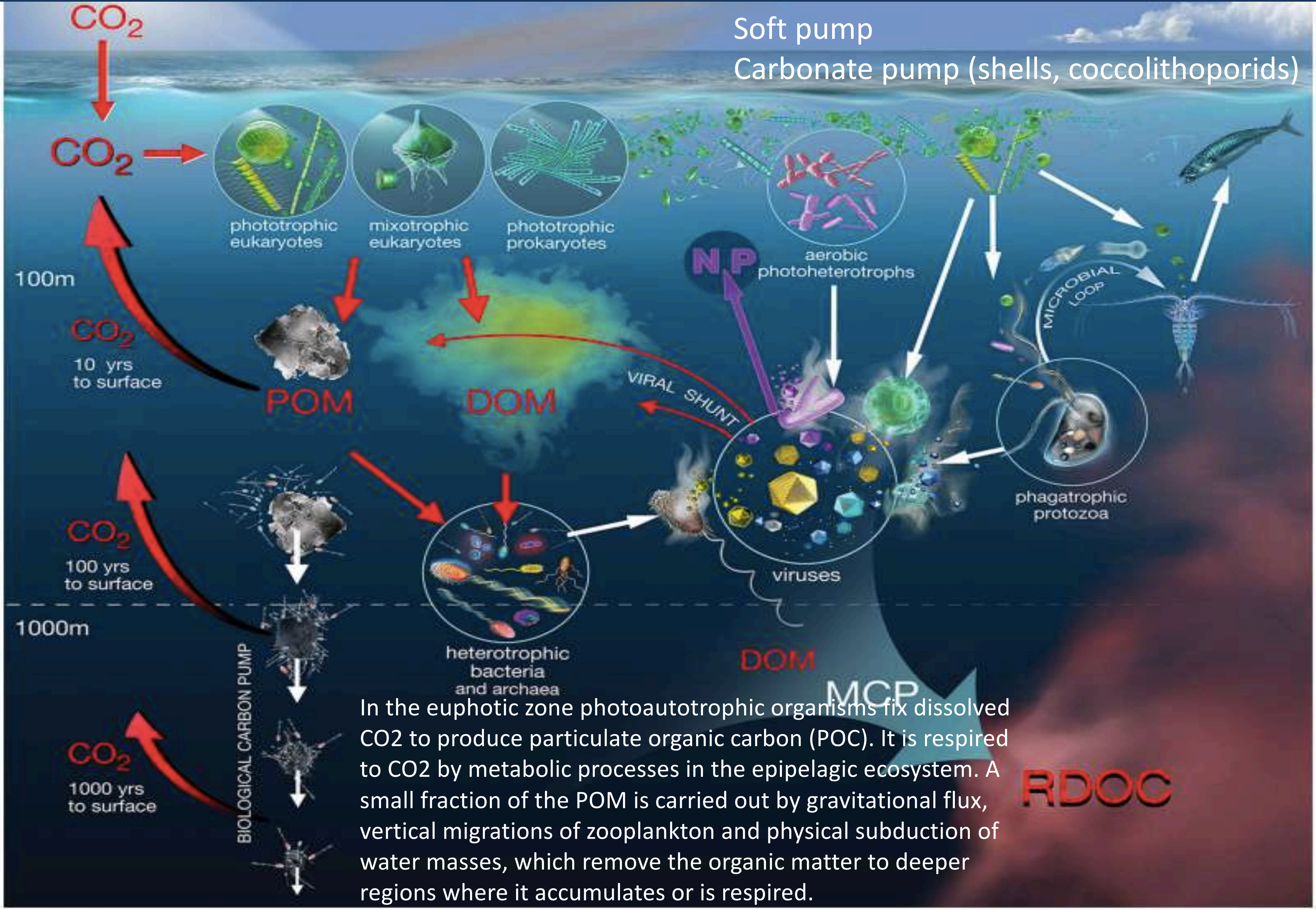
Table 1. Definitions and major impacts of the BCP, ML and MCP.

Concept	Definition	Major impacts and focus
Biological pump	A complex ecosystem process that transports particulate organic carbon from the epipelagic zone to the deep interior of the ocean and further to the ocean floor	Sequestration of atmospheric CO_2 through vertical transportation of living biomass to marine sediments; focusing on sediment storage
Microbial loop	A 'feedback' pathway of loss of the primary production to the environment in the form of dissolved organic matter and the utilization of the latter by bacteria that feed the protozoa, which enter the food chain	The role of bacteria in sequestering nutrients from the environment, which are consumed by protozoa; focusing on organismal populations above thermocline
Microbial carbon pump	A conceptual framework for understanding the role of microbial processes in the production of recalcitrant dissolved organic matter in the ocean water column	Sequestration of atmospheric CO_2 through transformation of labile organic matter to recalcitrant organic matter; focusing on capacity of the ocean to store atmospheric CO_2


Zhang et al, 2018

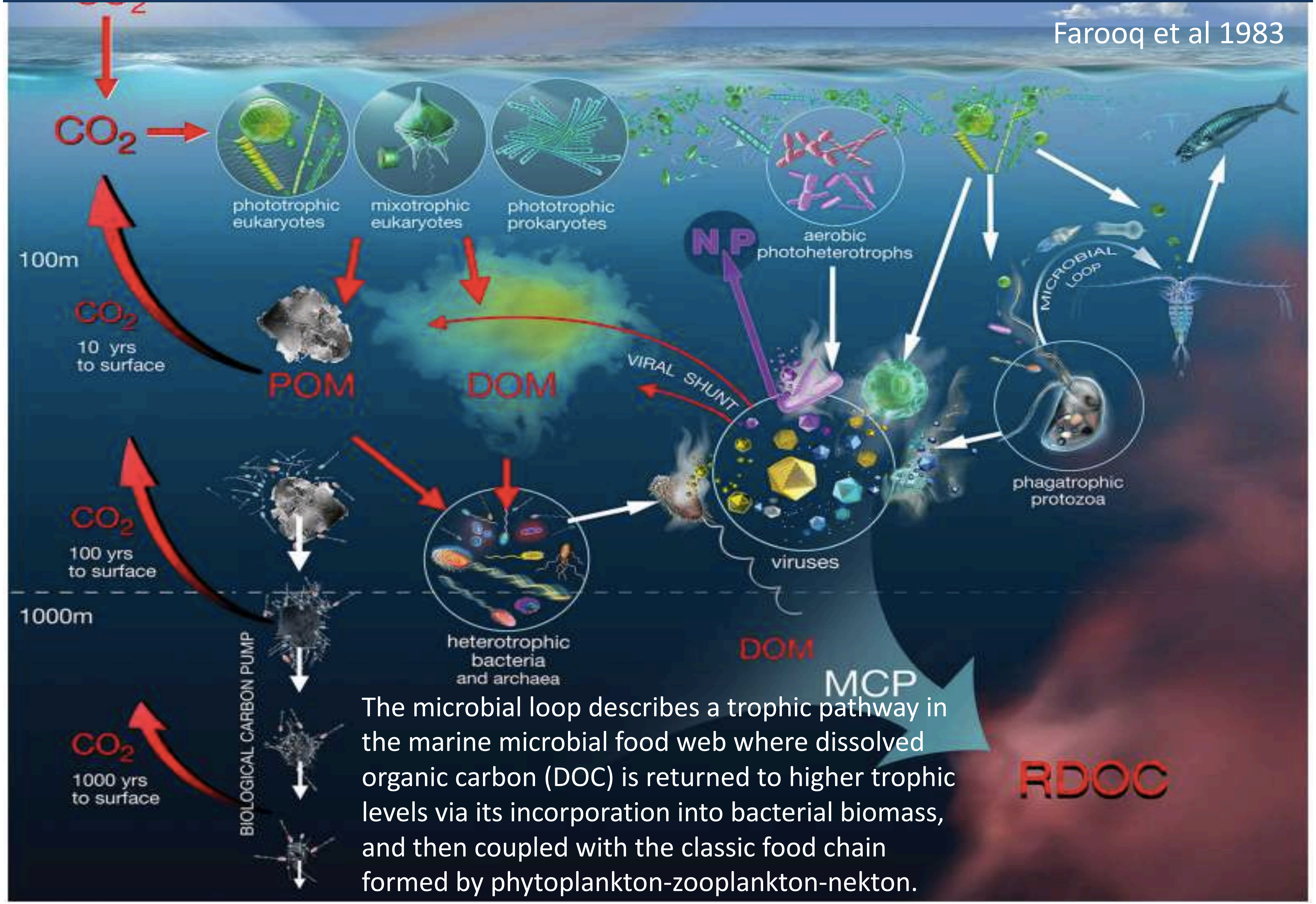
Biological Carbon Pump

Soft pump
Carbonate pump (shells, coccolithoporids)



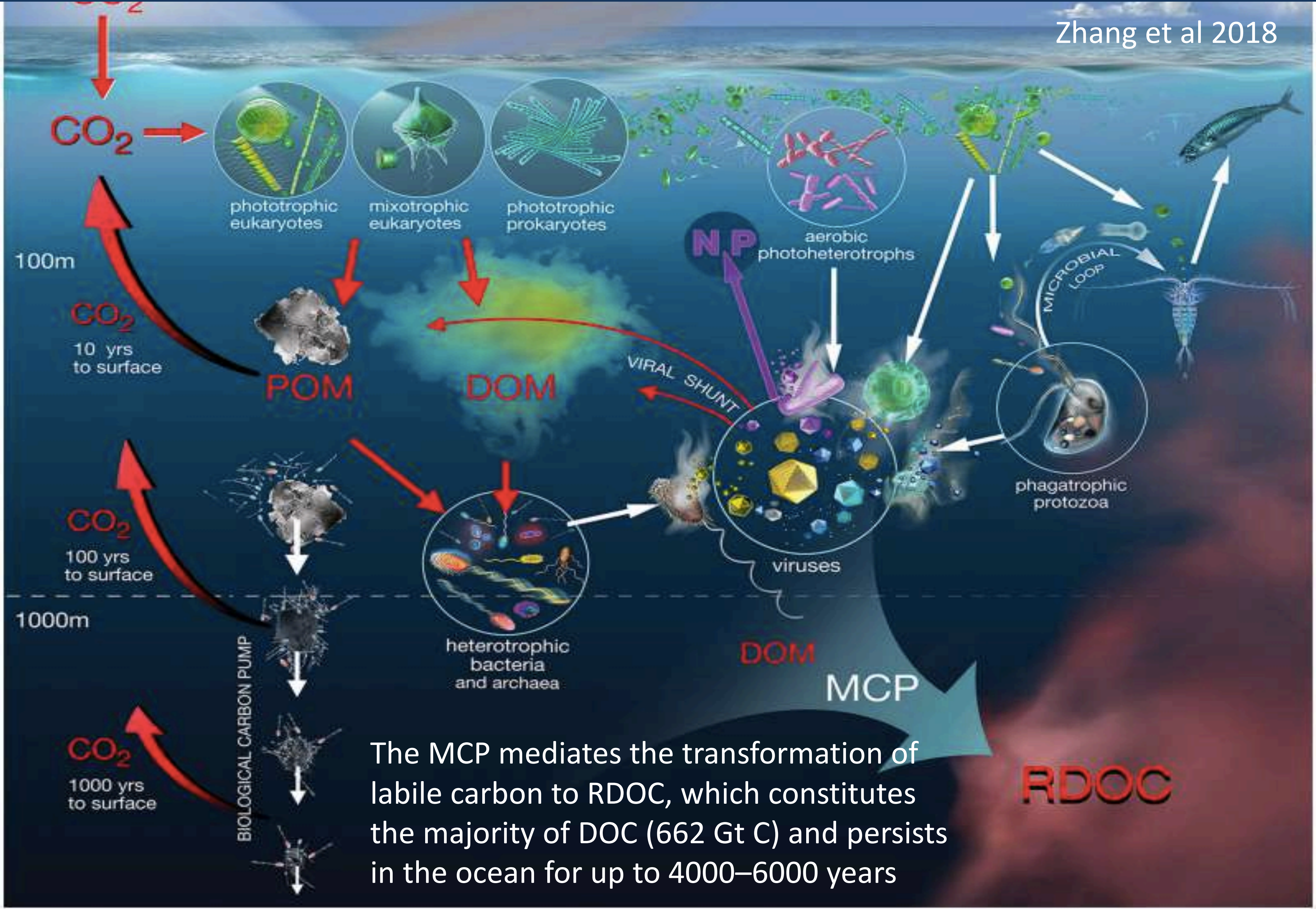
In the euphotic zone photoautotrophic organisms fix dissolved CO2 to produce particulate organic carbon (POC). It is respired to CO2 by metabolic processes in the epipelagic ecosystem. A small fraction of the POM is carried out by gravitational flux, vertical migrations of zooplankton and physical subduction of water masses, which remove the organic matter to deeper regions where it accumulates or is respired.

Microbial loop



The microbial loop describes a trophic pathway in the marine microbial food web where dissolved organic carbon (DOC) is returned to higher trophic levels via its incorporation into bacterial biomass, and then coupled with the classic food chain formed by phytoplankton-zooplankton-nekton.

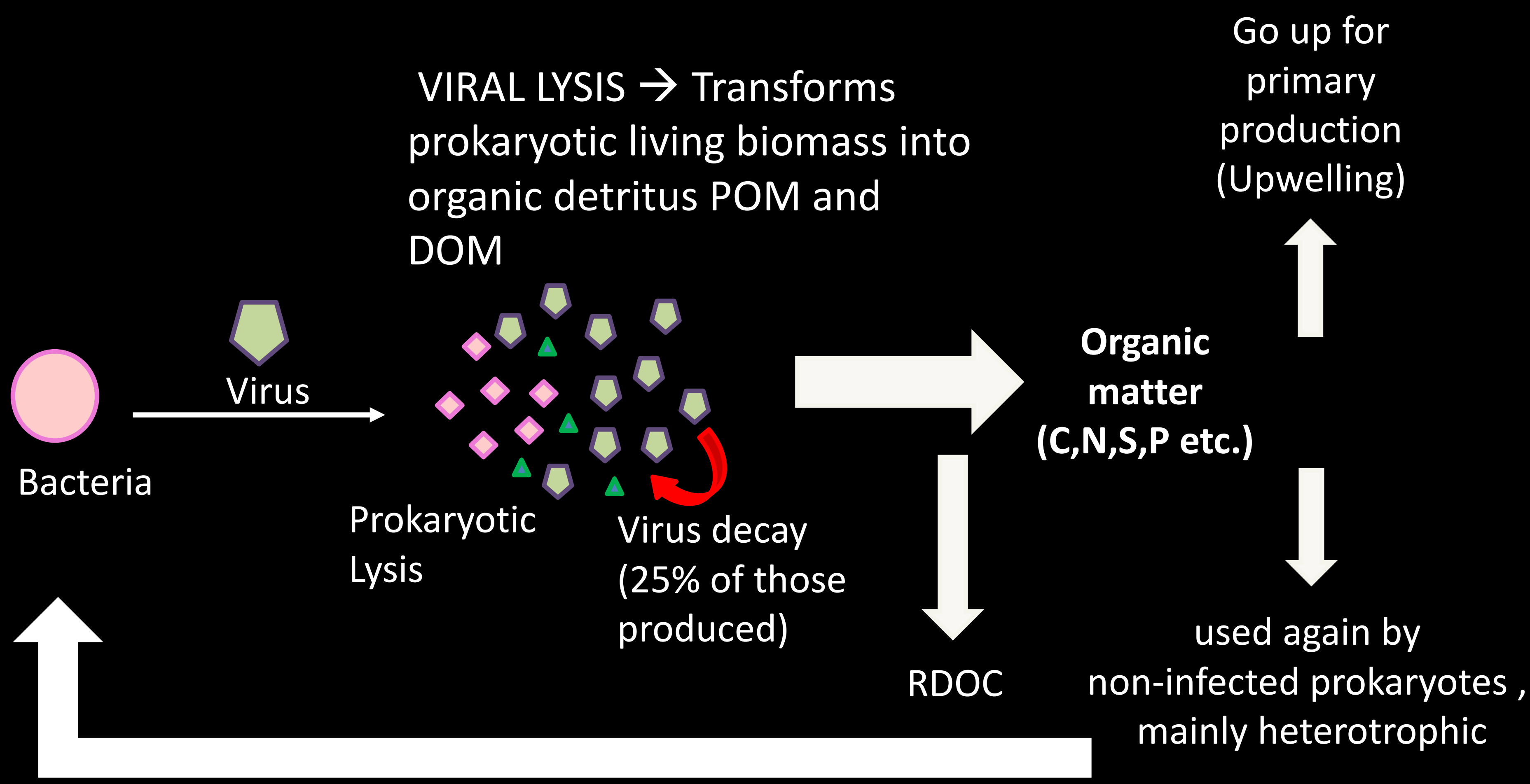
Microbial Carbon Pump



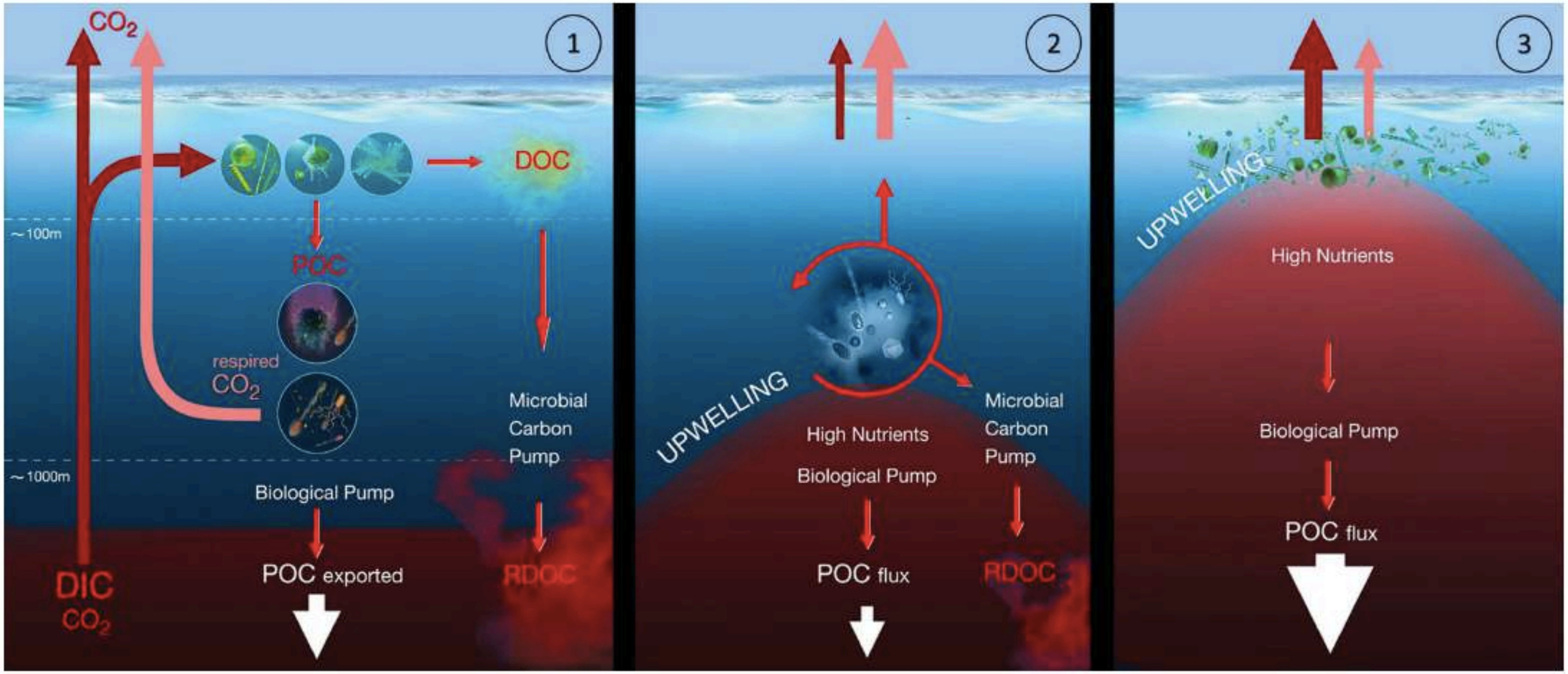
The MCP mediates the transformation of labile carbon to RDOC, which constitutes the majority of DOC (662 Gt C) and persists in the ocean for up to 4000–6000 years

Viral shunt

This process sustains a high prokaryotic biomass and provides an important contribution to prokaryotic metabolism, allowing the system to cope with the severe organic resource limitation of deep-sea ecosystems



The viral shunt, releasing on a global scale , **37-50 megatons of carbon per year**, is an essential source of labile organic detritus in the deep-sea ecosystems



(1) Functioning of the BCP and the MCP in a non-upwelling region of the ocean. (2) Dominance of the MCP in scenario 1 where the total upward CO2 flux exceeds downward POC export flux: nutrients are injected only into the lower layer of the euphotic zone; *Prochlorococcus* is dominant; CO2 outgassing exceeds POC export; the MCP is the prevailing mechanism for carbon sequestration. (3) Dominance of the BCP in scenario 2 where the downward POC flux exceeds the total upward CO2 flux: nutrients are injected into the upper layer of the euphotic zone; diatoms are dominant; POC export exceeds CO2 outgassing; the BCP is the prevailing mechanism for carbon sequestration.

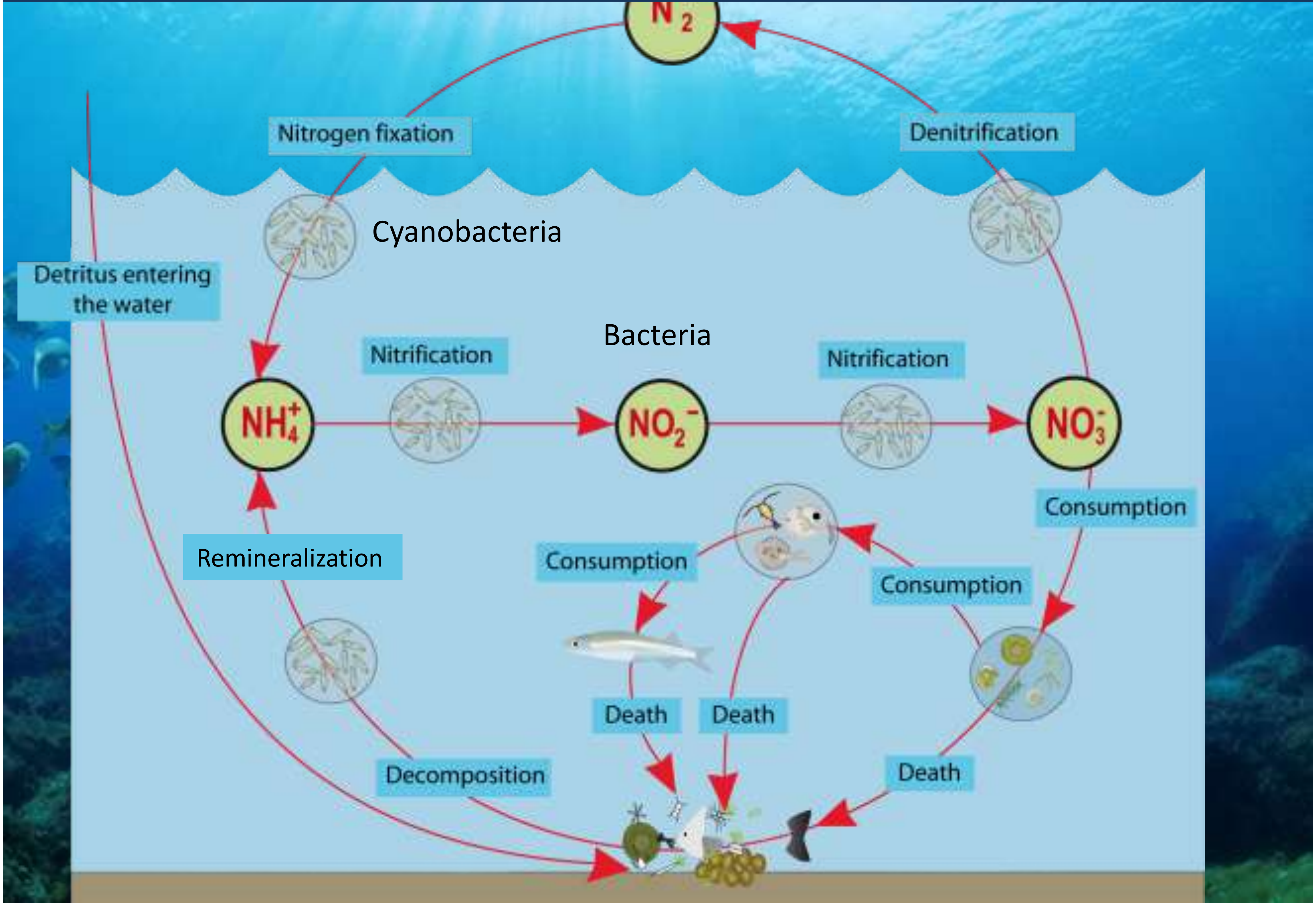
Terrestrial export of nutrients





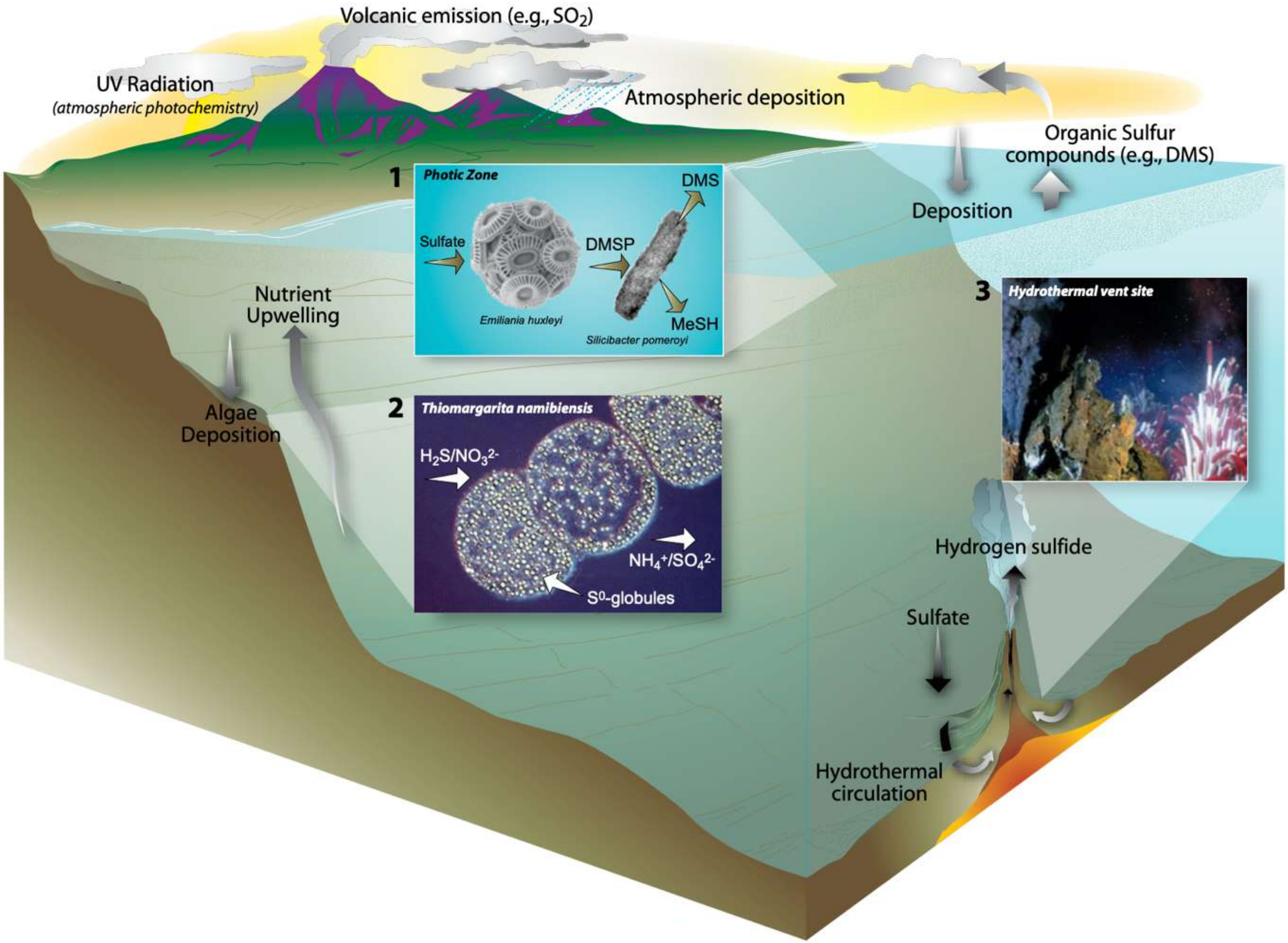
Rivers and atmospheric plume

N cycle



N 2
Nitrogen fixation
Denitrification
Cyanobacteria
Detritus entering the water
Bacteria
Nitrification
Nitrification
NH4+
NO2-
NO3-
Consumption
Remineralization
Consumption
Consumption
Death
Death
Death
Decomposition

S cycle

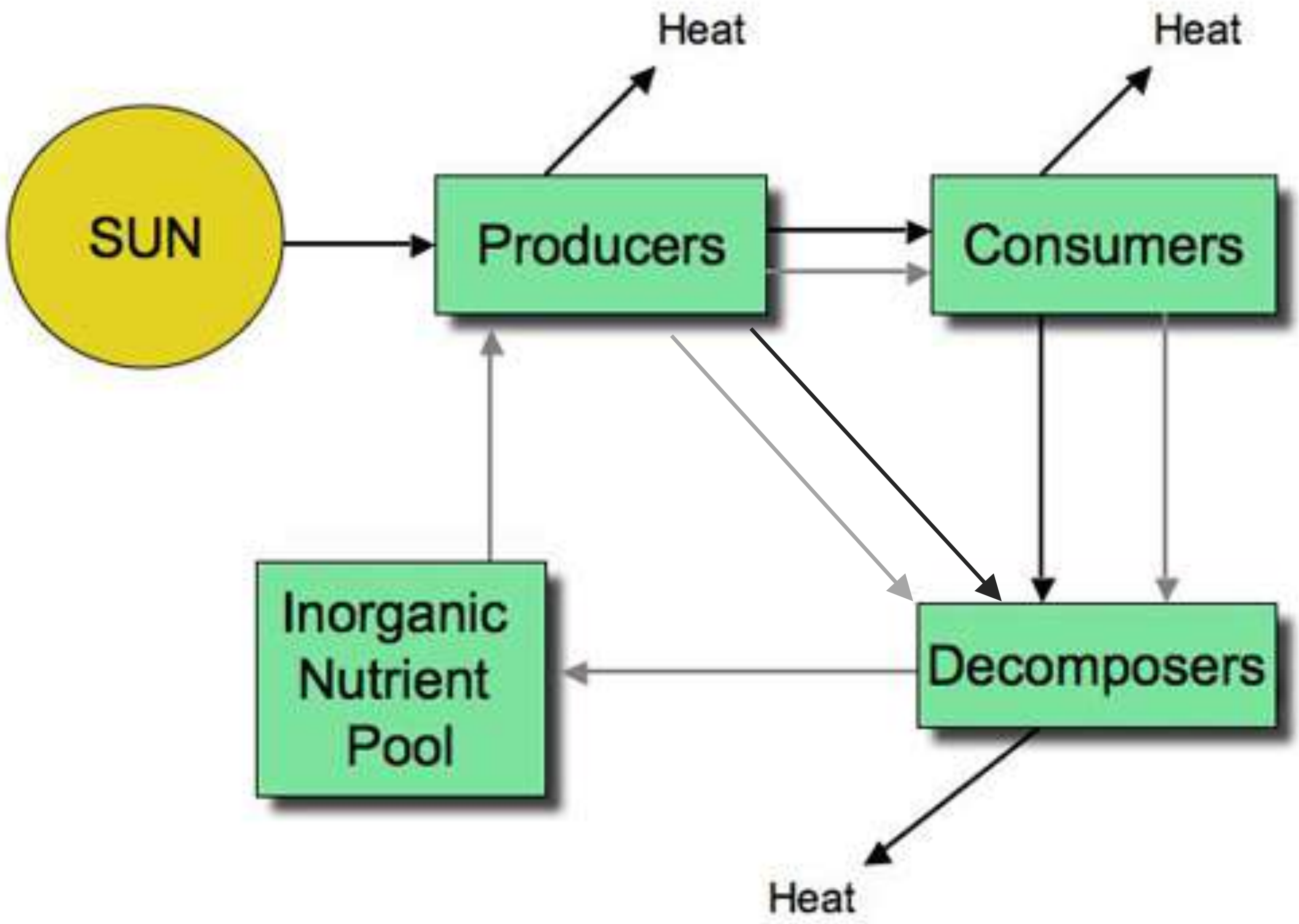


Volcanic emission (e.g., SO_2)
UV Radiation
(atmospheric photochemistry)
Atmospheric deposition
Organic Sulfur compounds (e.g., DMS)
Deposition
1
Photic Zone
DMS
Sulfate
DMSP
MeSH
Emiliania huxleyi
Silicibacter pomeroyi
Nutrient Upwelling
Algae Deposition
2
Thiomargarita namibiensis
H_2S/NO_3^{2-}
NH_4^+/SO_4^{2-}
S^0-globules
3
Hydrothermal vent site
Hydrogen sulfide
Sulfate
Hydrothermal circulation

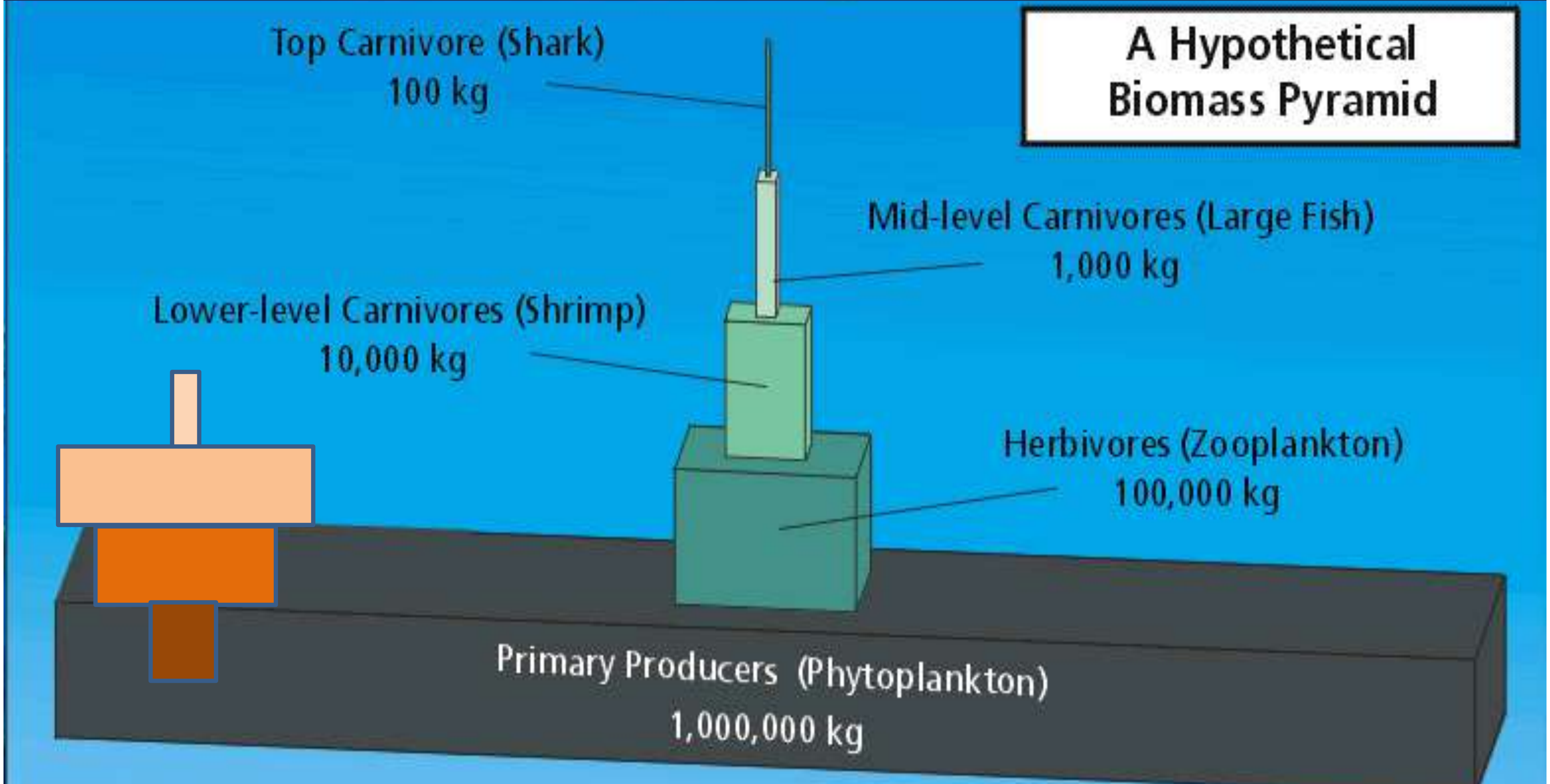
Trophic webs

1 law of thermodynamics

2 law of thermodynamics



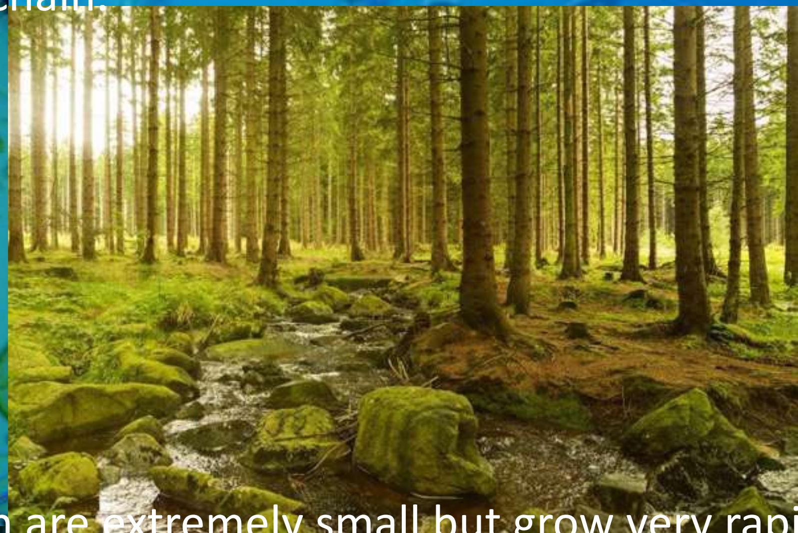
Energy flow



Efficiency of energy transfer is low, 10% on average at each trophic level. This is reflected in the biomass ratio between levels. Most of energy is lost in movement, excretions, fecal dejections, heat, so that moving from the basis (primary producers) to higher levels, the total sustainable biomass is drastically reduced. In some cases, in marine environments, the pyramid can be inverted because of differences in temporal turnover of organisms across levels

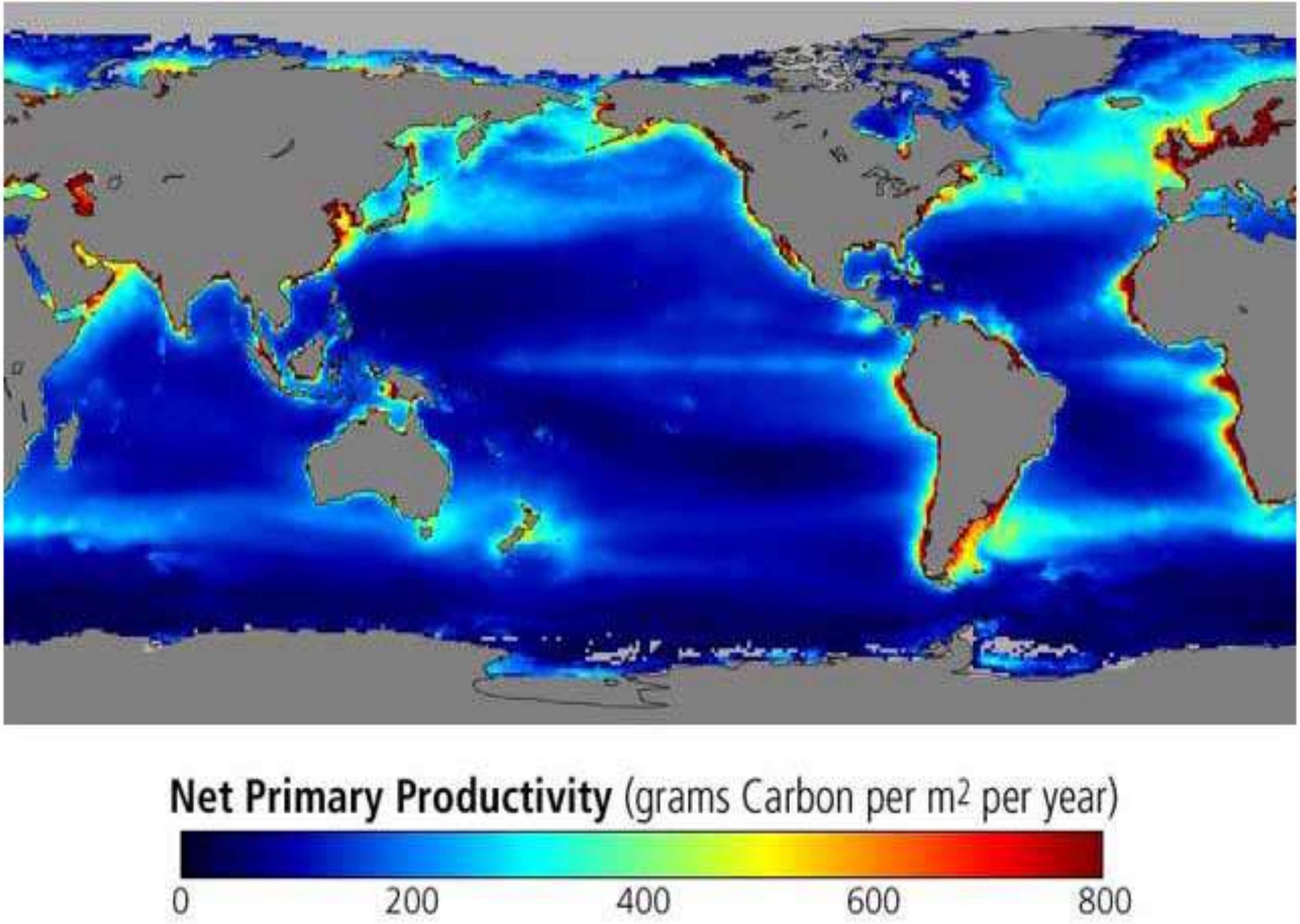
Differences between land and sea

Because of these energy losses, **most terrestrial ecosystems have no more than five trophic levels**, and **marine ecosystems generally have no more than seven**. This is likely due to differences in the fundamental characteristics of land and marine primary organisms. In marine ecosystems, microscopic phytoplankton carry out most of the photosynthesis that occurs, while plants do most of this work on land. Phytoplankton are small organisms with extremely simple structures, so most of their primary production is consumed and used for energy by grazing organisms that feed on them. In contrast, a large fraction of the biomass that land plants produce cannot be used by herbivores for food, so proportionately less of the energy fixed through primary production travels up the food chain.

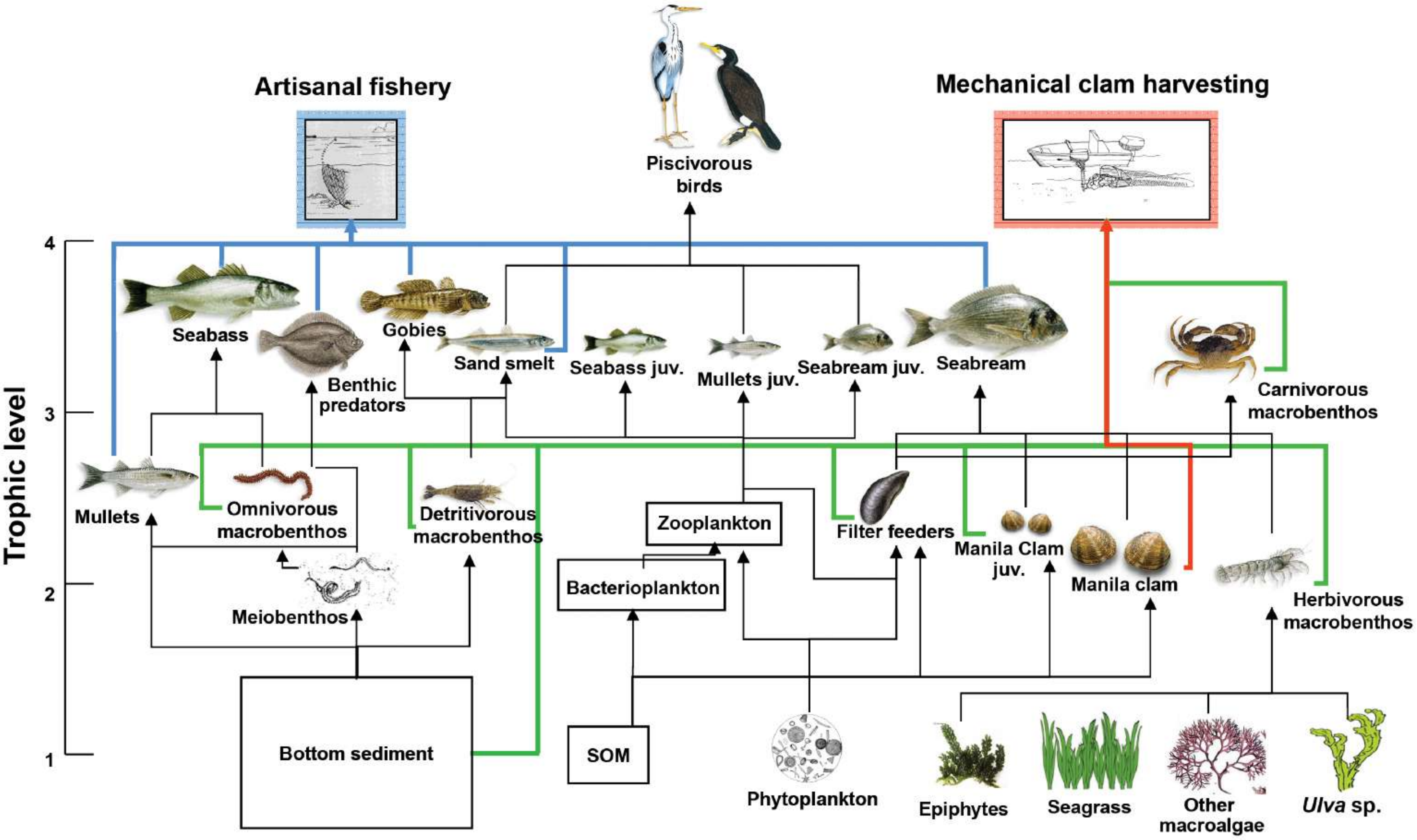


Growth rates may also be a factor. Phytoplankton are extremely small but grow very rapidly, so they support large populations of herbivores even though there may be fewer algae than herbivores at any given moment. In contrast, land plants may take years to reach maturity, so an average carbon atom spends a longer residence time at the primary producer level on land than it does in a marine ecosystem. In addition, locomotion costs are generally higher for terrestrial organisms compared to those in aquatic environments.

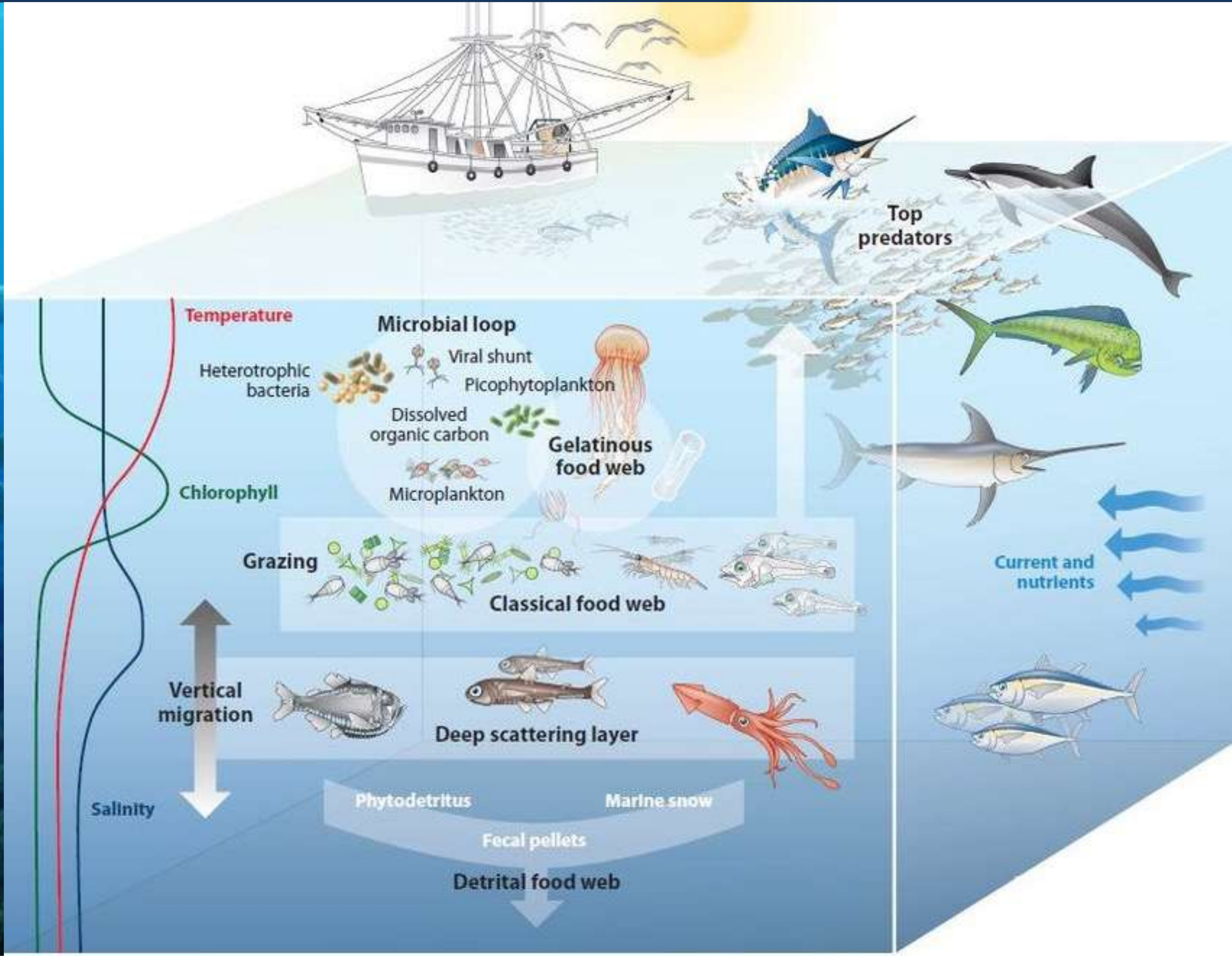
Total primary production in the ocean



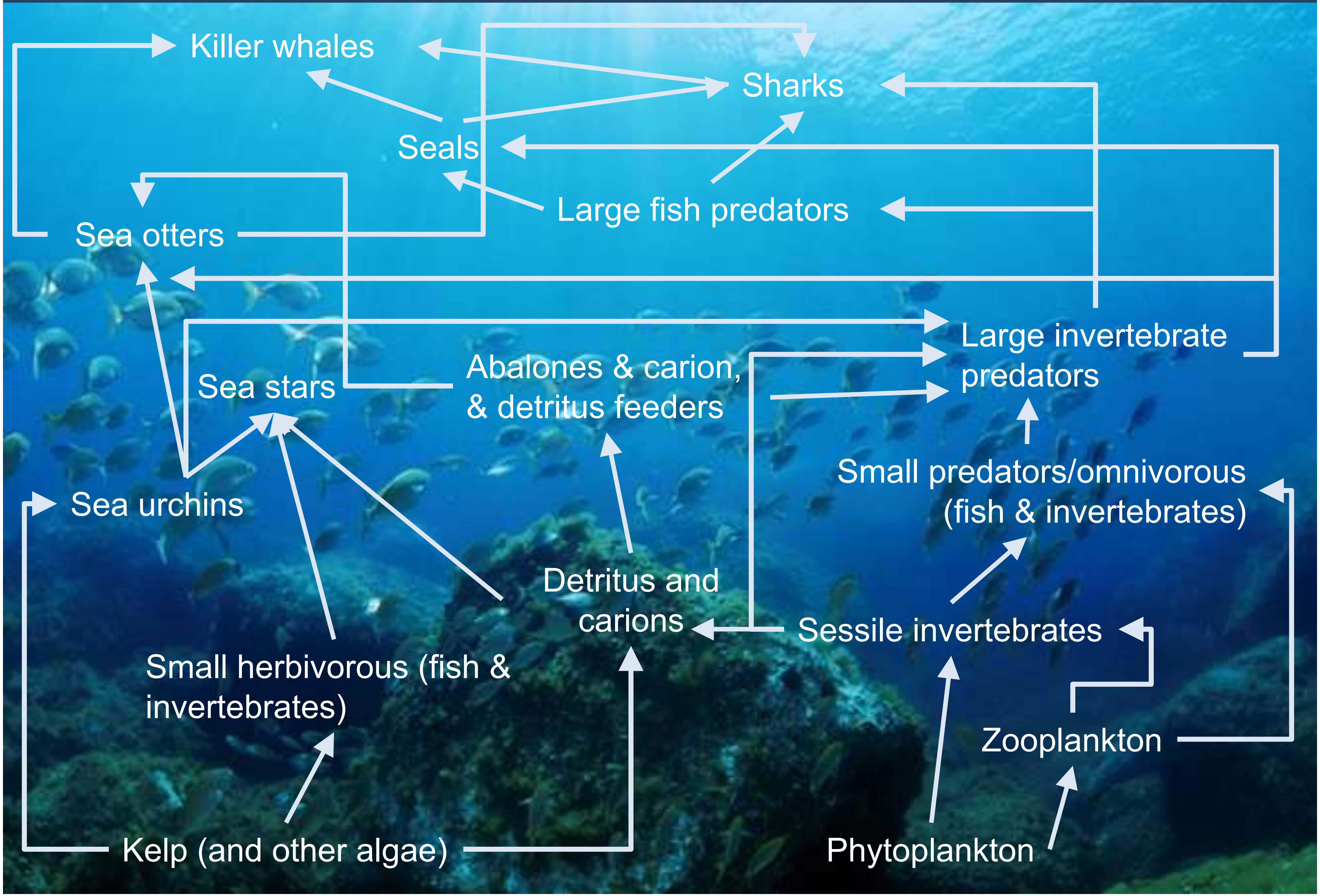
Trophic webs: coastal Mediterranean



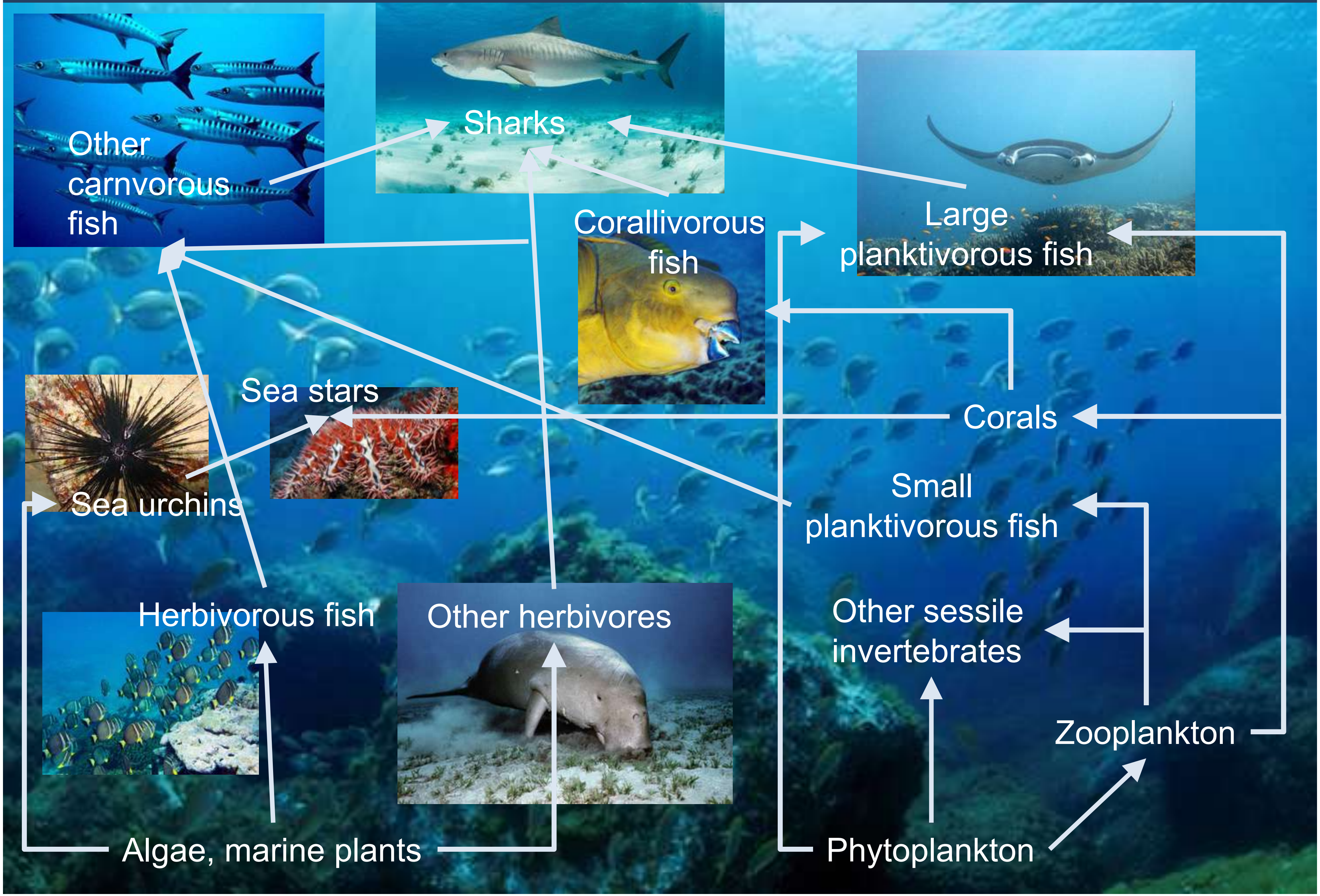
Trophic webs: pelagic



Trophic web: kelp forests



Trophic web: coral reefs



Keystone species

A keystone species is an organism that helps define an entire ecosystem. Without its keystone species, the ecosystem would be dramatically different or cease to exist.

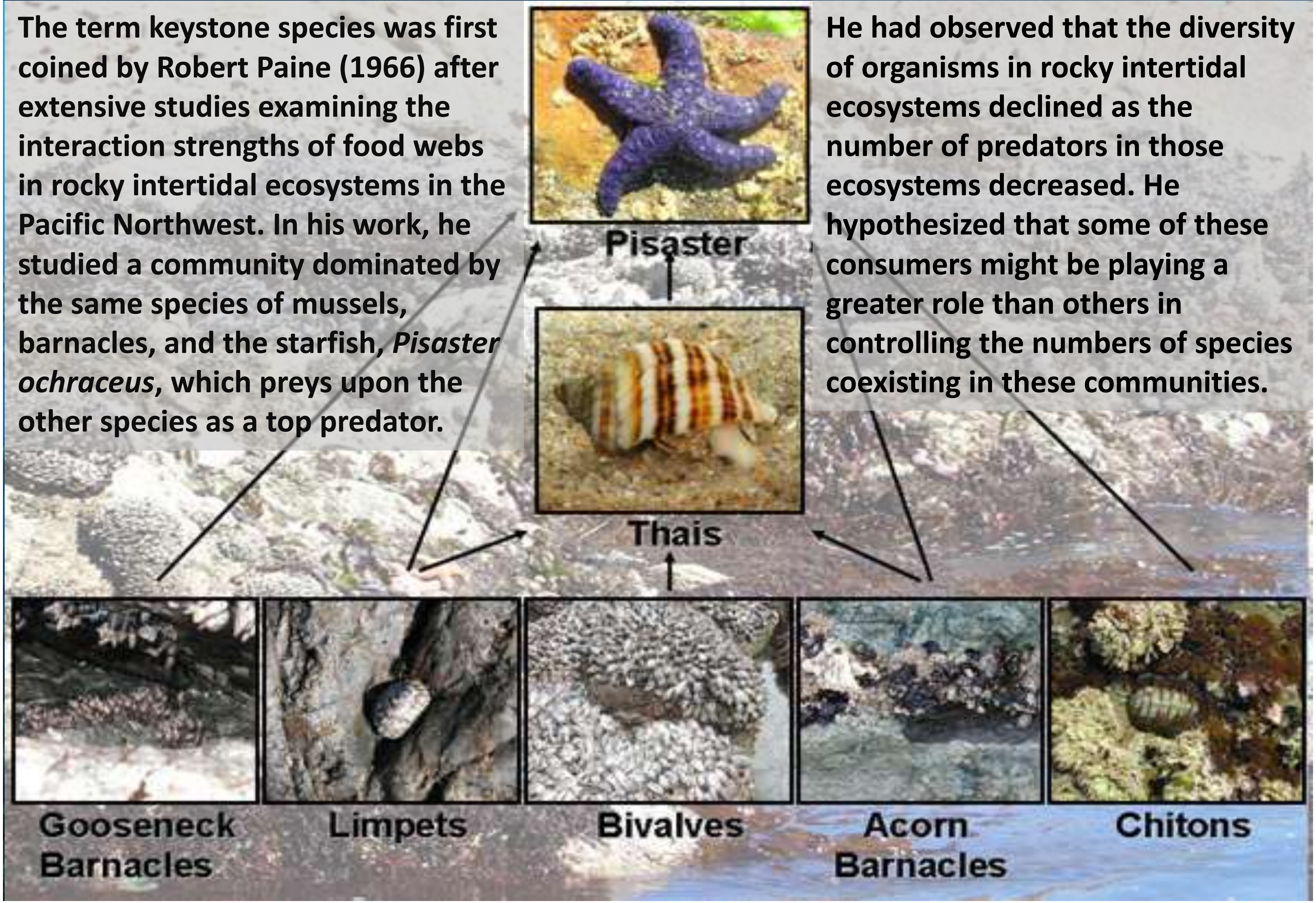
Keystone species have low functional redundancy. This means that if the species were to disappear from the ecosystem, no other species would be able to fill its ecological niche.

They could be predators or herbivores or producers.
Keystone can have either small population size or large number of individuals. Generally, in the case of predators, small numbers can have strong effects on ecosytems.

Paine's work

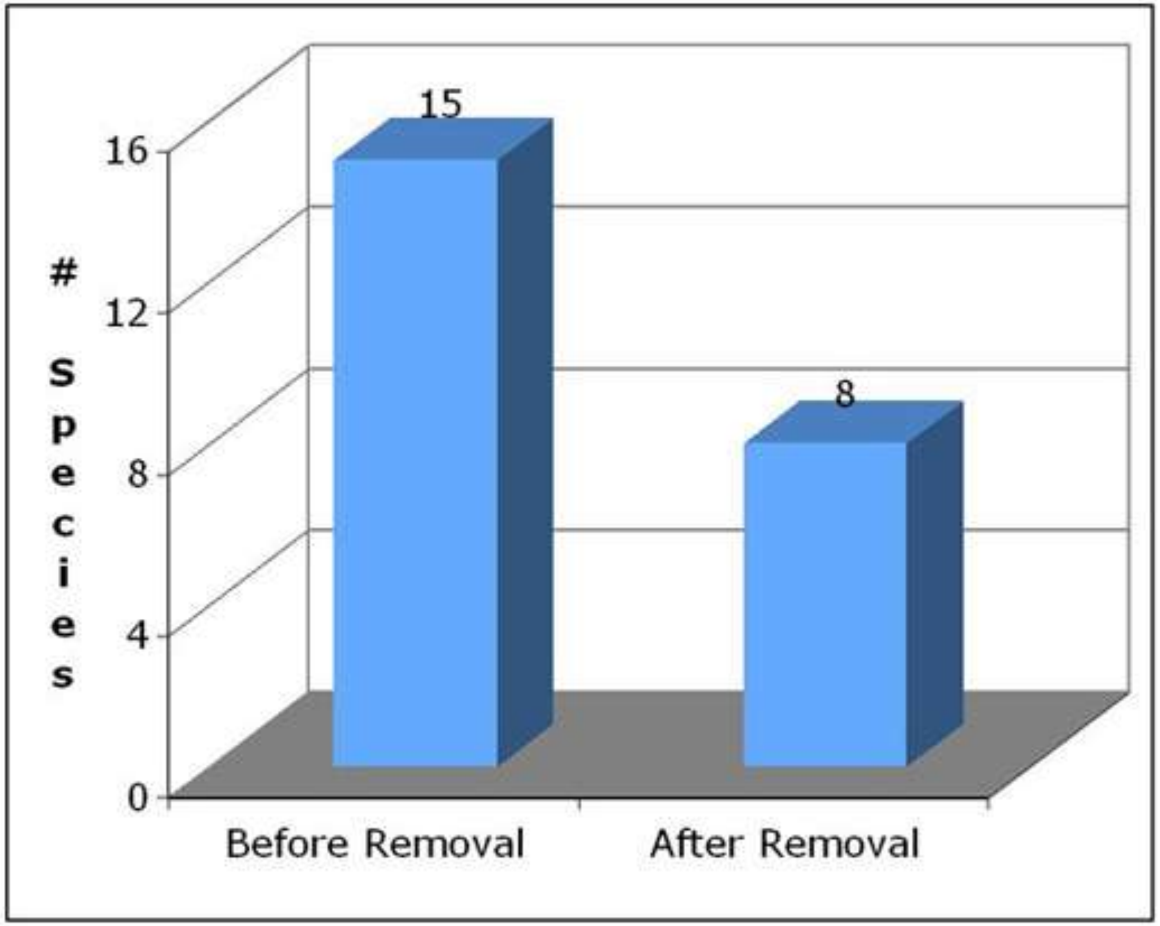
The term keystone species was first coined by Robert Paine (1966) after extensive studies examining the interaction strengths of food webs in rocky intertidal ecosystems in the Pacific Northwest. In his work, he studied a community dominated by the same species of mussels, barnacles, and the starfish, *Pisaster ochraceus*, which preys upon the other species as a top predator.

He had observed that the diversity of organisms in rocky intertidal ecosystems declined as the number of predators in those ecosystems decreased. He hypothesized that some of these consumers might be playing a greater role than others in controlling the numbers of species coexisting in these communities.



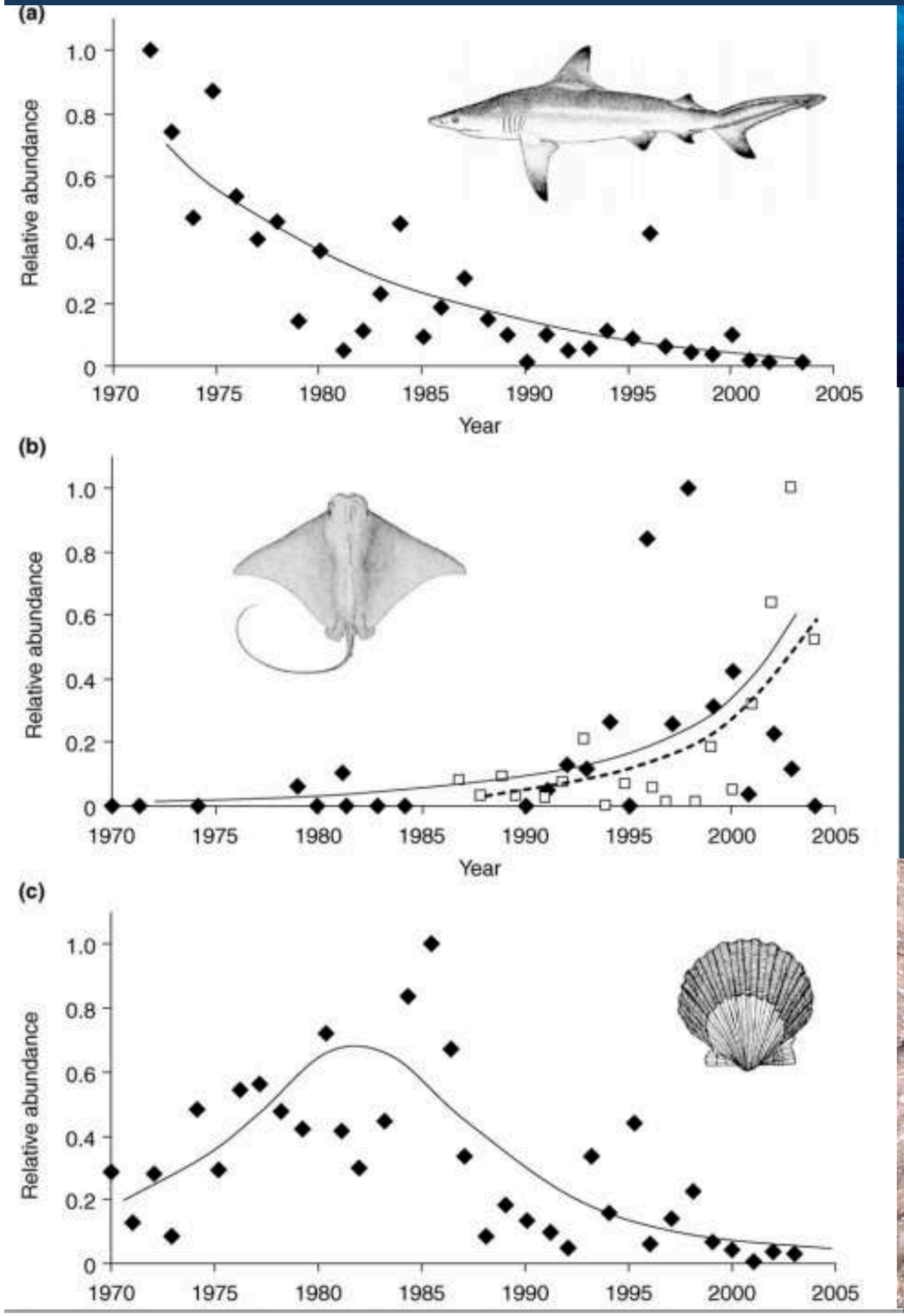
Paine's experiment

He tested his hypothesis in an experiment in which an area of the intertidal was kept free of starfish, comparing them with an undisturbed control area of equal size.
He observed dramatic changes after *Pisaster* was artificially removed compared with the control area that remained unchanged in its species number and distribution. Aftern removal of starfishes the other species began to compete.



Within three months the barnacle, ***Balanus glandula***, became dominant and after 9 months, it was replaced by another barnacle ***Mitella*** and the mussel ***Mytilus***. The succession of species wiped out populations of benthic algae, causing some species, such as the limpet, to emigrate because of lack of food and/or space. After a year of the starfish's removal, species diversity significantly decreased in the study area from fifteen to eight species

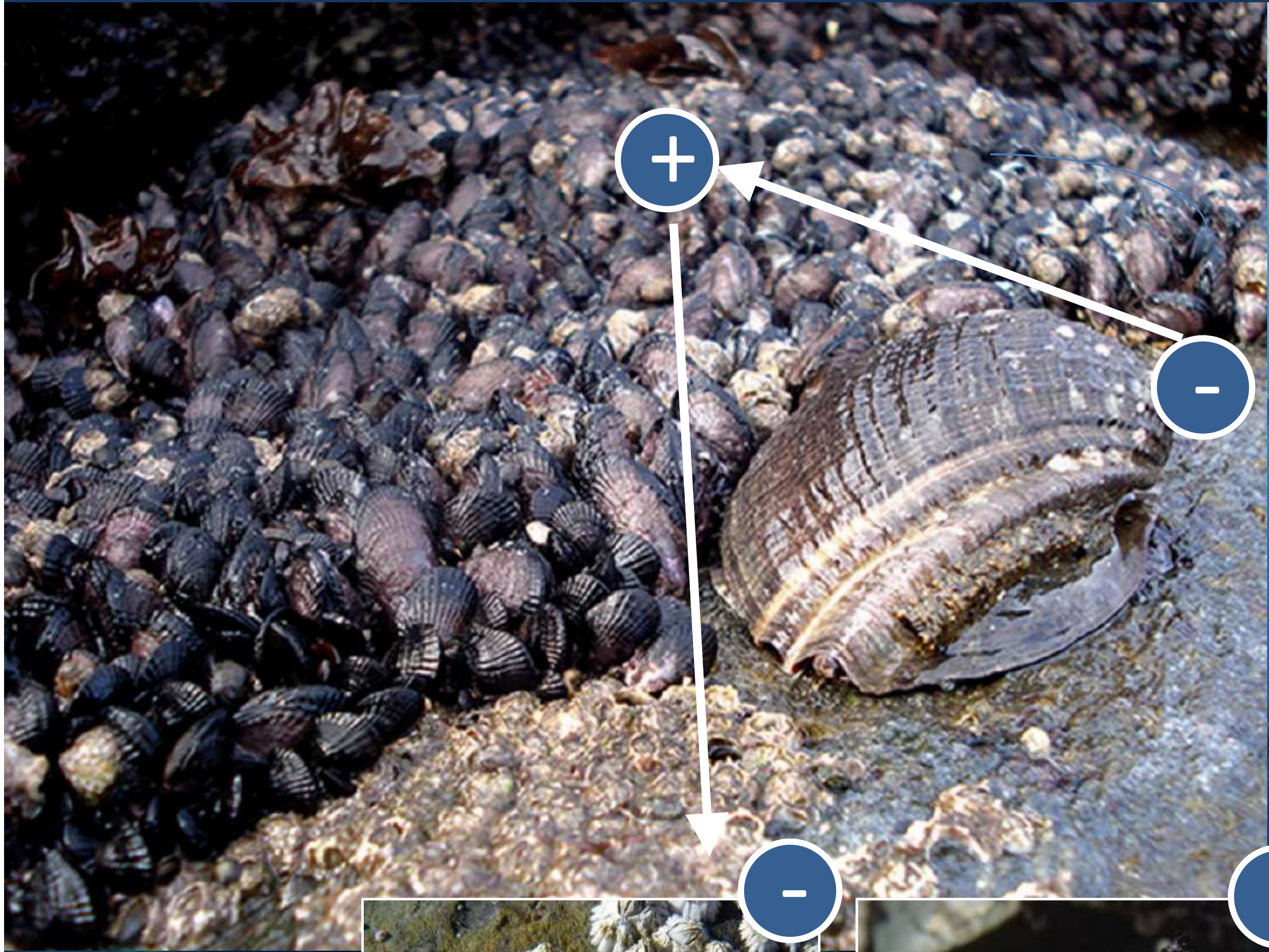
Large predators



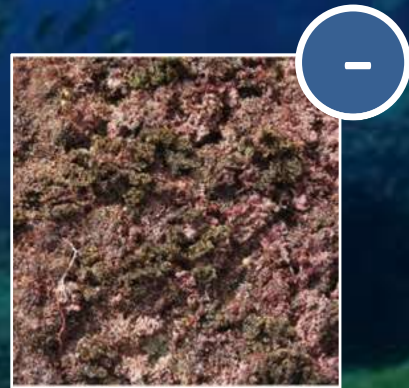
Sharks play an important role, removing weak and/or sick fish. In this example, the decline of sharks in the eastern Atlantic (USA) lead to increasing population of rays (release of mesopredators), and to a decrease in scallops.

Heithous et al., 2007

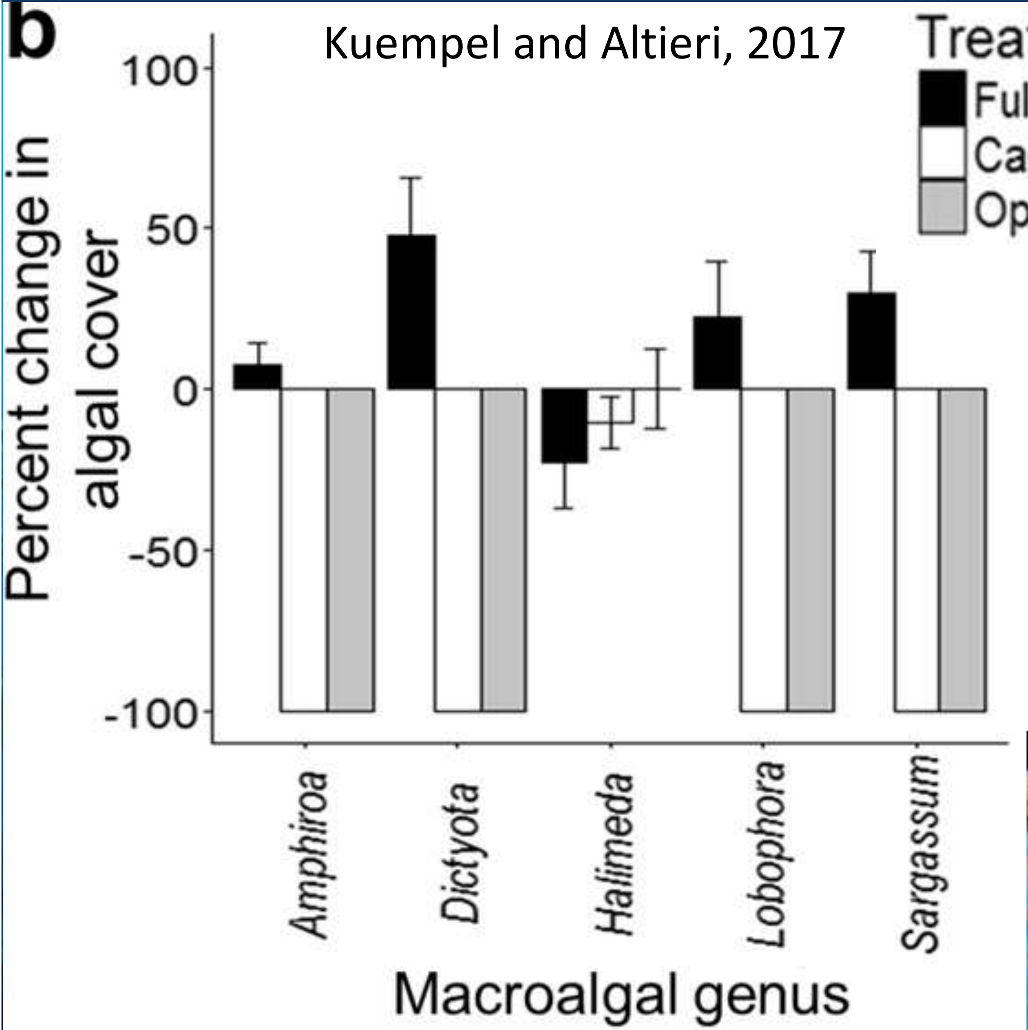
Small predators



Decline in predator snails *C. concholepas* allows mussles *Perumytilus* to overcompete barnacles, macroalgae and herbivorous snails *Fissurella*.



Herbivores



Key role in maintaing coral reefs healthy removing algal turf, dead corals and preventing the dominance of algae after disturbance

Foundation species

Foundation species are a particular keystone type. They have a pivotal role in creating and maintaining a habitat

Ecosystem engineering

Box 1. Examples of marine ecosystem engineers categorized by structures formed

Coleman & Williams 2002

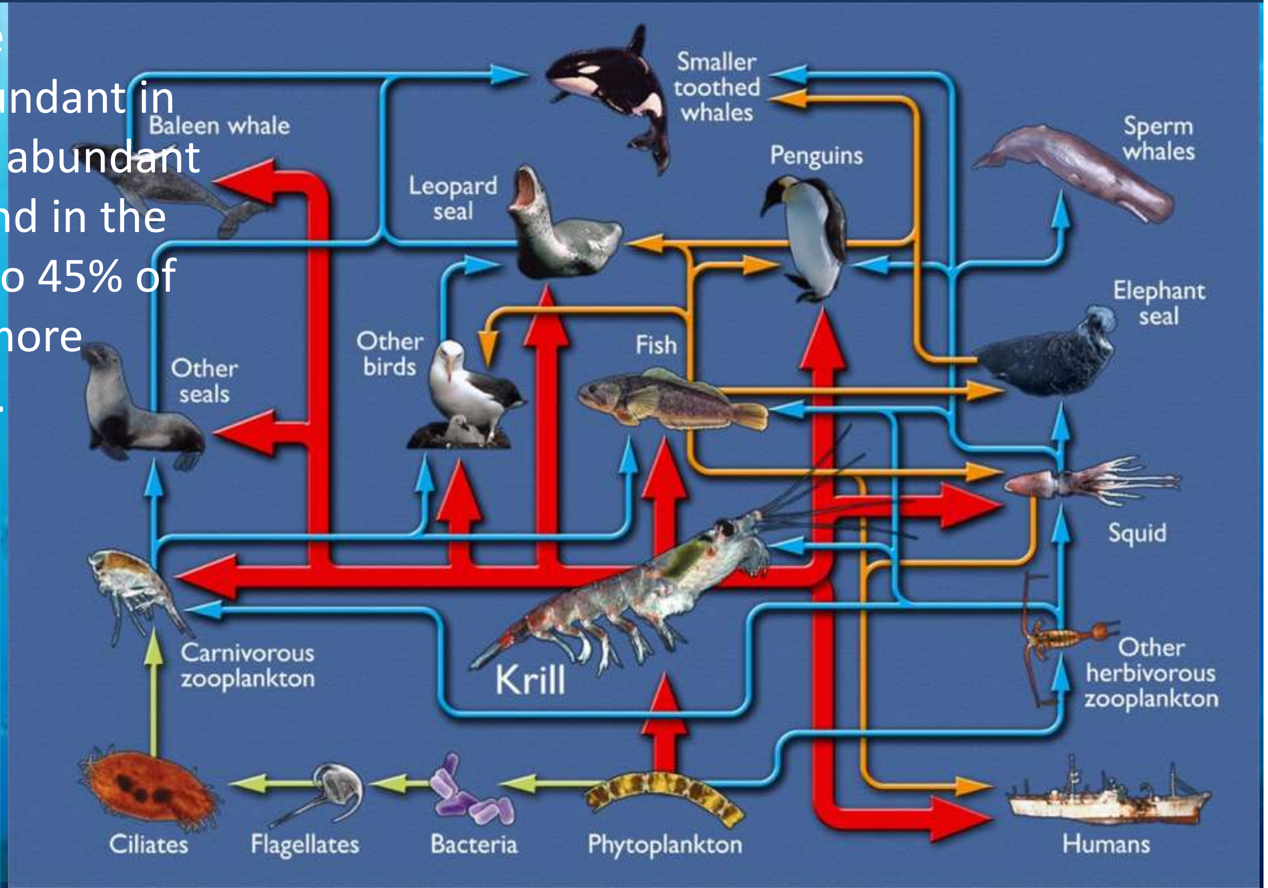
The following examples of widespread marine ecosystem engineers all increase the structural complexity of the habitat, the local biomass, and the local biodiversity, with additional ecological influences distinctive to each category.

- Corals, oysters, vermetid gastropods, sabellid worms and crustose coralline algae construct large solid mineralized reefs [a–d]. These provide settlement substratum for other organisms and provide refuge from predation.
- Marine plants (e.g. seagrasses and kelps) [a] form canopies of vegetation in nearshore waters. They modify water flow, entrain larvae and provide refuge from predation.
- Bivalve molluscs (e.g. mussels and clams) [a] build thick shellfish beds and mats on rocky shores and in soft sediments. The structure provided by shells and by byssal threads of molluscs serve to ameliorate environmental extremes, deposit organic matter, fertilize sediments and promote growth of marine plants [e,f].
- Tilefish, groupers, clams, amphipods, specific types of shrimps (callianassid, alpheid), sea cucumbers, fiddler crabs and worms form excavations and burrows [g], sometimes meters deep.
- While foraging, herbivorous sea turtles [h] and dugongs [i] create large gaps in seagrass beds. Dugongs 'bulldoze' through vegetation and sediments.

Ecosystem engineers are organisms that create, modify or maintain habitats (or microhabitats) by causing physical state changes in biotic and abiotic materials that, directly or indirectly, modulate the availability of resources to other species. They can be allogenic (modifying existing physical environment) or autogenic (providing physical structures)

Keystone for trophic importance

Krill (Euphausiacea) are shrimp-like crustaceans that are extremely abundant in polar waters. In the Arctic they are abundant in waters on the Atlantic portion and in the Bering Sea. Krill can constitute up to 45% of zooplankton catches but krill are, more prominent in the Sourthern Ocean.

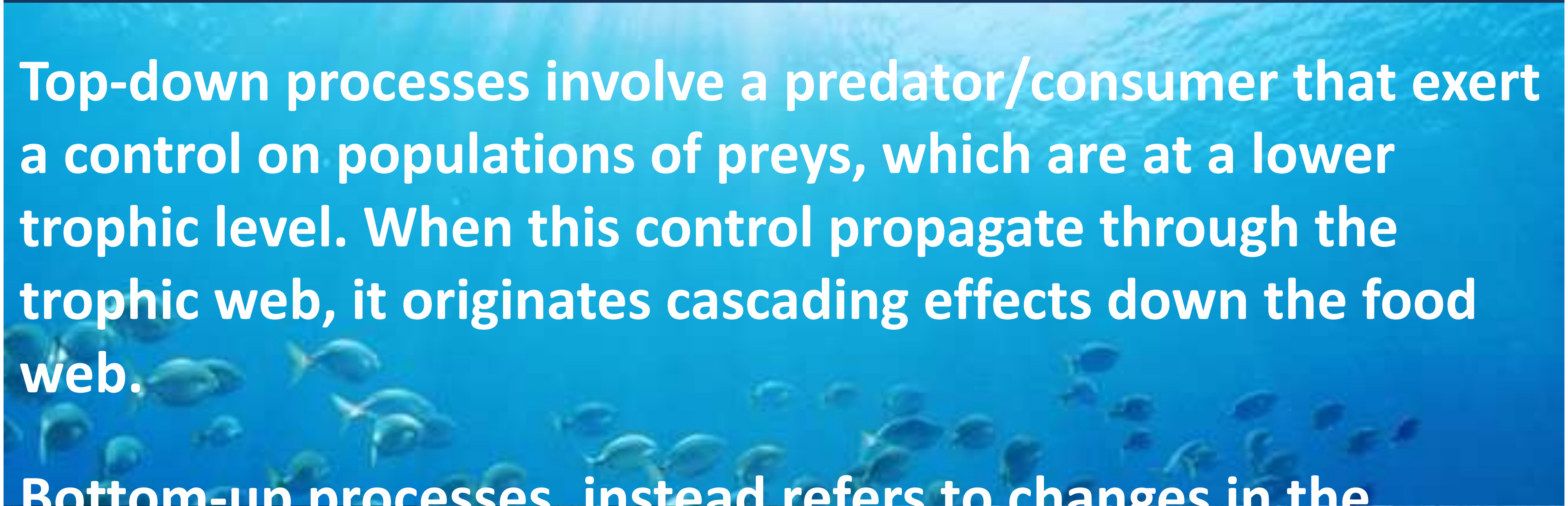


Antarctic krill *Euphausia superba* often dominates the zooplankton community in numbers and biomass.
Krill are highly influential organisms, capable of grazing as much as 55% of the net primary production and sustaining the functioning of the whole marine ecosystem in the Antarctic (Flores et al., 2012). Many polar organisms, from zooplankton to whales rely on krill as a primary food resource. Its estimated biomass Reach >400 million tons (Flores et al., 2012).

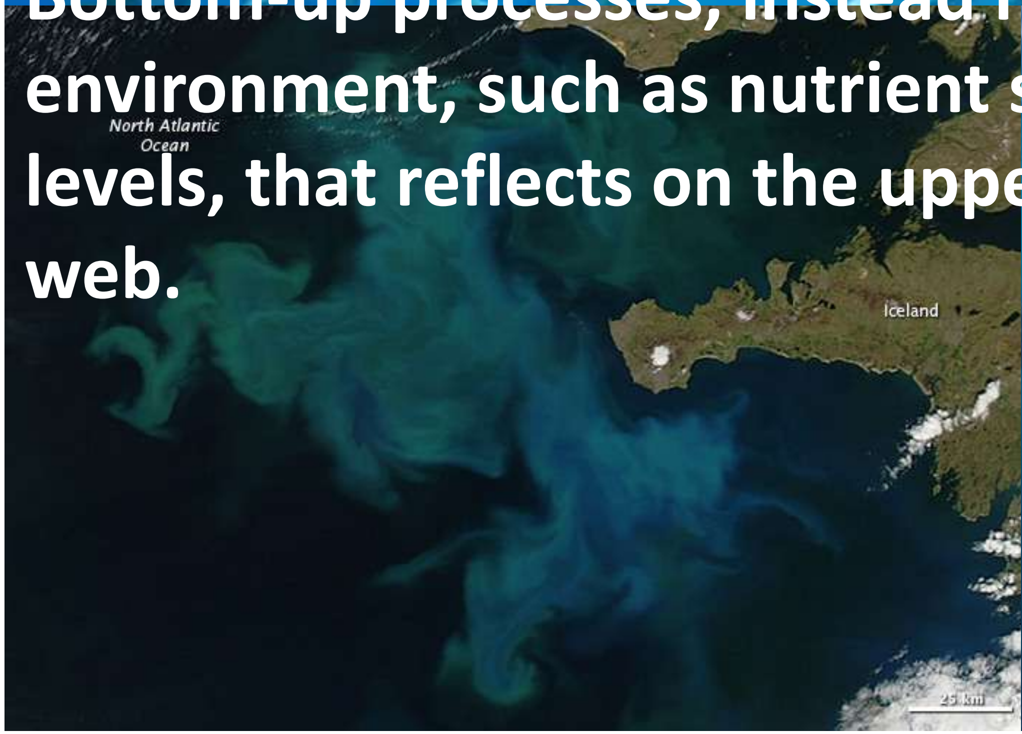

Crab-eater seal
(*Lobodon carcinophaga*)

Top-down and bottom-up

Top-down processes involve a predator/consumer that exert a control on populations of preys, which are at a lower trophic level. When this control propagate through the trophic web, it originates cascading effects down the food web.



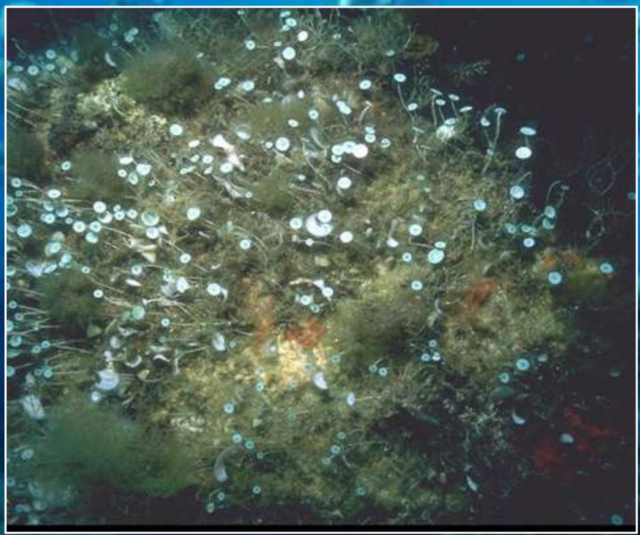
Bottom-up processes, instead refers to changes in the environment, such as nutrient supply, or in the lower trophic levels, that reflects on the upper levels through the trophic web.

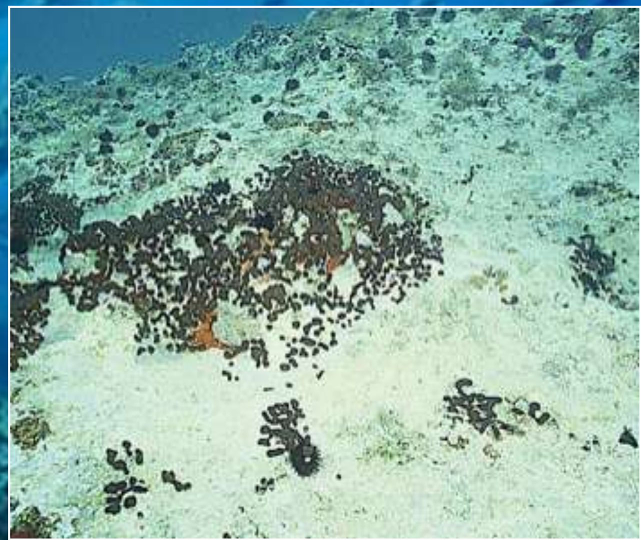


Mediterranean top-down processes

Subtidal rocky reefs in the Mediterranean Sea are basically found in between two opposite states:

1) Macroalgal stands and macrozoobenthic species
2) barren grounds





Sea urchin grazing

Arbacia lixula

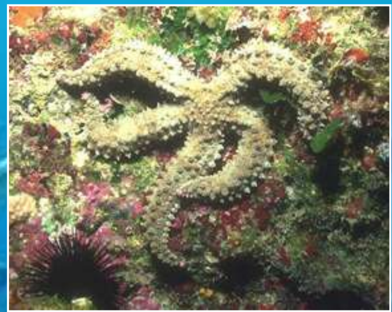
Paracentrotus lividus

Grazing of sea urchins on macroalgae (although sea urchins graze also epiphytes, and other organisms on the substrate) are major responsible of transition between the two states when they reach high densities. Other factors could participate to the formation of barren grounds. For example, exposition to wave action in highly exposed sites, or limited nutrinet supply for macroalgae in oligotrophic waters.

Sea urchin predators

There are many species able to control sea urchin population, and especially seabreams, but also seastars, crabs and gastropods

Diplodus sargus



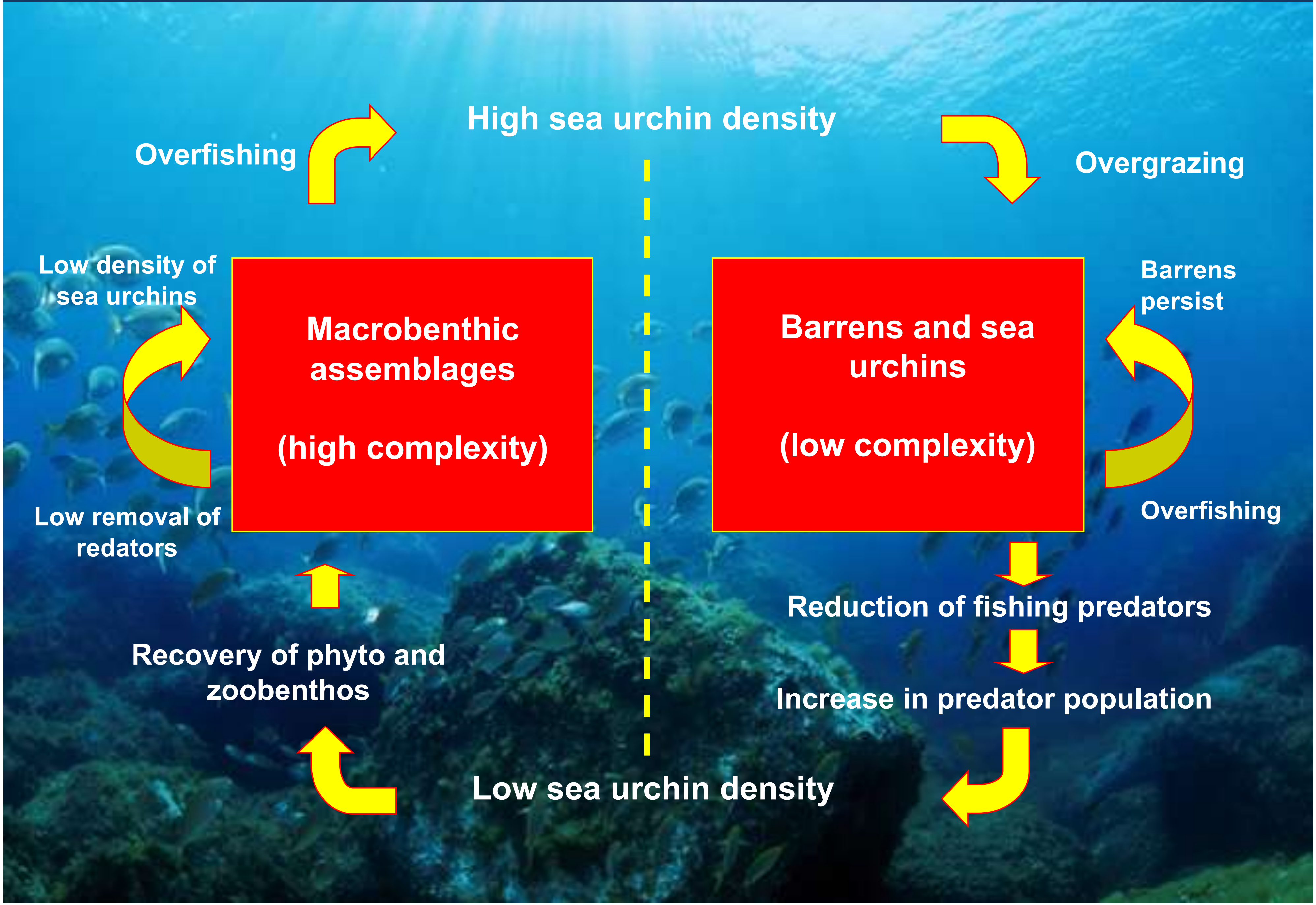
Marthasterias glacialis

Eriphia spinifrons

Coris julis

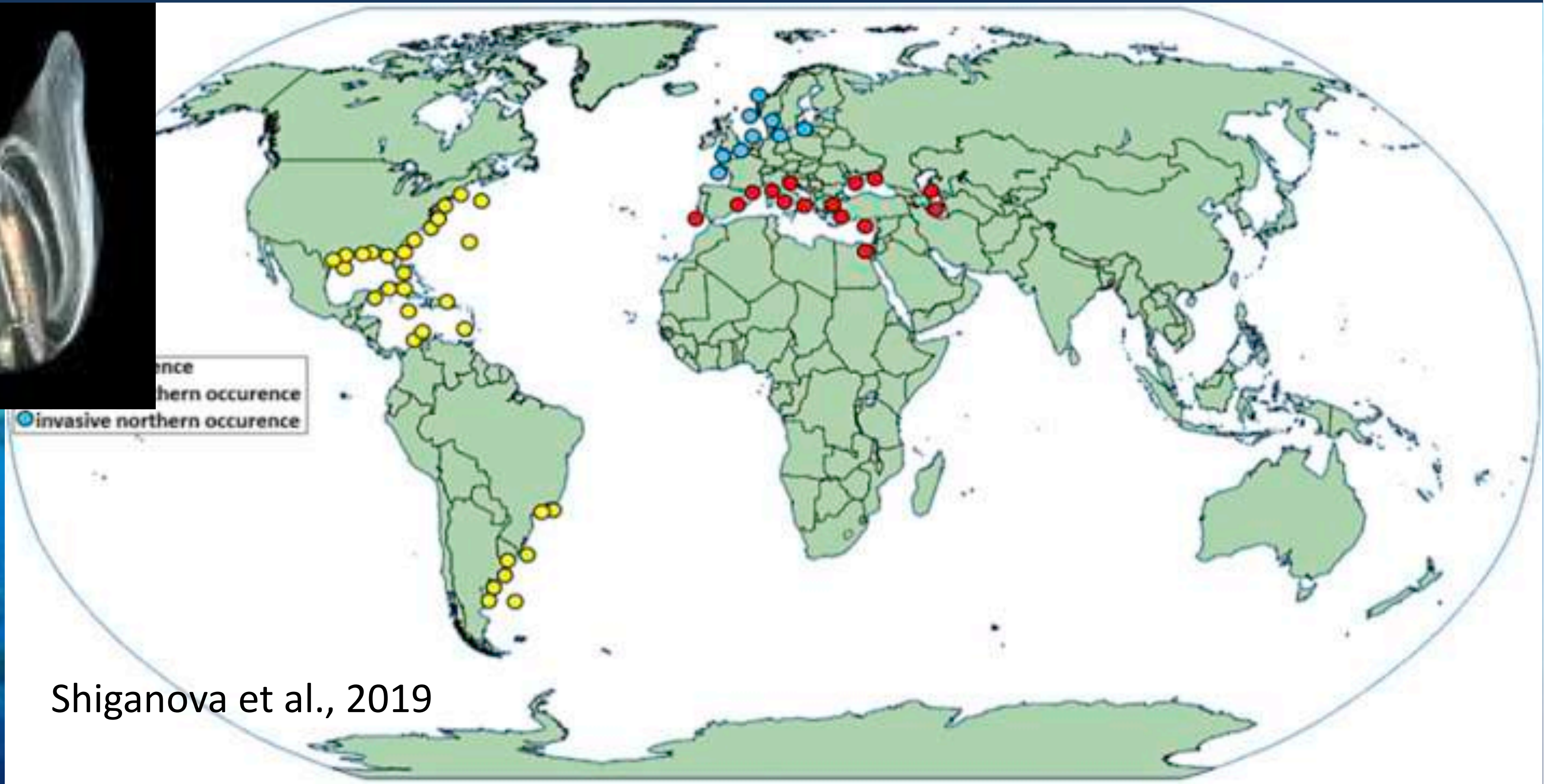
Hexaplex trunculus

Mechanism



High sea urchin density
Overfishing
Overgrazing
Low density of sea urchins
Macrobenthic assemblages
(high complexity)
Barrens and sea urchins
(low complexity)
Barrens persist
Low removal of redators
Overfishing
Reduction of fishing predators
Recovery of phyto and zoobenthos
Increase in predator population
Low sea urchin density

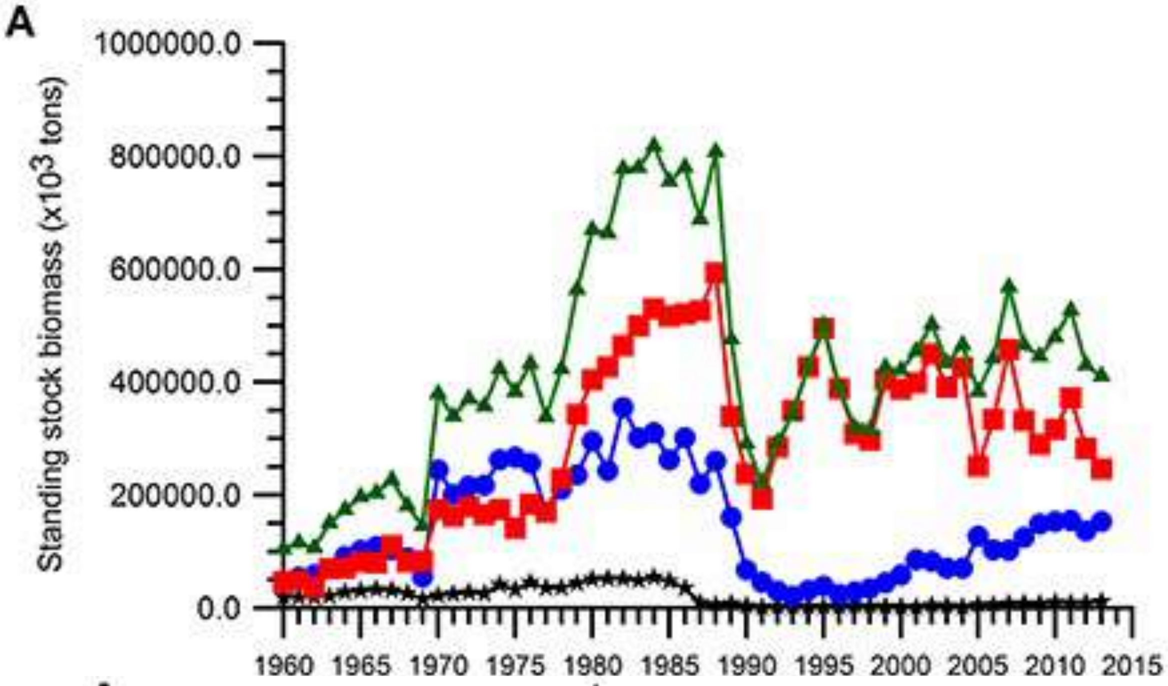
Top-down from invasive predators

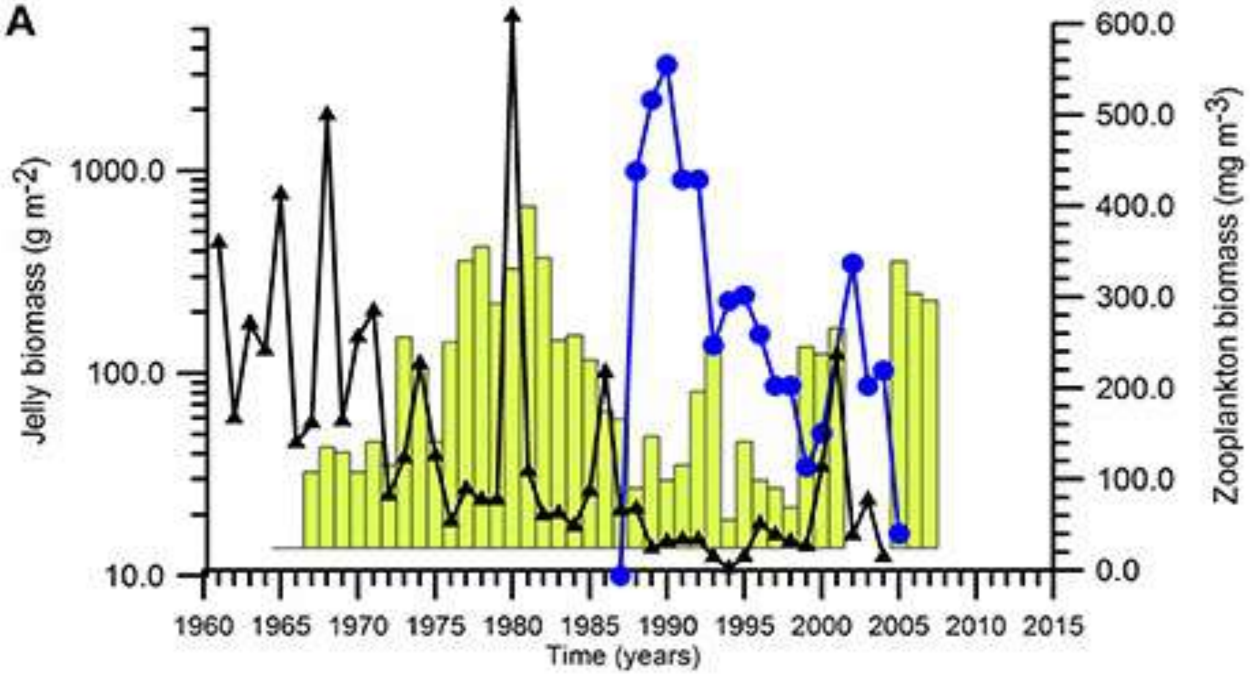


Shiganova et al., 2019

Mnemiopsis leidyi introduced in 1980 in the Black Sea. Blooms up to 7600 individuals per m^3. Now spread in Mediterranean Sea, also in the Adriatic Sea.
Wide range of tolerance to temperature and salinity. Predator of plankton, including fish eggs and larvae. Introduced with ballast waters in '80s the Black Sea in , native from western Atlantic Ocean.

Effects on fish populations



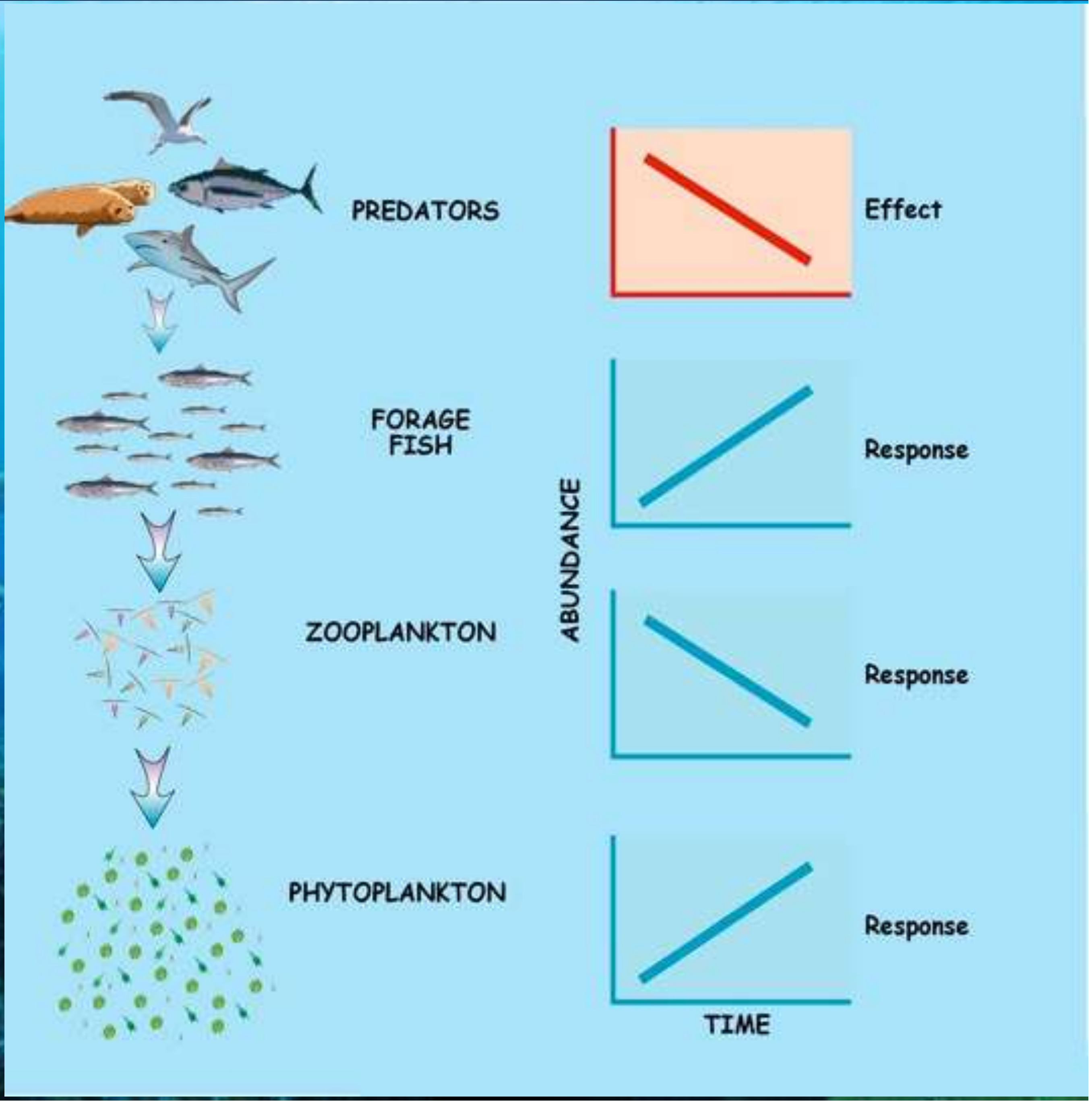


Concurrent effects due to pollution, overfishing and finally the introduction of the ctenophores lead fish socks and fishery to collapse.

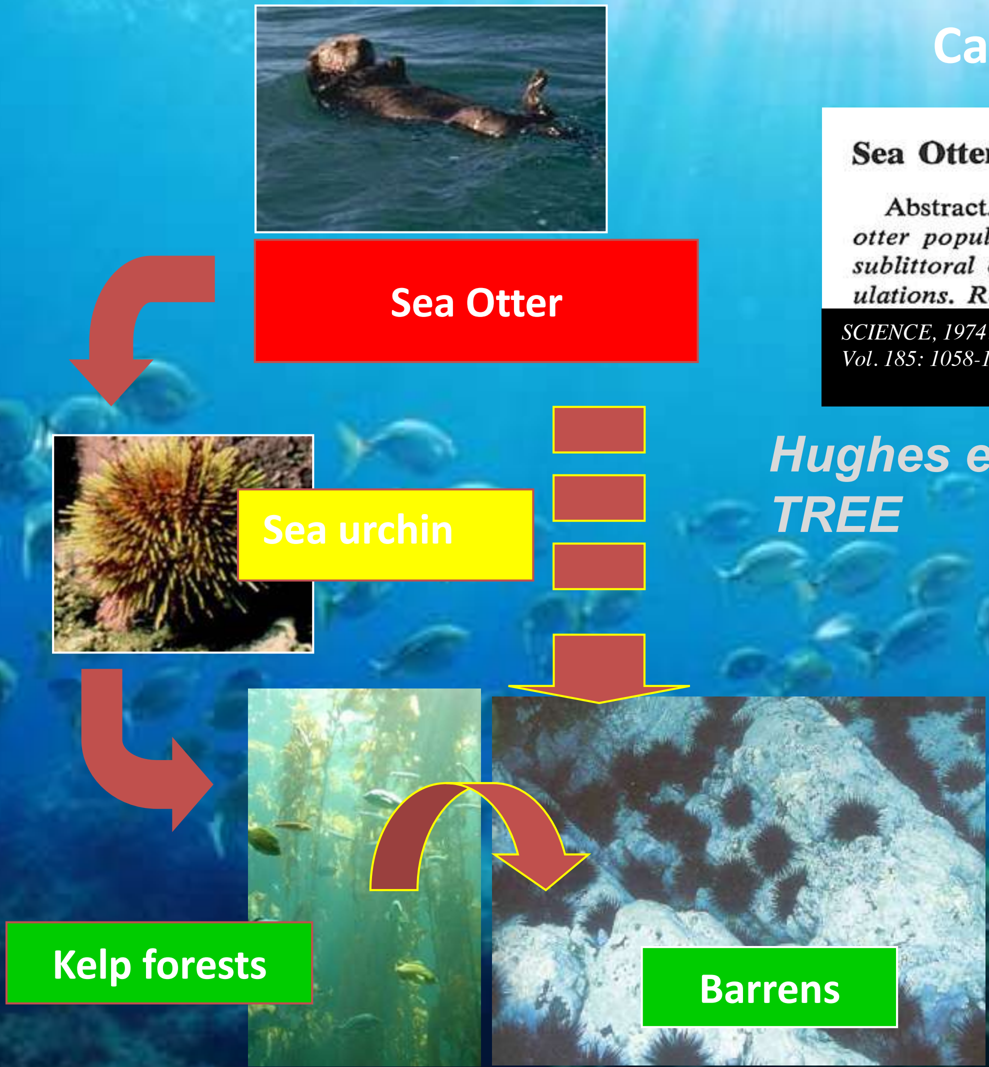
Double effect of predation of *Mnemiopsis*: direct reduction of recruitment of fish due to predation on egg and larval stages, and indirect effect through competition due to predation on zooplankton

Trophic cascades

Trophic cascades occur when top-down control causes drastic changes in the ecosystem through effects that propagate downwards the food web.(Pace et al. 1999). In ecosystems that are strongly structured by predation, reducing top predator abundance can alter several lower trophic levels.



Trophic cascades



Cascading effects if sea otter are removed

Hughes et al., 2005 TREE

Sea Otters: Their Role in Structuring Nearshore Communities

Abstract. *A comparison of western Aleutian Islands with and without sea otter populations shows that this species is important in determining littoral and sublittoral community structure. Sea otters control herbivorous invertebrate populations. Removal of sea otters causes increased herbivory and ultimately results*

SCIENCE, 1974.
Vol. 185: 1058-1060

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INFERENCE IN ECOLOGY: THE SEA URCHIN PHENOMENON IN THE NORTHWESTERN ATLANTIC

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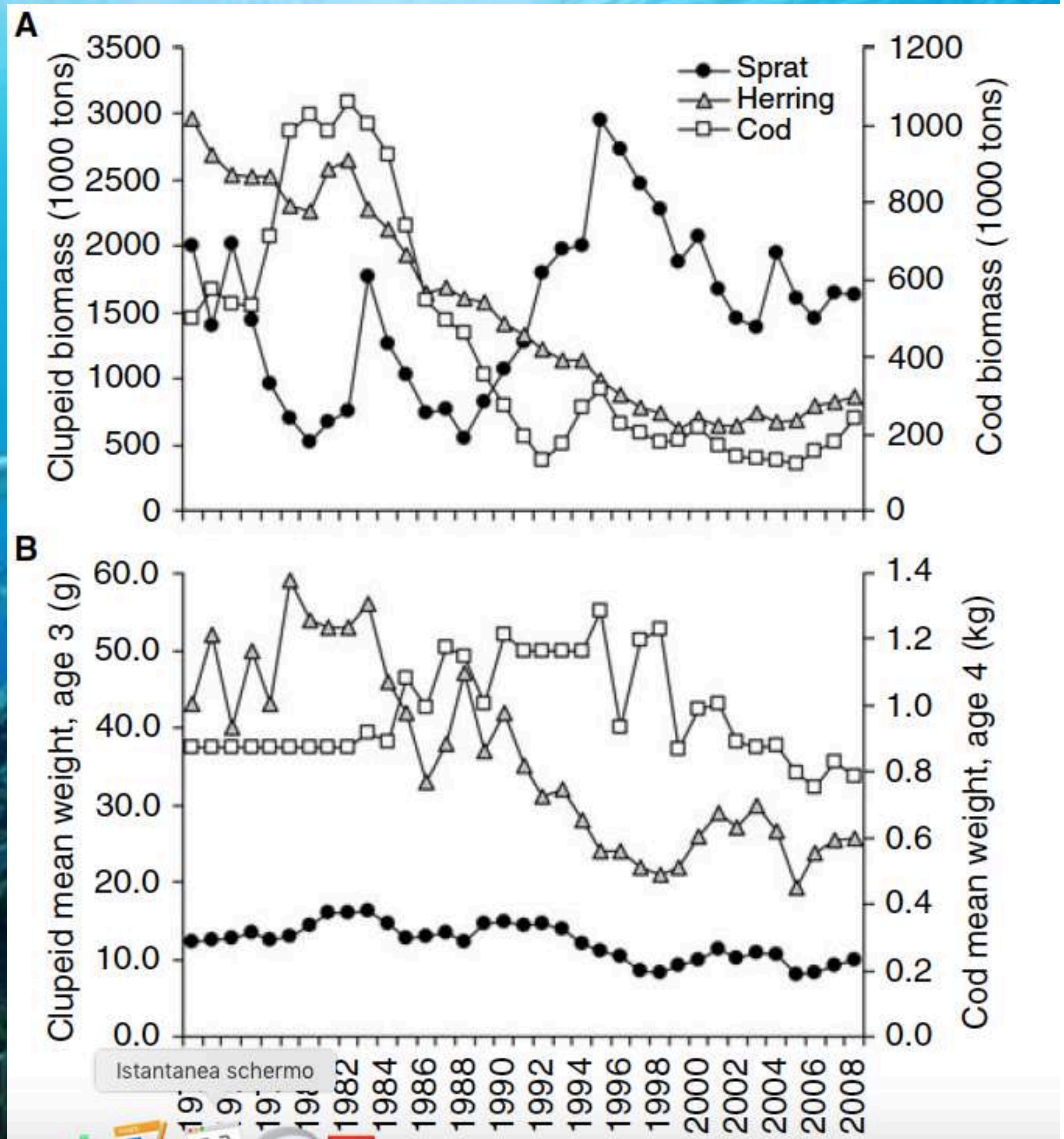
A fundamental concern in ecology is the absence of a consensus on how to "do" this science. Over the past few years, diametrically opposed treatises have

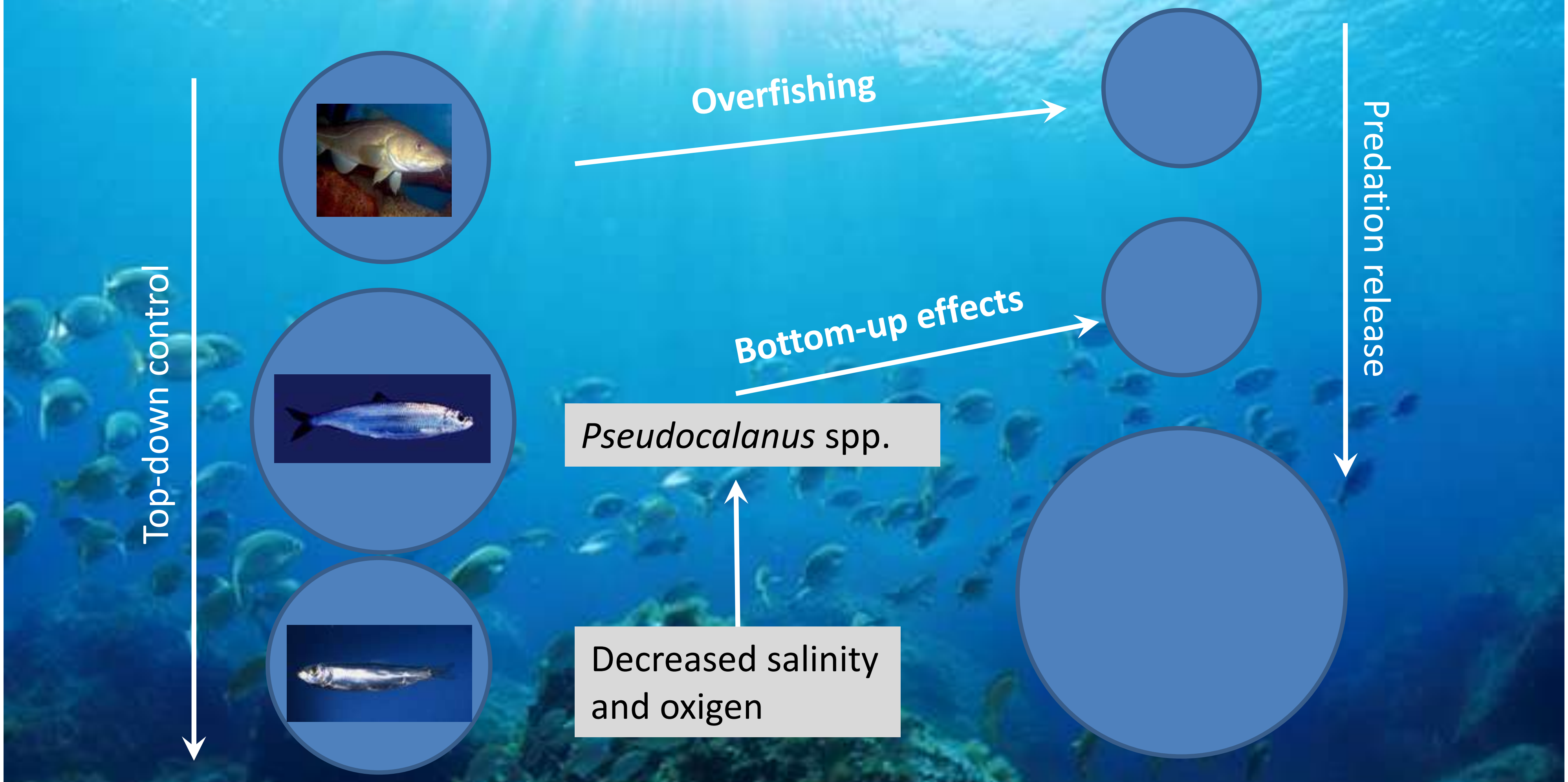
Top-down control of sea urchins in kelp forest (Western Pacific, USA)

Top-down and bottom up

Strong reductions in the abundance of a top predator (cod) has also been reported to cause a tropic cascade in the relatively simple Baltic food chain, involving a subsequent increase in the zooplanktivorous sprat, which in turn affected the biomass, species and stage composition, as well as the vertical distribution of zooplankton (Casini *et al.,* 2008).



Top-down and bottom up



Changes in the Baltic Sea were primarily bottom-up, strongly structured by salinity, but top-down forcing related to changes in cod abundance also shapes the ecosystem. (Flinkman et al. 1998; Casini et al., 2011)

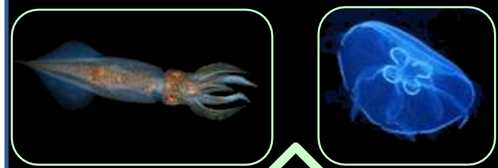
Bottom up prevailing

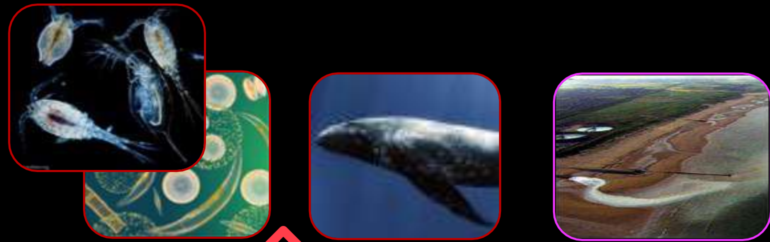
Top-down control is likely to occur in simple trophic webs, where there is a strong predation control on lower trophic levels. This process is more likely in closed basins and coastal areas. In pelagic food webs and open sea the dominant process is likely to be related to bottom up effects. One possibility, in accordance with a predominant view of oceanographers, is that these ecosystems are structured from the bottom-up (resource limitation) and top-down control by oceanic predators is truly rare. (Baum and Worm, 2009)


High degree of connectance among and within species
Prevalence of omnivory and dietary breadth
Ontogenetic diet shifts
Predator diversity may dampen cascading effects except where non-selective fisheries deplete entire predator functional groups.
Simultaneous exploitation of predator and prey can inhibit prey responses

Trophic cascade leading to regime shifts could be rare in open ocean ecosystems

Benthic – pelagic coupling





Life cycles

Pelagic or planktonic species lay eggs, or have larval or juvenile stages in benthos

Benthic species spent part of their life as adult, juvenile or larvae in plankton

Trophic webs

Herbivores and predators from the water column feed on benthos

Benthic species have adults or juveniles feeding on plankton or on larval - juveniles of nekton

Organic matter

Planktonic species have resting stages in benthos. Organic matter (fecal pellets, dead organisms, etc.) fall on the bottom

Resting stages disclose and turn back to the plankton. Benthic species feed on particles and could turn in the water column via life cycles

Biogeochemical cycles

Nutrients and gases reach the bottom and can turn back as living matter or through upwelling

Life cycles

Benthic species spent part of their life as adult, juvenile or larvae in plankton

Pelagic or planktonic species lay eggs, or have larval or juvenile stages in benthos

Life cycles connect pelagic and benthic domain as, depending on the life stage, species belong to benthos or plankton and pelagos

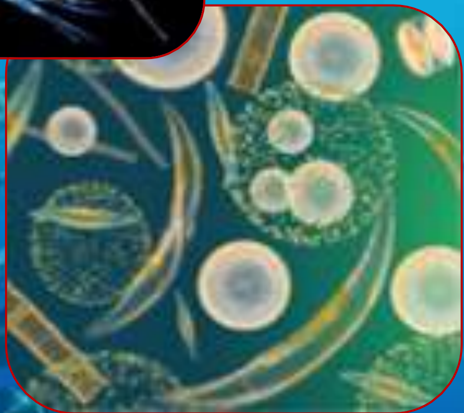
Trophic webs

Predator-prey relationships across different compartments connect benthos, nekton and plankton allowing energy flow from the bottom to the water column and viceversa

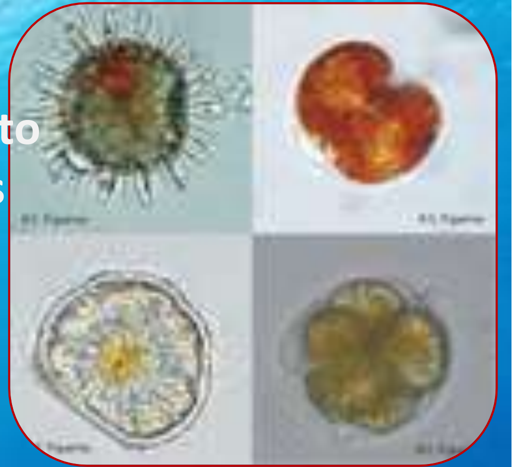
Herbivores and predators from the water column feed on benthos

Benthic species have adults or juveniles feeding on plankton or on larval -juveniles of nekton

Organic matter



Planktonic species have resting stages in benthos. Resting stages disclose and turn back to the plankton. Meiofauna prey on resting stages modifying future blooms.



Organic matter (fecal pellets, dead organisms, etc.) fall on the bottom. Upwelling re-suspend nutrients in the upper layer triggering phytoplankton blooms

Biogeochemical cycles

Nutrients and gases reach the bottom and can turn back as living matter or through upwelling. Shells of calcifying organisms, or silica shells of diatoms also export elements to the sea bottom.