Kelp

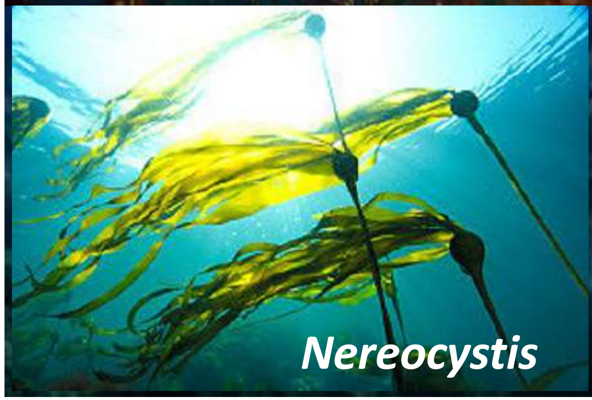
- Ochrophyta – Phaeophyceae – Order: Laminariales
- About 20 Mya
- Large marine brown algae
- Typical of cold-temperate areas and rocky substrates
- Depth 2->30 m
- Fast growth rates (up to 60 cm per day)

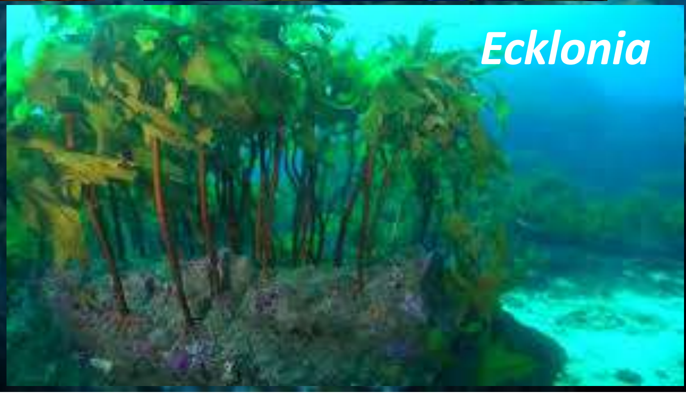
Kelp common name including >150 species complex

	LAMINARIALES	
	GENERE	SPECIE
Emisfero Nord :		
Artico	4	13
W-N Pacifico	16	50
E-N Pacifico	20	44
W-N Atlantico	5	13
E-N Atlantico	6	24
Emisfero Sud:		
Sud Africa	3	4
Australia S	4	5
Nuova Zelanda	4	7


Macrocystis


Laminaria


Nereocystis

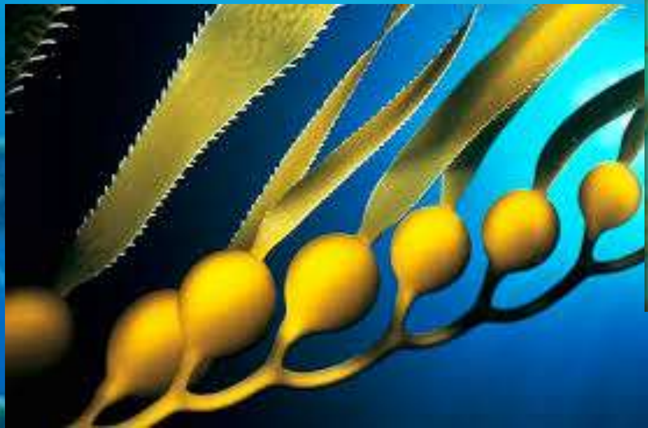

Ecklonia

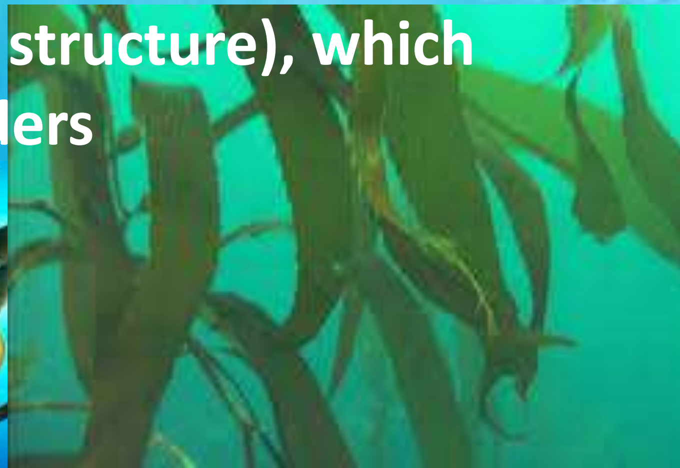

Lessonia

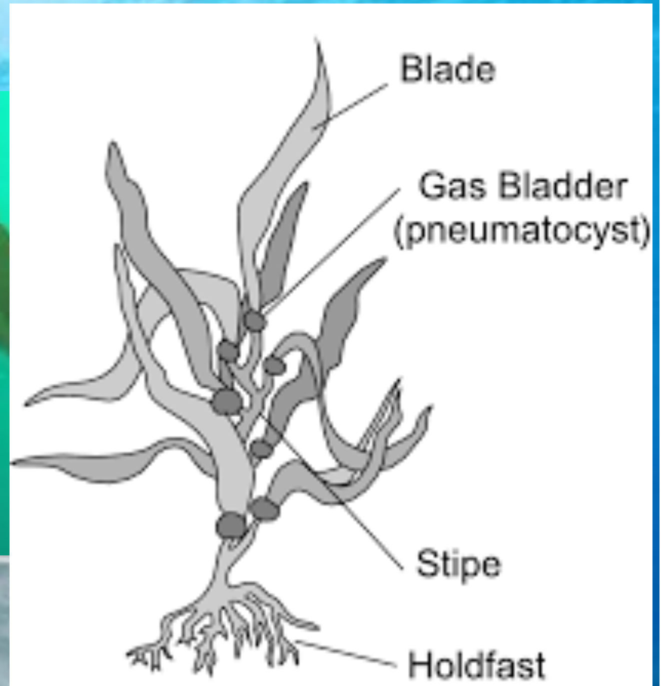
Three-dimensional structure

Kelp has three parts:

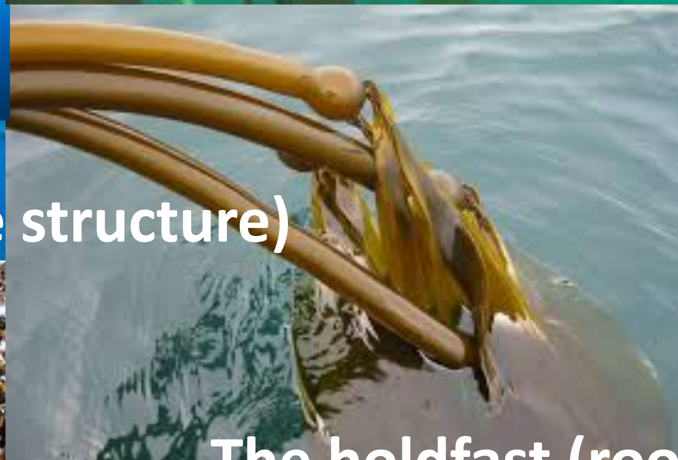
The blade (the leaf-like structure), which are buoyed by air bladders

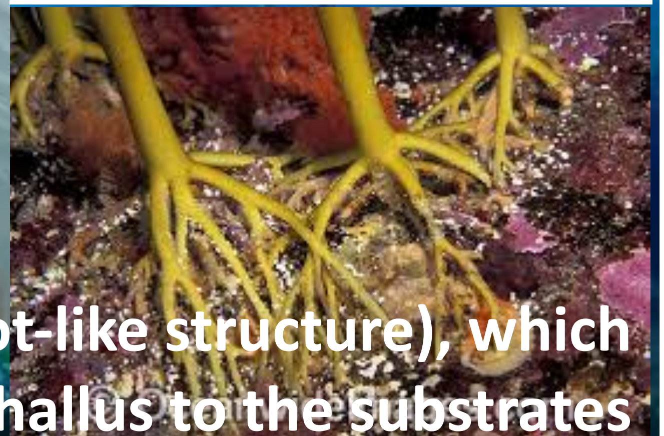






The stipe (the stem-like structure)





The holdfast (root-like structure), which anchor the thallus to the substrates

Thalli do not dry up at low tide because cell walls contain a mucilaginous, water retaining material

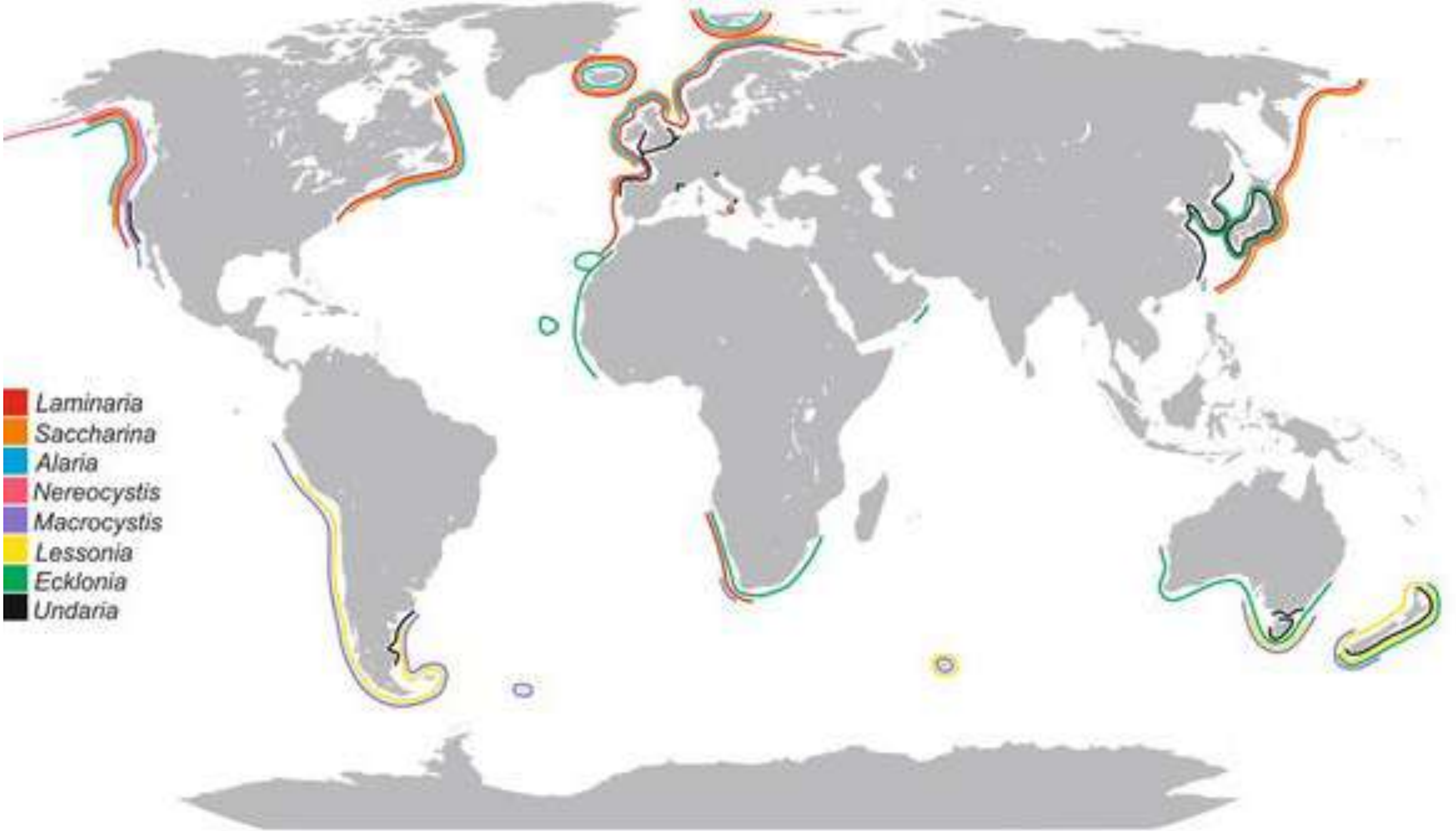
Forests

They form large and dense underwater forests (thalli until 50 m height), similar to terrestrial ones, hosting a variety of species among their fronds and in the understorey. Kelps are the most prominent constituents of the lower intertidal and subtidal of Atlantic and Pacific rocky shores of temperate regions of both the Northern and Southern Hemisphere.

As for terrestrial deciduous forests, kelp forests exhibit strong seasonality. Starting from late summer, kelp start to shed old blades. Winter storms and wave action drastically reduce kelp fronds. From late spring kelp renew from vegetative growth and new recruits.

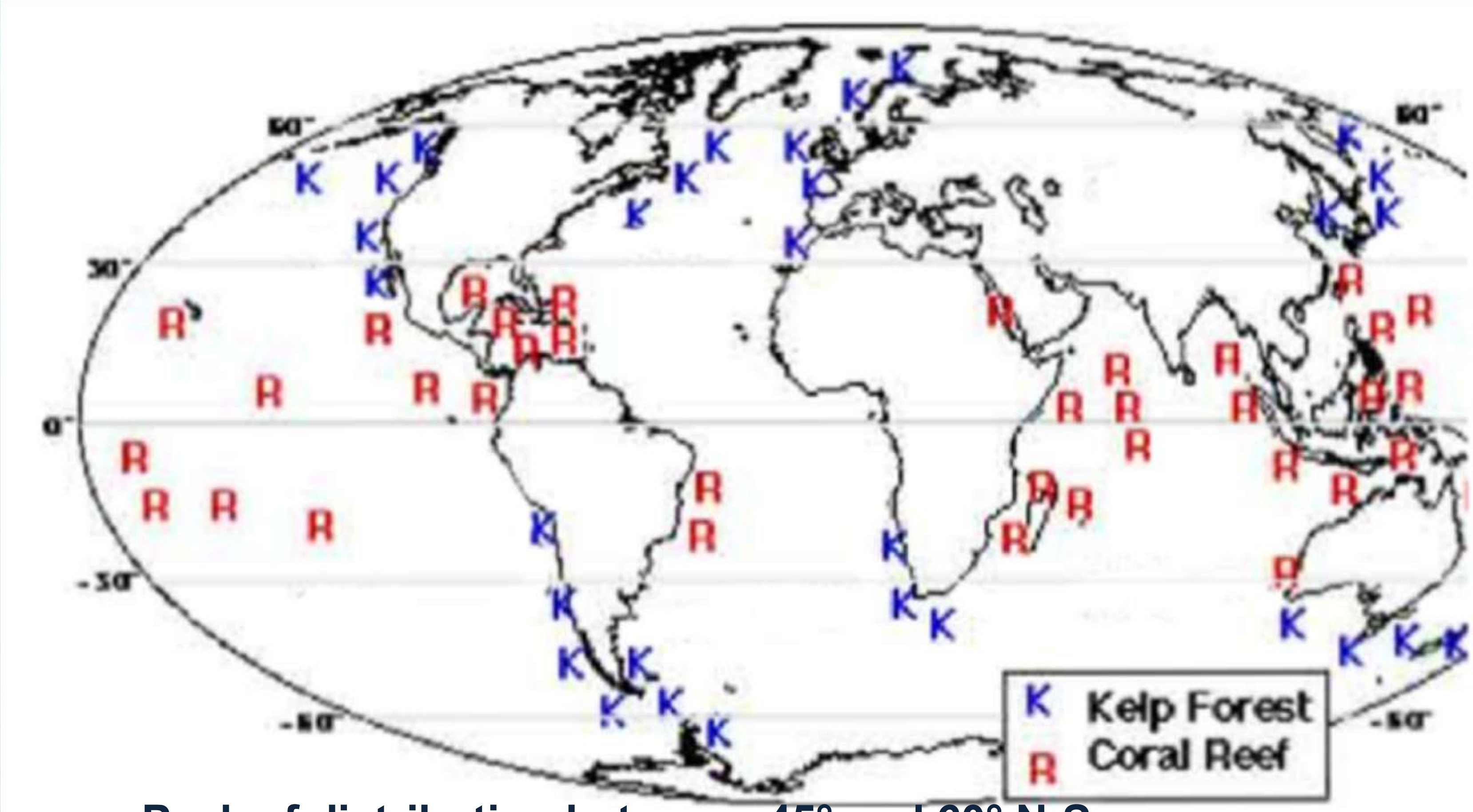
© Tom Boyd Images 2009

Distribution



Factors influencing distribution

Geographical distribution is limited by ice and light poleward and by water temperature and limited nutrient availability towards tropical zones
Kelp require nutrient-rich water with temperatures between 6 and 14 °C
Most productive kelp areas in presence of upwelling, which provides cold currents and nutrient supply.



Peak of distribution between 45° and 60° N-S

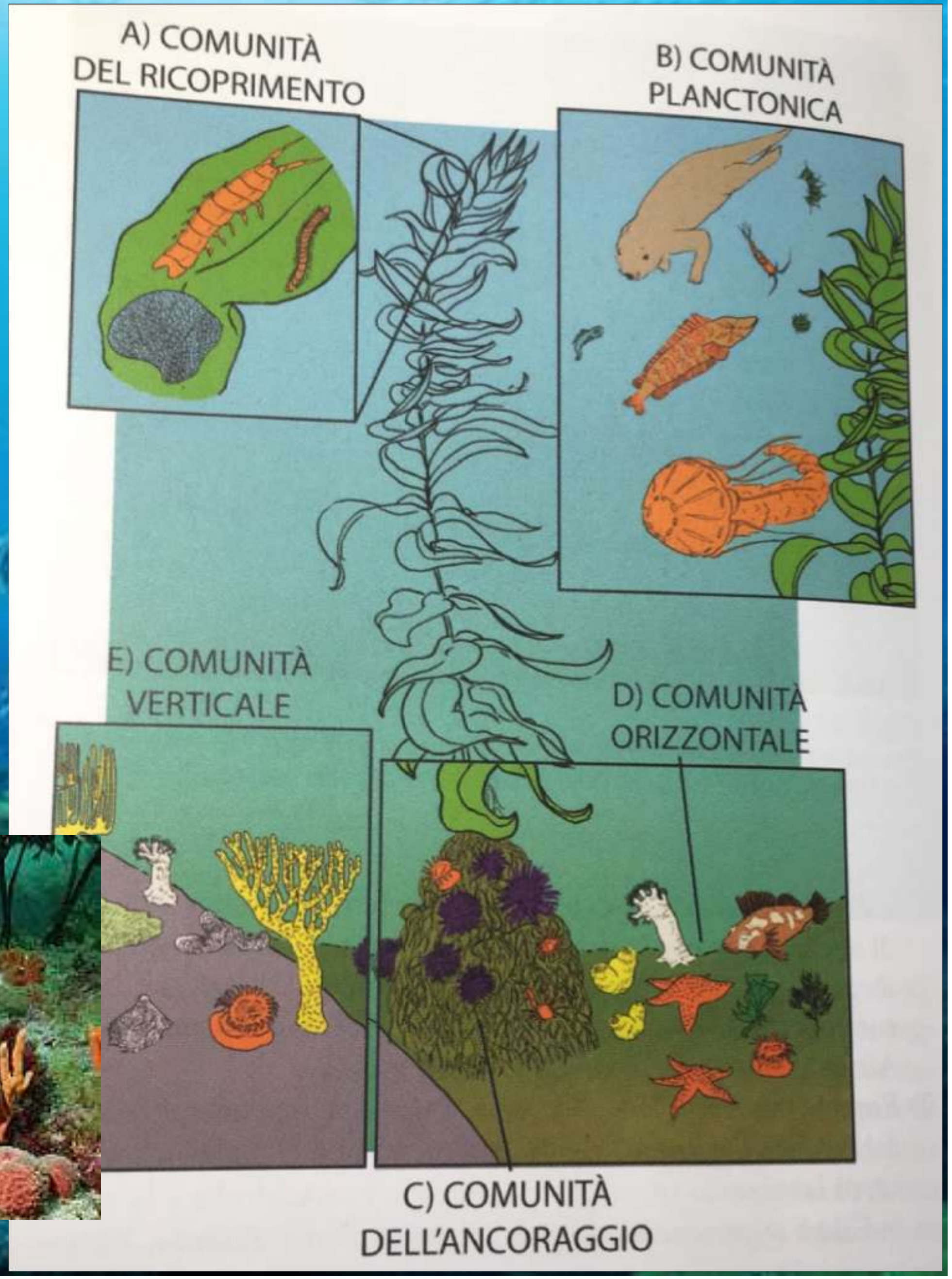
Biodiversity

Kelp forests are structurally complex and highly productive components of cold-water rocky marine coastlines, hosting thousands species including algae, invertebrates and vertebrates

Ecological role and functioning

Size and 3-d structure modify the seascape and provide habitat for different assemblages and vertical stratification.

Cyanea capillata

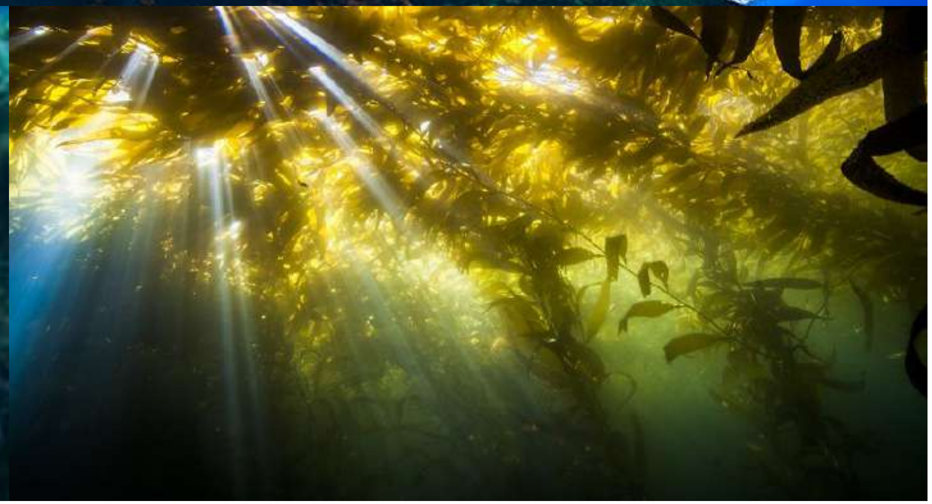


Ecological role and functioning

Habitat
Refuge
Nursery
Secondary substrate
Food
Oxygen
Primary production
Hunting grounds

Ecological role and functioning

Modify environmental conditions
Light
Hydrodynamism
Coastal protection from erosion

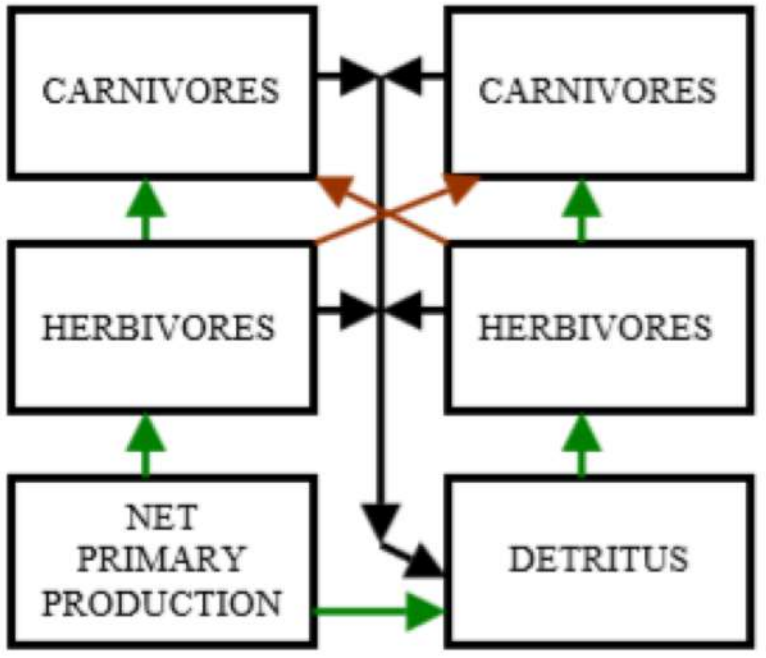


Productivity

Steneck, 2002

FOREST TYPE	ANNUAL NET PRODUCTION (dry kg / m^2 / yr)
Tropical rain forest	2.2
Tropical seasonal forest	1.6
Temperate evergreen forest	1.3
Temperate deciduous forest	1.2
Boreal forest	0.8
Giant kelp forest	2.2

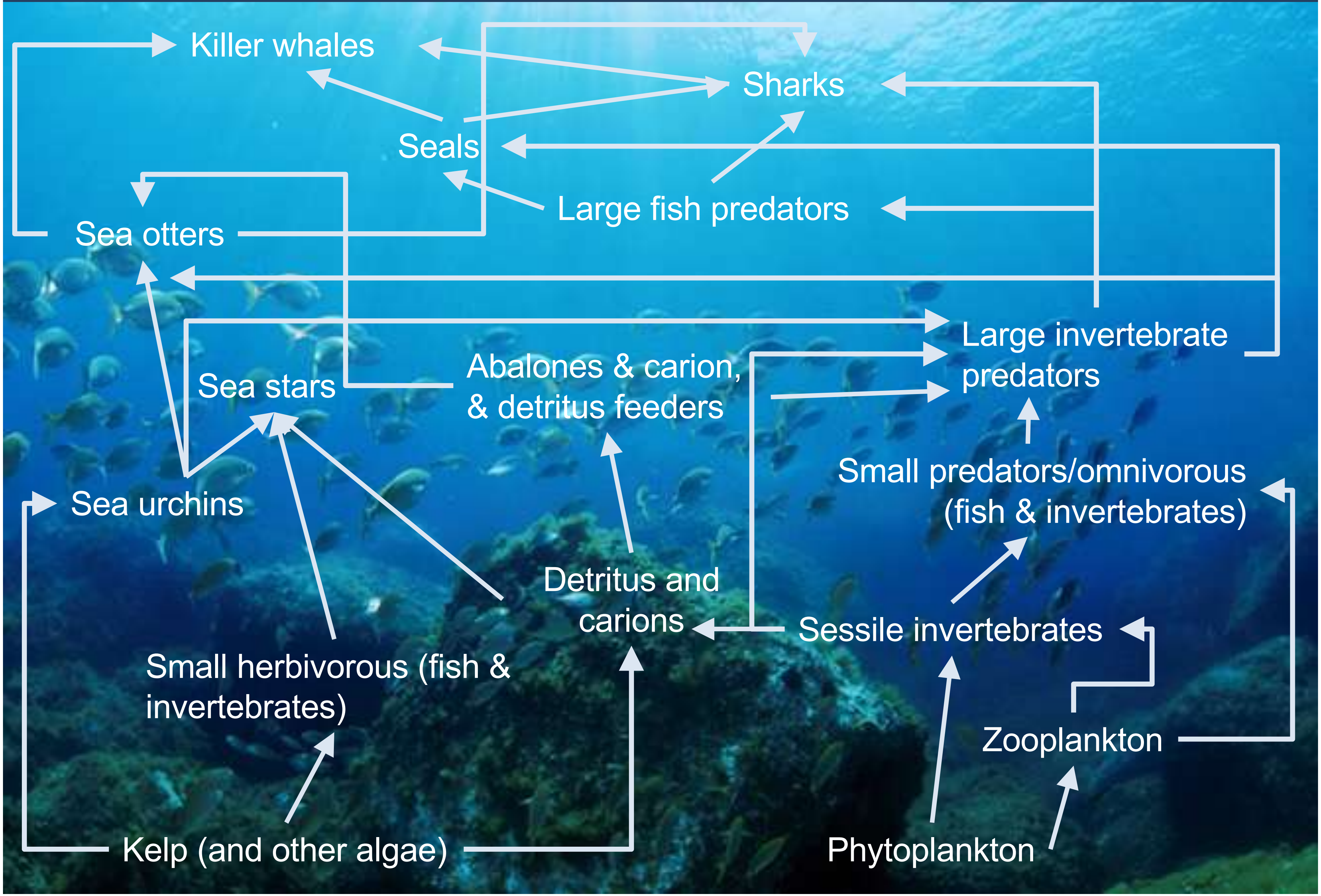
Productivity is very high, comparable to most productive terrestrial forests. In contrast, however, low storage of biomass. Most of kelp biomass, as detritus, is decomposed, consumed, or exported. Therefore, kelp provide biomass for adjacent low-productivity habitats (e.g., deeper waters).



Kelly, 2005

Figure 1 Simplified Food Chain.

Trophic web


Killer whales
Sharks
Seals
Large fish predators
Sea otters
Large invertebrate predators
Sea stars
Abalones & carion, & detritus feeders
Small predators/omnivorous (fish & invertebrates)
Sea urchins
Detritus and carions
Sessile invertebrates
Small herbivorous (fish & invertebrates)
Zooplankton
Kelp (and other algae)
Phytoplankton

Human impacts

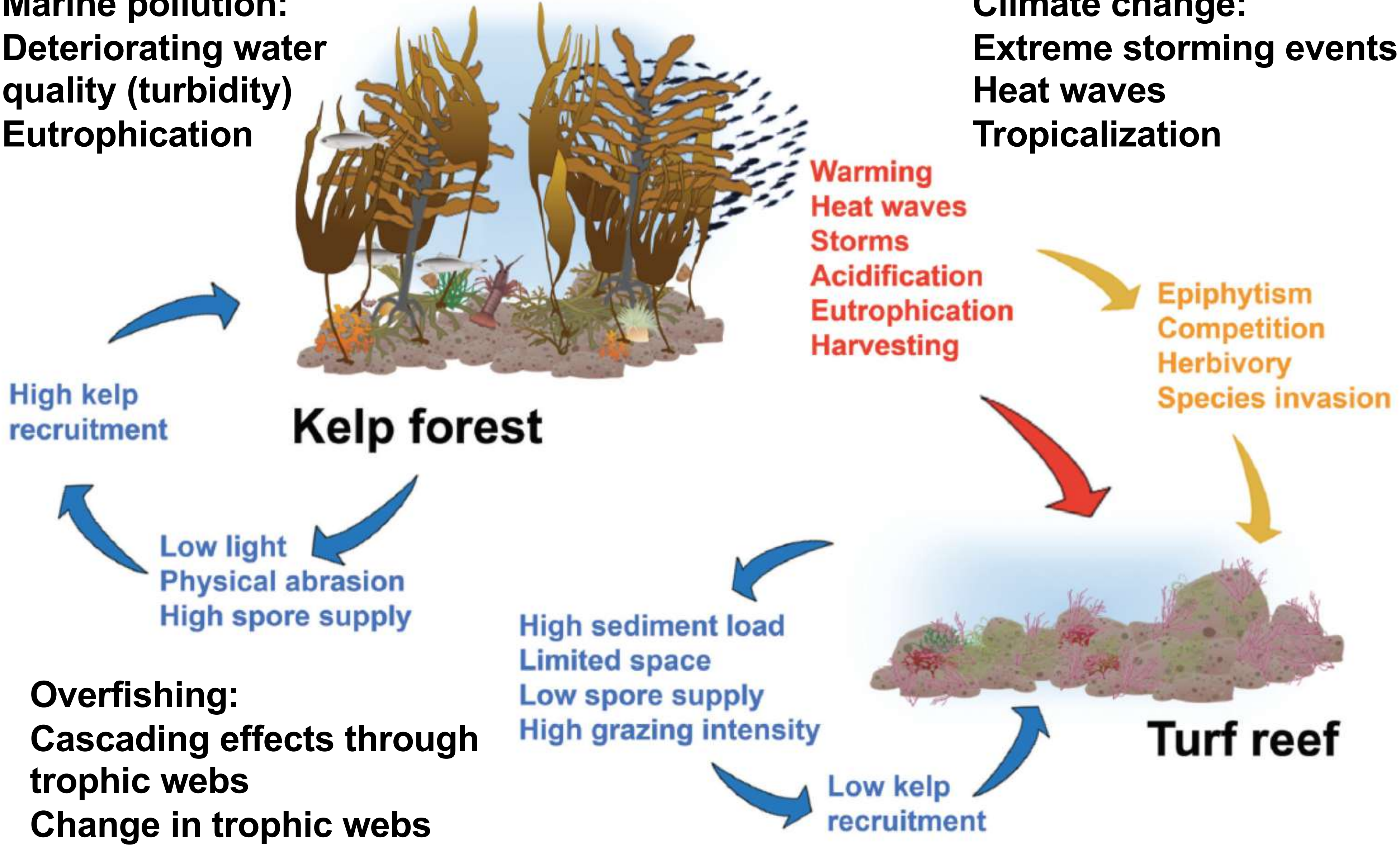
Kelp ash (= sodium carbonate) obtained burning the algae.
This practice since early XVII century for production of glass, soap, and fertilizer.
XIX → Iodine extraction from ashes.
XX → Alginate for food, pharmaceuticals
Aquaculture

overexploitation

Human impacts

Marine pollution:
Deteriorating water quality (turbidity)
Eutrophication

Climate change:
Extreme storming events
Heat waves
Tropicalization



Overfishing:
Cascading effects through trophic webs
Change in trophic webs

Filbee-Dexter and Wernberg, 2018

Human impacts

Filbee-Dexter and Wernberg, 2018

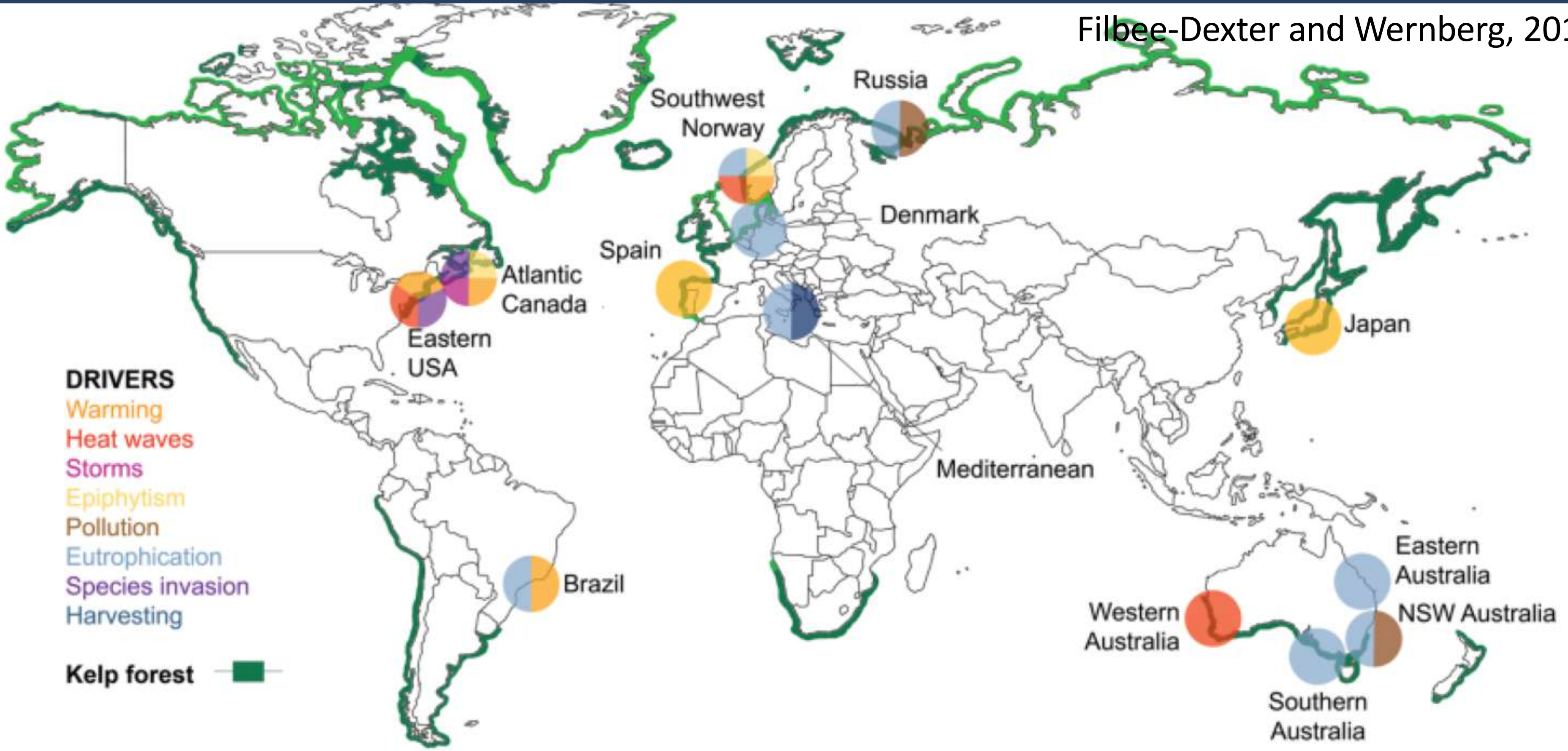
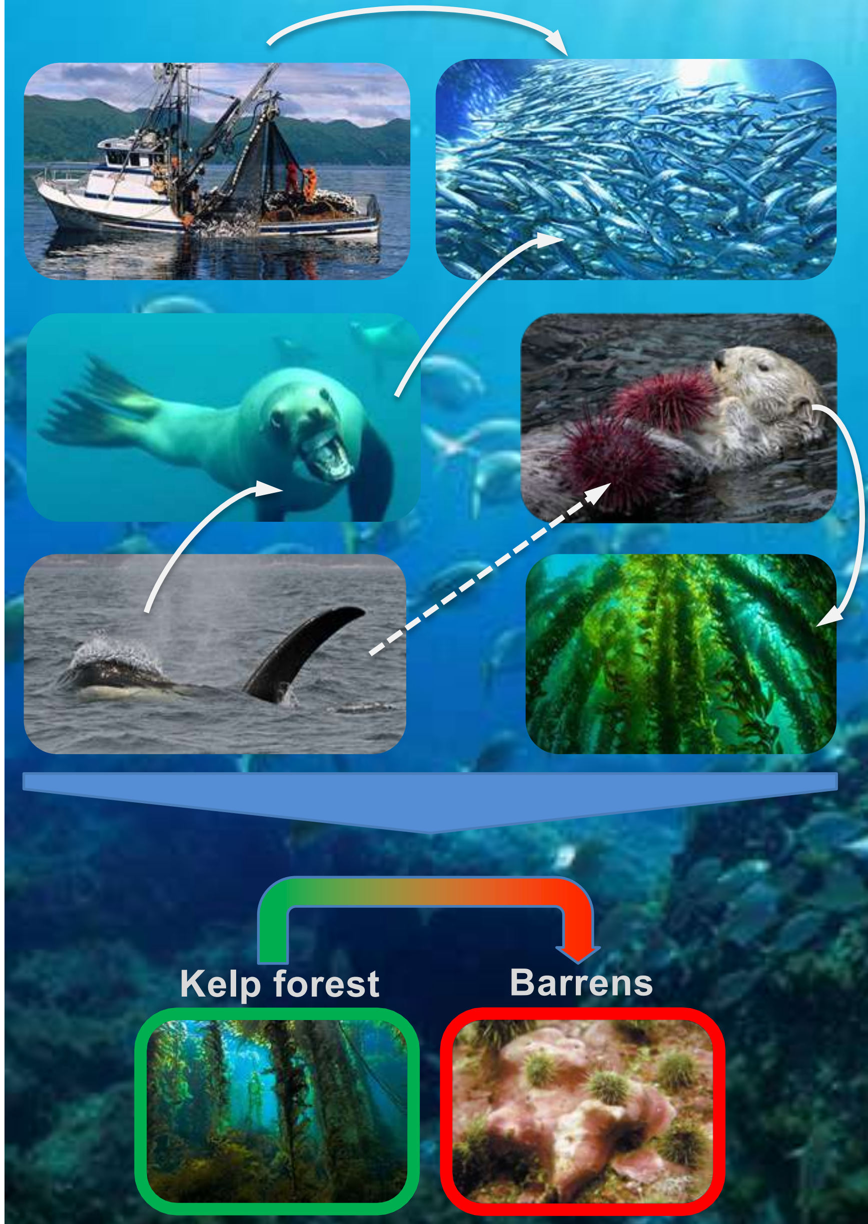


Figure 3. A global map showing the locations of shifts from habitat-forming macroalgae to turfs (circles) overlaid on the approximate distribution of global kelp forests (green; light green unknown but inferred from habitat requirements; Filbee-Dexter and Scheibling 2014). The slice colors of circles indicate different drivers implicated in the shift. See table 2 for further details.

The numbers of living creatures of all Orders whose existence intimately depends on kelp is wonderful ... I can only compare these great aquatic forests of the southern hemisphere with the terrestrial ones in the intertropical regions. Yet if in any country a forest was destroyed, I do not believe as many species of animals would perish as would here from the destruction of kelp. (C. Darwin, 1839)

Regime shifts: Aleutian Archipelago

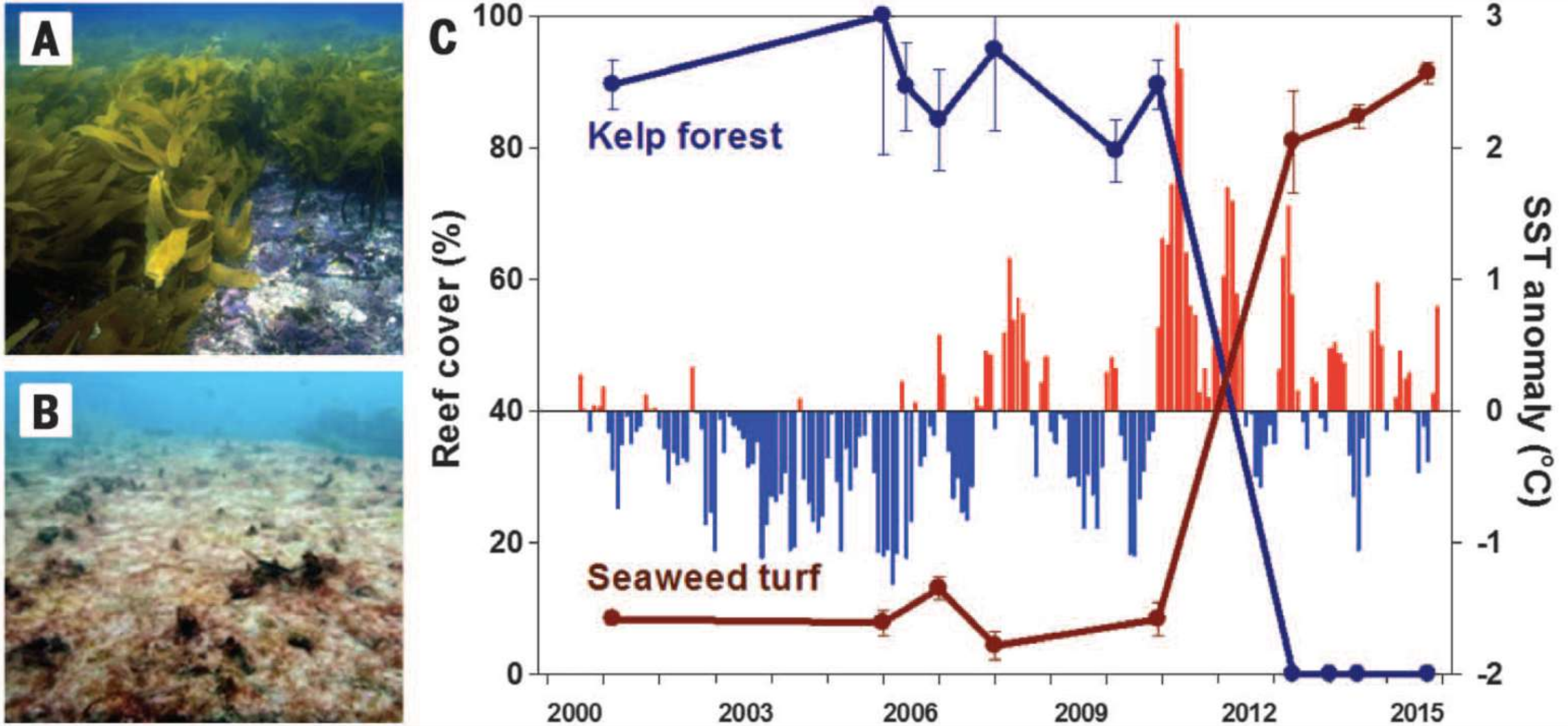


Potential effects of warming period at the end of 70s. Decrease in phytoplankton and consequently of zooplankton. Bottom up effects on herrings and planktivore fish, reduction of marine mammals.

This copupled with overfishing, and reduction of marine mammals. Attracting orcas towards otters. Predation release on sea urchins that increased their population. Grazing pressure increased with consequent collapse of kelp forests

Regime shifts: SW Australia kelp

Extreme marine heat waves forced a 100-km range contraction of extensive kelp forests and saw temperate species replaced by seaweeds, invertebrates, corals, and fishes characteristic of subtropical and tropical waters.
Wernberg et al. 2016



Soft corals

Octocorallia

8-fold symmetry,
most of them symbionts
calcium carbonate or protein skeleton
Do not form reefs

Corallium rubrum

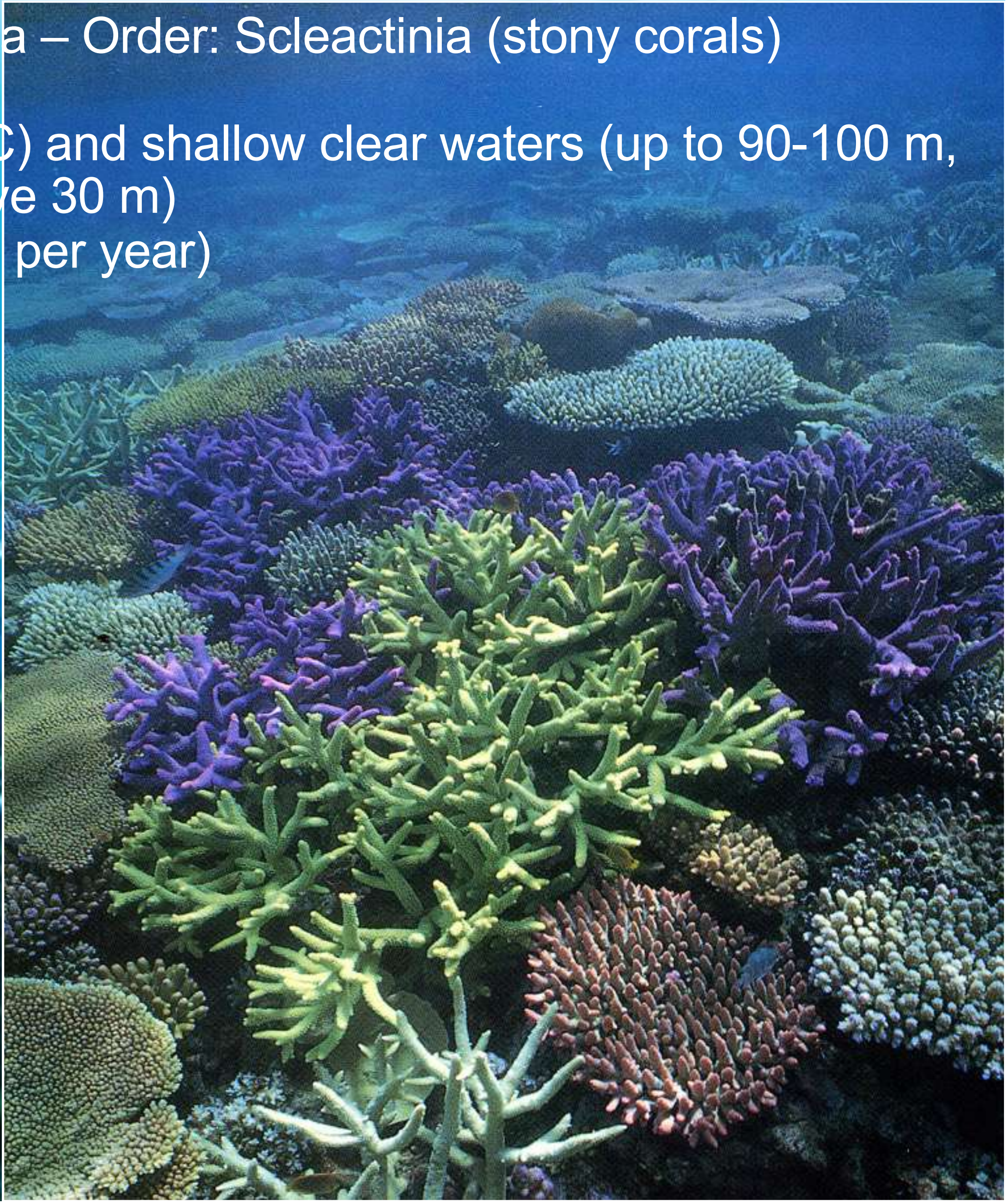
‘True’ Corals are Hexacorallia, Scleractinia, also known as madreporarians or stony corals

Reef-building corals

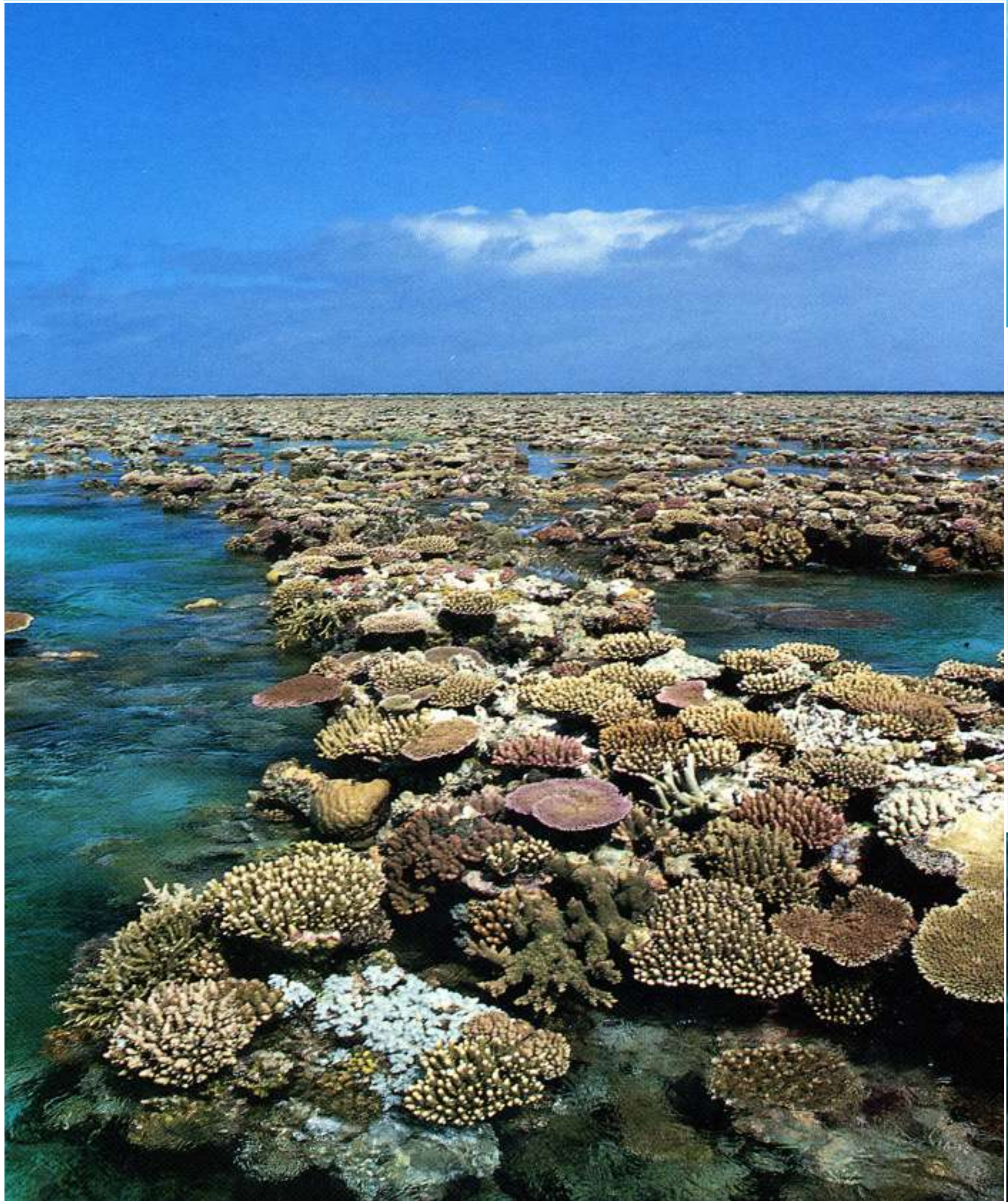
Cnidaria – Anthozoa – Hexacorallia – Order: Scleactinia (stony corals)
Hermatipic corals (reef-building)
Typical of tropical areas (20-25° C) and shallow clear waters (up to 90-100 m, but their optimal for growth is above 30 m)
Low growth rates (0.5 up to 20 cm per year)

Hermatypic corals are those corals which build reefs by depositing hard calcareous material (calcium carbonate, aragonite) for their skeletons, forming the hard structure of the reef. Corals that do not contribute to reef development are referred to as **ahermatypic** (non-reef building) species.
Present day reefs have 5000-10000 y

Coral reefs are among the most biodiverse marine ecosystems of the planet



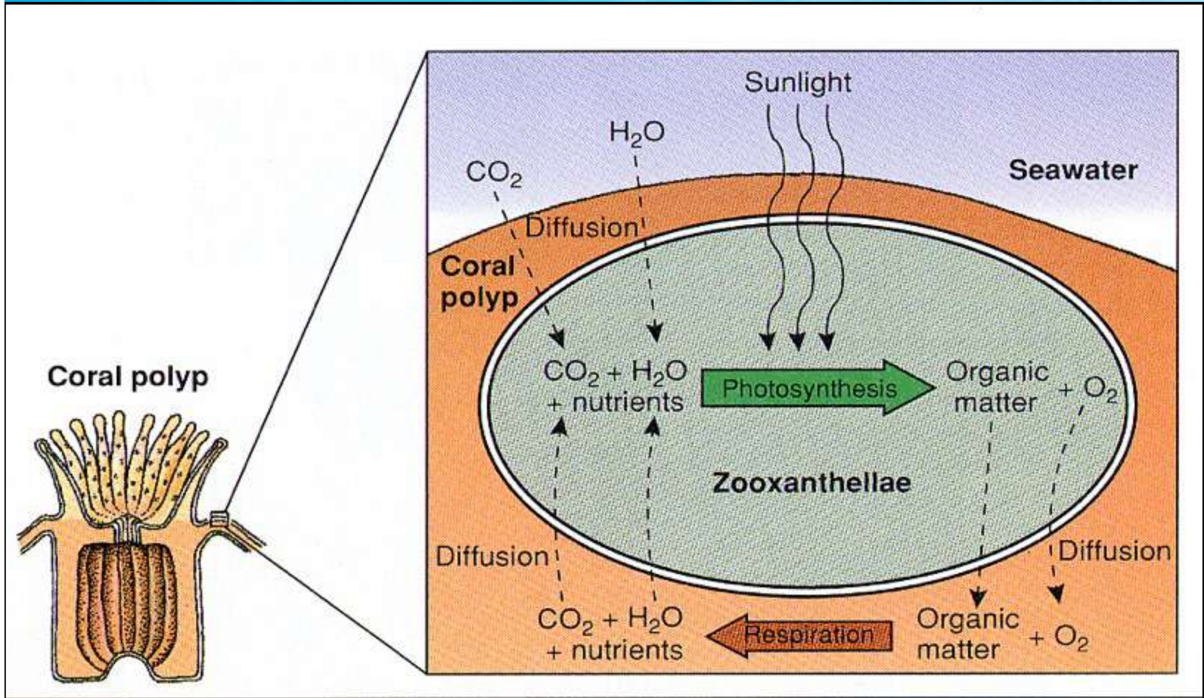
Reef-building corals

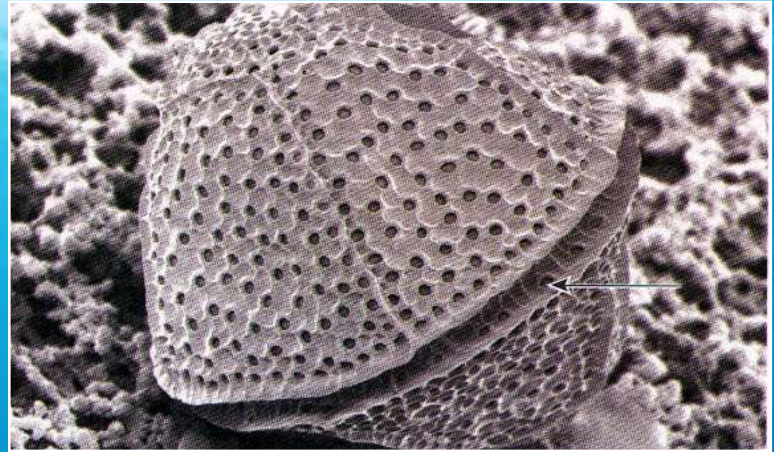


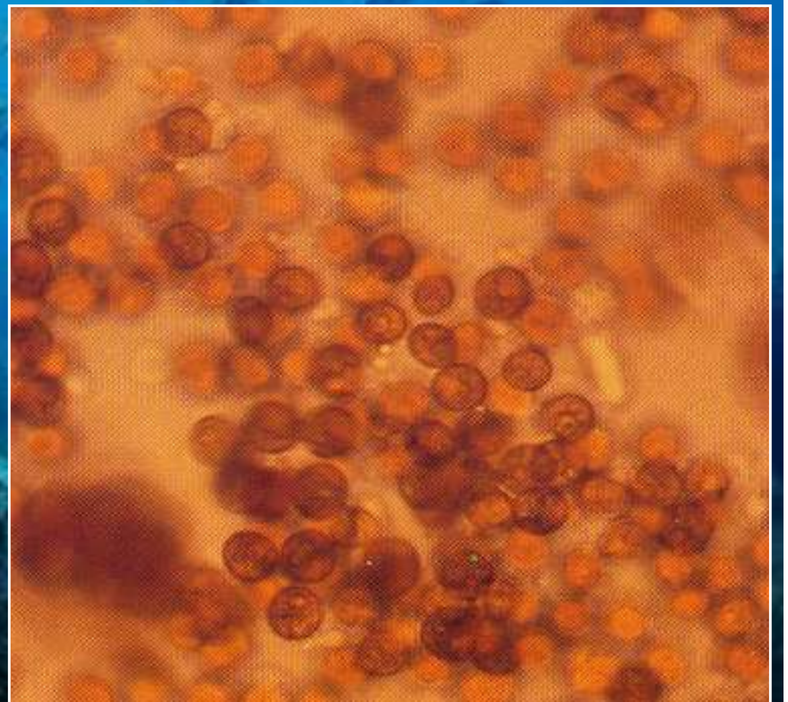
Corals are covered by mucus allowing retaining humidity and avoiding desiccation during low tide periods

In the majority of cases corals host mutualistic symbionts (Protista: Dinoflagellata) allowing higher performance in nutrient-poor environments

Symbiosis

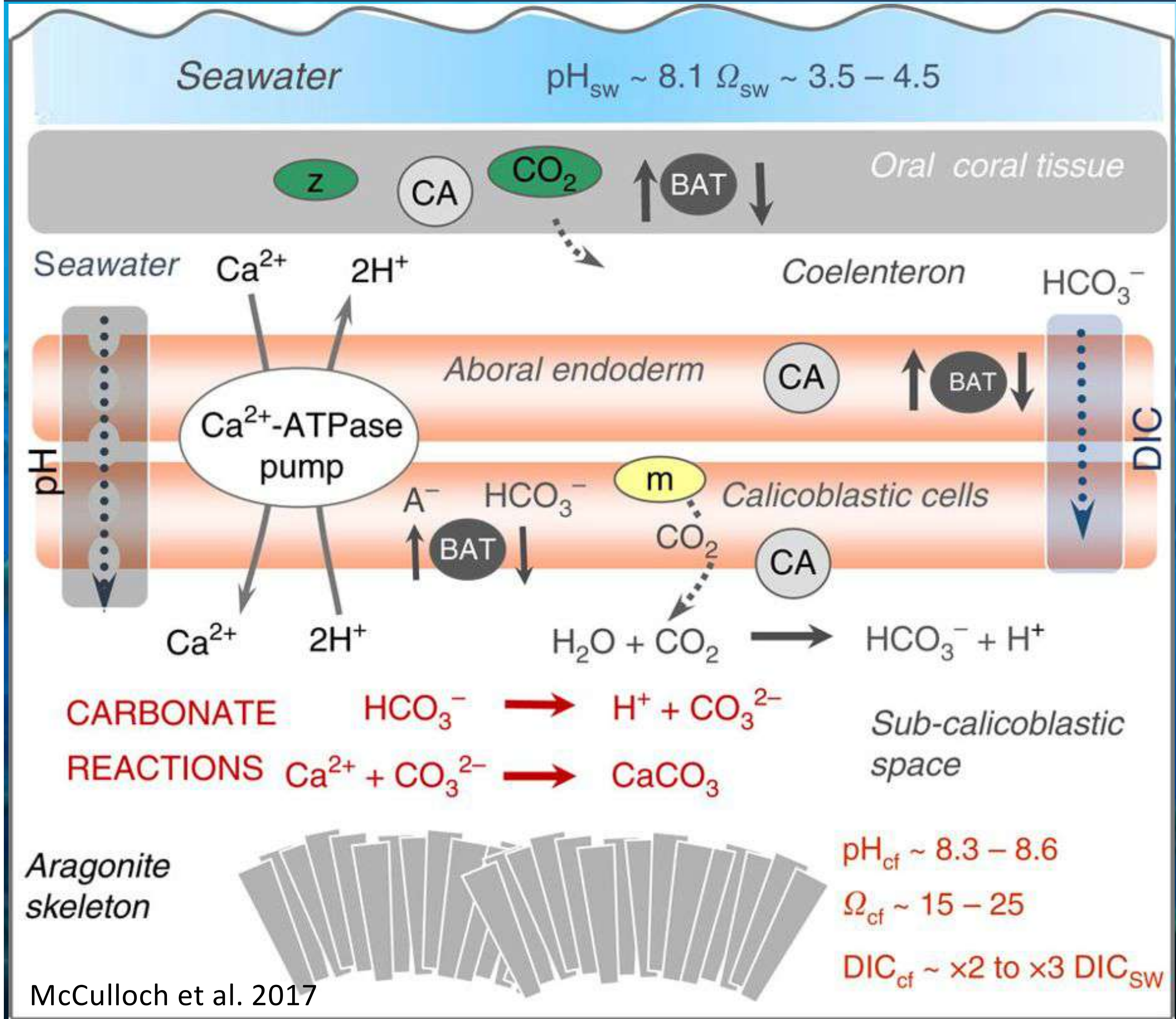






Zooxanthellae are dinoflagellates living in the cells of *gastrodermis* (the inner tissue of polyps), but also in other tissues. They are photosynthetic organisms that exploit CO_2 (dissolved and produced by coral respiration) to synthetize carbohydrates. There are millions zooxanthellae per cm^2 in coral tissues. They provide energy to corals, allowing them to thrive and helping skeletogenesis. Corals in turn, provide shelter, CO_2, and nutrients to zooxanthellae.

Skeletogenesis



McCulloch et al. 2017

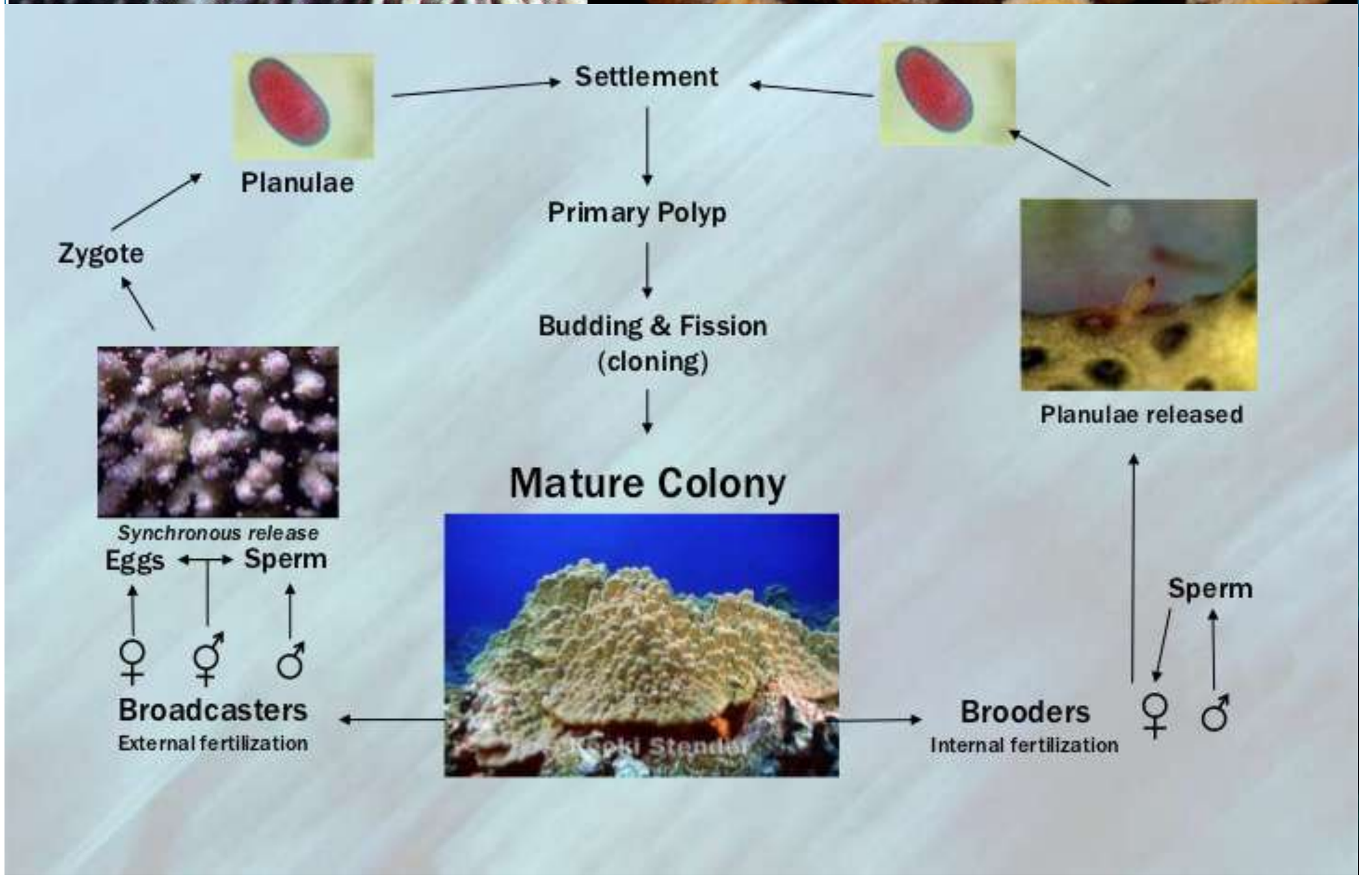
Z: zooxanthellae
CA: carbonic anhydrases
BAT: bicarbonate anion transporters

HCO_3^- are transported by BAT in the calcification fluid between calicoblastic cells and skeleton. It is also produced by CA, from CO_2 and H_2O. CO_3^{--} are formed and Ca^{++}ATPase pump Ca^{++} exchanging with 2 H^+. This increases pH and saturation of aragonite, which in turn allows formation and precipitation of $CaCO_3$ adding aragonite crystal to the coral skeleton.

A comprehensive understanding of the mechanism is still to be achieved.

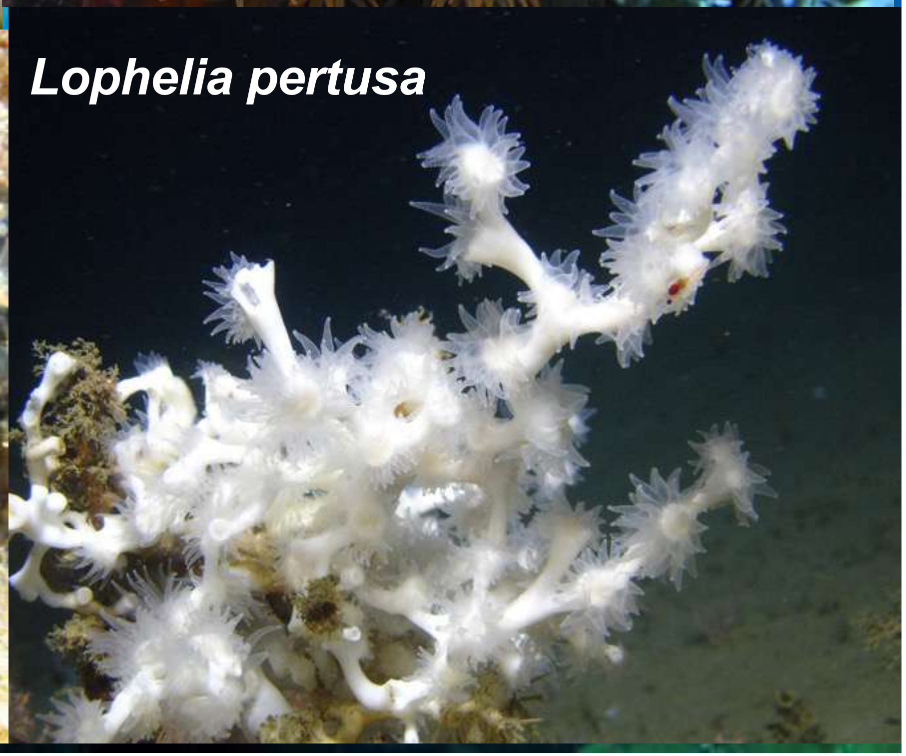
During daylight higher calcification speed, because photosynthesis helps providing energy for the process, and Ca^{++}ATPase is active.

Reproduction

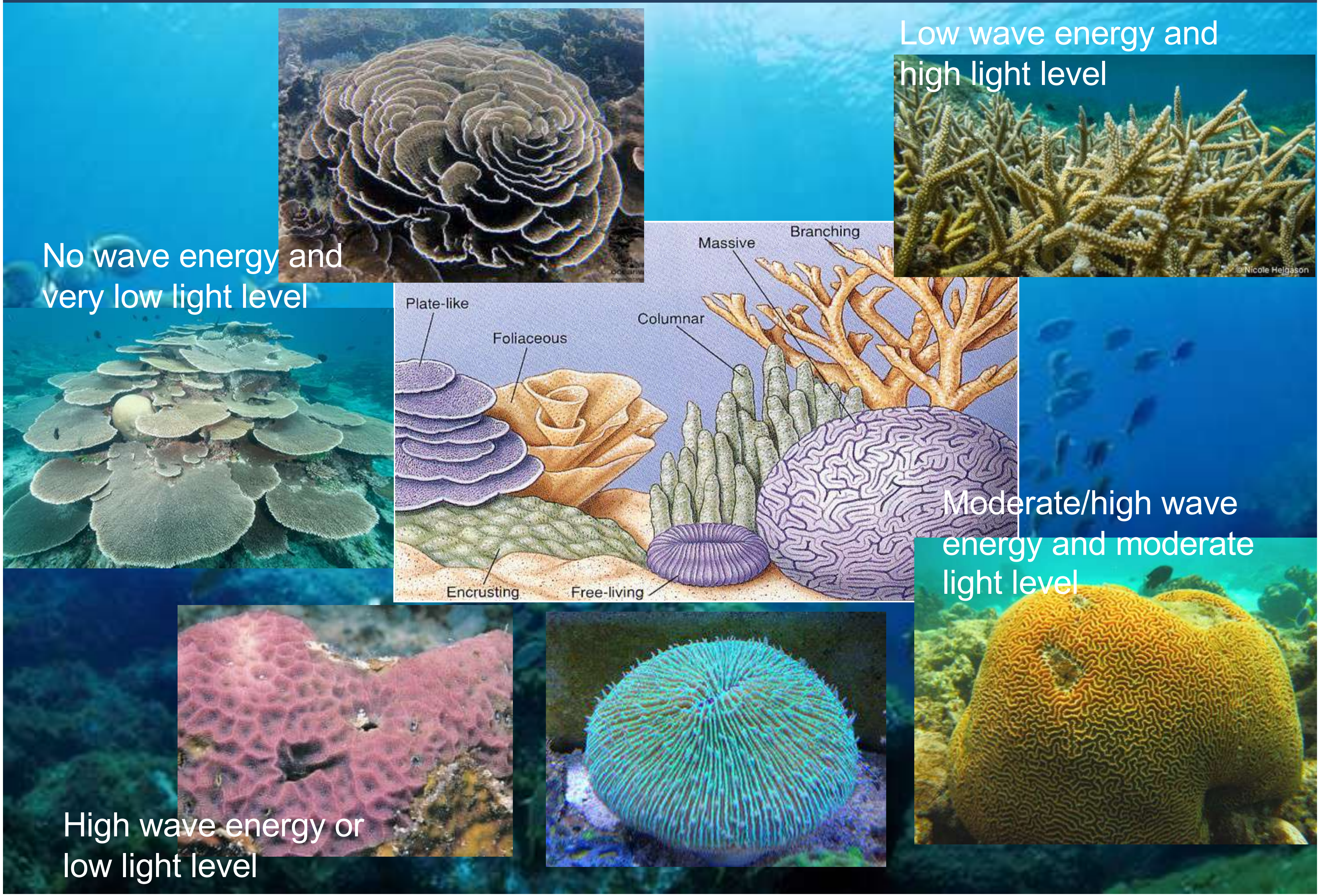


Corals are hermaphrodites.
In most cases they spawn eggs and sperm in the seawater, in synchrony. Others are brooders. In this case fertilization happens within the gastrovascular cavity, originating larvae (planulae) which are then released in the seawater.

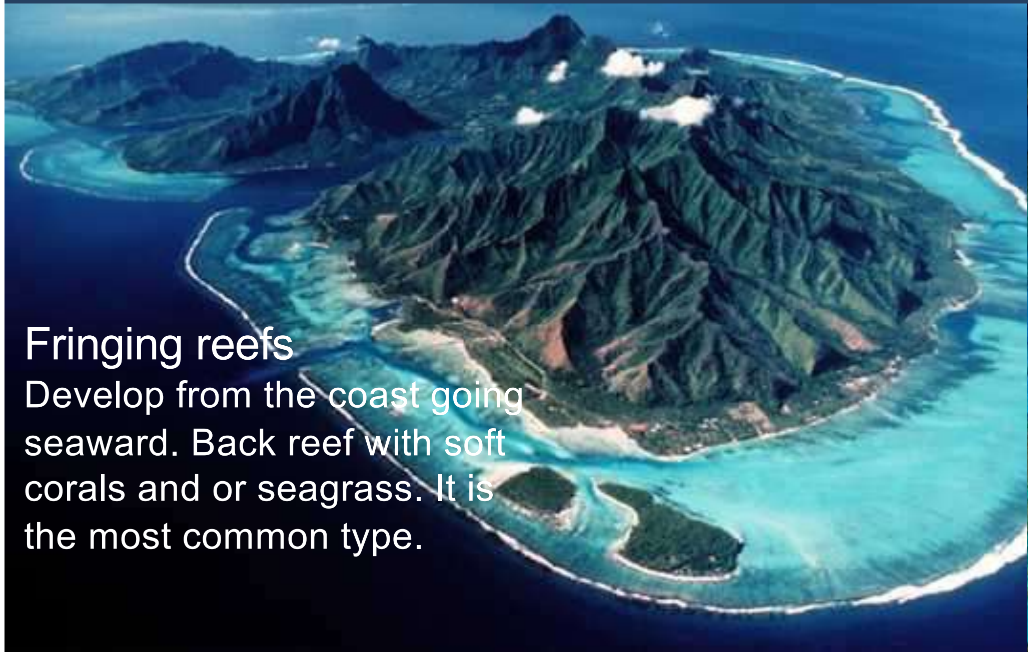
Mediterranean stony corals



Three-dimensional structure



Types of coral reefs

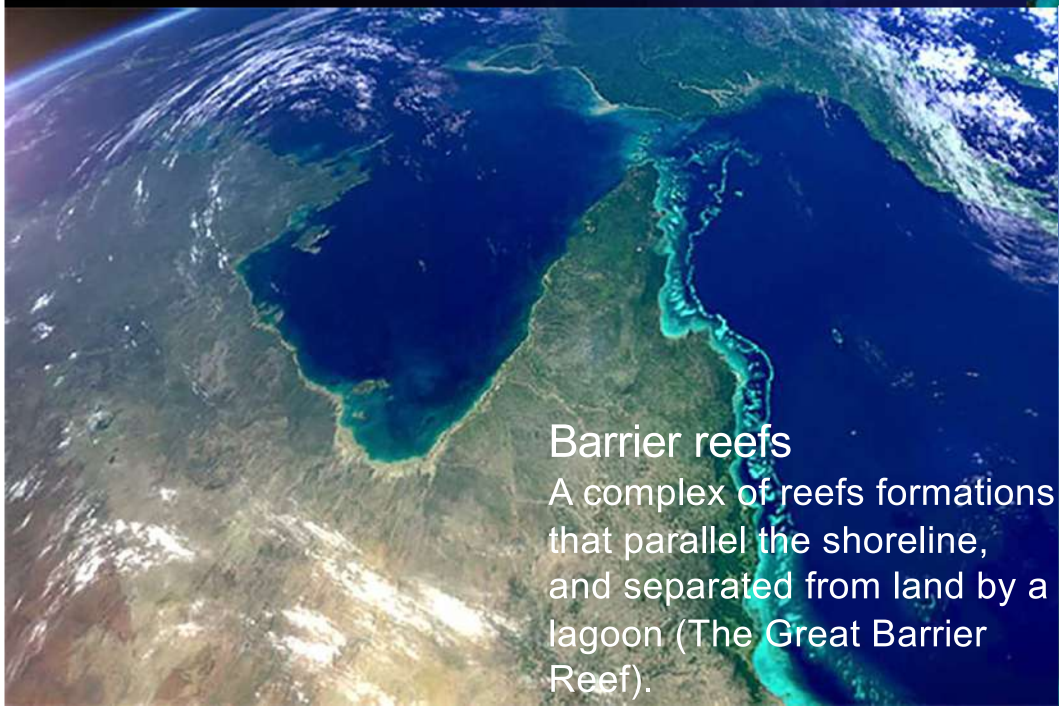


Fringing reefs

Develop from the coast going seaward. Back reef with soft corals and or seagrass. It is the most common type.

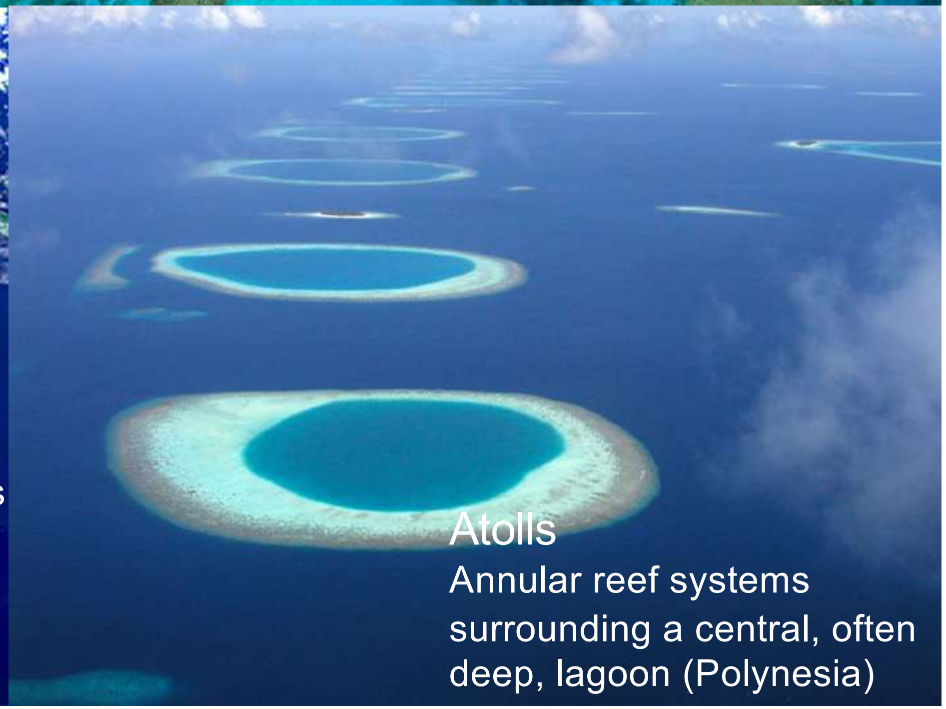
Platform reefs

Isolated reefs developing from the island or continental shelf in sheltered areas, often surrounding very shallow lagoons (e.g. Bahamas).



Barrier reefs

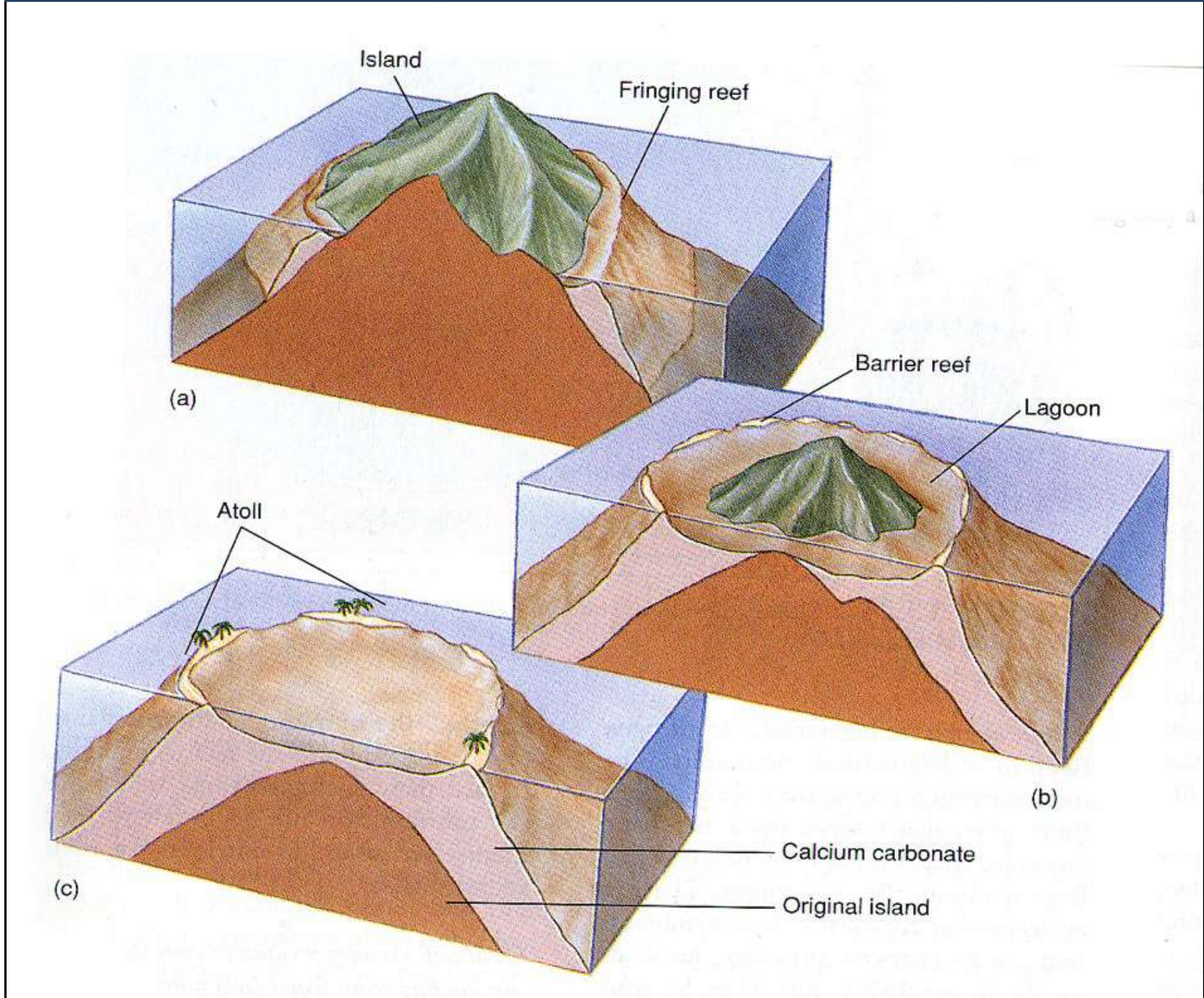
A complex of reefs formations that parallel the shoreline, and separated from land by a lagoon (The Great Barrier Reef).



Atolls

Annular reef systems surrounding a central, often deep, lagoon (Polynesia)

Atolls formation

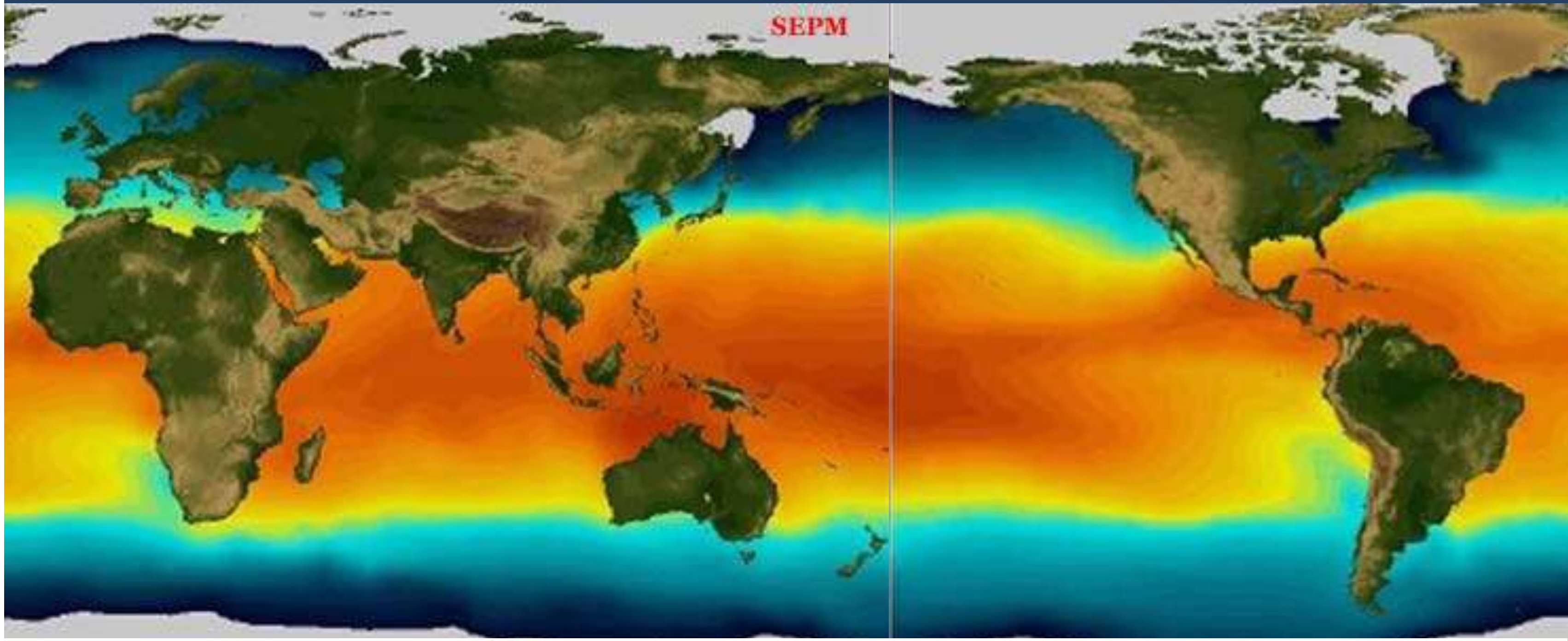


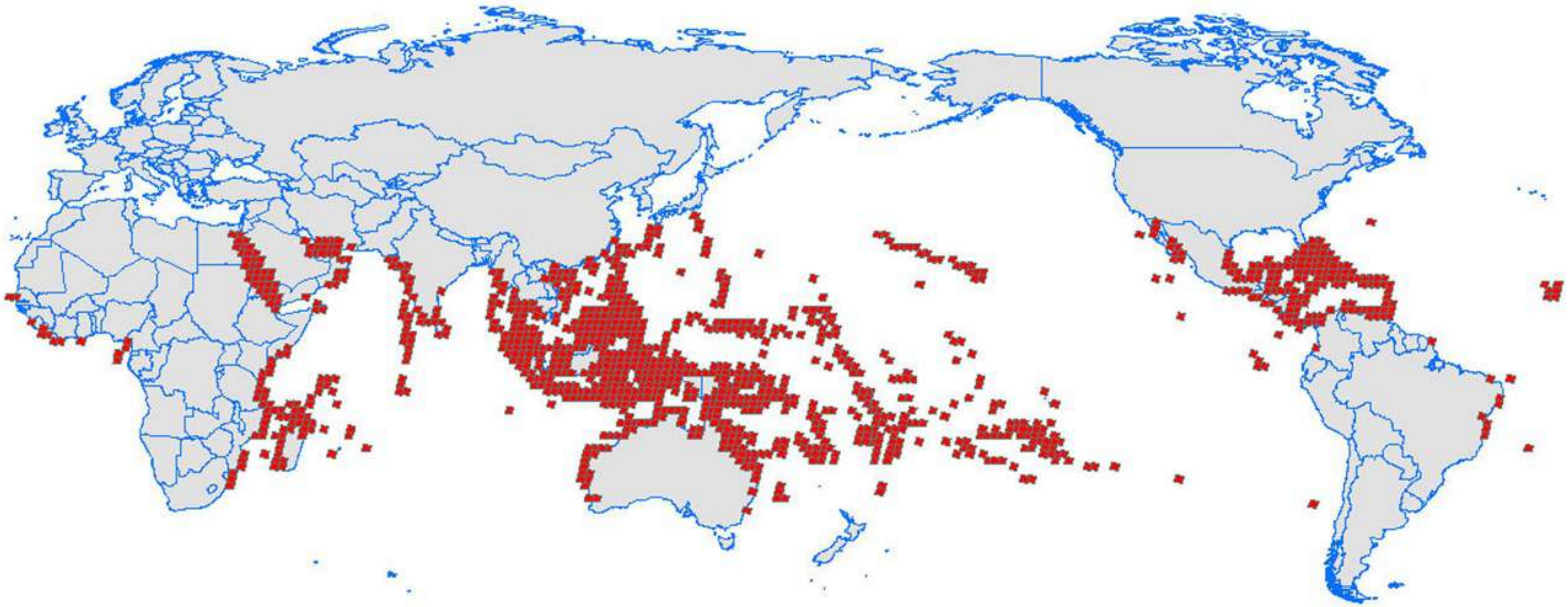
a. Volcanic islands rise from the sea bottom and begin to be colonized by corals forming a reef around them (fringing reefs).

b. Once activity has ceased, subsidence, and/or sea level rise, lead the island to sink, whereas corals continue to grow forming a barrier reef that surrounds a lagoon

c. Finally, the island completely sinks and is covered by carbonate deposit from corals that continue to grow towards the surface forming the atoll.

Distribution





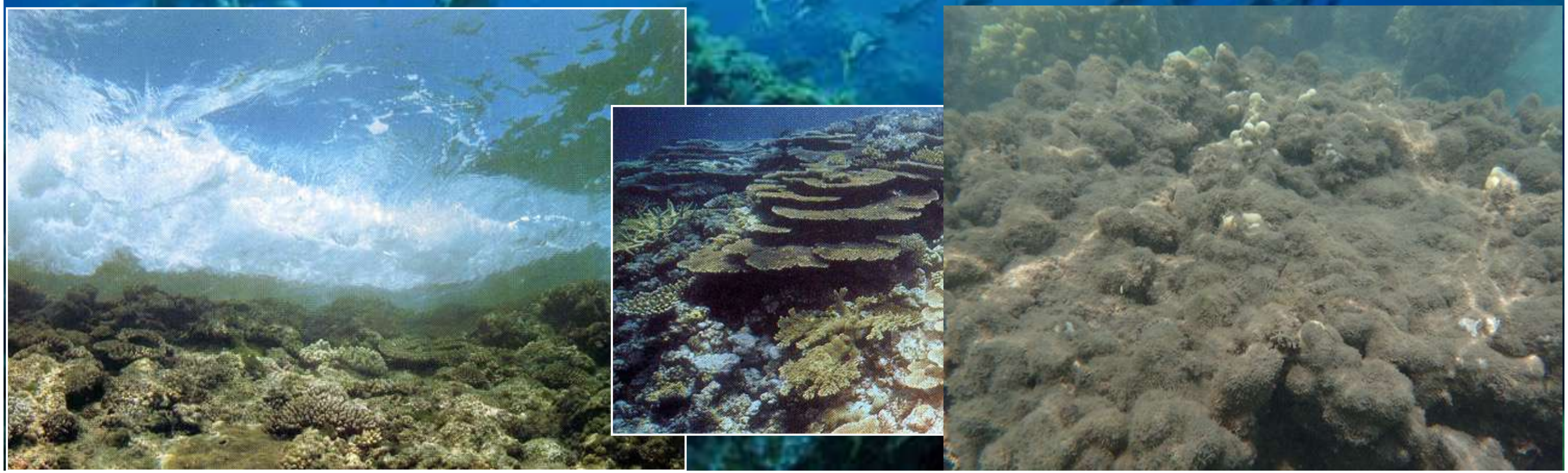
Global distribution of coral reefs is delimited northward and southward by the 20° C isotherm.

'Hotspots' of presence are the Indo-Pacific and the Caribbean.

Surface water temperature, therefore, is one of the most important factors limiting reef distribution at global scale

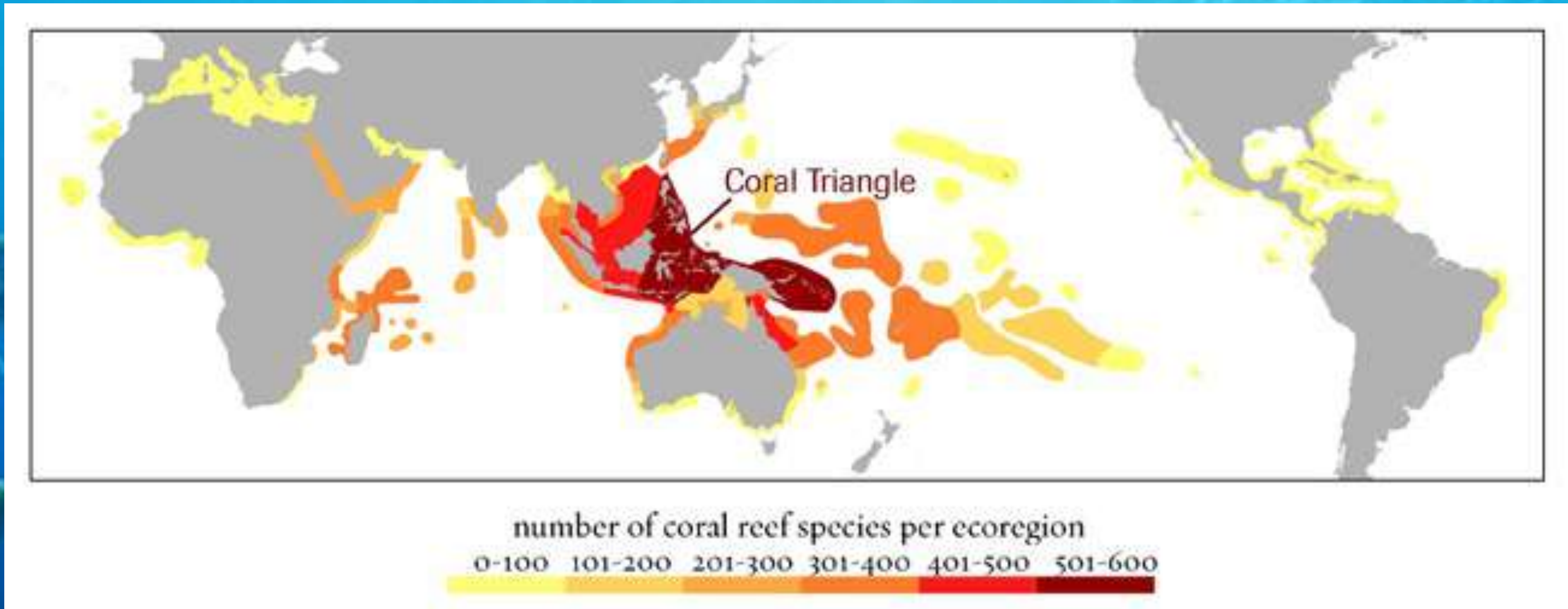
Factors influencing distribution

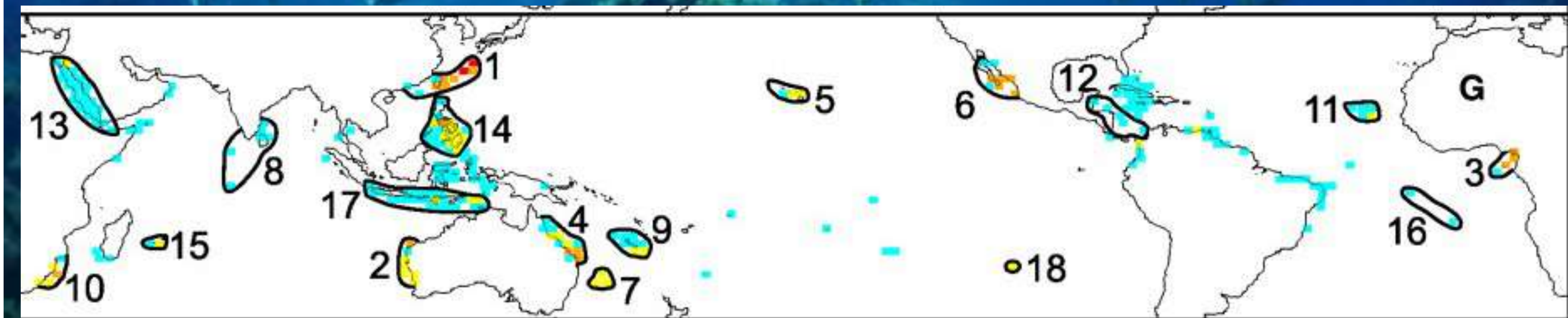
Temperature (warm waters, 20°C)
Light (appropriate irradiation for photosynthetic activity, 20°N-S, limiting depth, influencing vertical distribution of different coral morphologies)
Salinity (>32-35 ‰, scant or no osmoregulation and higher salinity affect photosynthetic rates)
Sedimentation (increased turbidity affect photosynthesis by limiting light penetration, affect polyp predation, facilitate competing species such as turf algae)
Hydrodynamism (tide levels influence emersion time and therefore exposure to air, sunlight; wave action increase erosion and influence vertical distribution of different coral morphologies)



Biodiversity

Coral reefs cover 0.17% of Earth surface but account for 25-30% of global marine biodiversity (Reaka-Kudla 1997; Knowlton et al., 2010)

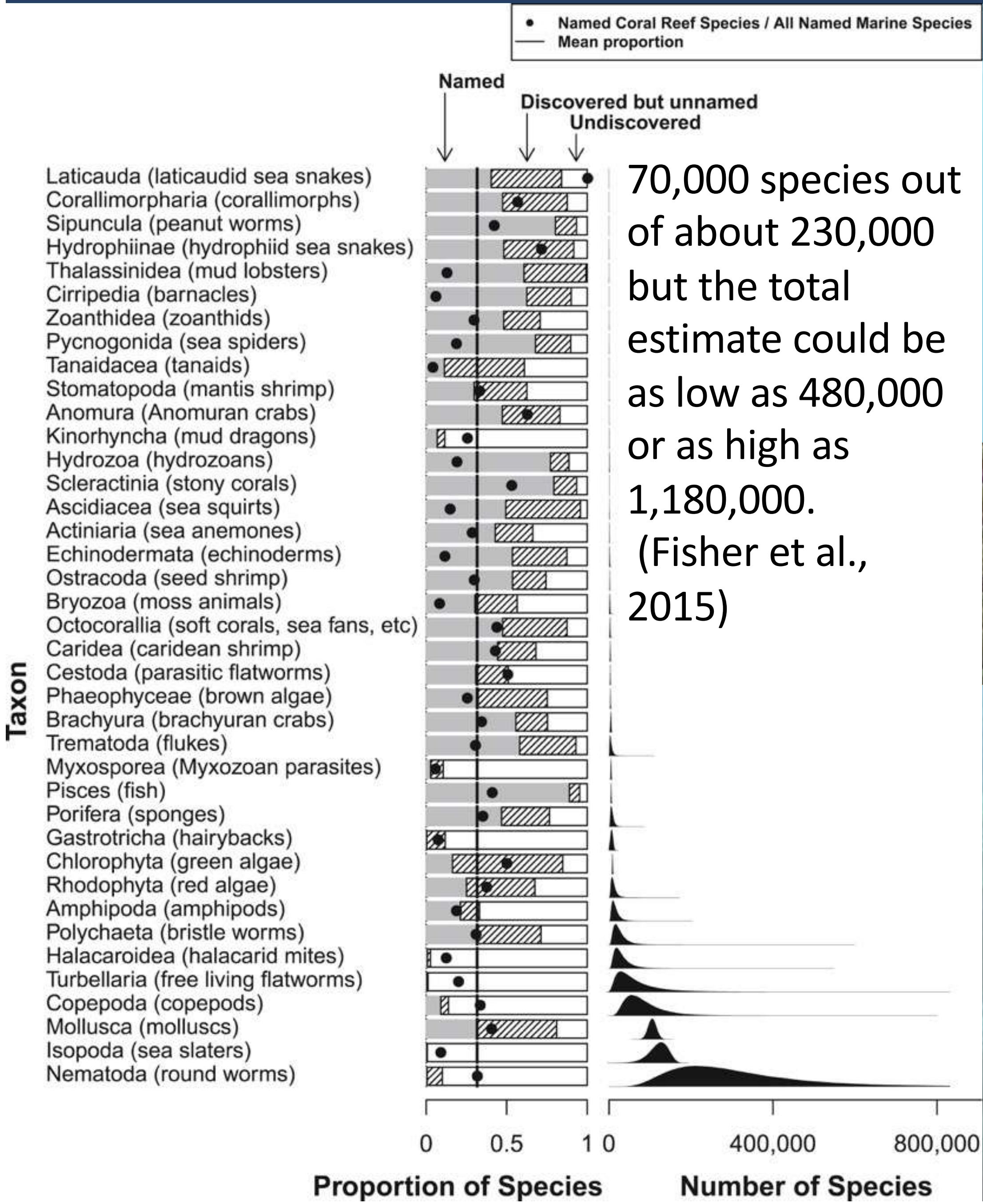


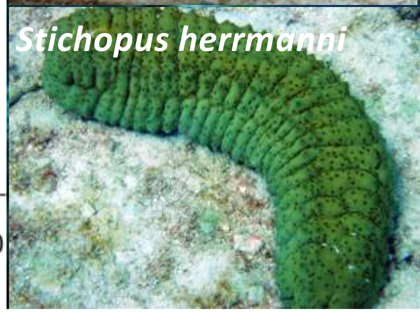


Hotspots of endemisms considering corals, snails, fish, and lobsters (Roberts et al., 2002)

Biodiversity

70,000 species out of about 230,000 but the total estimate could be as low as 480,000 or as high as 1,180,000.
(Fisher et al., 2015)



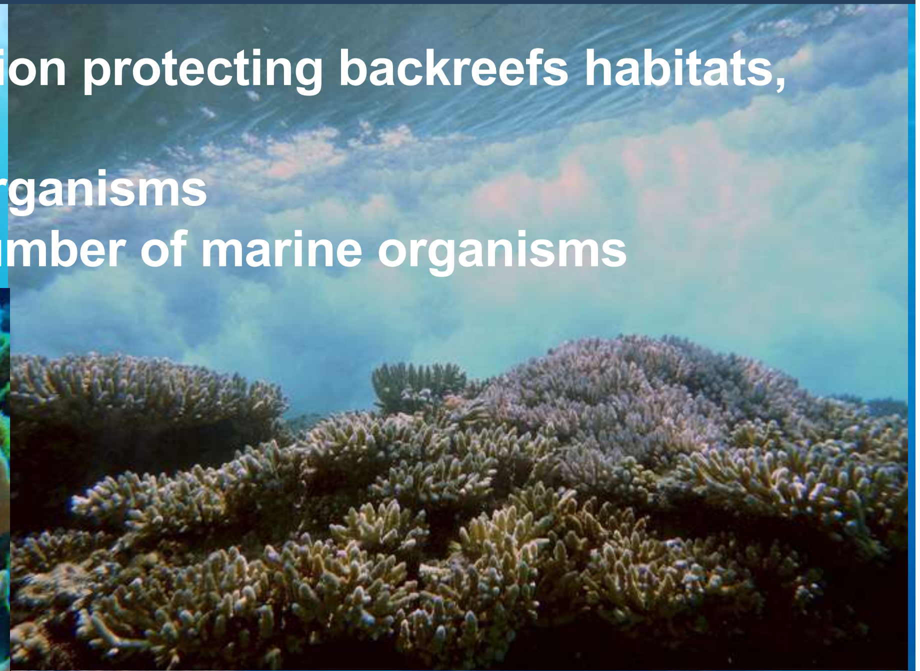


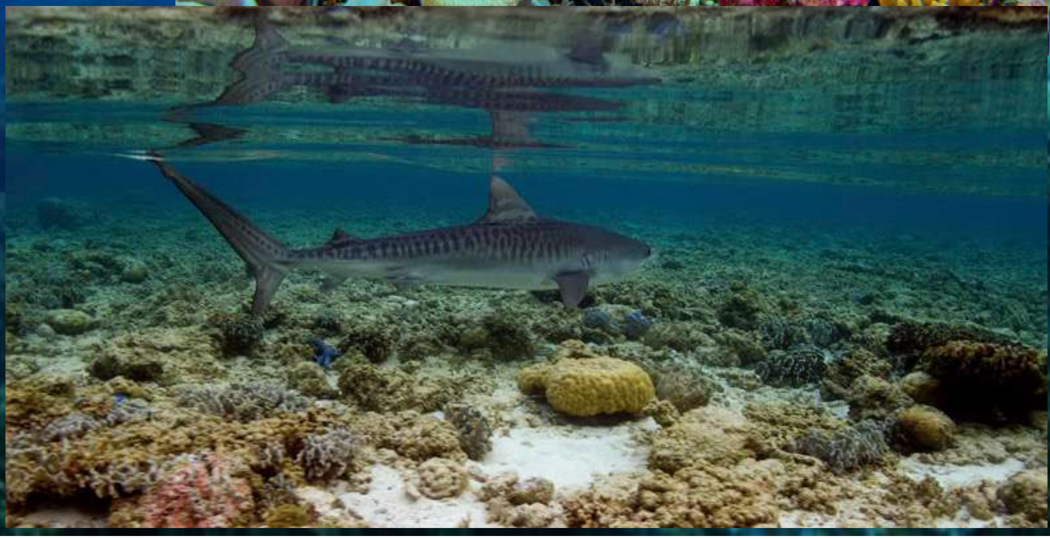
Ecological role and functioning

Coral reefs act as a shield against wave action protecting backreefs habitats, such as seagrass

Create substrate for settlement of marine organisms

Provide food, refuge, nursery areas for a number of marine organisms





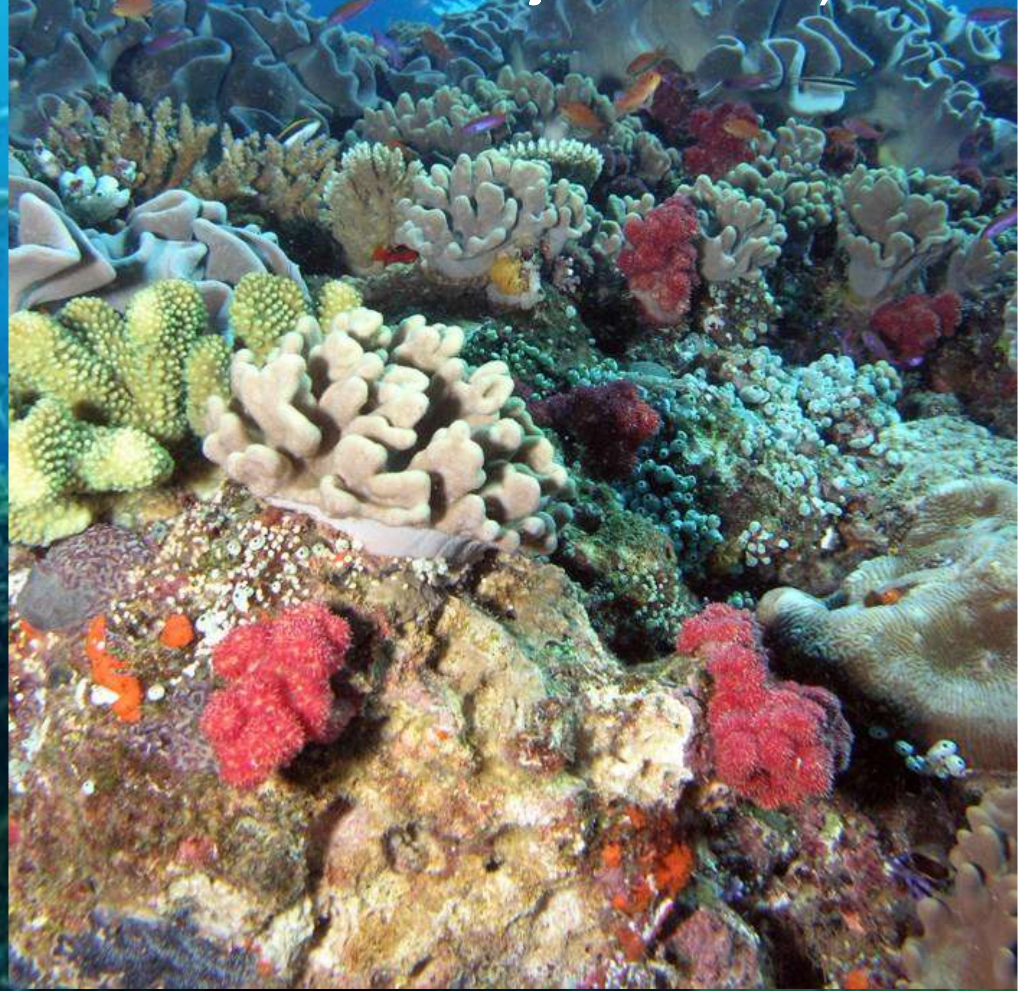
Productivity

Coral reefs cover some 600000 km^2 of the Earth's surface (0.17% of the ocean surface). Gross CO_2 fixation is relatively high (700×10^{12} g C year^{-1}), but most of this material is recycled within the reefs.
Net production of organic material is much smaller, of the order 20×10^{12} g C year^{-1} (15% is buried in reef structure, 10% is available for sustained human harvest, and the remaining 75% is available for export from coral reefs to adjacent areas).
(Crossland et al., 1991)

Unlike rain forests, the contribution of coral reefs to organic CO_2 fixation is relatively minor. Moreover, the calcification process releases CO_2:

$CO_2 + H_2O \rightarrow CH_2O + O_2$
$Ca^{++} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$

Coral reefs are sink of inorganic carbon imprisoned in their calcium carbonate structure.



Goods and services

Food. Coral reefs provide 9 to 12% of the world catch of edible fish, clams, lobsters, crabs, sea cucumbers (up to 20-25% for developing countries) (Moberg & Folke, 1999).

Mineral resources. Construction materials for local populations.

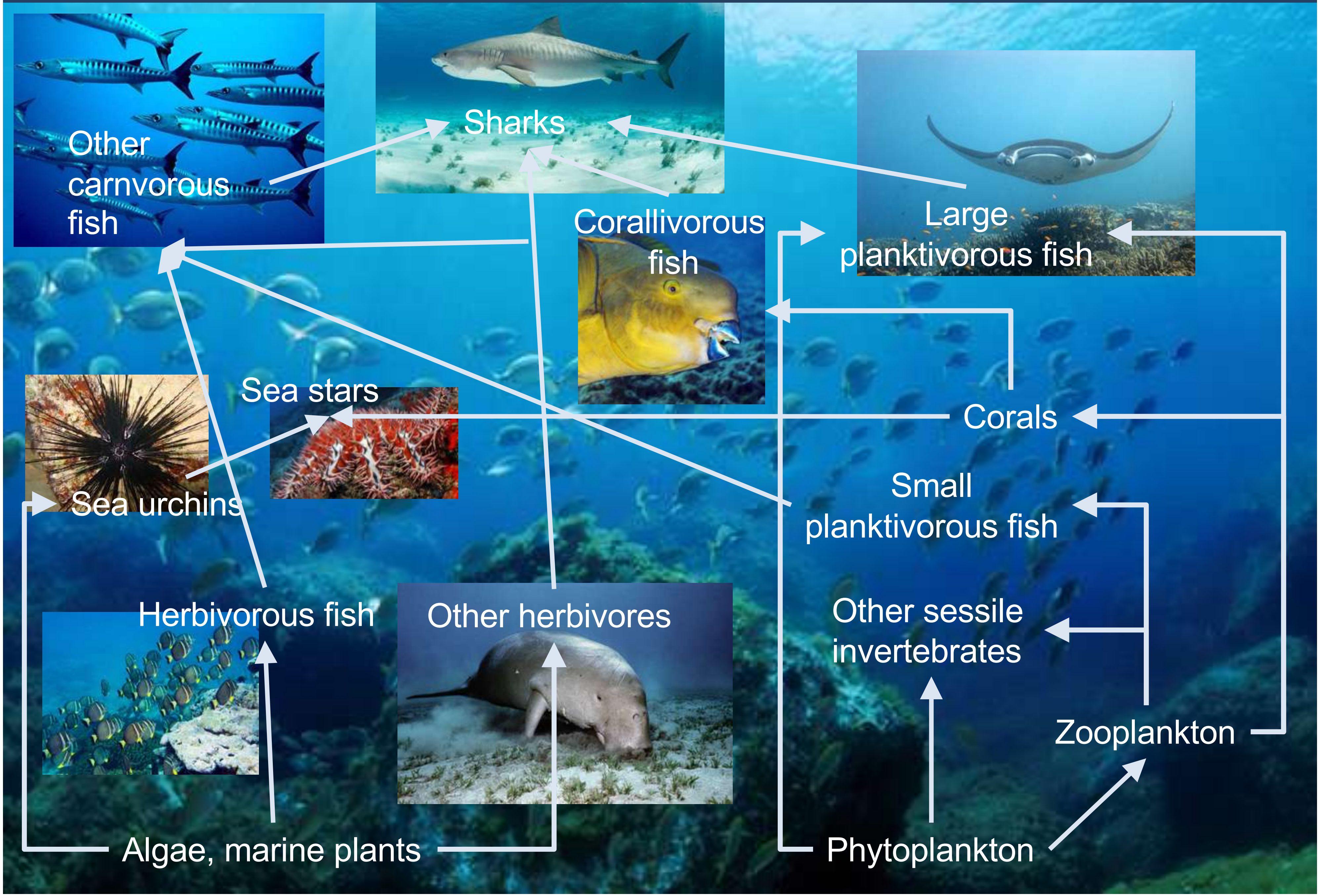
Medical resources. Marine invertebrates in coral reefs represent a potential supply of new drugs for human health.

Coastal Protection. Protection of coastline from the wave action.

Live Resources. Fishing reserve for aquariology, pearl farming.

Tourism and cultural heritage.

Trophic web

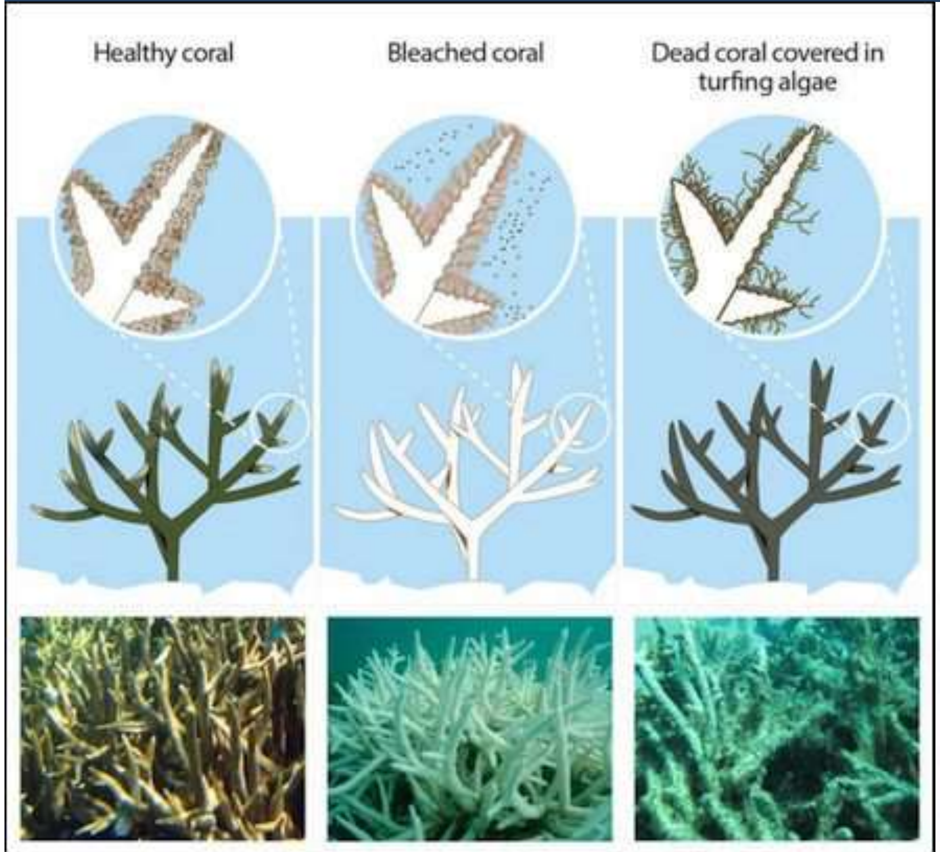


Other carnvorous fish
Sharks
Corallivorous fish
Large planktivorous fish
Sea stars
Sea urchins
Corals
Small planktivorous fish
Herbivorous fish
Other herbivores
Other sessile invertebrates
Zooplankton
Algae, marine plants
Phytoplankton

Threats

Climate change (increasing extreme storm events, acidification, heat waves, sea level rise)
Eutrophication and increase in sedimentation rates
Oil spills – Pollution

Bleaching



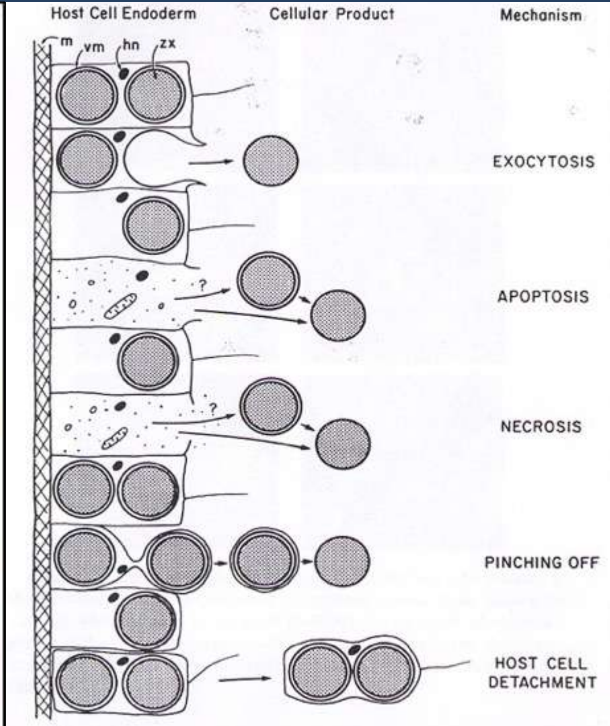


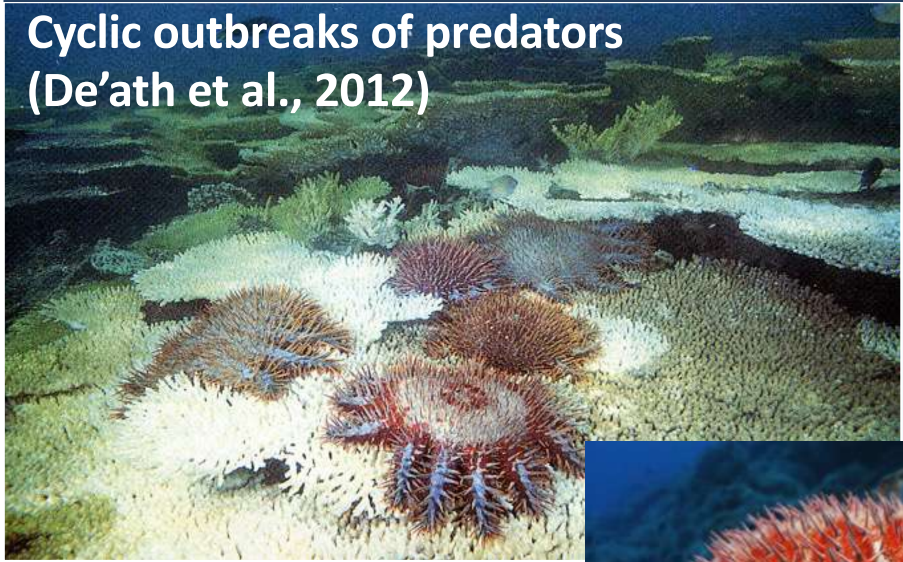
Figure 1. A schematic representation of five potential mechanisms by which zooxanthellae could be released from the endoderm of cnidarians, and the cellular entities associated with each mechanism. m, mesoglea; vm, host vacuolar membrane; hn, host cell nucleus; zx, zooxanthella (shaded for clarity of presentation).

Coral bleaching occurs when corals expel their symbiotic zooxanthellae. Zooxanthellae are responsible of colours of polyps (because they have photosynthetic pigments), so that when they are lost the colony appears "bleached".

This phenomenon happens when corals experience stressful conditions, due to changes in the environment. Several factors could determine bleaching: changes in pH, nutrient and freshwater inputs, but especially sharp increases (or decreases) in seawater temperature.

It could be reversible, if the cause of bleaching is not intense or prolonged.

Diseases – Invasion – Predation



Cyclic outbreaks of predators
(De'ath et al., 2012)

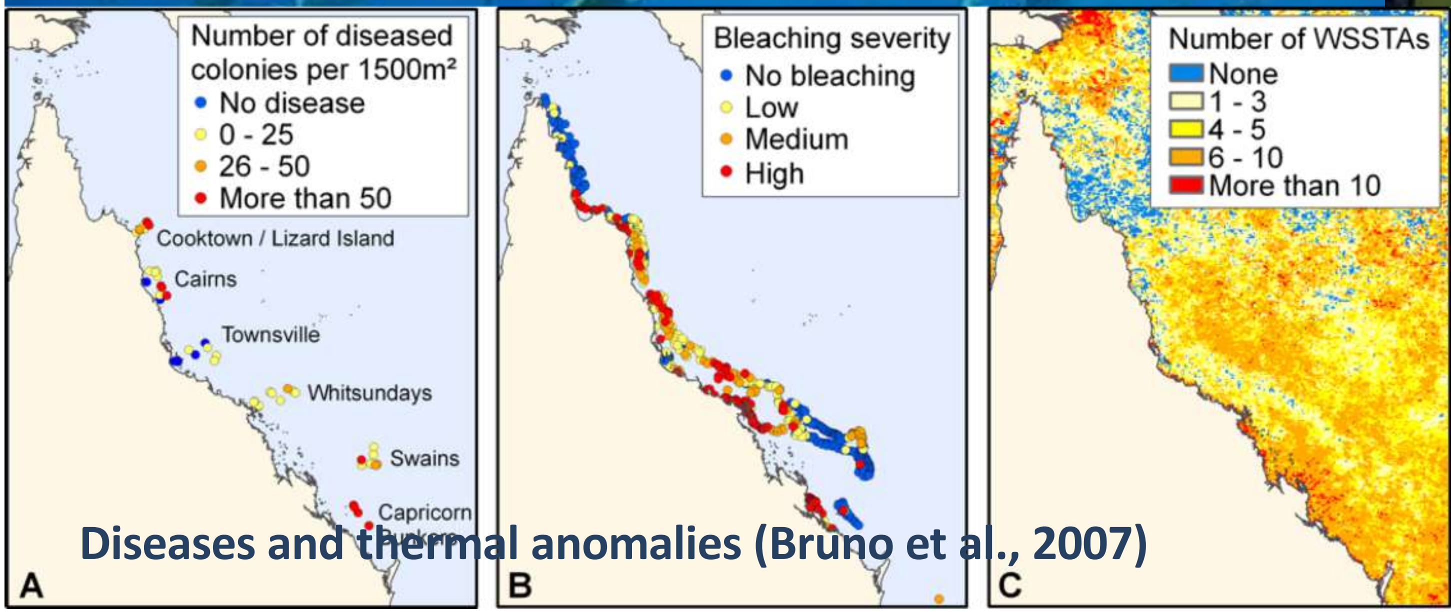
Acanthaster planci

Rats, birds, and… coral reefs
(Graham et al., 2018)

Black-band disease
(Cyanobacteria)

White-band disease
(Bacteria)

Aspergillosis in sea fan
associated to coral reefs



Diseases and thermal anomalies (Bruno et al., 2007)

Overexploitation

25% of local fishers exploit coral reef fish (Teh et al., 2013)

Coral mining
for buildings,
lime
production,
tourism

Regime shifts: Caribbean reefs

Caribbean Sea, from the 70s until now. Again, overfishing and exploitation of corals damaged the reef. Herbivore fish were exploited as commercial targets. These species controls turf algae on the reefs avoiding excessive proliferation of these competitors of corals. Fortunately, reduction of fish population and their herbivory was compensated by sea urchins, which allowed to maintain low abundance of turf forming algal species. However, extreme atmospheric events further damaged the reefs, and also nutrient enrichment from human discharge stimulate algal production. Finally, a disease drastically reduced sea urchin populations and algal blooms were out of control.