MARINE ECOLOGY

Course Information

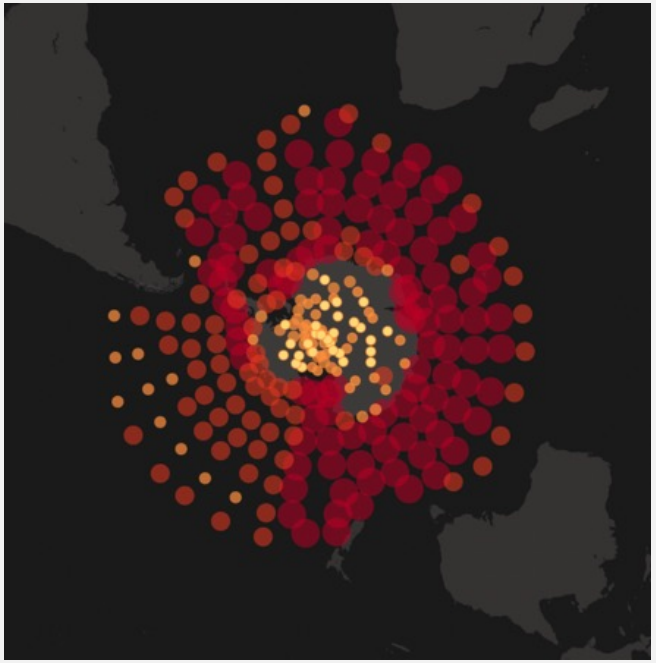
Anton Van de Putte

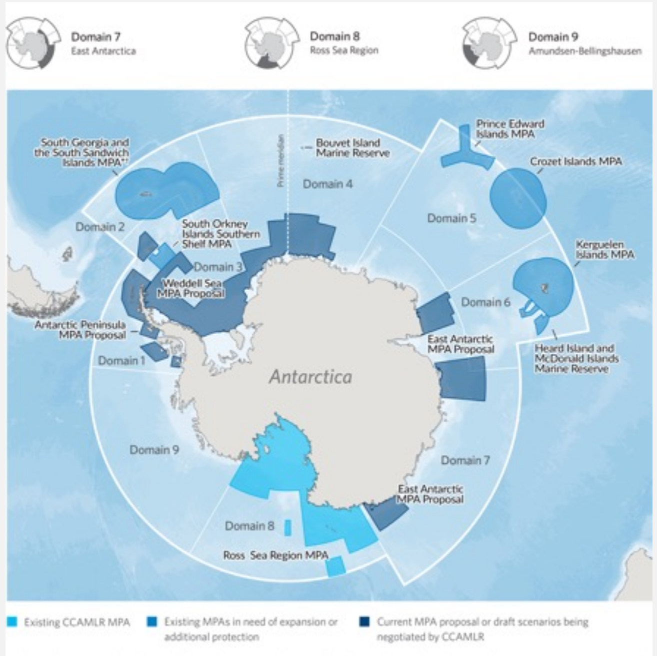
2022 – 2023

RESEARCHER

Data manager

Policy advisor





CONTACT

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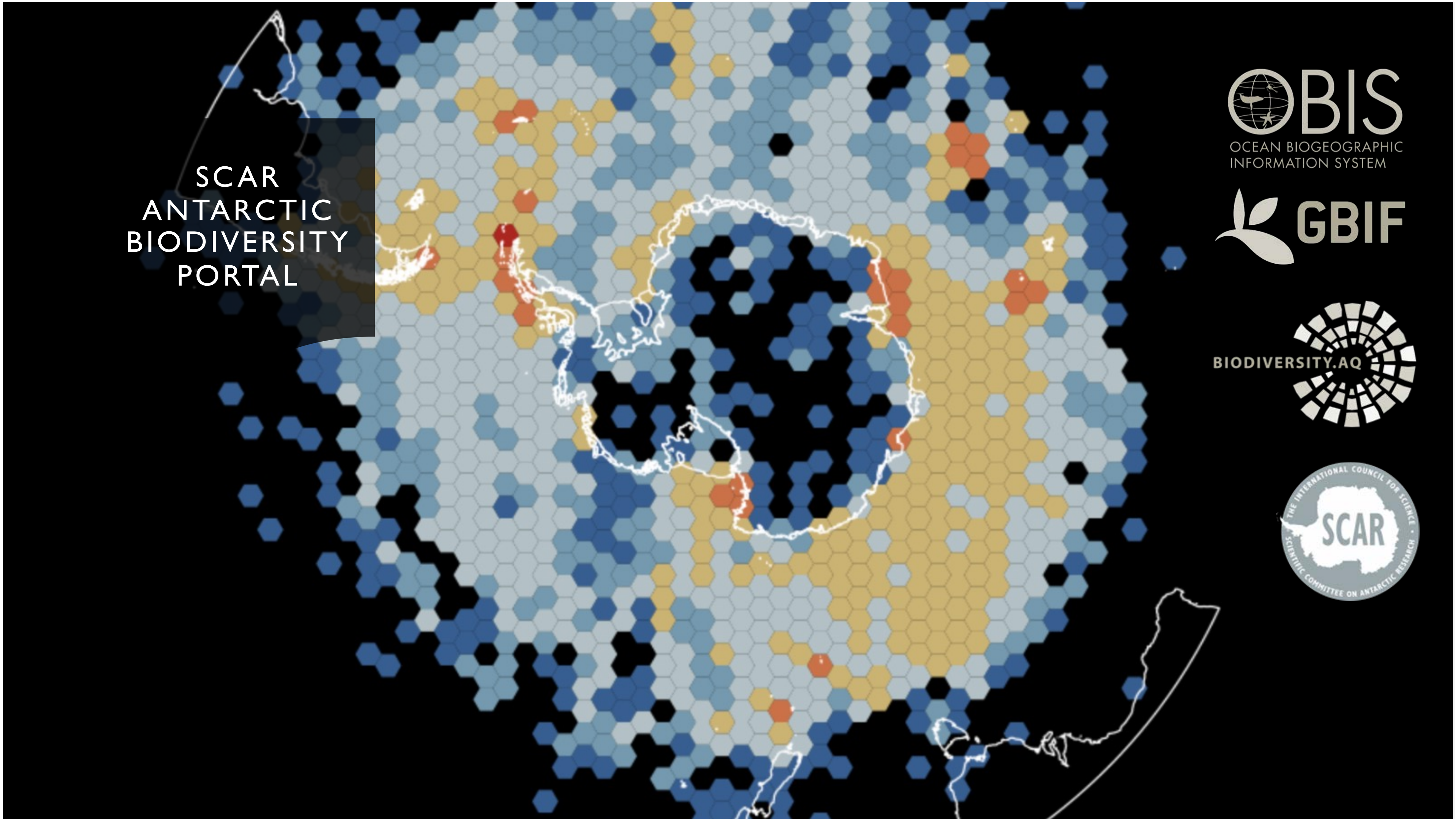
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THE INTERNATIONAL COUNCIL FOR SCIENCE
SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

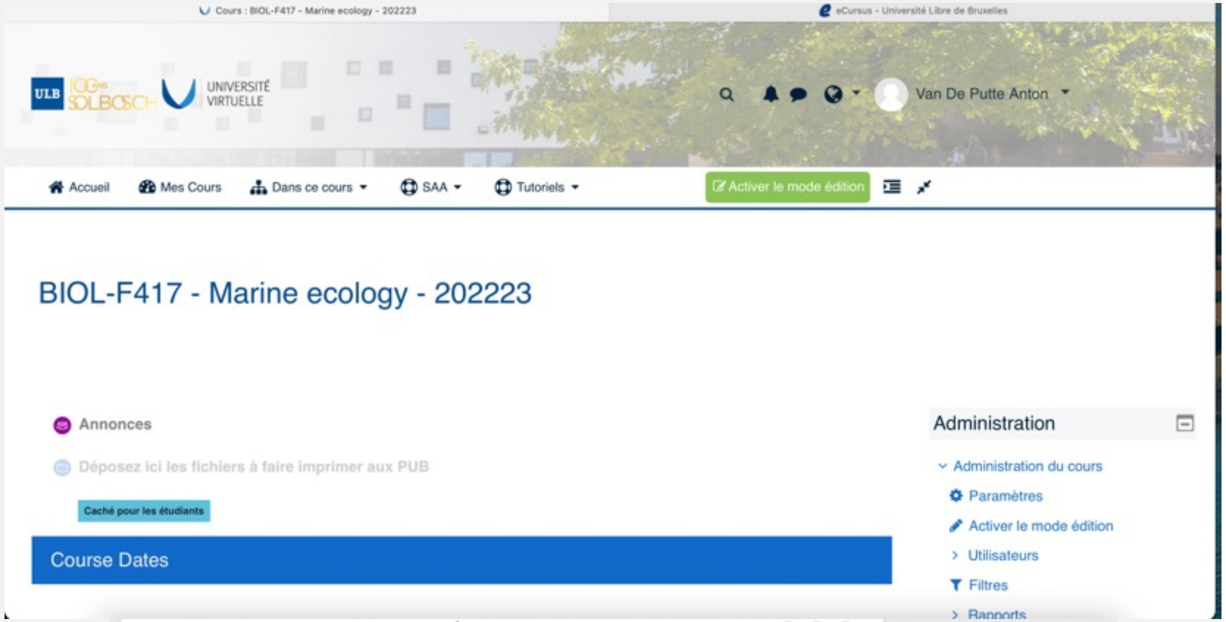
COURSE SHEDULE

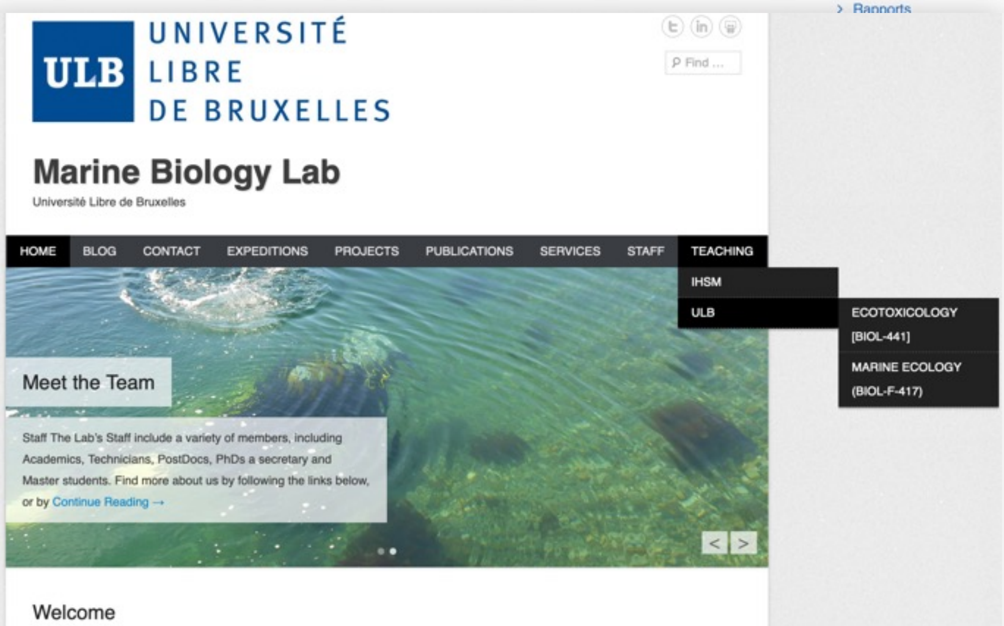
Date	Time	Lecture	Lecturer	Location
05/10/2022	09:00-12:00	Oceanography, geology, history, and technology	MK	VUB
12/10/2022	09:00-12:00	Benthic biological processes	AVdP	ULB, UC2.236
18/10/2022	08:00-18:00	Excursion with Simon Stevin (ULB students)	MK + AVdP	Oostend
19/10/2022	08:00-18:00	Excursion with Simon Stevin (VUB students)	MK + AVdP	Oostend
26/10/2022	**08:00-11:00**	Analysis of data collected during the excursion	MK	VUB, 2 computer rooms
02/11/2022		VUB/ULB is closed		
09/11/2022	09:00-12:00	Coral reef ecology	MK	VUB
16/11/2022	09:00-12:00	Pelagic biological processes	AVdP	ULB, UC2.236
23/11/2022	09:00-12:00	Practical	AVdP	ULB, UC2.236
30/11/2022	09:00-12:00	Connectivity of populations	MK	VUB
07/12/2022	09:00-12:00	Case study: Southern Ocean + global change in the ocean	AVdP	ULB, UC2.236
14/12/2022	09:00-12:00	Questions	AVdP+MK	ULB, UC2.236

COURSE INFORMATION

- https://uv.ulb.ac.be/

- https://biomar.ulb.ac.be





TEACHING SUPPORTS

- Slides of the course
- Books
  - At the « Bibliothèque des Sciences et Techniques »
  - Both ULB and VUB students have access (for the latter, contact the desk in the library)
  - Advanced course: not covered by a single book, even not by multiple ones; several parts based on original scientific literature
  - « Framework »: Valiela I. 2015. Marine Ecological Processes. Springer (on line version available).

BOOKS

- « Framework »: Valiela I. 2015. **Marine Ecological Processes**. Springer.
- Thurman HV. 1990. **Essentials of oceanography** 3rd ed. Columbus, Ohio : Merrill Pub. Co
- Segar DA 2007. **An introduction to ocean sciences 2nd edition**. Minneapolis/St. Paul, MN: West Pub.
- Levinton JS 1995. **Marine biology : function, biodiversity, ecology**. New York : Oxford University Press 420 p.
- Sheppard Ch 2000. **Seas at the millennium : an environmental evaluation** New York : Pergamon
- Steele, John H.2001 **Encyclopedia of ocean sciences vol 1-6**

ENGLISH

Taught in English but

- Most of us are not native speakers
- Not an English language course
- Do not hesitate to ask questions (rather small audience)

Exam

- In English (prefered)
- But you have the right to have it in French (ULB students) or in Dutch (VUB students) (NB: Tropimundo in English, mandatory)

THE COURSE WITHIN YOUR MASTER

Marine Biology does not stop at the end of the course!

Depending on your cursus further excursions during your Master on temperate or tropical shores: you'll need what you learned in this course!

(ULB MA-BIOR A-D: BIOL-F-416 Stage de Biologie marine)

EVALUATION

- **Method(s) of evaluation**
- Oral examination starting with the critical presentation of a scientific article in relation with the course (submitted for approval to the titular)
- Written reports for the practicals
- **Mark calculation method (including weighting of intermediary marks)**
- If the marks for the oral exam and practicals are both higher or equal to 8/20, then the final mark will be calculated as 70% for the oral exam and 30% for the practicals.If the mark of either the oral exam or the practicals is lower than 8/20, then the final mark will be the lower of these.

EXAM

Oral, 30 minutes long

Time and data will be planned together with you

Be present 30 minutes in advance

EXAM STRUCTURE

- 10 minutes
  PowerPoint presentation of a scientific article in direct relationship with the course
  - Short introduction to the question
  - Short explanation of the experiments designed to answer the question (do not enter into the details of the "Materials and Methods" section)
  - Results (to be supported by graphs/tables)
  - Discussion and conclusions
  - Your own critical assessment of the presented article
    - are the results convincing?
    - Is the statistical support sufficient?
    - do results support the conclusions?
- 10 minutes
  discussion of the subject of the paper
- 10 minutes
  general questions for the course

EXAM STRATEGY

- For the discussion, the knowledge of the course is necessary!
- This discussion may possibly bring you to other subjects (transverse comparisons).
- So, if you choose an article on the impact of global change on coral reefs, expect questions dealing with coral reefs but also on chemical oceanography or on top-down control in benthic ecosystems (for instance).
- Articles from Nature and Science are hard!

EXAM ARTICLE

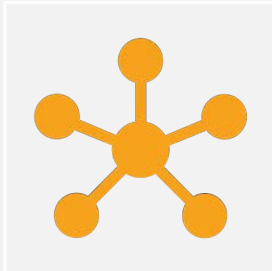
- a recent (not earlier than 2016) scientific research article
- not a review, not a descriptive faunistic list, not a data paper, not a popular science paper
- avoid inventories or natural history of a species or taxon
- in relationship with the course
- ecological processes; effects of global change; connectivity in the marine environment
- in case of a modelling article, be sure to master the modelling aspects (be able to explain how an independent variable is acting on the dependent variables)

EXAM ARTICLE EXAMPLES

- Are fisheries impacting breeding seabirds of the North Sea?
- Are coral reef sea urchins controlled by bottom-up or top-down factors?
- Do the introduced starfish *Asterias amurensis* have an impact in Southern Australia?
- Do food or wave impact control biodiversity on sandy beaches?

QUESTIONS

MARINE ECOLOGY

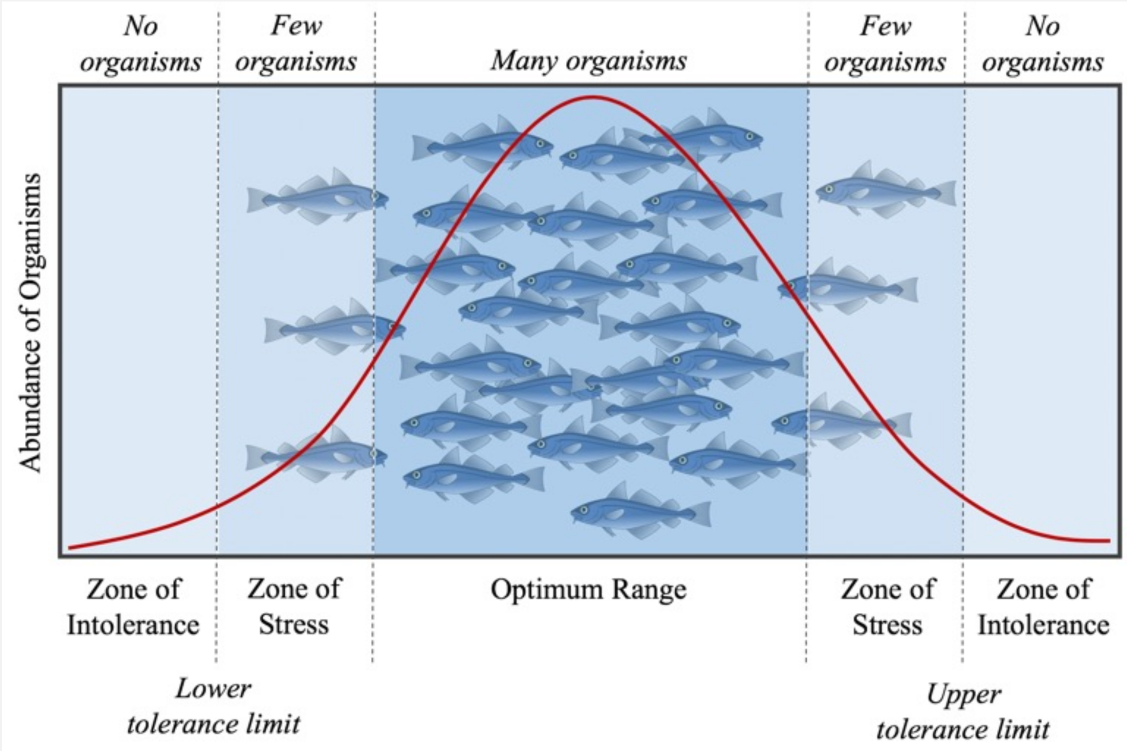


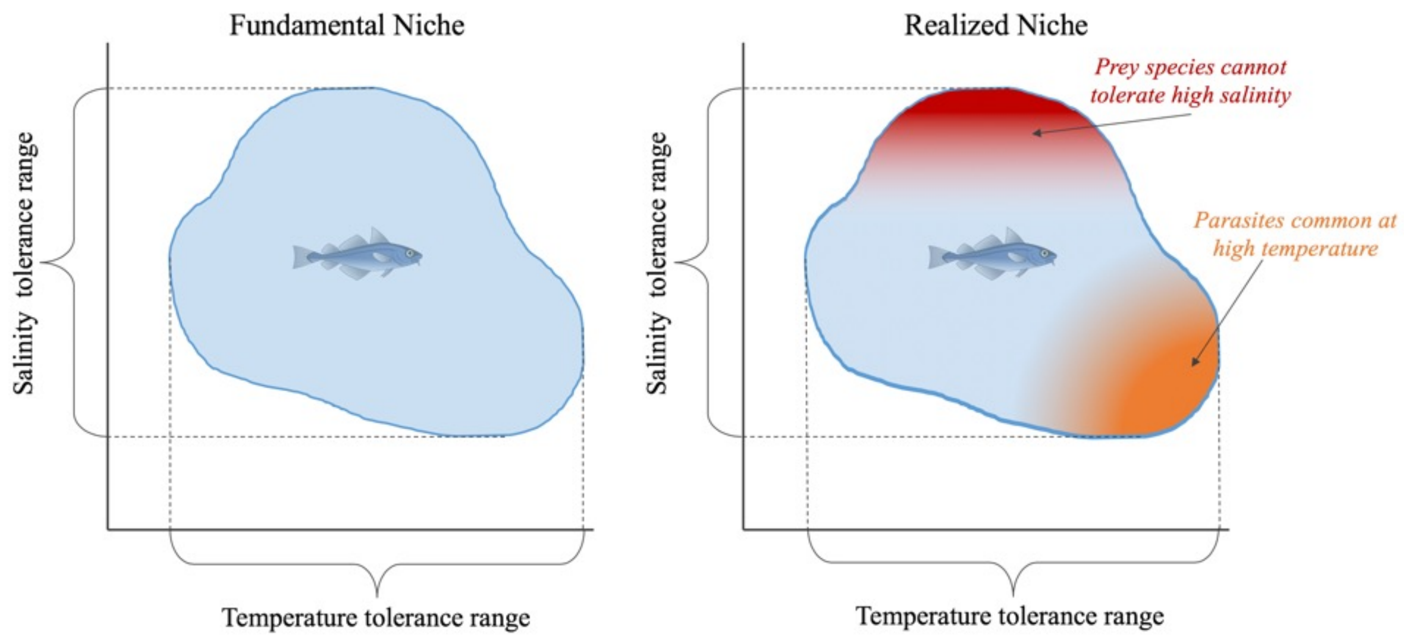
Marine relating to or found in the sea (Ocean, Sea, Estuary)

Ecology the study of organisms and how they interact with the environment around them

ECOLOGICAL NICHE

- abiotic and biotic
- to, reproduce, and surgrowvive





FUNDAMENTAL VS REALIZED NICHE

PRINCIPLE OF ALLOCATION

- Finite quantity of resources
- Zero sum game
- leads to trade-offs

BENTHIC BIOLOGICAL PROCESSES

BENTHIC BIOLOGICAL PROCESSES

1. Divisions of the benthic environment

2. Primary producers

- 2.1. Main taxa
- 2.2. Factors controlling benthic primary production

3. Benthic consumers

- 3.1. Classification
- 3.2. Factors controlling benthic consumers

BENTHIC ZONE

Bénthos: 'the depths'

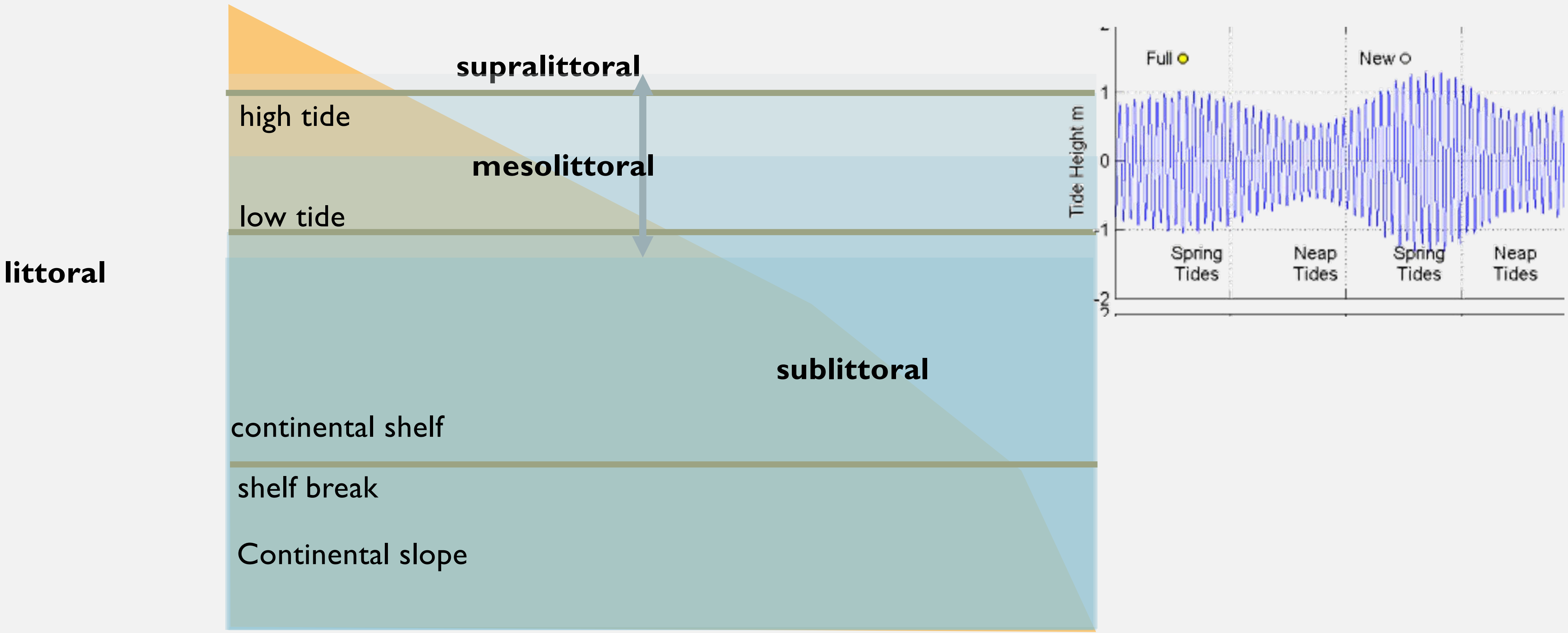
lowest level: the sediment surface and some sub-surface layers

1. DIVISIONS OF THE BENTHIC ENVIRONMENT

I. CHARACTERISTICS OF THE BENTHIC DOMAIN

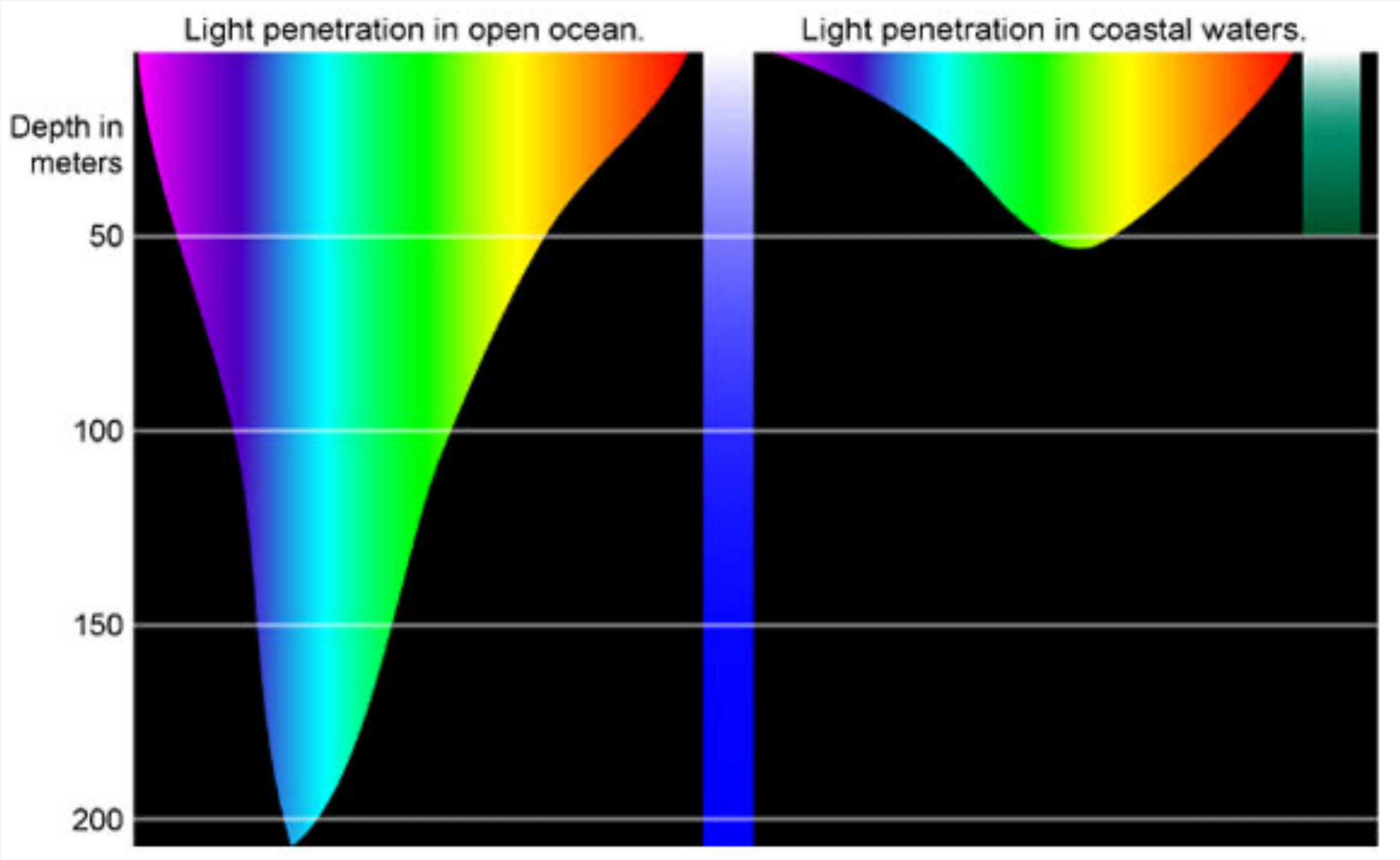
- Position on the shore
- Available Light
- Depth
- Substrate

Position on the shore



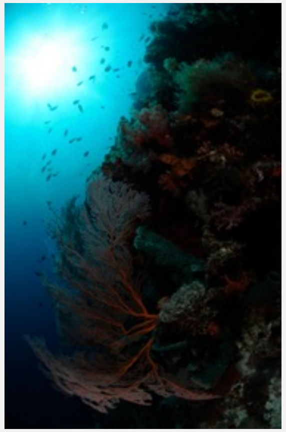
Available Light

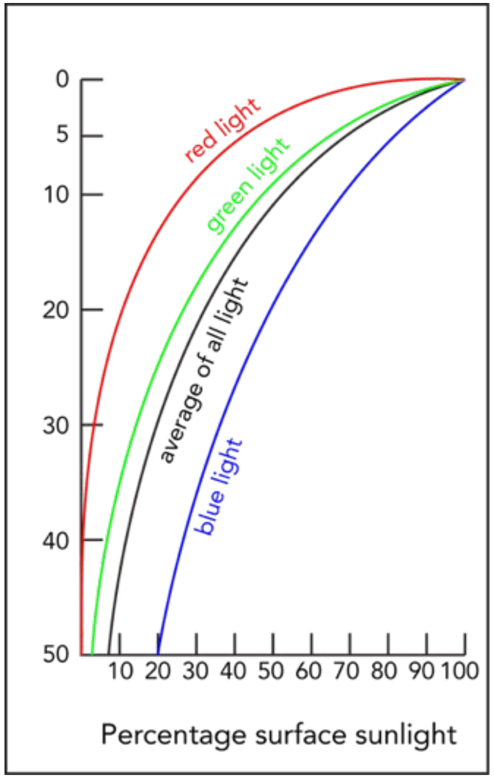
- Reflection/rarefraction
- Absorption
- Scattering

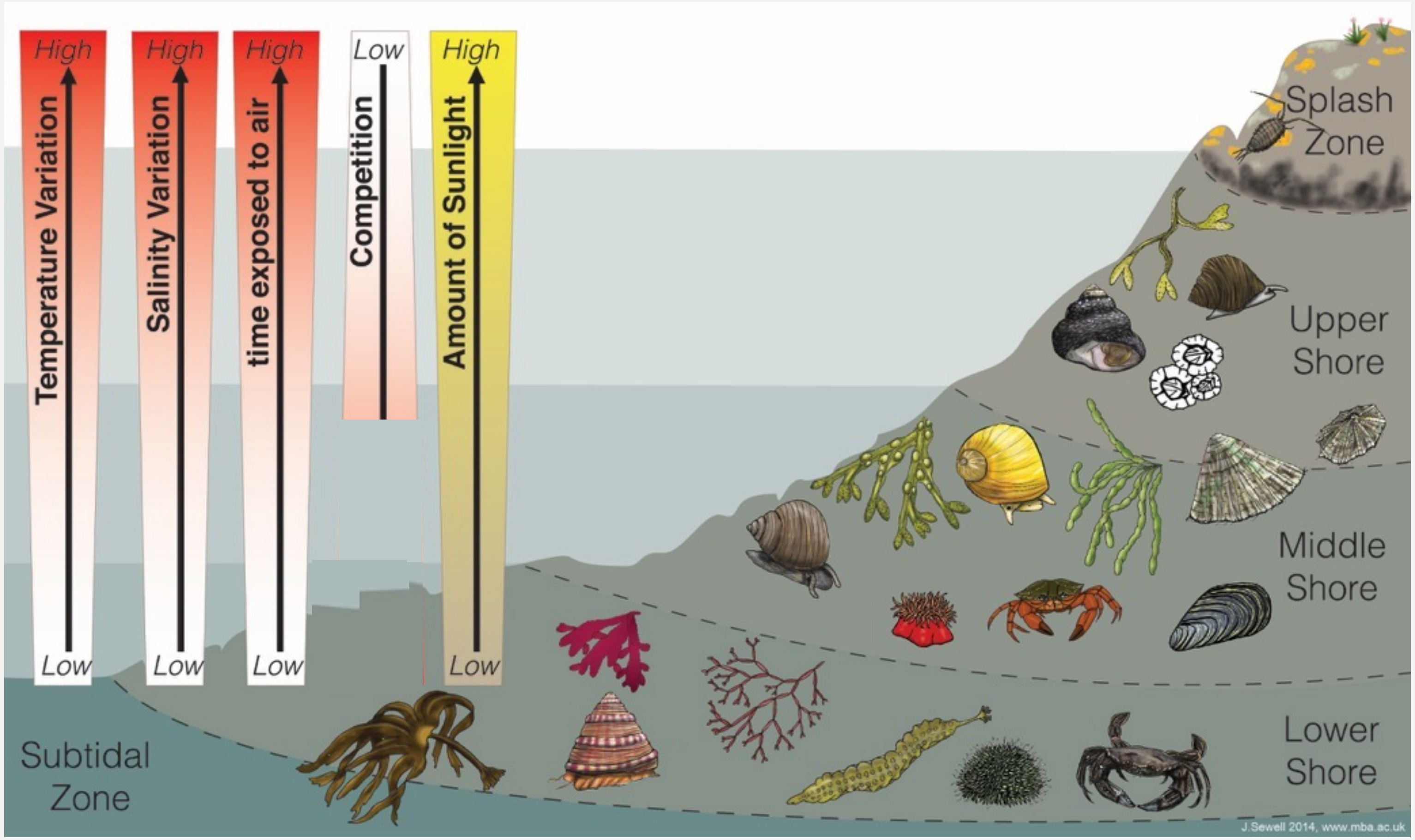


Available Light

Attenuation



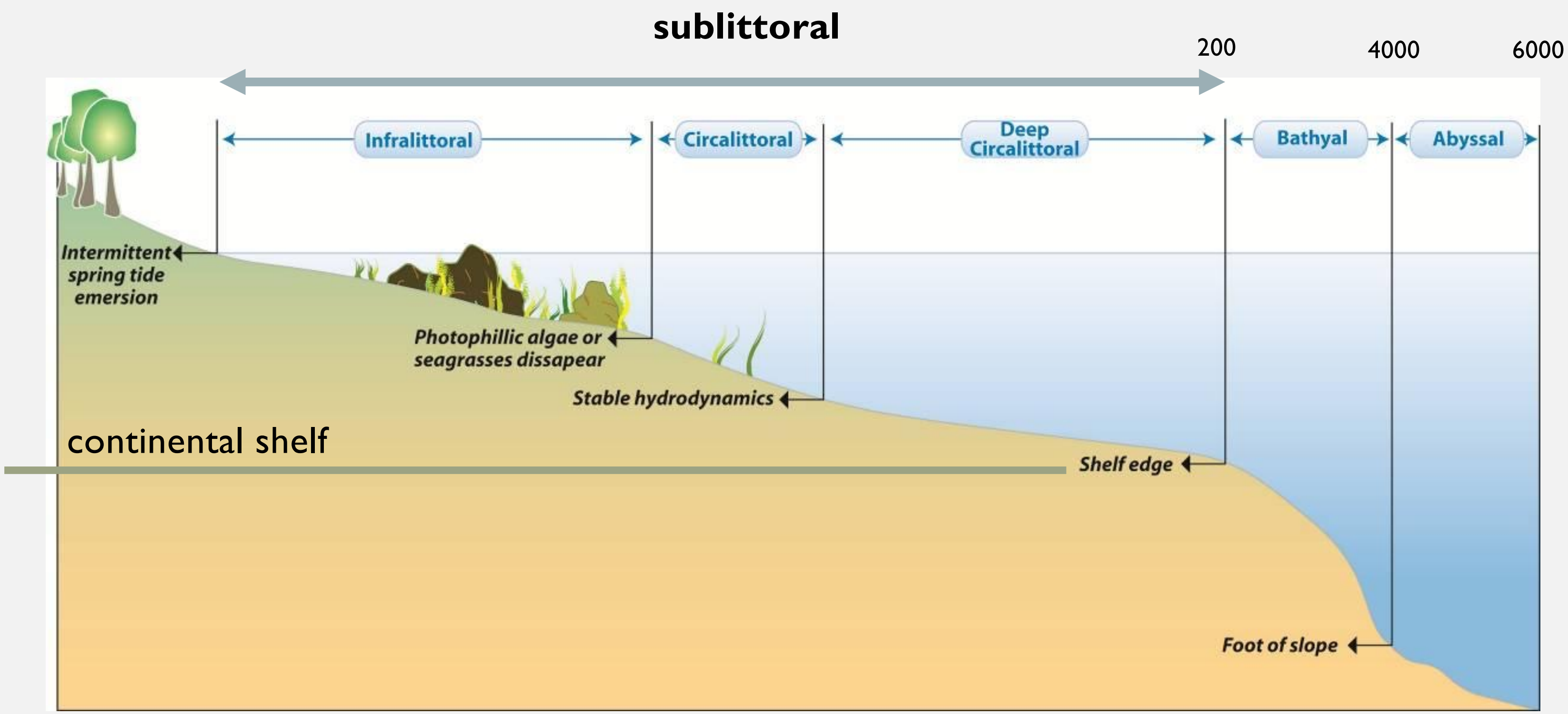


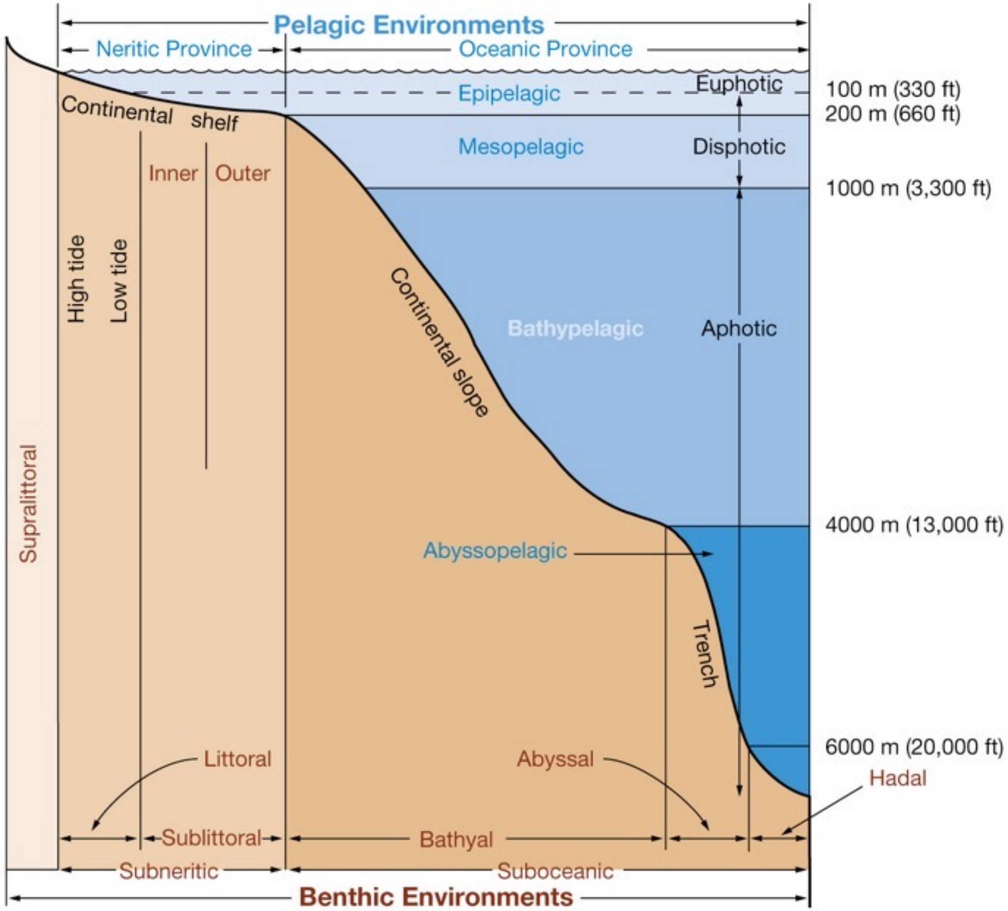


A schematic diagram of a rocky shore in the British Isles, showing the basic 'zones' and how environmental conditions change with height up the shore. © Marine Biological Association

infralittoral:
Continuous immersion except at low waters of spring tide

Circalittoral:
Compensation depth of the algae tolerating the lowest light intensities (150-200m)




Pelagic Environments
Neritic Province
Oceanic Province
Epipelagic
Euphotic
100 m (330 ft)
200 m (660 ft)
Continental shelf
Mesopelagic
Disphotic
Inner
Outer
1000 m (3,300 ft)
High tide
Low tide
Continental slope
Bathypelagic
Aphotic
Supralittoral
4000 m (13,000 ft)
Abyssopelagic
Trench
6000 m (20,000 ft)
Littoral
Abyssal
Hadal
Sublittoral
Bathyal
Subneritic
Suboceanic
Benthic Environments

DEPTH

Tide level or depth	Zone	Characteristics
	Supralittoral	Saline moistening Continuous emersion except at extreme high waters of spring tide
Mean high water of spring tide		
	Mesolittoral	Daily cycles of immersion and emersion
Mean low water of neap tide		
	Infralittoral	Continuous immersion except at low waters of spring tide
Compensation depth of seagrasses or photophilic algae 15-20m at high lat. 30-40 m Mediterranean 80 m intertropical regions		
	Circalittoral	
Compensation depth of the algae tolerating the lowest light intensities (150-200m)		
	Bathyal	Continental slope and its foothills
3500-4000m		
	Abyssal	Abyssal plains Hydrothermal vents
6000-6500m		
	Hadal	Deep trenches

1.1. ZONES OF THE BENTHIC DOMAIN

Substrate

- Hard substrate (immobile) vs. Soft subtrate (possible resuspension)
- Depends on
  - Hydrodynamism and particle size
  - Slope of the substrate

https://pxhere.com/en/photo/1347376

https://pixabay.com/photos/gravel-beach-stone-marine-texture-3873008/

Hard substrate

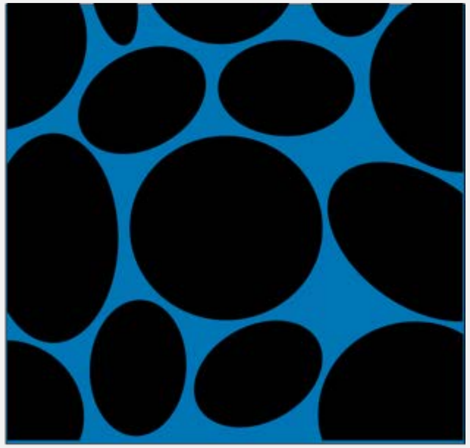
Substrate

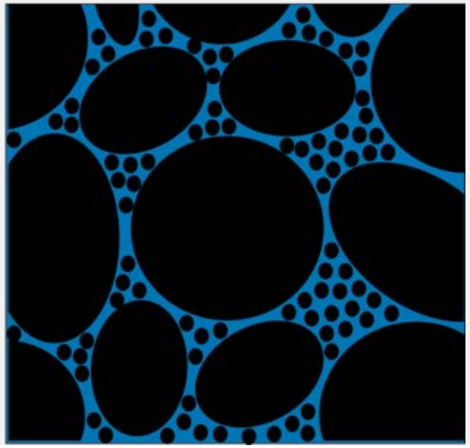
- Hard substrate (immobile) vs. Soft subtrate (possible resuspension)
- Depends on
  - Hydrodynamism and particle size
  - Slope of the substrate

Soft substrates

Substrate
Soft substrate

- Inorganic particles
- Organic particles
- Interstitial water
- Physical characteristics
  1. Size = function of hydrodynamism
     - Coarse sediments: few organic particles
     - Very fine sediments: instable for macrofauna
  2. Homogeneity
     - Well sorted: homogenous grain size
     - Poorly sorted: heterogenous grain size
  3. Porosity: $V_{interstitial} / V_{total}$
     - Depends on grain size and homogeneity of the sediment
     - Oxygen level
     - Important for meiofauna





Substrate

Classification according to grain size

Particle sizes

φ scale	Size range (metric)	Aggregate class (Wentworth)	Other names
< -8	> 256 mm	Boulder	
-6 to -8	64–256 mm	Cobble	
-5 to -6	32–64 mm	Very coarse gravel	Pebble
-4 to -5	16–32 mm	Coarse gravel	Pebble
-3 to -4	8–16 mm	Medium gravel	Pebble
-2 to -3	4–8 mm	Fine gravel	Pebble
-1 to -2	2–4 mm	Very fine gravel	Granule
0 to -1	1–2 mm	Very coarse sand	
1 to 0	0.5–1 mm	Coarse sand	
2 to 1	0.25–0.5 mm	Medium sand	
3 to 2	125–250 μm	Fine sand	
4 to 3	62.5–125 μm	Very fine sand	
8 to 4	3.9–62.5 μm	Silt	Mud
> 8	< 3.9 μm	Clay	Mud
>10	< 1 μm	Colloid	Mud

2. Primary Producers

3. Consumers

2 PRIMARY PRODUCERS

2.1. Main Taxa

- Bacteria
- Eukaryota
- Protozoa
- Plantae

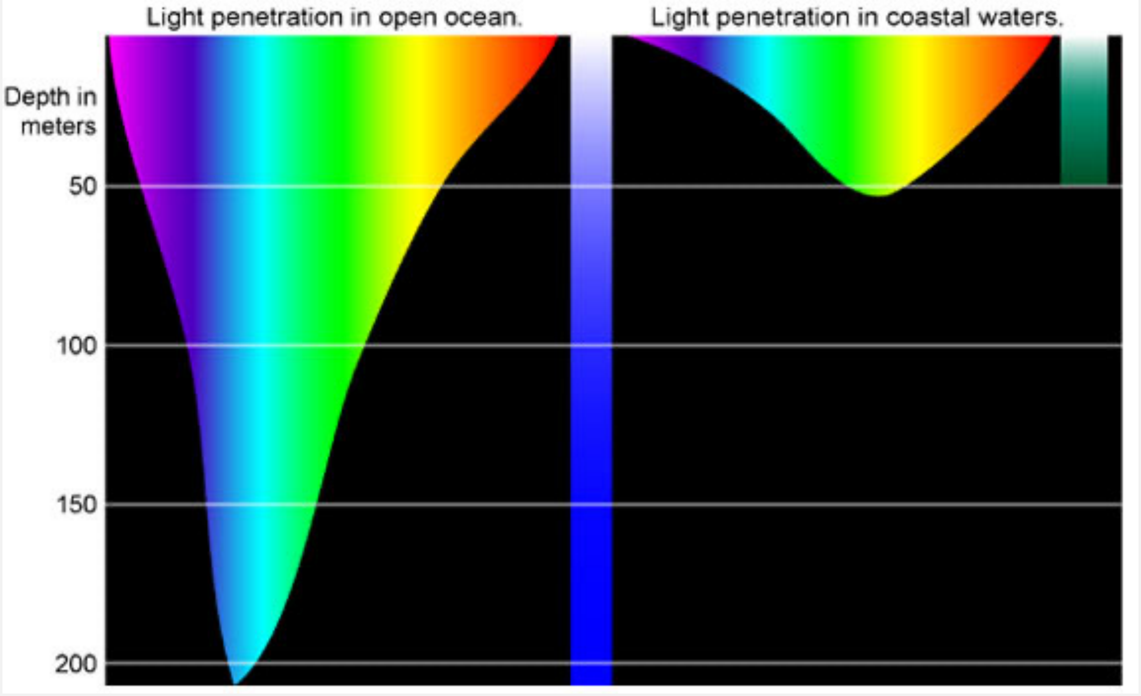
2.1.2. Factors controlling benthic Primary producers

BACTERIA

Photosynthetic

Chemoautotrophic

2.1 PHOTOSYNTHETIC PRIMARY PRODUCERS



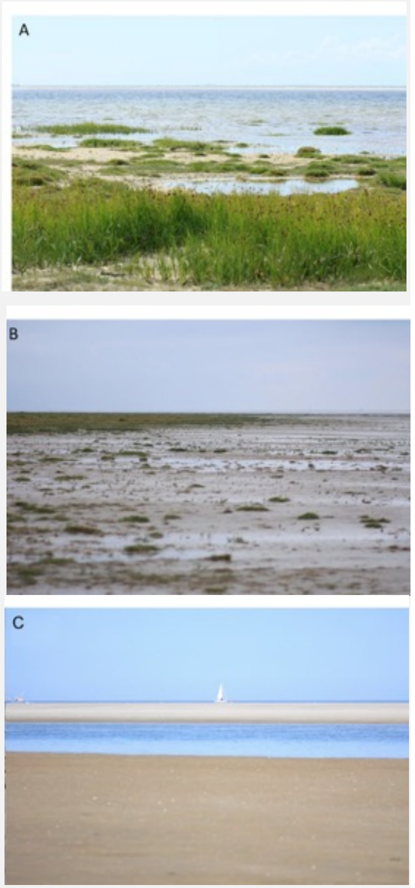
Light penetration in open ocean and coastal water, showing the different depths to which each colour will penetrate (By NOAA – National Oceanic and Atmospheric Administration [Public domain], via Wikimedia Commons).

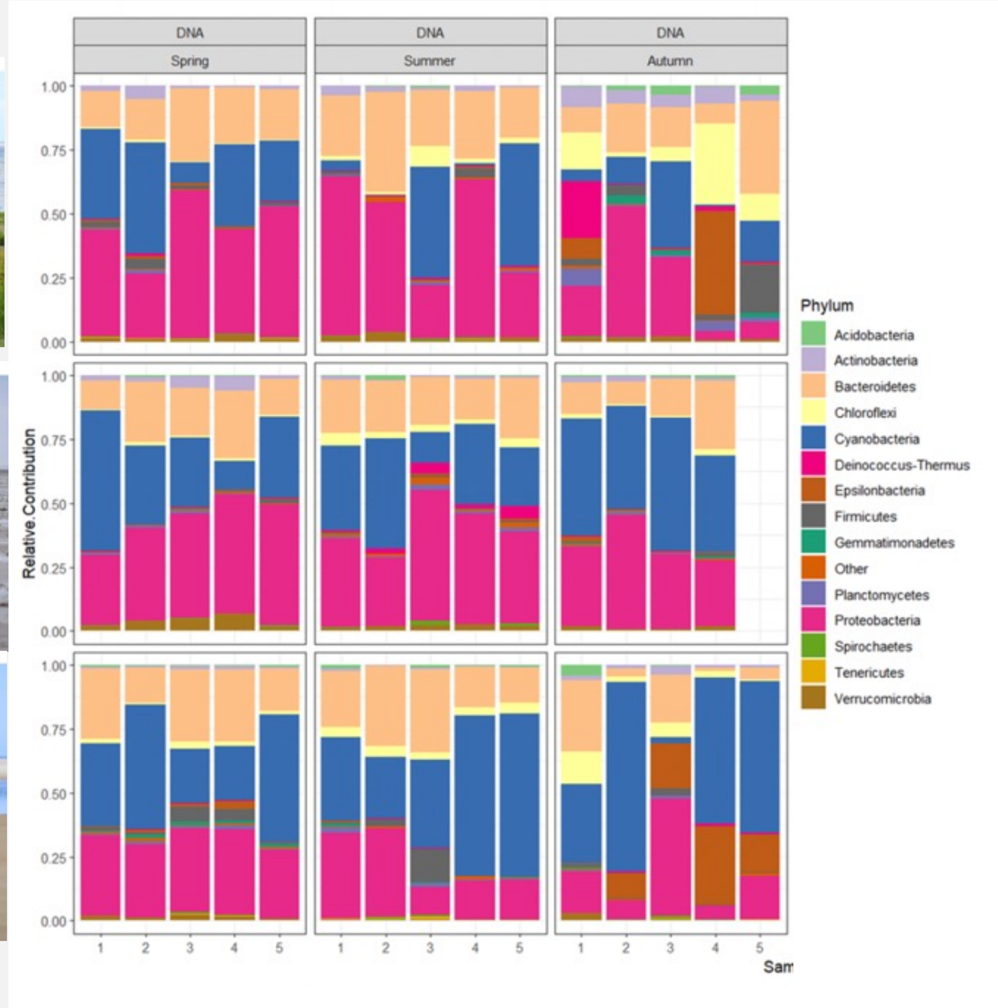
PHOTOSYNTHETIC PRIMARY PRODUCERS

Domain	Kingdom	Phylum	
Bacteria			Cyanobacteria • Chla, phycocyanin, phycoerythrin • Able to fix N2 • Mats on tidal mudflats (anoxic interstitial water)

CYANOBACTERIA

- Chla, phycocyanin, phycoerythrin
- Able to fix N2
- Mats on tidal mudflats (anoxic interstitial water)





Seasonal development of a coastal microbial mat. Cardoso et al. 2019

Schiermonnikoog. (**A**) Dune station, (**B**) Intermediate station, (**C**) Tidal station

CHEMOAUTOTROPHIC PRIMARY PRODUCERS

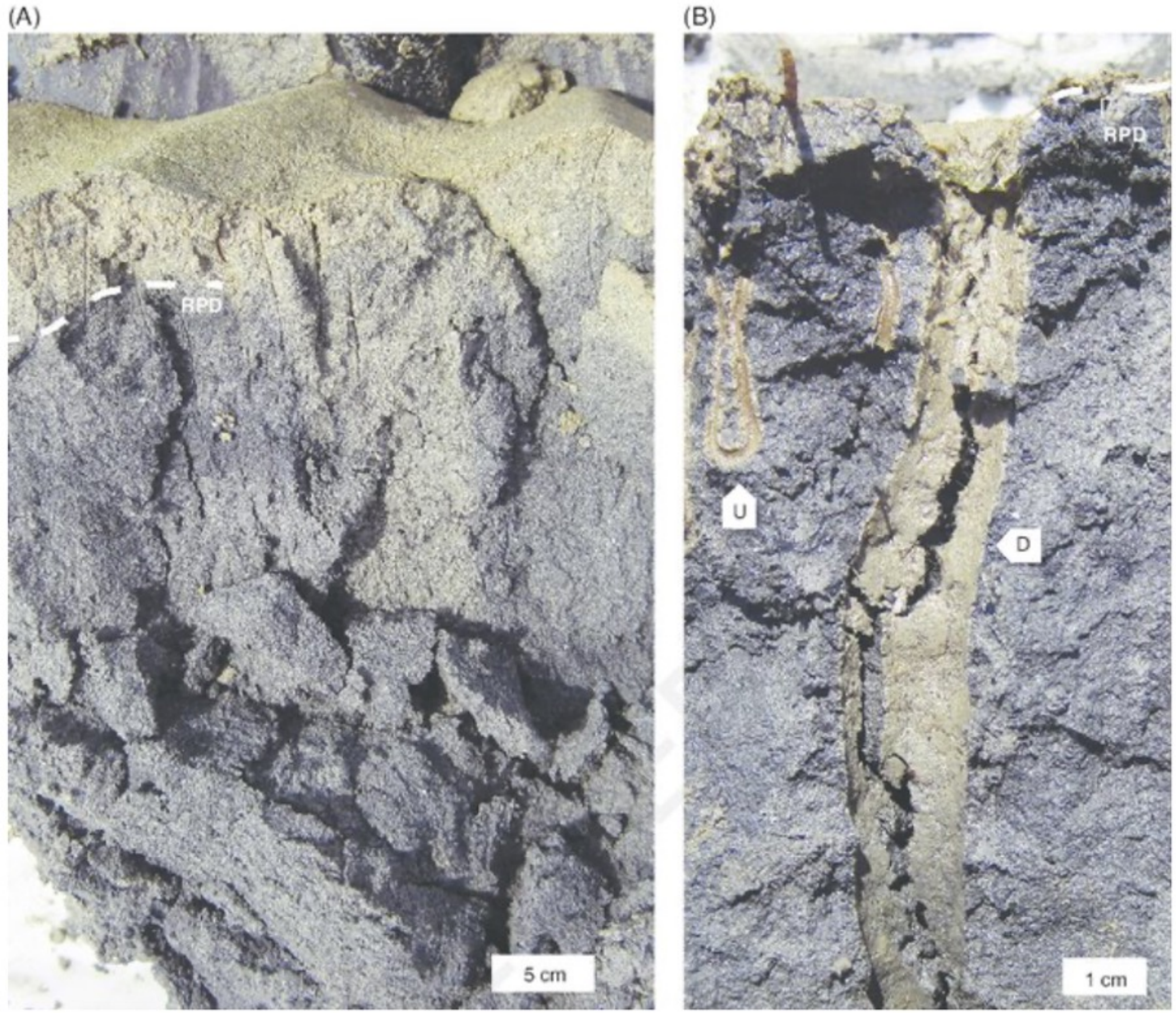
Table 1-1. Major Electron Donors, Acceptors, and End Products for the Three Major Types of Primary Production[a]

	Electron donor (reductants)	Electron acceptor (oxidants)	Oxidized end products
Photosynthesis			
Oxygenic	H_2O	CO_2[b]	O_2
Anoxygenic	H_2S, H_2	CO_2[b]	S^0, SO_4^{2-}
Chemosynthesis			
Nitrifying bacteria	NO_2^-, NH_4^+, NH_2OH	O_2, NO_3^-	NO_3^-, NO_2^-
Sulfur bacteria[c]	H_2S, S^0, $S_2O_3^-$	O_2	S^0, SO_4^{2-}
Hydrogen bacteria[c]	H_2	O, SO_4	H_2O
Methane bacteria	CH_4	O_2	CO_2
Iron bacteria[c]	Fe^{2+}	O_2	Fe^{3+}
Carbon monoxide bacteria[c]	CO	H_2	CH_4

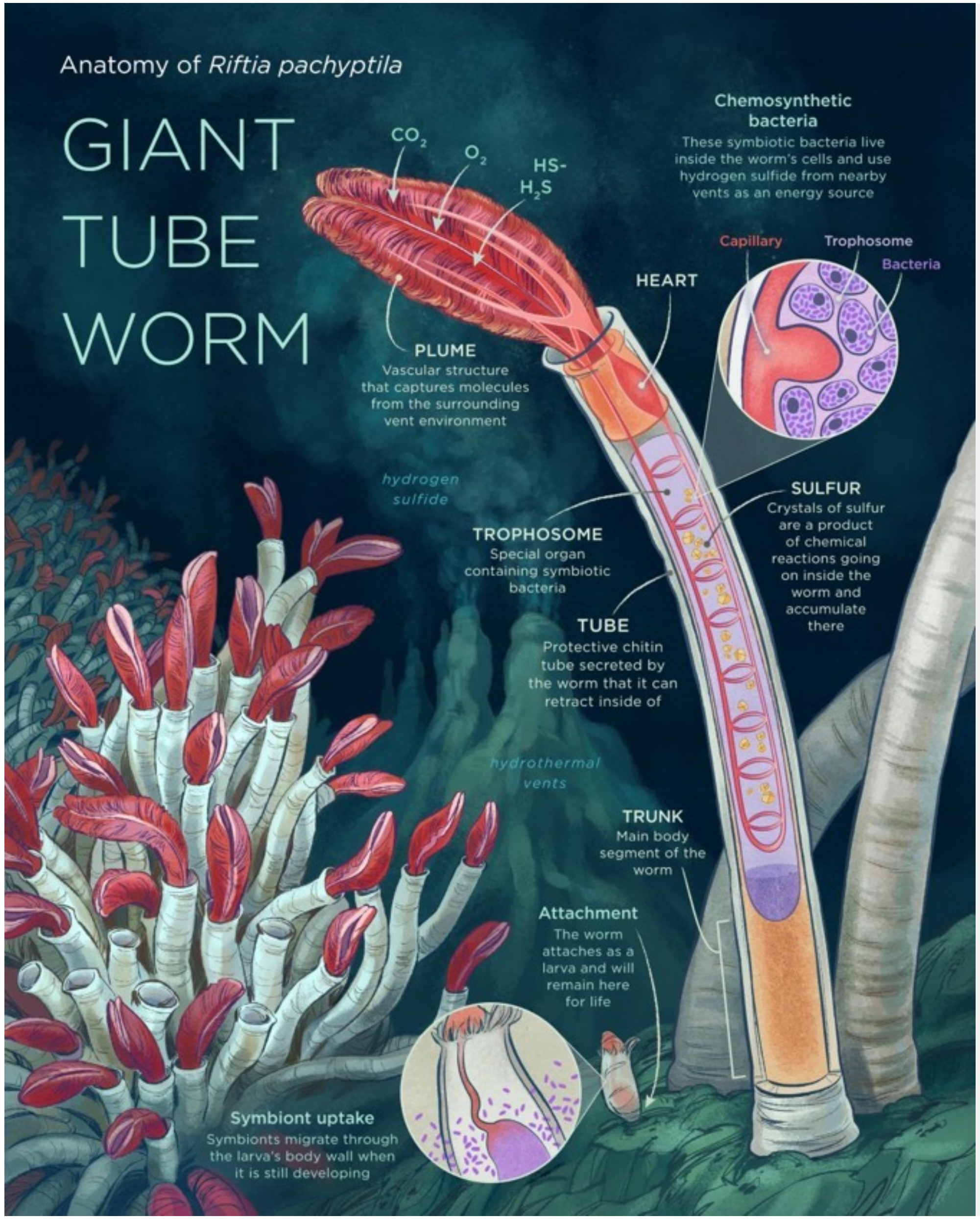
[a] From Fenchel and Blackburn (1979) and Parsons et al. (1977). There are many other possible chemosynthetic reactions and end products (see Tables 10-7, 10-8).
[b] Takes place if light furnishes the large amounts of energy needed to reduce the CO_2.
[c] These groups may also live heterotrophically, using a variety of organic compounds manufactured by other organisms as sources of energy (or electron donors), and with CO_2, H_2O, or more oxidized organic compounds as the end products.

- Interfaces oxic and anoxic zones
  - Sediments (RPD)
  - Decomposing organisms (whale carcasses)
  - Hydrothermal vents

Redox potential discontinuity (RPD). Redox potential discontinuity (RPD, dashed line) note a small U-shaped burrow (U: Arenicolites) and a decapod burrow (D. Parmaichnus or Thalassinoides).



- **STAGE 1:** MOBILE-SCAVENGER STAGE, MONTHS-5 YEARS
- **STAGE 2:** ENRICHMENT-OPPORTUNIST STAGE, MONTHS - 2 YEARS
- **STAGE 3:** SULPHOPHILIC STAGE, UP TO 50 YEARS

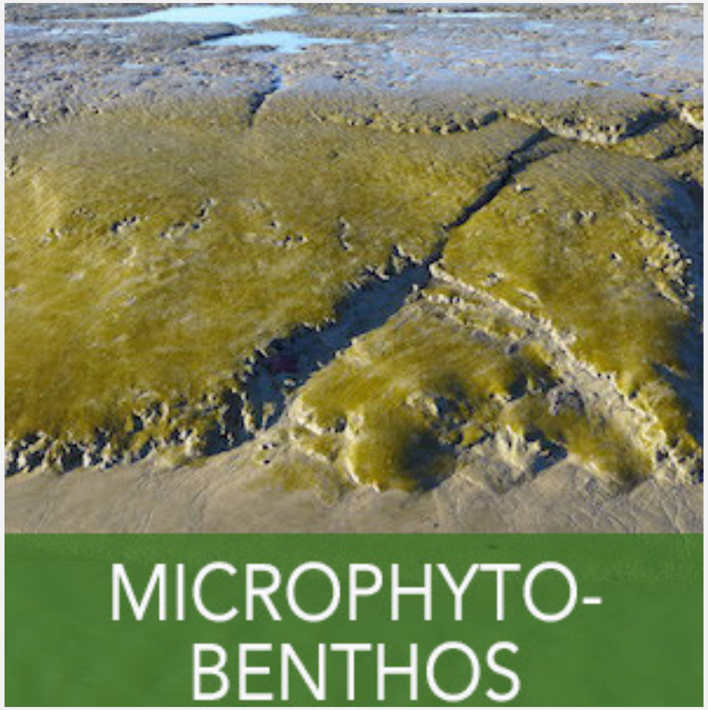


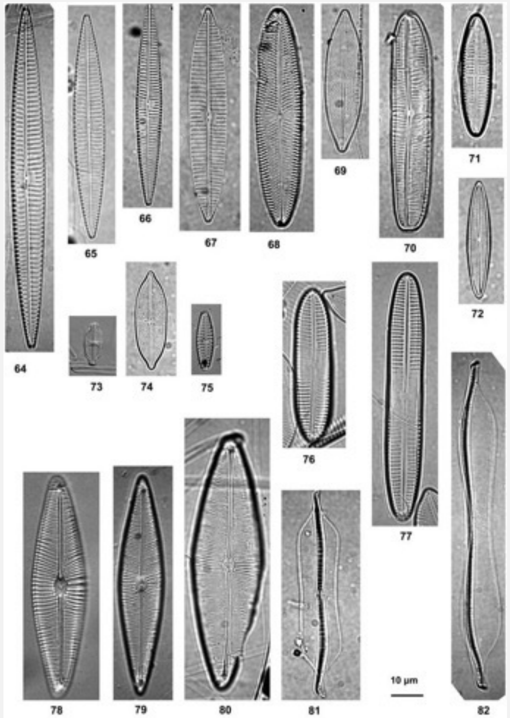
- Attachment
  - Worm attaches as larvae
- Symbiotic bacteria uptake during larval stage
  - Symbionts migrate through developing body
- Trunk
  - Main body segment
- Tube
  - Protective chitin tube
- Trophosome
  - Special organ containing symbionts
- Heart
- Plume
  - Captures molecules from surroundings

PHOTOSYNTHETIC PRIMARY PRODUCERS

Domain	Kingdom	Phylum	
Bacteria			Cyanobacteria • Chla, phycocyanin, phycoerythrin • Able to fix N2 • Mats on tidal mudflats (anoxic interstitial water)
Eukaryota	Chromista Chla, c abs green, yellow	Heterokontophyta	Microphytobenthos : principally pennate diatoms • Frequently mixotroph • Mats on tidal mudflats
			Phaeophyceae (brown algae) • Fucoxanthin, xantophyll, carotene • rocky shores
		Dinophyta	Zooxanthellae (Symbiodinium sp) Symbiont of cnidarians (incl reef-building corals)
	Plantae Chl a, b abs red, blue	Chlorophyta	Chlorophyceae (green algae) • Poor ability to store nutrients → eutrophic habitats
		Rhodophyta	Red algae Chl d, phycoerythrin (abs green), phycocyanin (abs blue)
		Spermatophyta	Flowering plants (soft bottom) • Seagrasses (Zostera, Posidonia, Thalassia…) • Saltmarsh plants (Spartina, Salicornia, …) • Mangroves

MICROPHYTOBENTHOS



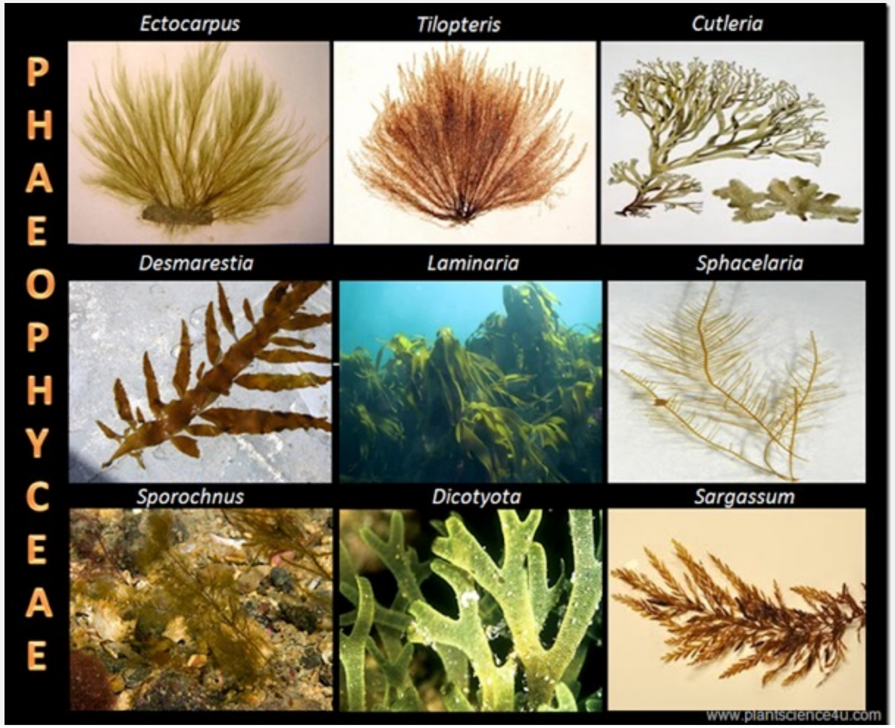


Microphytobenthos : principally pennate diatoms

- Frequently mixotroph
- Mats on tidal mudflats

PHAEOPHYCEAE (BROWN ALGAE)

- Fucoxanthin, xantophyll, carotene
- rocky shores
- dominant algae of intertidal zones and rocky infralittoral



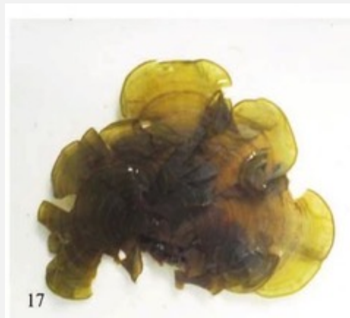
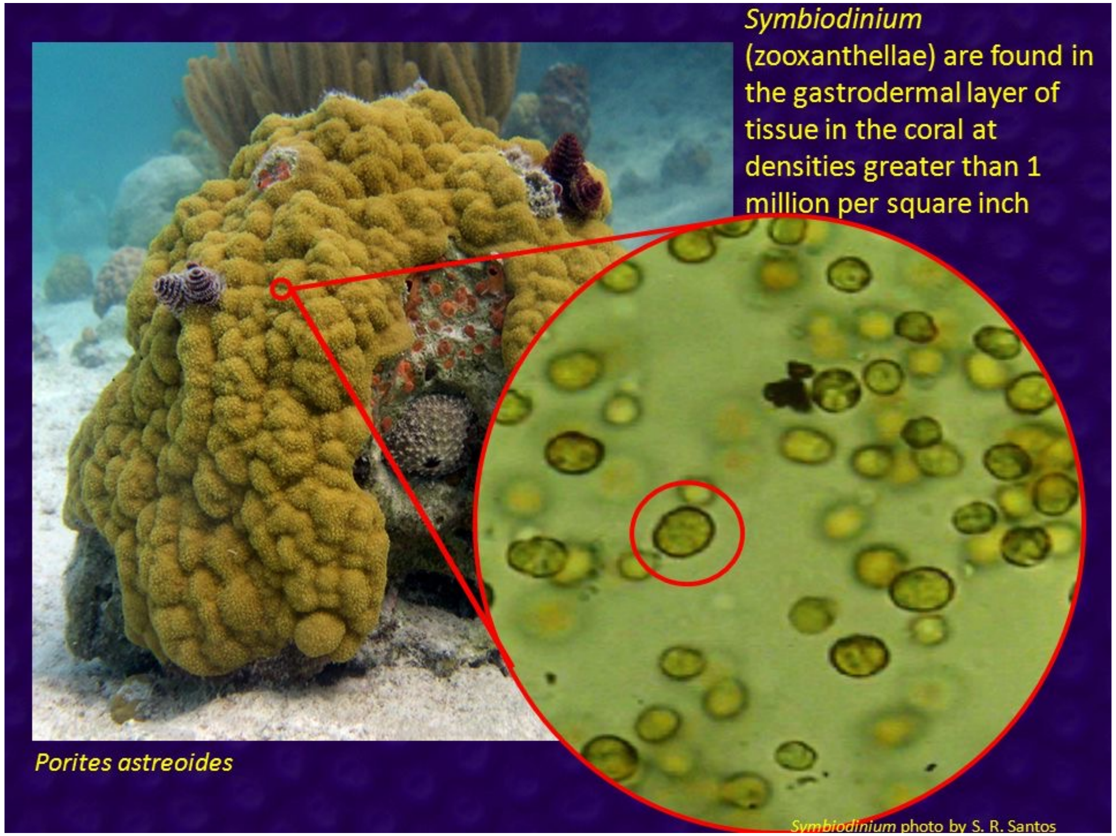


Fig. 15: *Turbinaria* sp.
Fig. 17: *Padina pavonica*.

Bhagyaraj & Vijaya 2016

ZOOXANTHELLAE (SYMBIODINIUM SP)

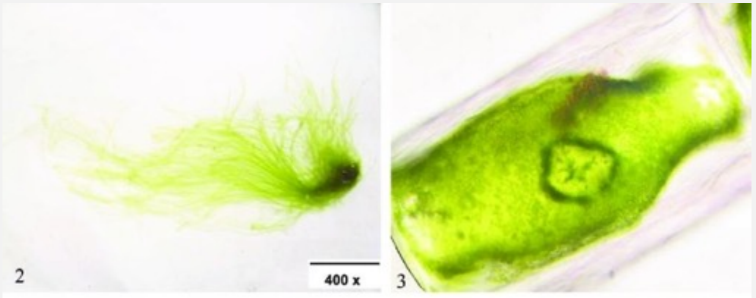


CHLOROPHYCEAE (GREEN ALGAE)

Chlorophyceae (green algae)

- Poor ability to store nutrients → eutrophic habitats

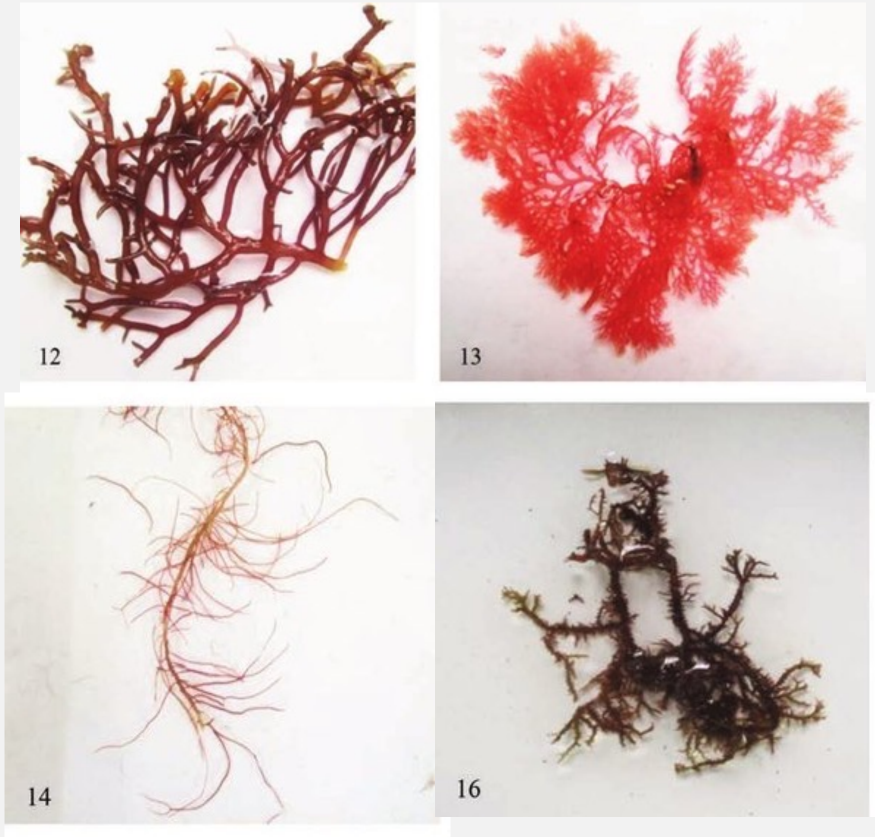
Fig. 2: *Ulva prolifera*.
Fig. 3: microphotograph of *Ulva prolifera* showing cellular contents.
Fig. 6: *Chaetomorpha linum*.
Fig. 7: *Ulva lactuca*.
Fig. 8: *Enteromorpha intestinalis*.
Fig. 9: *Caulerpa racemosa* and trumpet shaped ramuli of *C. racemosa*.
Fig. 10: *Halimeda tuna*.
Fig. 11: *Halimeda gracilis*. Bhagyaraj & Vijaya 2016



RHODOPHYTA (RED ALGAE)

- Fig. 12: *Kappaphycus alvarezii.*
  Fig. 13: *Portieria hornemannii.*
  Fig. 14: *Gracilaria verrucosa.*
  Fig. 16: *Hypnea musciformis.*

  Bhagyaraj & Vijaya 2016



Chl d, phycoerythrin (abs green), phycocyanin (abs blue)

FLOWERING PLANTS

Eelgrass *Zostera sp.*
© Project Seagrass

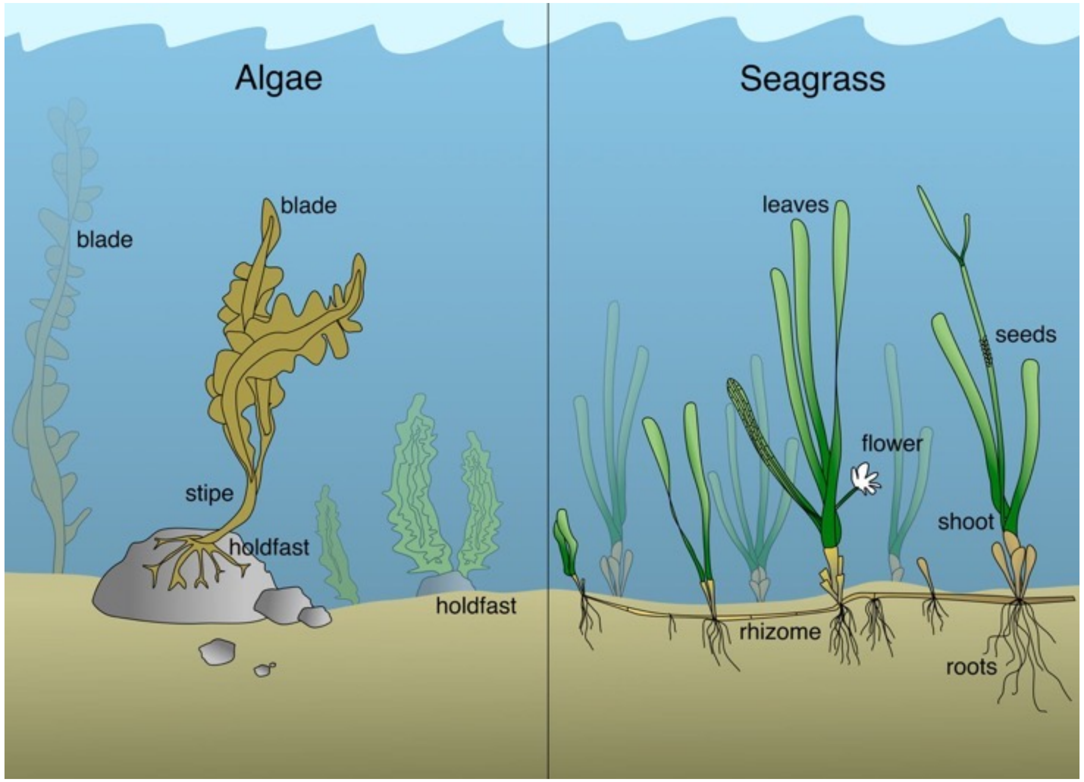
Common Cord-grass
Spartina anglica
© Bruno Nef, Waarnemingen.be

Mangrove © VUB

Flowering plants (soft bottom)

- Seagrasses (Zostera, Posidonia, Thalassia…)
- Saltmarsh plants (Spartina, Salicornia, …)
- Mangroves

ROCKY VS SOFT SUBSTRATE



2 PRIMARY PRODUCERS

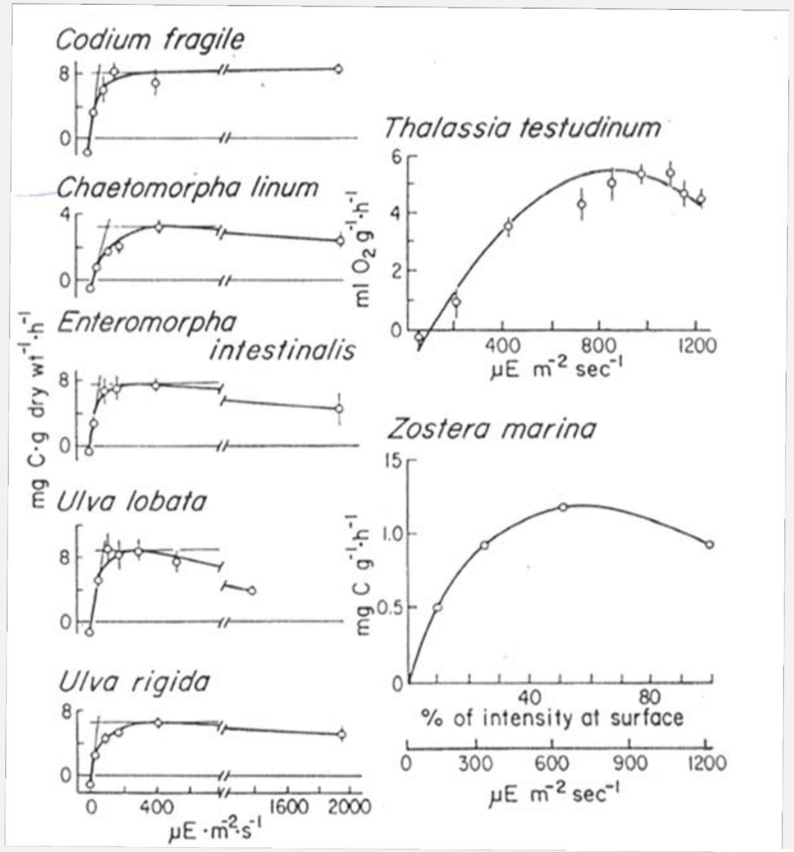
2.1. Main Taxa

2.1.2. Factors controlling benthic Primary producers

- light
  - bottom-up
  - Intensity
  - Wavelength
- Nutrients
- Substrate
- Emersion & Exposure
- Biotic interactions

LIGHT (BOTTOM-UP CONTROL)

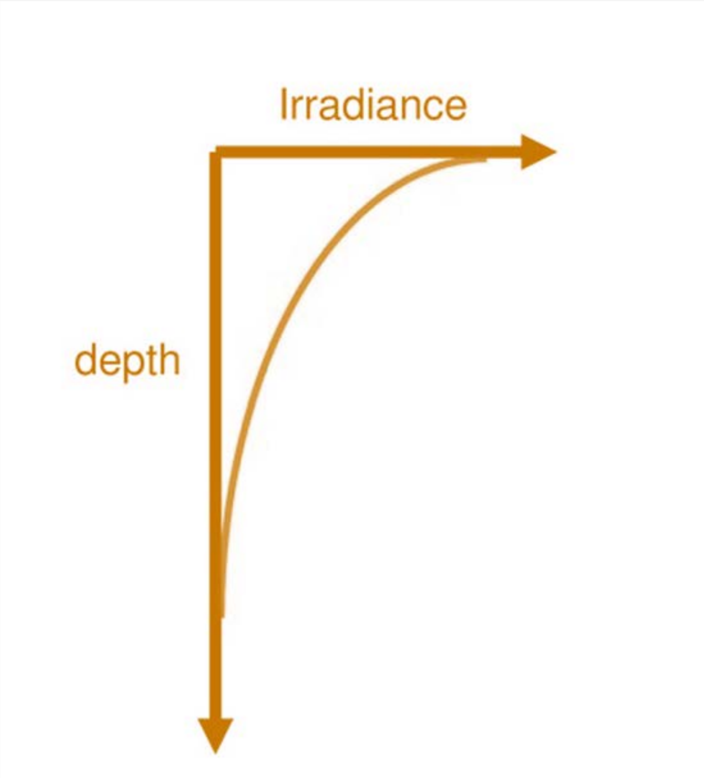
Wikipedia.org

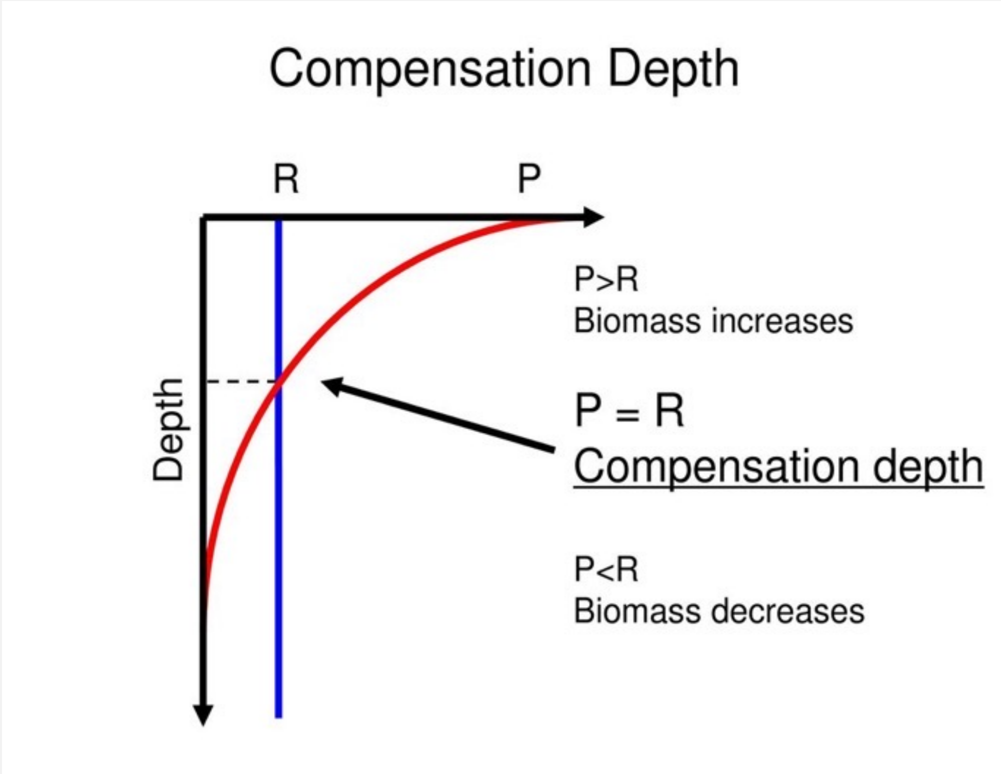


Inpn.mnhn.fr

Figure 2-6. Net photosynthesis versus light intensities for five green macroalgae and two seagrasses. The $\Delta P/\Delta I$ and P_{max} are shown in the macroalgal graphs as straight lines. Points are mean and standard deviations, shown as vertical lines. Adapted from Arnold and Murray (1980), Buesa (1975), and McRoy (1974).

LIGHT INTENSITY

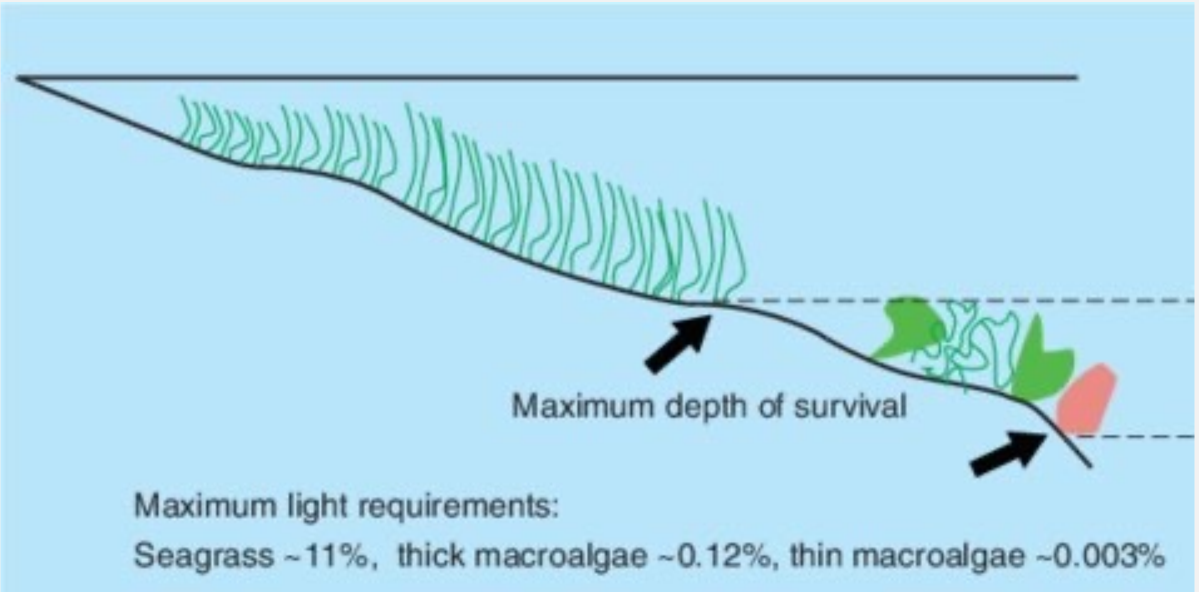


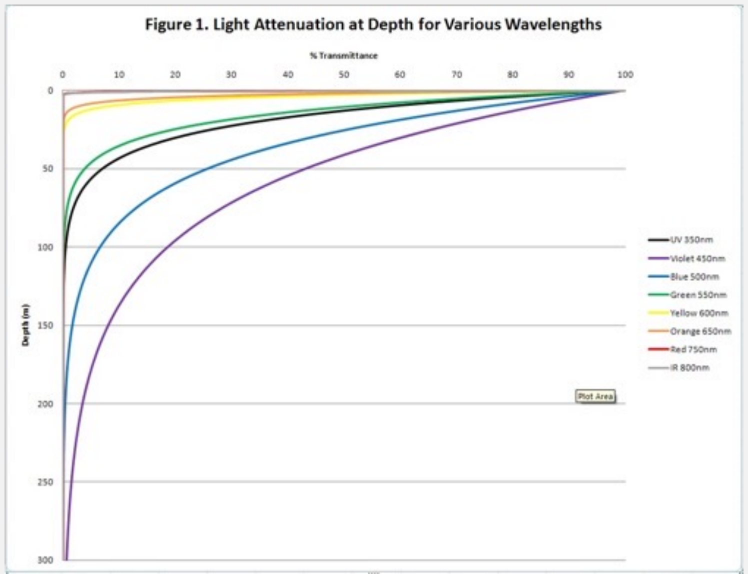


https://player.slideplayer.com/79/13031396

Light: wave length

- Different taxa have different compensation depths
- Flowering plants, green algae: absorb red
- Red algae: absorb blue (+ adapted pigments)





http://oceanographyclay1987.blogspot.com/2010/10/light-attenuation-in-ocean.html

LIGHT WAVELENGTH

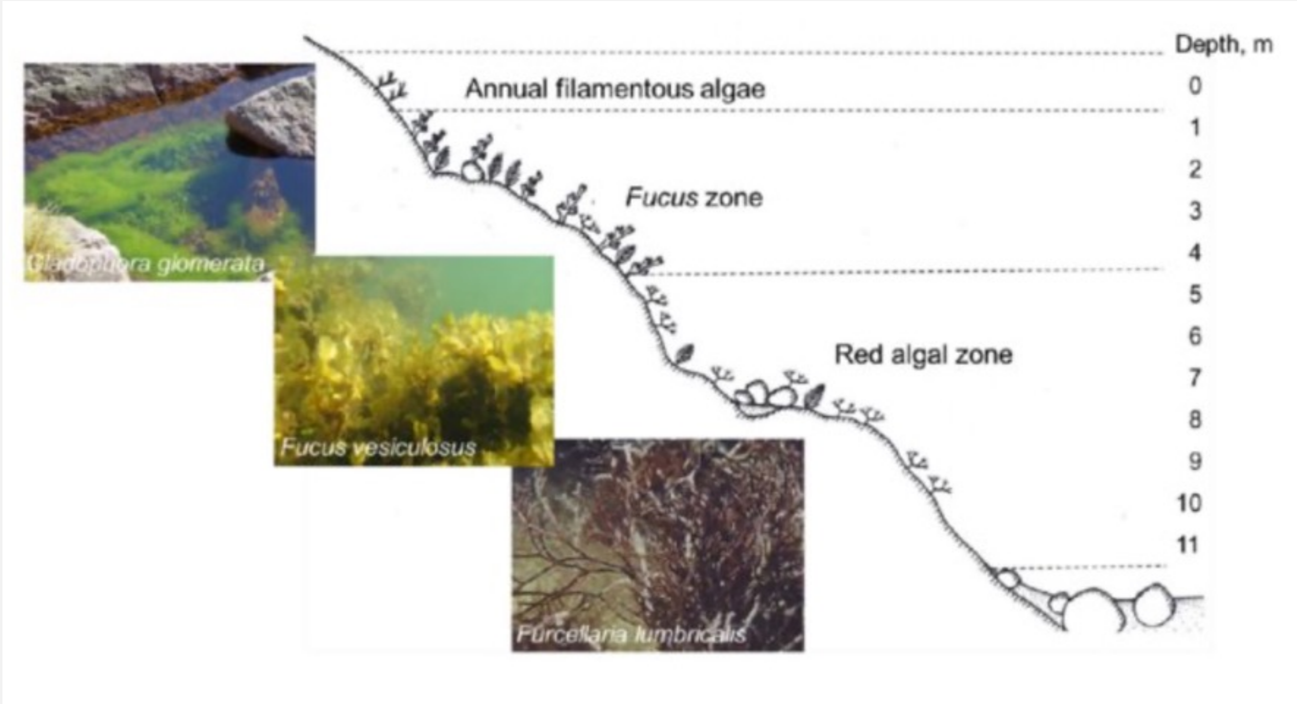
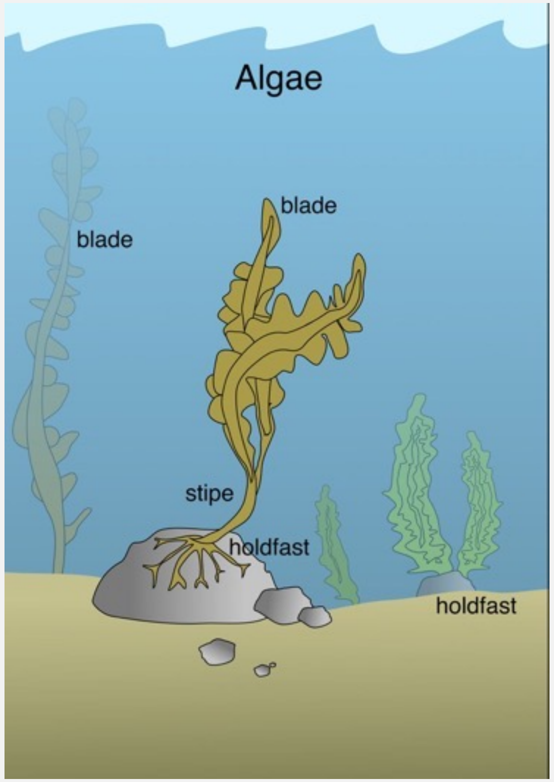


Figure 3. General zonation of macroalgal groups in northern Baltic rocky shores with species examples. Photos by Elina Leskinen.

ROCKY VS
SOFT
SUBSTRATE



NUTRIENTS (BOTTOM-UP CONTROL)

http://www.corpi.ku.lt/nemo/codium.html

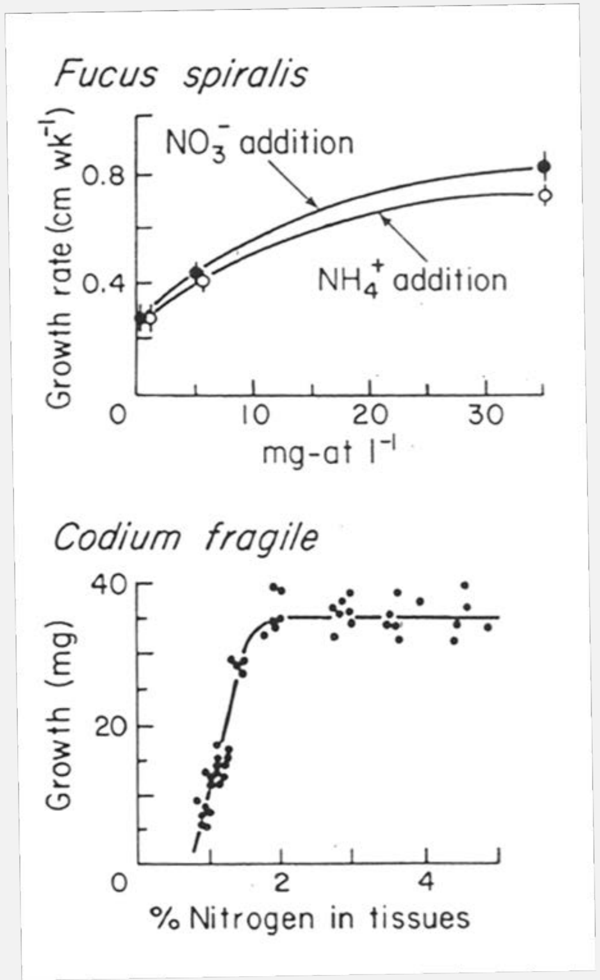


Figure 2-27. Top: Growth rate (elongation of fronds) of the brown alga *Fucus spiralis* in ambient concentrations (1.2 μg atom NO_3^- liter^{-1} and 1.7 μg atom NH_4^+ liter^{-1} and in cultures where additional NH_4^+ and NO_3^- were furnished. Adapted from Topinka and Robbins (1976). Bottom: Growth in weight of the green alga *Codium fragile* in relation to the percentage nitrogen in the tissues. Adapted from Hanisak (1979).

- Algae: no roots → nutrients > SW
- N possibly limiting

NUTRIENTS

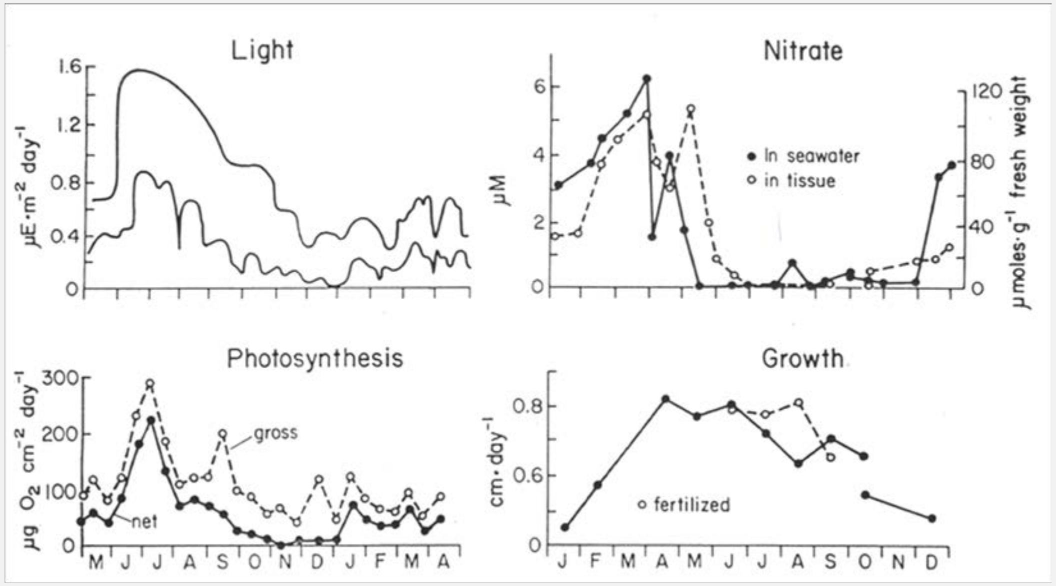
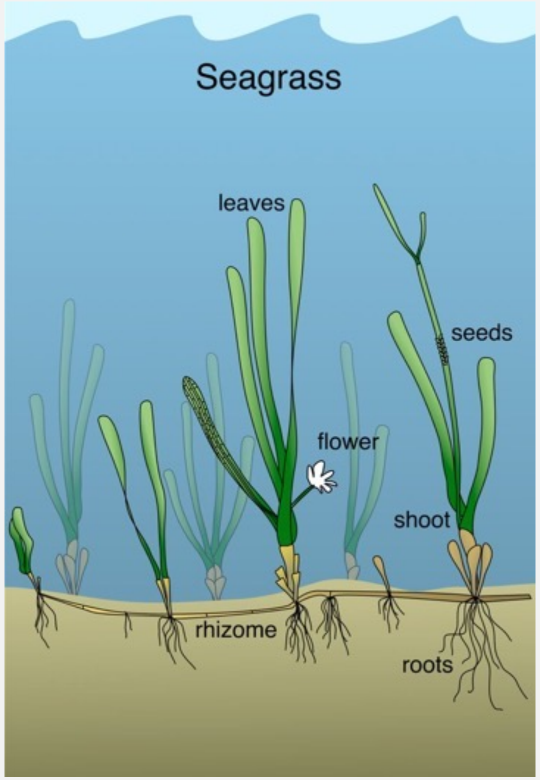


Figure 14-16. Seasonal cycle in growth and photosynthesis in the kelp *Laminaria longicruris* on the Nova Scotia coast. Left: Maximum and minimum light intensities (top) and rate of photosynthesis (bottom) during the year. Adapted from Hatcher et al. (1977). Right: Nitrate content in seawater and in tissues of kelp (top) and growth, as cm day^{-1} of blade elongation (bottom) in a kelp forest growing in water 18 m deep. Fertilization experiments done at site 9 m in depth; the growth rate of unfertilized kelp of 9 m was similar to that at 18 m. Adapted from Chapman and Craigie (1977).

joshfecteau.com

- Algae: no roots → nutrients > SW
- N possibly limiting if strong intra- or interspecific competition

ROCKY VS SOFT SUBSTRATE



NUTRIENTS

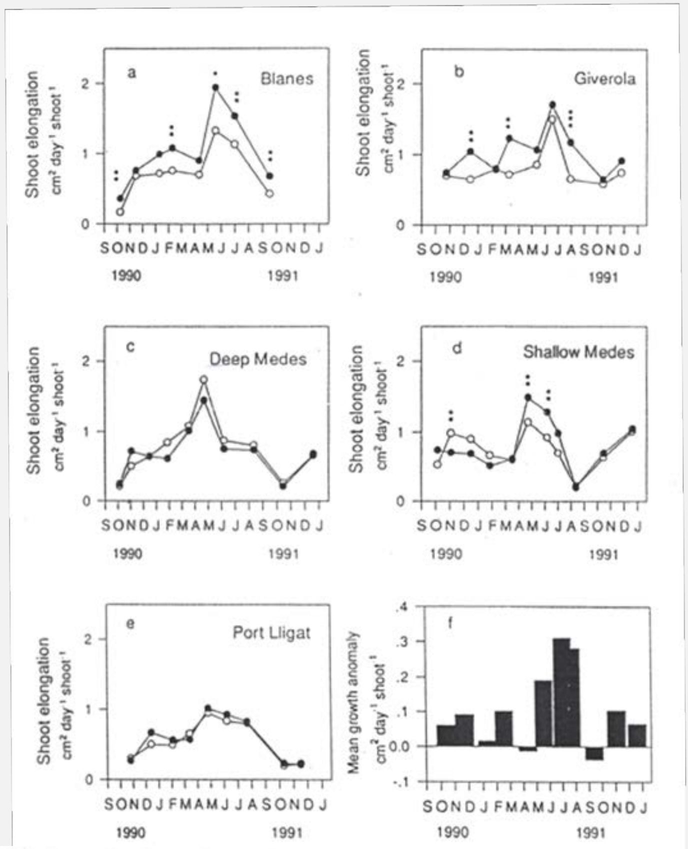
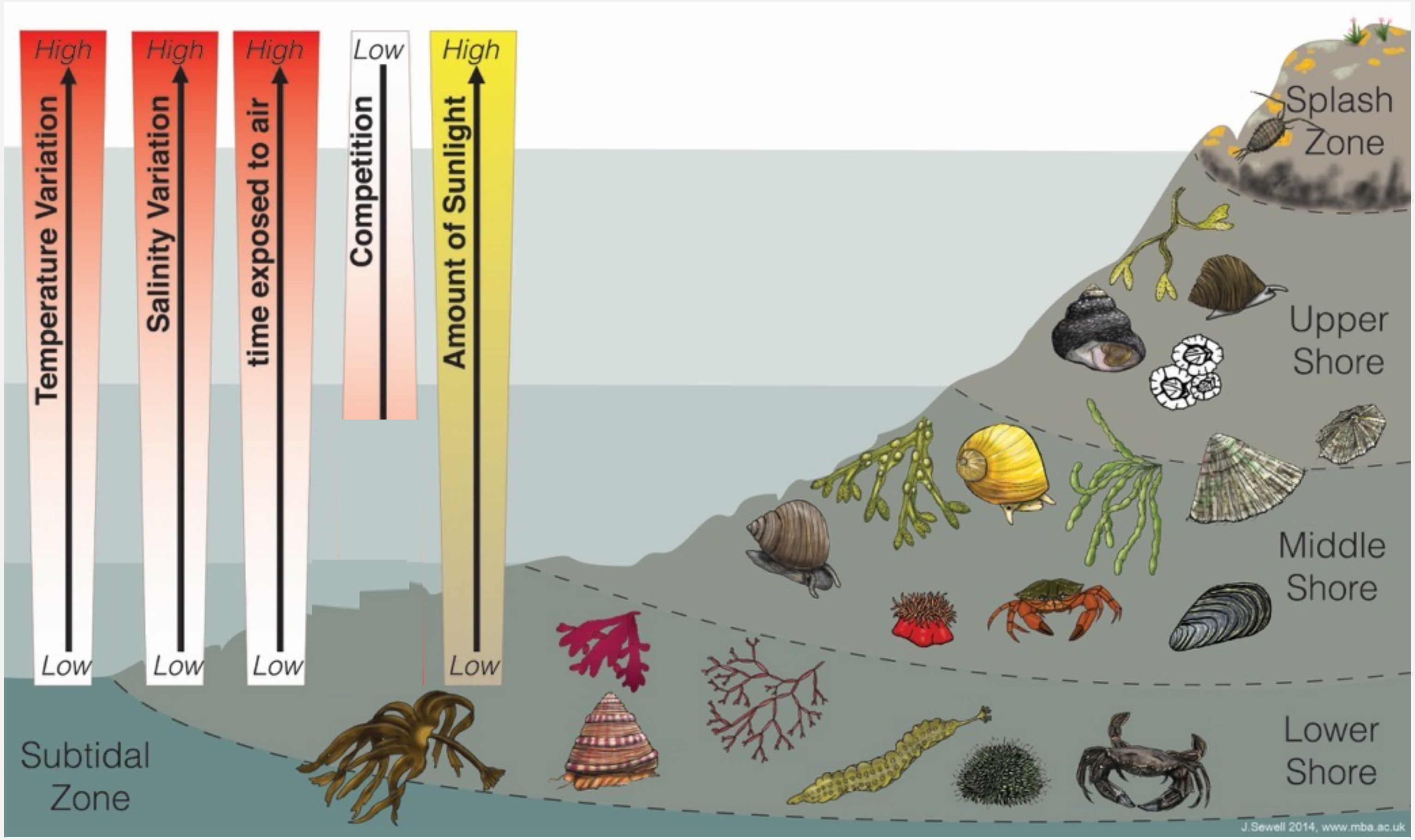


Fig. 1. *Posidonia oceanica*. (a to e) Seasonal changes in shoot elongation in control (o) and fertilized (•) plots at the 5 sites studied. (f) Mean growth anomaly relative to control (average growth in fertilized plots minus average growth in control plots). Asterisks indicate values significantly different from zero (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)

Alcoverro et al 1995

- Angiospermes: roots → nutrients > sediment interstitial SW

Posidonia oceanica



A schematic diagram of a rocky shore in the British Isles, showing the basic 'zones' and how environmental conditions change with height up the shore. © Marine Biological Association

EMERSION & EXPOSURE

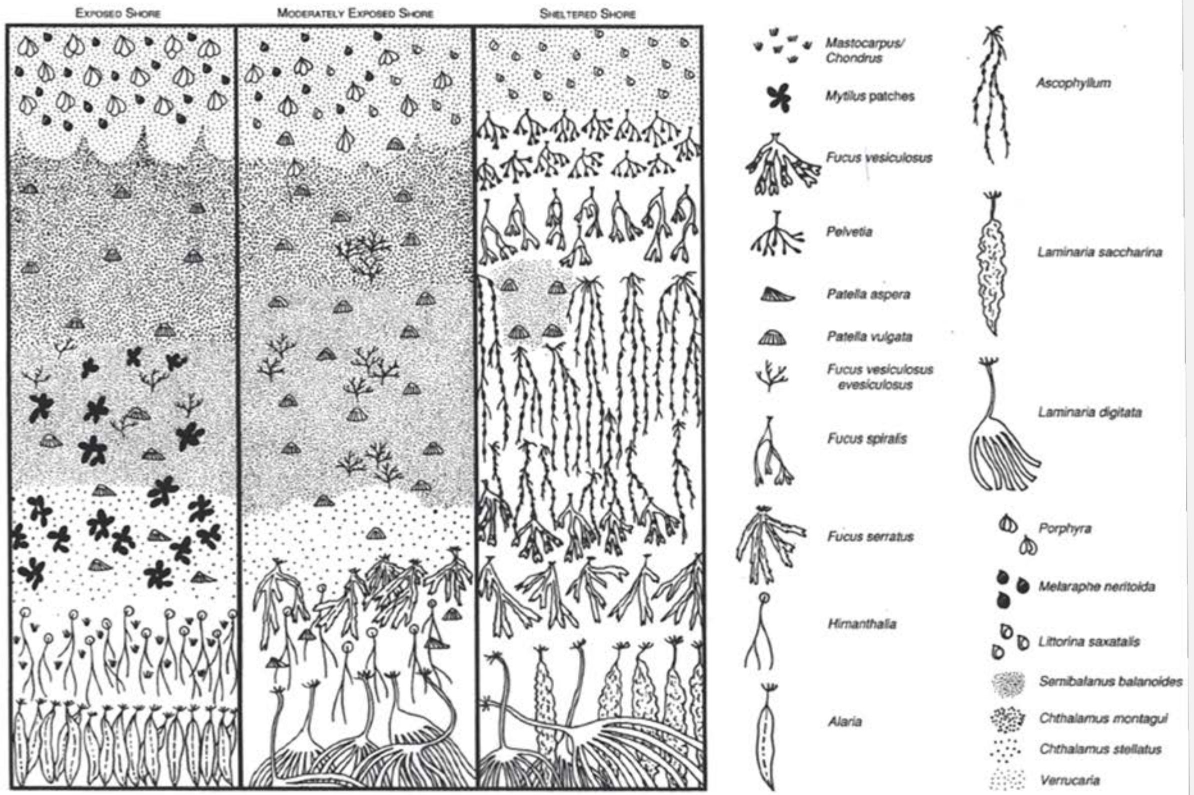


Fig. 5. Generalised diagram of a sheltered shore, a moderately exposed shore and an exposed shore on the west coast, showing the main zones of important shore organisms. (*After Ballantine, 1961*). Compare with Plate 1.

Intertidal zonation of algae

BIOTIC
INTERACTIONS

tide pools on rocky shores of New England

giant kelp forest

TIDE POOLS ON ROCKY SHORES OF NEW ENGLAND

razottoli.wordpress.com/

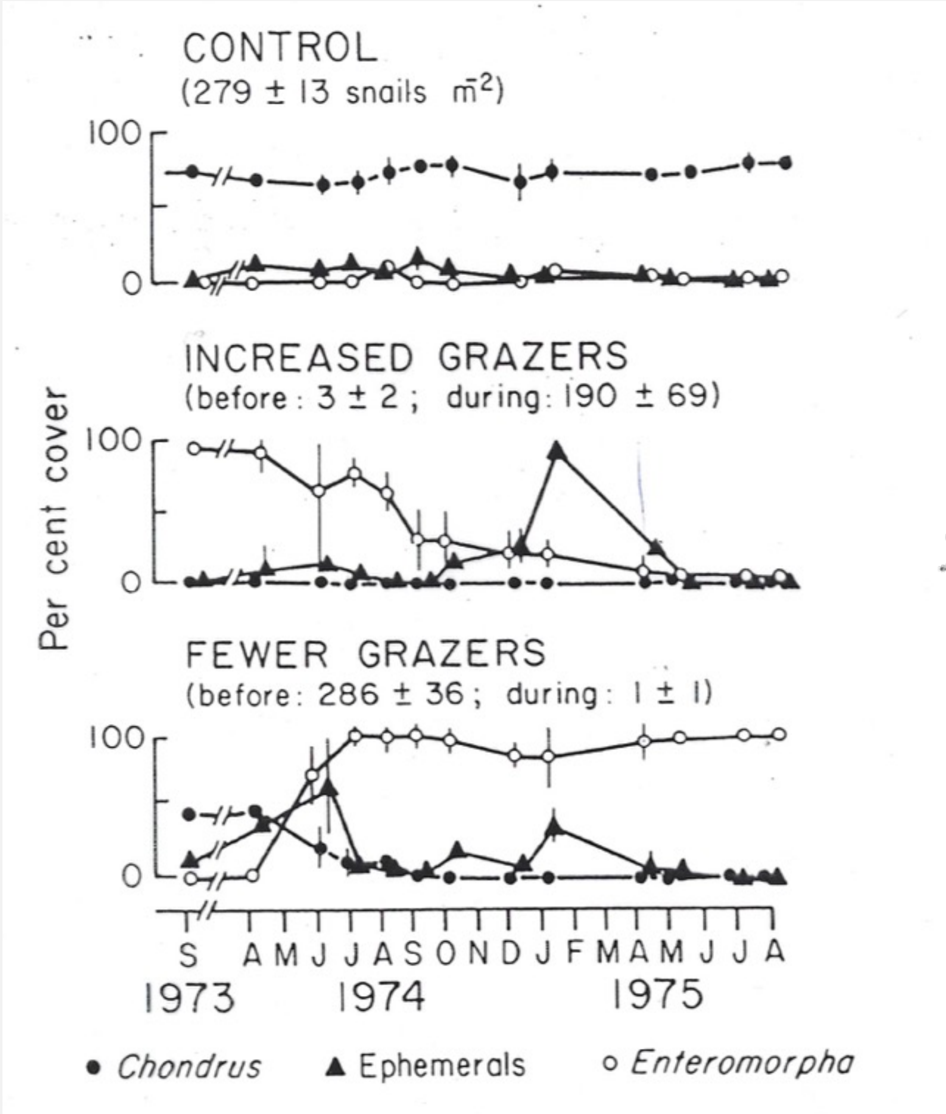
Enteromorpha sp. islaynaturalhistory.blogspot.com

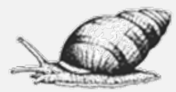
Littorina littorea

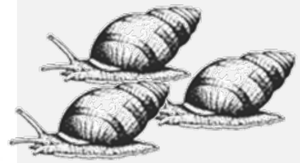
Nozères
Marinespecies.org

Chondrus crispus gulfofme.com

Figure 8-3. Experimental manipulation of a grazer snail (*Littorina littorea*) in tide pools in the higher reaches of the New England rocky intertidal zone. Adapted from Lubchenco (1978). © University of Chicago, reprinted by permission.







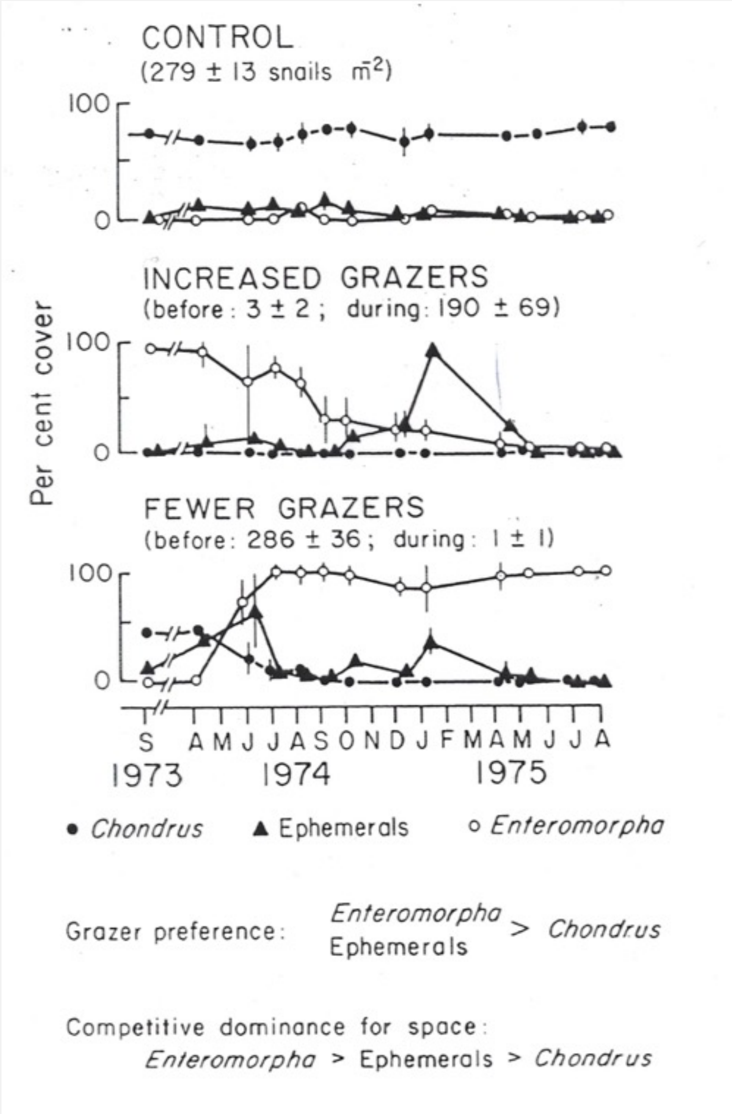
Grazer preference: *Enteromorpha*, Ephemerals > *Chondrus*

Competitive dominance for space: *Enteromorpha* > Ephemerals > *Chondrus*

TIDE POOLS ON ROCKY SHORES OF NEW ENGLAND

- Grazer controls the composition of the P1 community, allowing the less competitive species to become dominant

- ➢ Top-down control by the grazer
- ➢ Competition for light/space between algae



BIOTIC INTERACTIONS

tide pools on rocky shores of New England

giant kelp forest

Giant Kelp, *Macrocystis pyrifera*

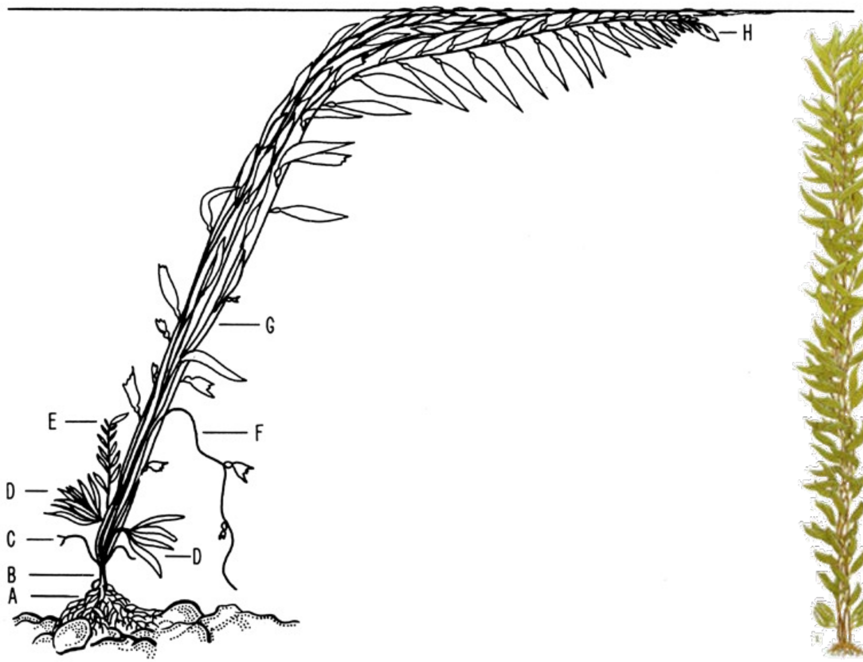
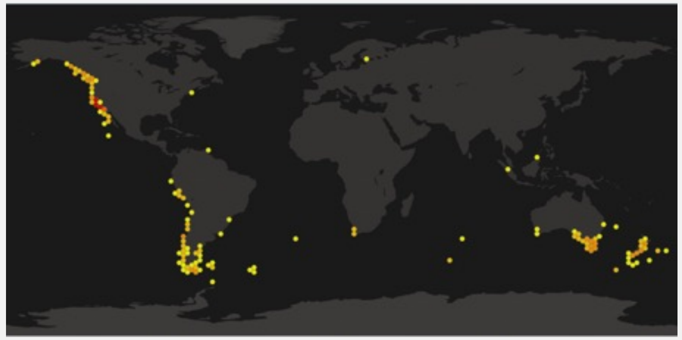


FIGURE 1. Diagram of a mature plant of the giant kelp, *Macrocystis pyrifera*, one to two years old, standing in 20 to 30 feet of water. A, holdfast; B, primary stipe; C, stub of an old frond; D, sporophyll clusters; E, juvenile frond; F, senile frond; G, stipe bundle; H, apical blade of mature frond, giving rise to additional blades.



© Andrea Dingeldein

Lovell and Libby Langstroth © California Academy of Sciences

Laminaria dentigera

© Andrea Dingeldein

Pterygophora californica

2.1. PRIMARY PRODUCERS

2.1.2. FACTORS CONTROLLING BENTHIC PI

BIOTIC INTERACTIONS: EX. GIANT KELP FOREST

inverts.wallawalla.edu

Strongylocentrotus franciscanus

1974-77: disease → ☨ sea urchins

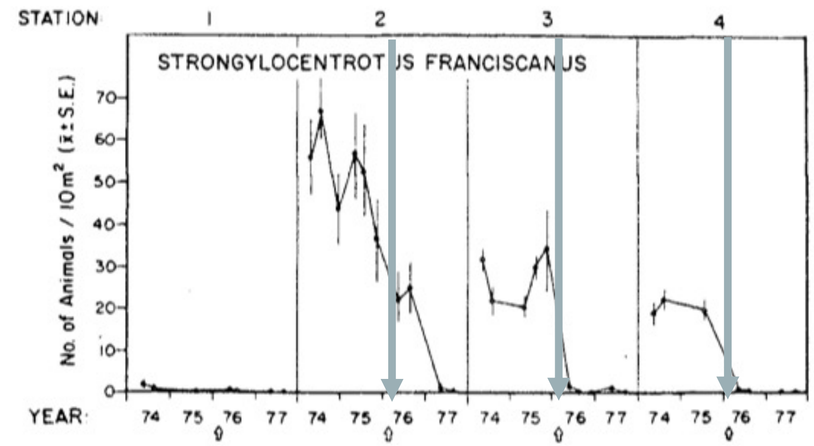


Fig. 1. *Strongylocentrotus franciscanus*. Changes in densities of sea urchins between 1974 and 1977 within the four stations (each 625 m^2) off Point Santa Cruz, California. Arrows indicate time of mass mortality of sea urchins

- Release of the top-down control by the grazer

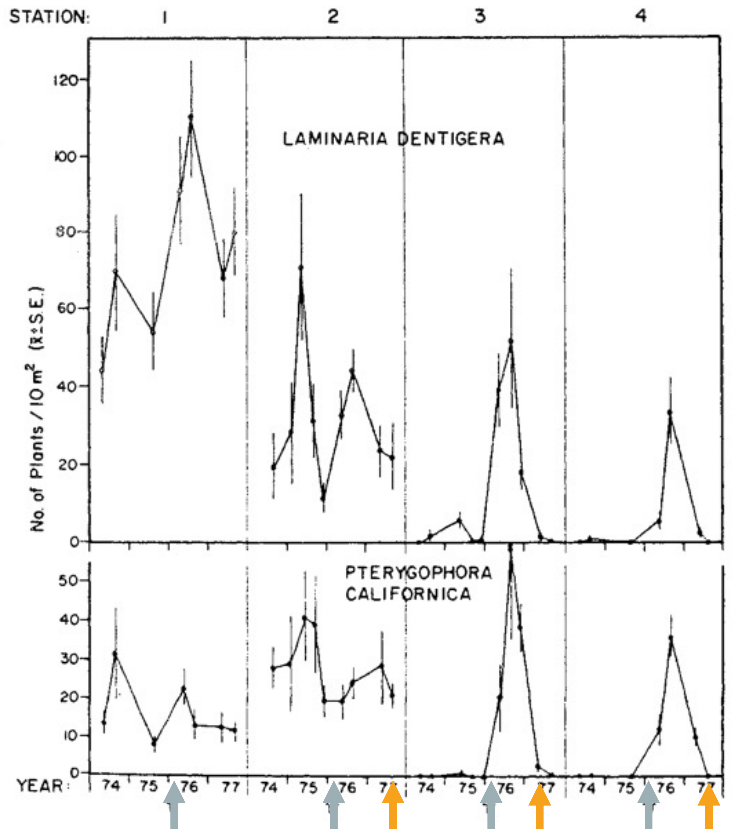


Fig. 4. *Laminaria dentigera* and *Pterygophora californica*. Changes in densities of understory laminarians between 1974 and 1977 within the four 625 m^2 stations off Point Santa Cruz, California. Arrows indicate time of mass mortality of sea urchins

Understory kelp plants, responded rapidly to the decreased in densities of sea urchins

in 1977 numerous dead and bladeless stipes of *L. dentigera* and *P.californica* were conspicuous at Stations 3 and 4, and nearly no live plants were found.

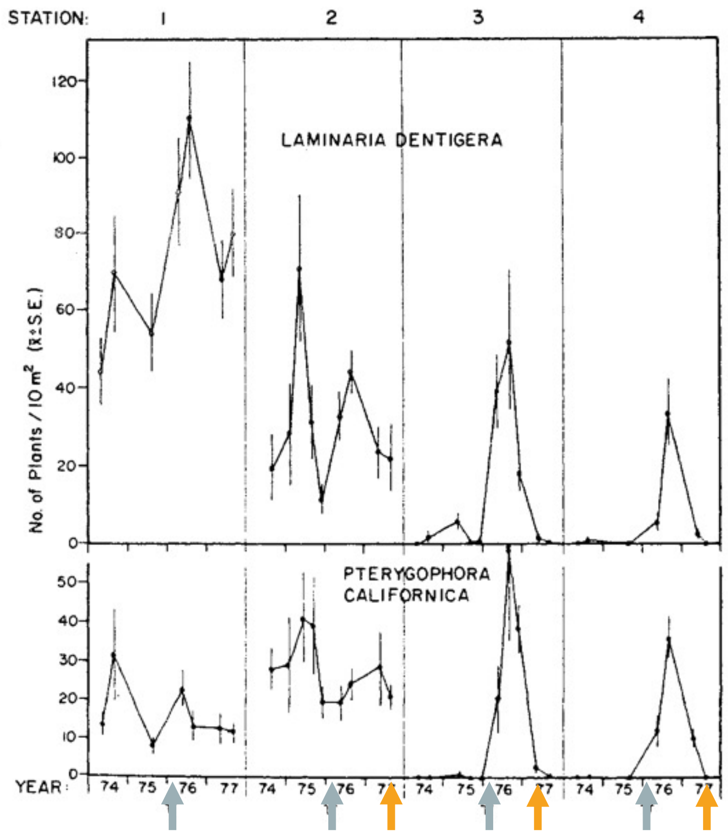


Fig. 4. *Laminaria dentigera* and *Pterygophora californica*. Changes in densities of understory laminarians between 1974 and 1977 within the four 625 m^2 stations off Point Santa Cruz, California. Arrows indicate time of mass mortality of sea urchins

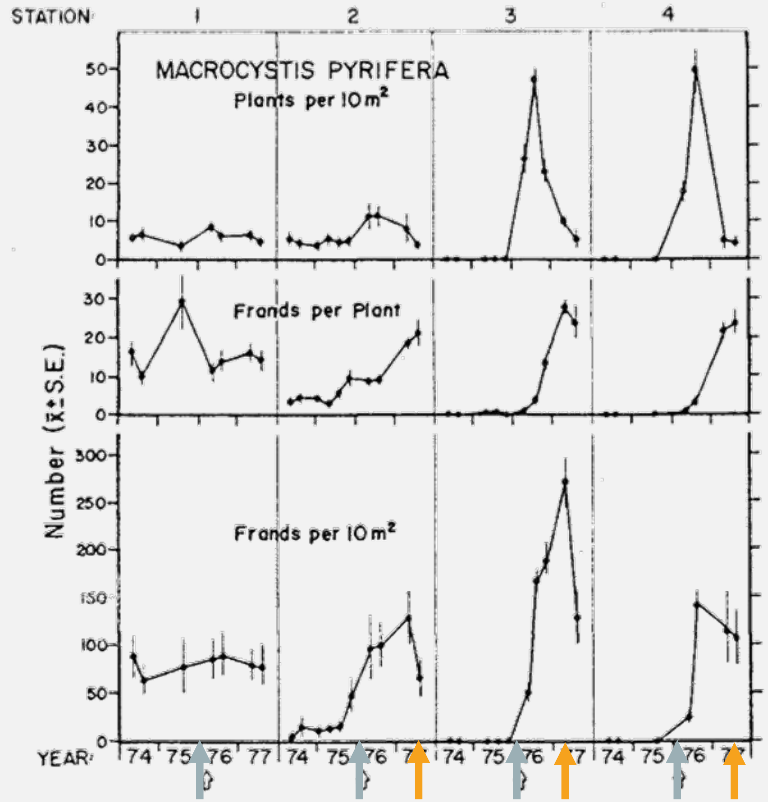


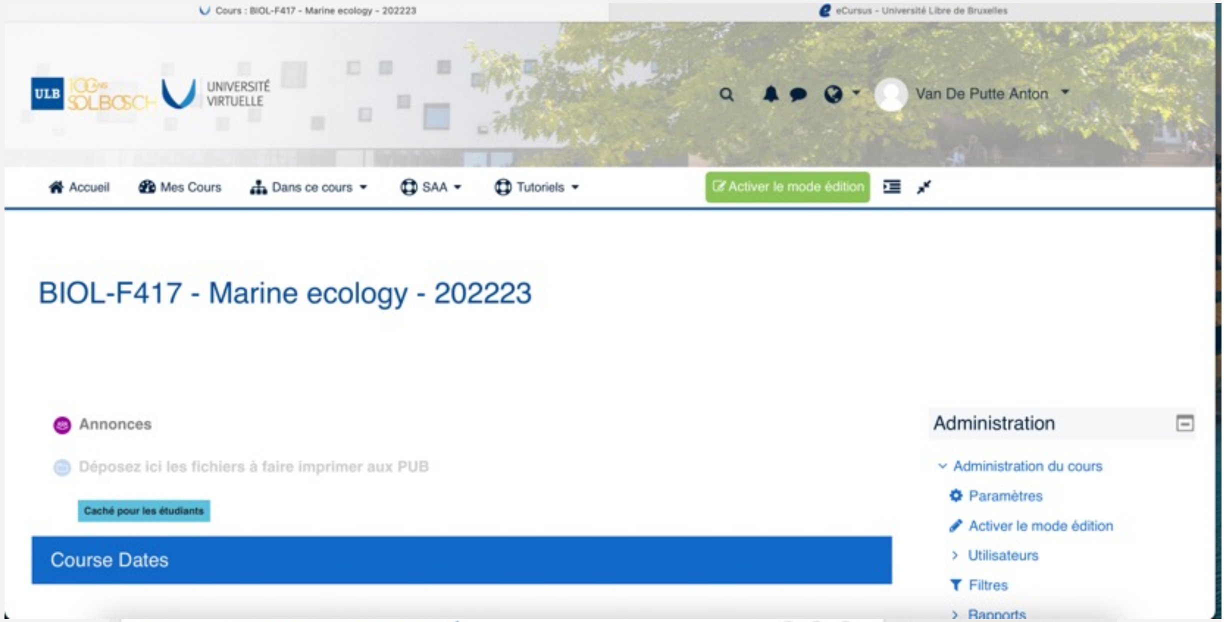
Fig. 2. *Macrocystis pyrifera*. Changes in plant densities, plant sizes, and frond densities of giant kelp between 1974 and 1977 within the four 625 m^2 stations off Point Santa Cruz, California. Arrows indicate time of mass mortality of sea urchins

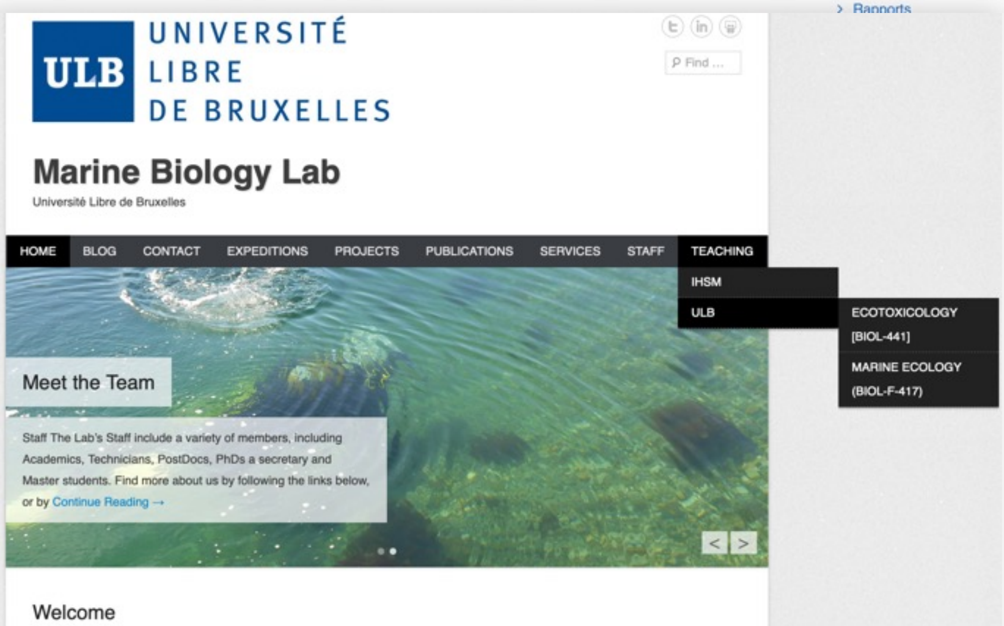
Inter and Intraspecific competition

COURSE INFORMATION

- https://uv.ulb.ac.be/

- https://biomar.ulb.ac.be





EXAM

- Oral, 30 minutes long
- Time and data will be planned together with you
- Be present 30 minutes in advance

3 CONSUMERS

3.1. Classification

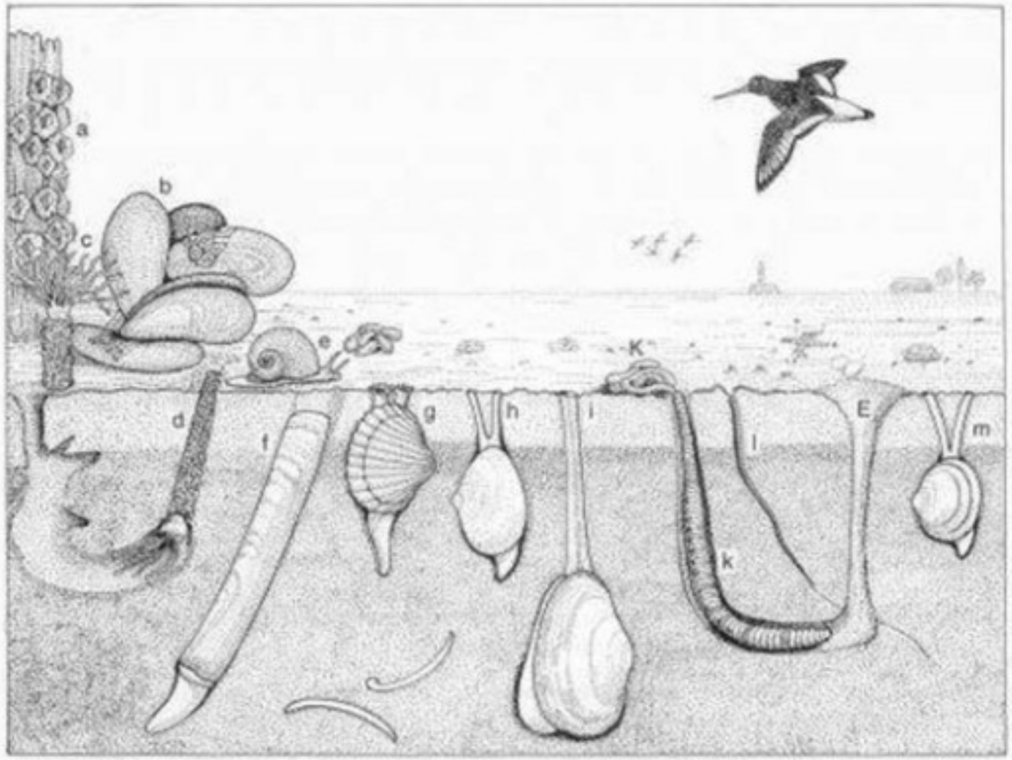
- localisation
- Size
- diet

3.2. Factors controlling benthic consumers

3.3. Biotic Interactions

LOCALIZATION

- According to
  - Epifauna
  - Infaunal/Endofauna
    - Burrowers
    - Perforators
    - Interstitial fauna

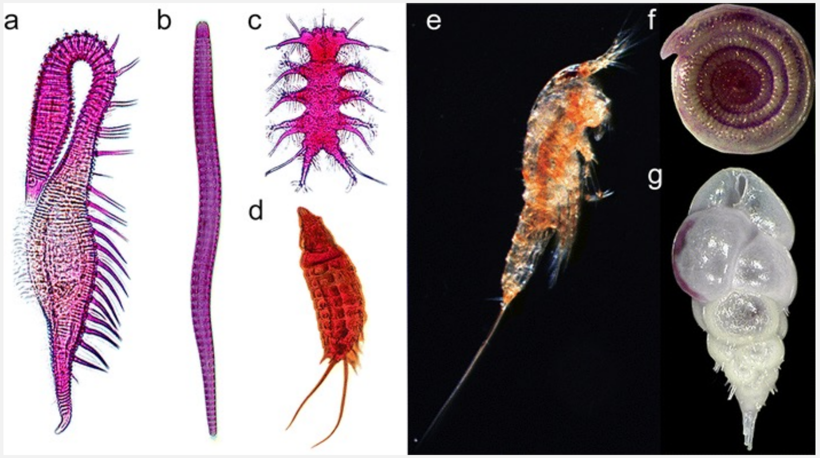


Profile of the sea floor showing typical **infaunal/epifauna** organisms (from Pierre Tardent).

a) Barnacles (Balaniden)
b) Blue mussels (*Mytilus edulis*)
c) Polychaete *Lanice conchilega*,
d) Polychaete *Lagis koreni*,
e) Snail *Littorina littorea*,
f) Rasor clam (*Ensis americanus*),
g) Bivalve *Cerastoderma edule*,
h) Bivalve *Scrobicularia plana*,
i) Bivalve *Mya arenaria*
k) Polychaet *Arenicola marina*,
l) Polychaete *Hediste diversicolor*,
m) Bivalve *Macoma balthica*

SIZE

	Macrofauna
2- 0.5 mm	
	Meiofauna
100 – 40 µm	
	Microfauna



Zeppilli et al 2015

FEEDING TYPE

- - suspensivorous: feeding on particles caught in the water column
- - depositivorous: feeding on sediment
- - herbivorous: feeding on primary producers
- - carnivorous: feeding on consumers
- - detritivorous: feeding detritus

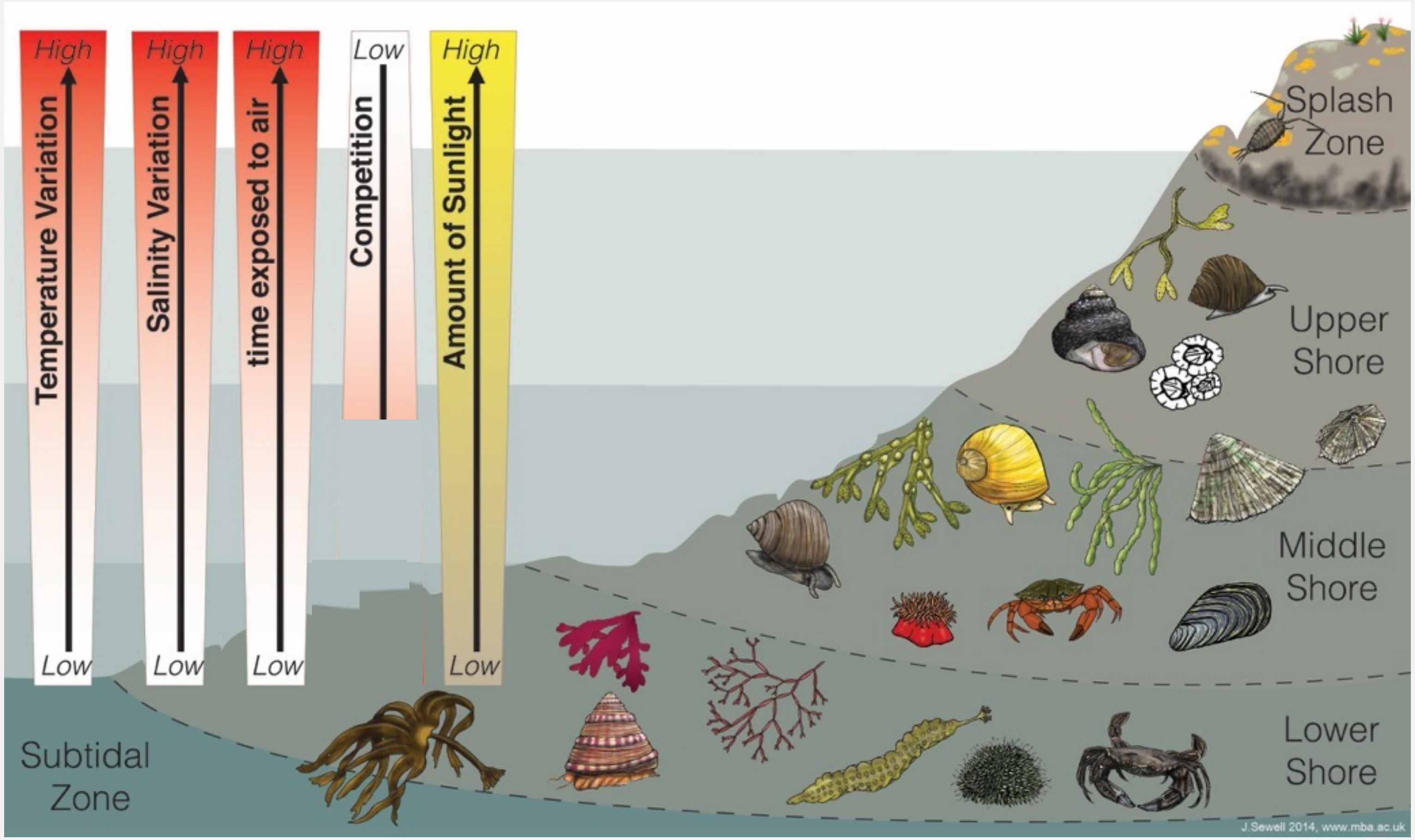
3 CONSUMERS

3.1. Classification

3.2. Factors controlling benthic consumers

- Substrate
- Emersion

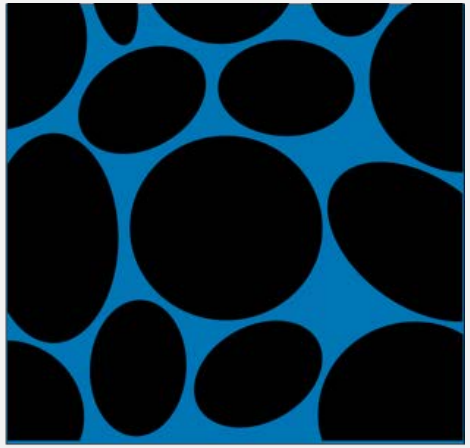
3.3. Biotic Interactions

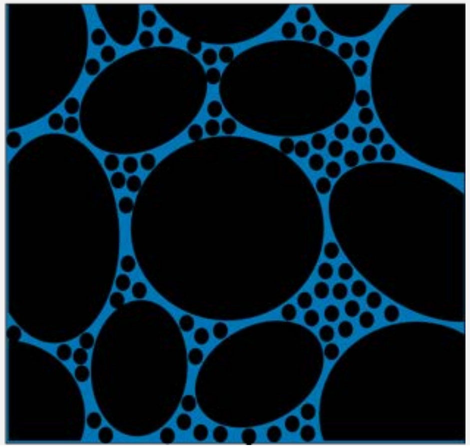


A schematic diagram of a rocky shore in the British Isles, showing the basic ‘zones’ and how environmental conditions change with height up the shore. © Marine Biological Association

Substrate
Soft substrate

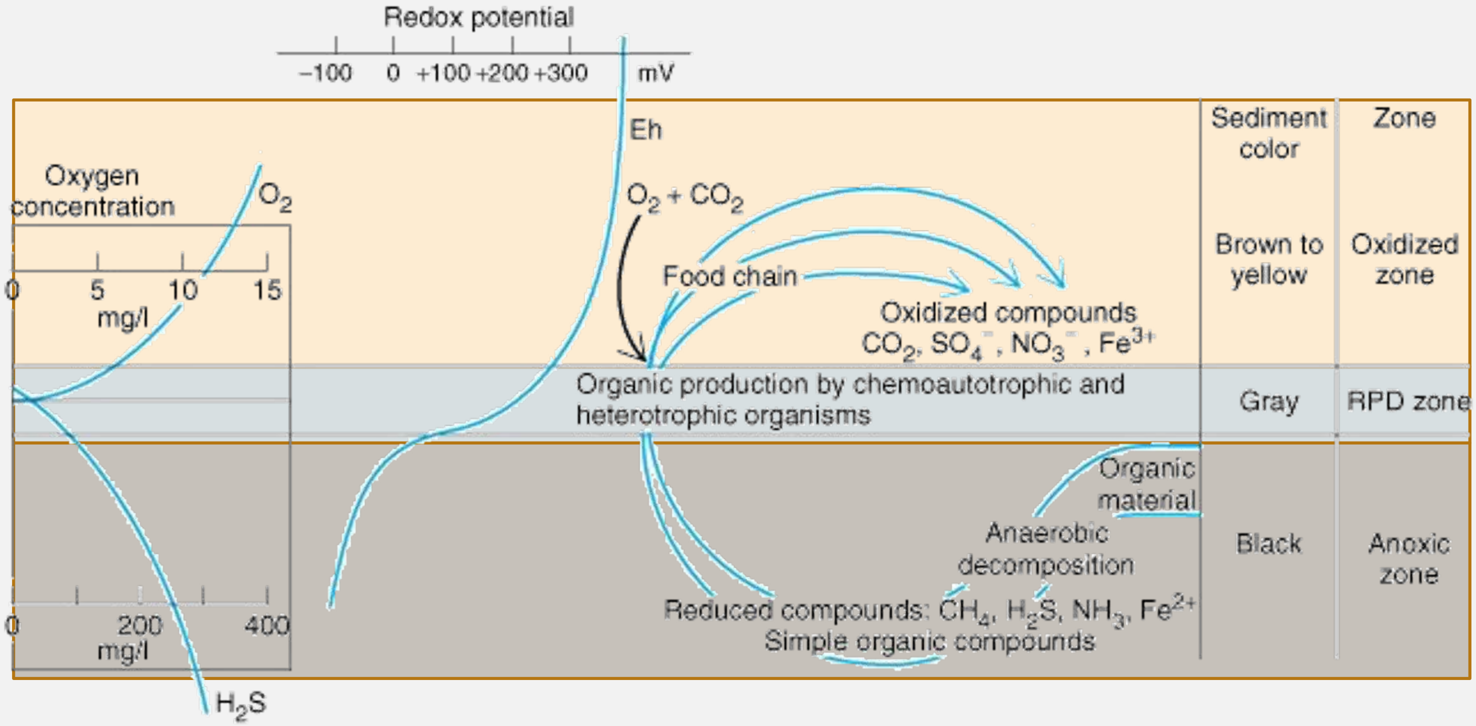
- Inorganic particles
- Organic particles
- Interstitial water
- Physical characteristics
  1. Size = function of hydrodynamism
     - Coarse sediments: few organic particles
     - Very fine sediments: instable for macrofauna
  2. Homogeneity
     - Well sorted: homogenous grain size
     - Poorly sorted: heterogenous grain size
  3. Porosity: $V_{interstitial} / V_{total}$
     - Depends on grain size and homogeneity of the sediment
     - Oxygen level
     - Important for meiofauna



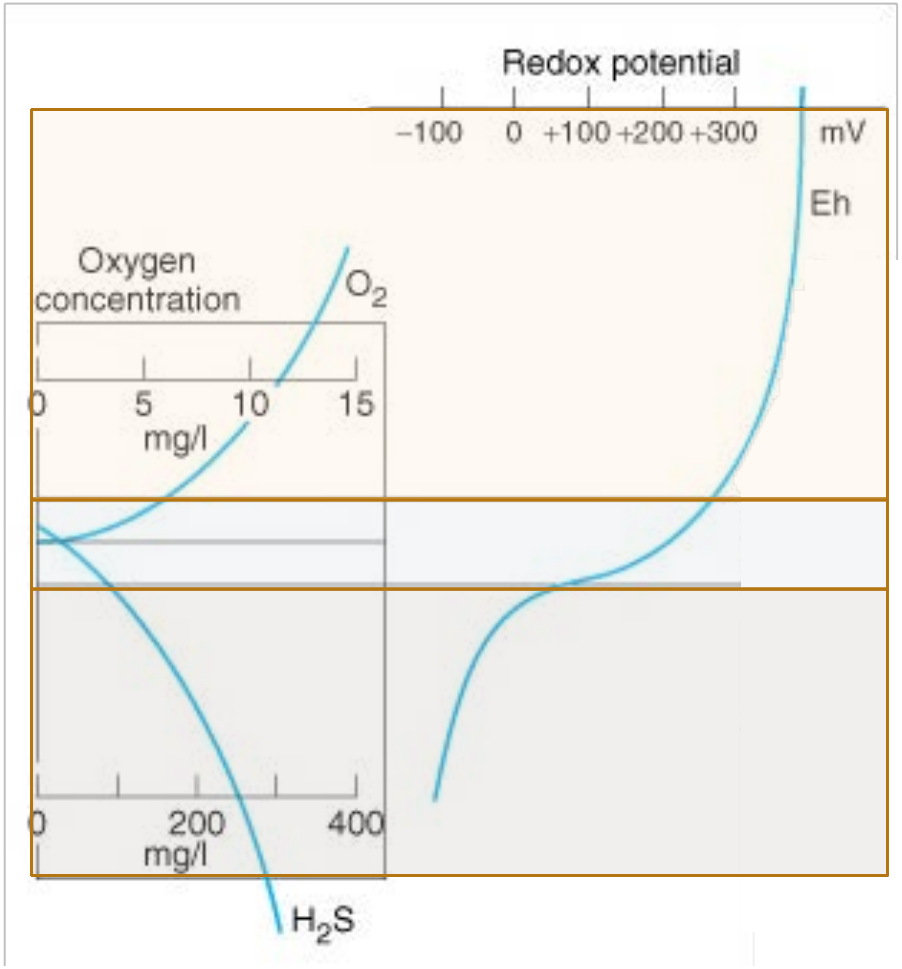


SOFT SUBSTRATE

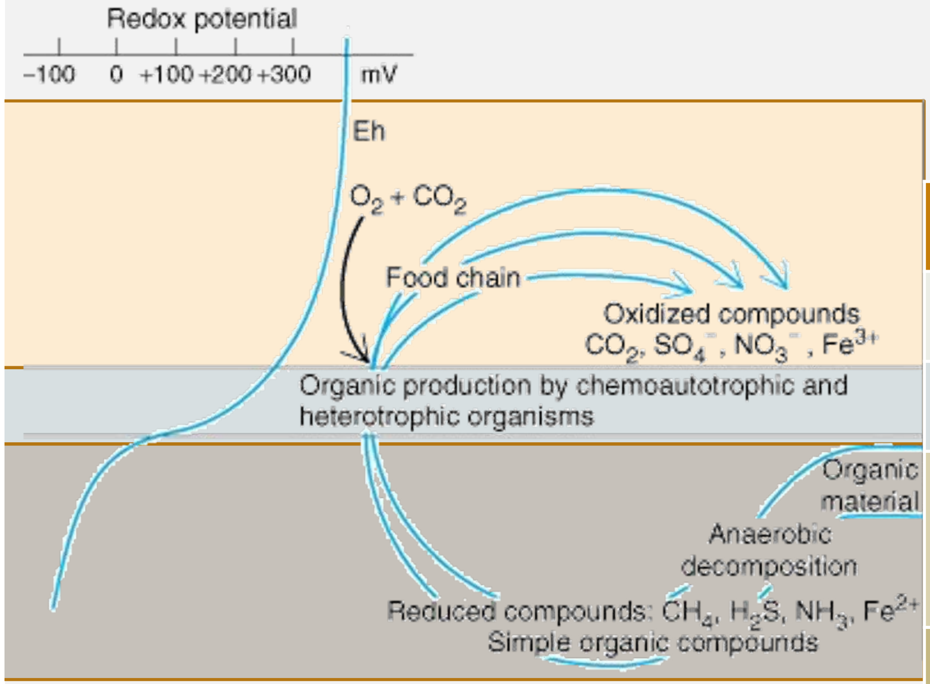
- Chemical characteristics



- Chemical characteristics
  - Diffusion of O_2 from the interface SW - sediment
  - Consumption of O_2 in the superficial layers by aerobic bacteriae
  - → progressive ↓ of $[O_2]$ in interstitial water
  - → brutal change in oxydo-reduction potential: redox potential discontinuity (RPD) = interface aerobic – anaerobic layers
  - Depth of the RPD will depend on:
    - Hydrodynamism
    - Grain size and sorting

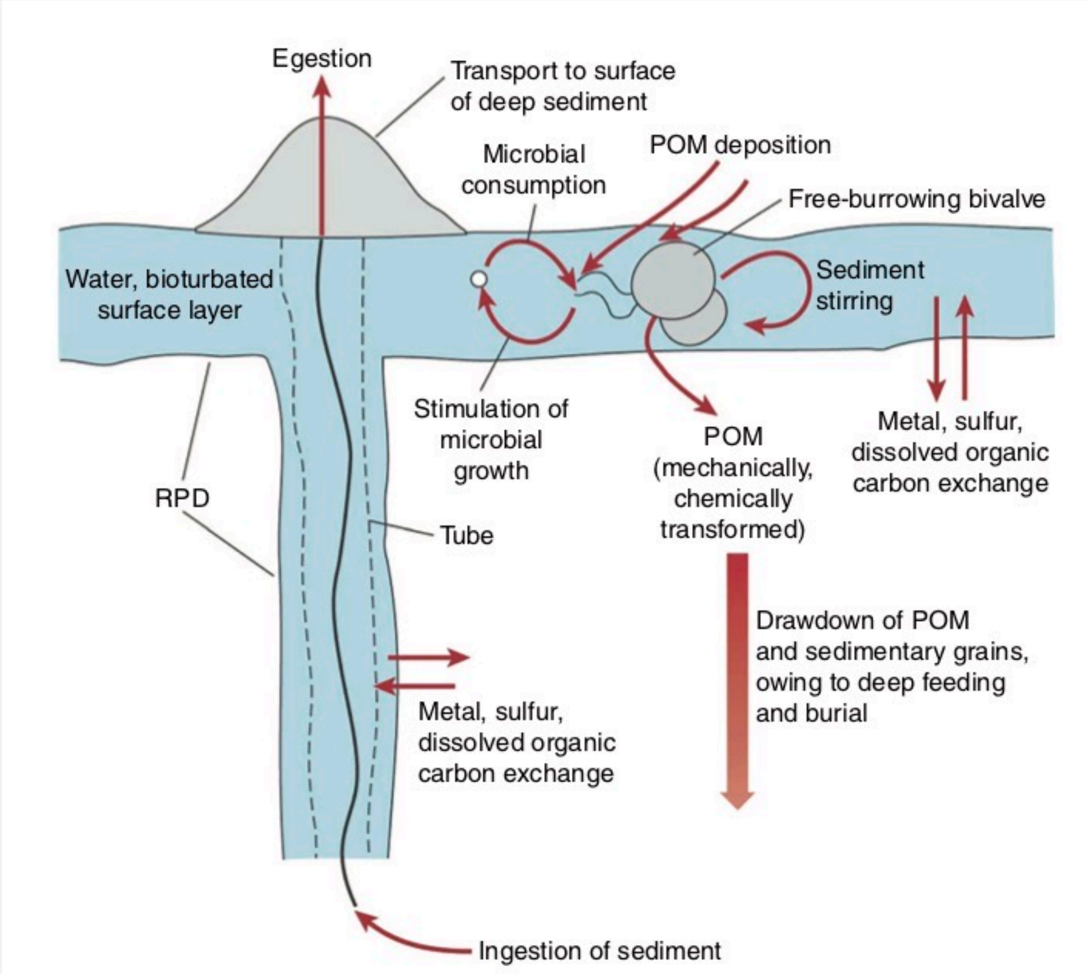


SOFT SUBSTRATE



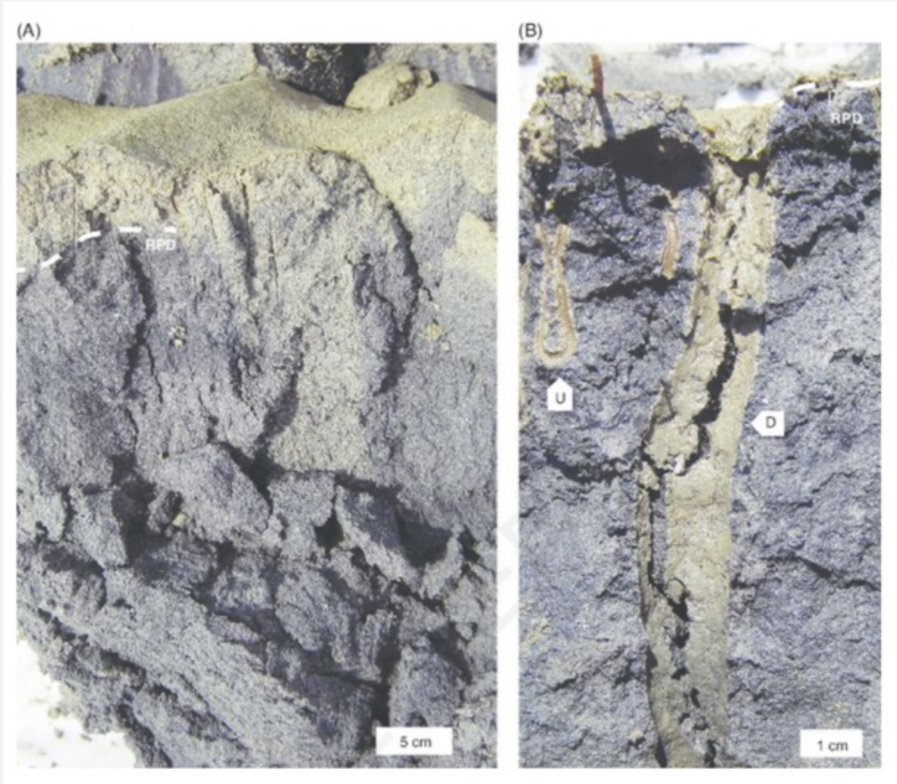
Sediment	Bacteria	Characteristics
oxic	aerobic (some photosynthetic)	
RPD	chemosynthetic sulfur bacteria	oxidize H_2S
	fermenting bacteria	anaerobic heterotrophs transform organic compounds into fatty acids and alcohols by glycolysis
anoxic	Sulfatoreducing bacteria	reduce SO_4^{2-} into H_2S
	Methane-producing bacteria	transform organic compounds into CH_4

- Chemical characteristics
  - Vertical zonation of eucaryotes
  - Meiofauna temporarily below RPD
  - Some protozoa able to live below the RPD (symbiotic bacteria)
  - Most of the meiofauna and all the macrofauna above the RPD
  - But… the RPD is not always horizontal! = bioturbation



Levinton 1995

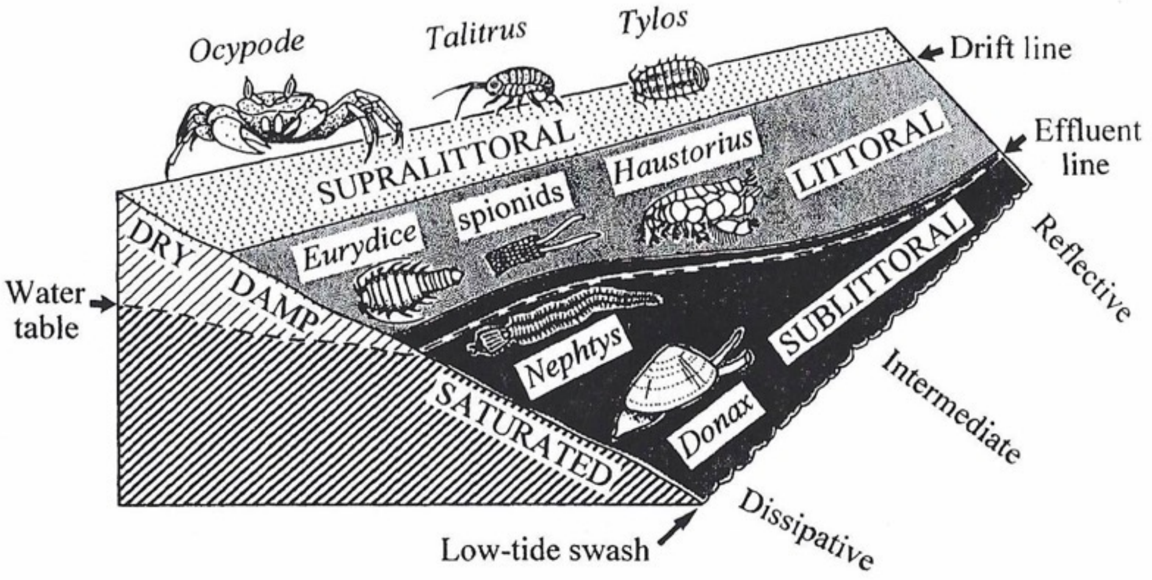
- Redox potential discontinuity (RPD). Redox potential discontinuity (RPD, dashed line) note a small U-shaped burrow (*U. Arenicolites*) and a decapod burrow (*D. Parmaichnus* or *Thalassinoides*).
- © Baucon & Felletti 2016



Soft substrate

Dessication, temperature, salinity, hydrodynamism

Scheme of zonation on sandy shores, showing changes from dissipative to reflective beaches. (After McLachlan and Jaramillo, 1995.)



Intertidal zonation of metazoa

3 CONSUMERS

3.1. Classification

3.2. Factors controlling benthic consumers

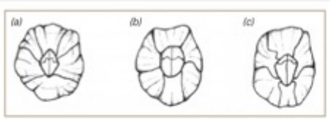
3.3. Biotic Interactions

- *Abiotic factors and biotic interactions*
- Biotic Interactions

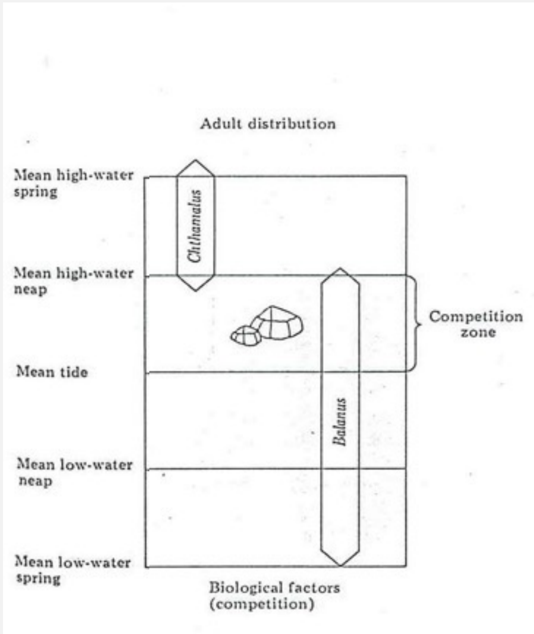
Rocky substrate

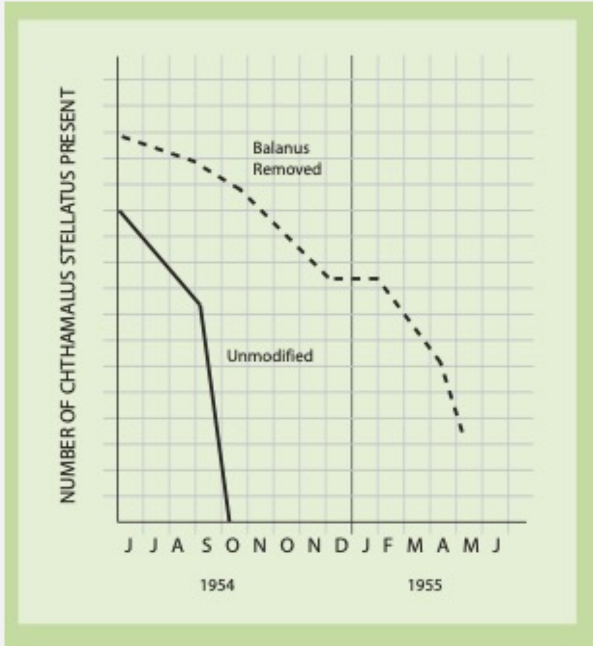
Abiotic factors and biotic interactions

Chthamalus stellatus



(a) *Semibalanus balanoides*
(b) *Chthamalus stellatus*
(c) *Chthamalus montagui*
Three British barnacle species; note that, in **Chthamalus**, the central lines cross at right angles.

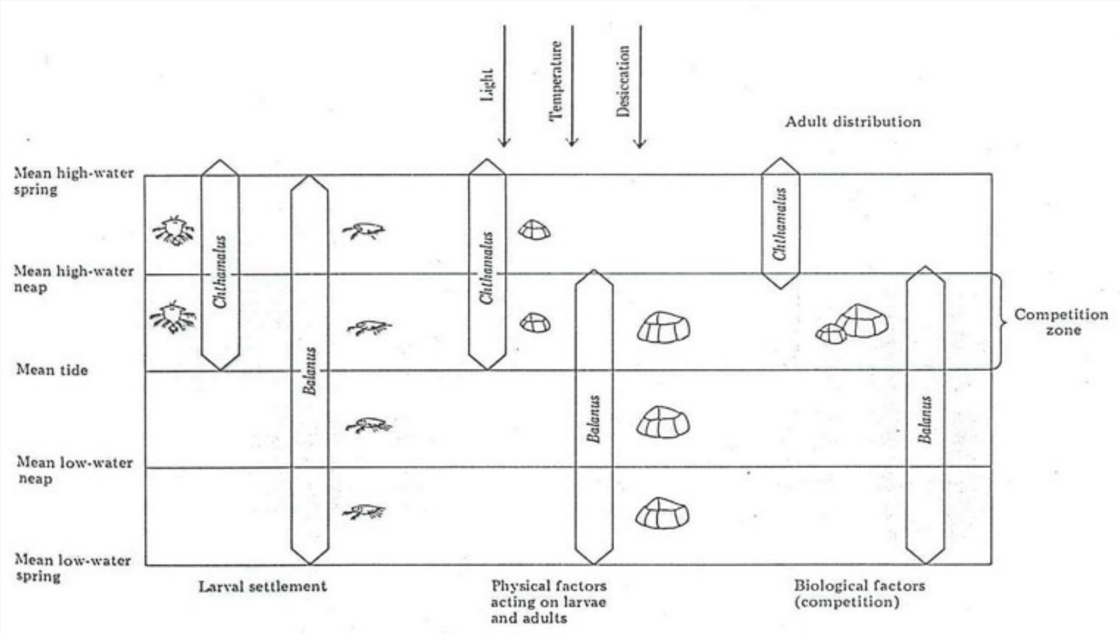




(Semi)balanus balanoides

Rocky substrate

Abiotic factors and biotic interactions



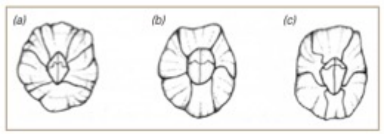
Chthamalus stellatus

Semibalanus balanoides

- Larvae of two barnacles, *Chthamalus stellatus* and *Semibalanus balanoides*, settle out over a broad area
- Physical factors, mainly dessiccation, limit survival of *S. balanoides* above mean high water of neap tides
- Competition between *S. balanoides* and *C. stellatus* in the zone between mean tide and mean high water of neap tides eliminates *C. stellatus*.

Rocky substrate
Abiotic factors and biotic interactions

Chthamalus stellatus



(a) *Semibalanus balanoides*
(b) *Chthamalus stellatus*
(c) *Chthamalus montagui*

Three British barnacle species; note that, in ***Chthamalus****, the central lines cross at right angles.*

Le Roux/wikipedia commons

Semibalanus balanoides

Chthamalus montagui

Maggs/wikipedia

BIOTIC INTERACTIONS

Rocky shores

tide pools on rocky shores of New England

giant kelp forest

Sandy/muddy shores

Corophium vs Nereis

Fish & crabs

razottoli.wordpress.com/

Predators

Asterias forbesi

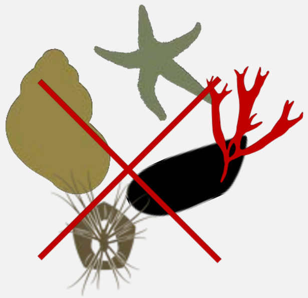
Thais/Nucella lapillus

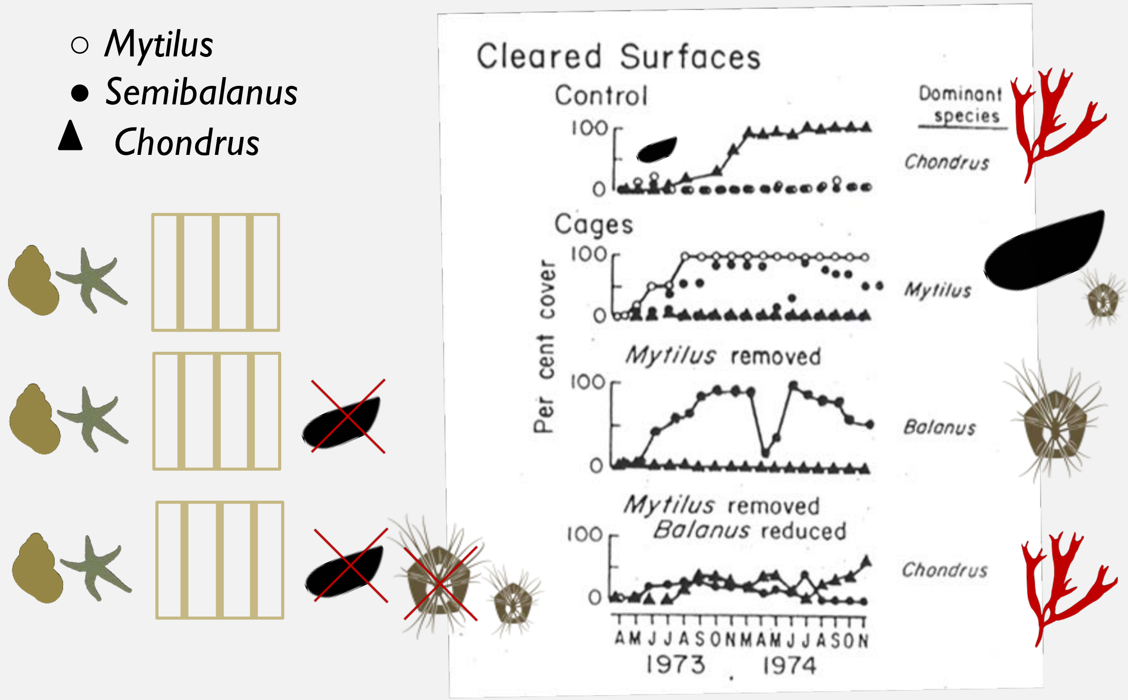
Prey

Mytilus edulis

Semibalanus balanoides

Chondrus crispus



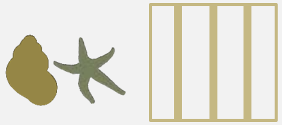


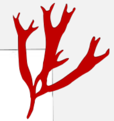
- Top-down control by predators
- Competition for space

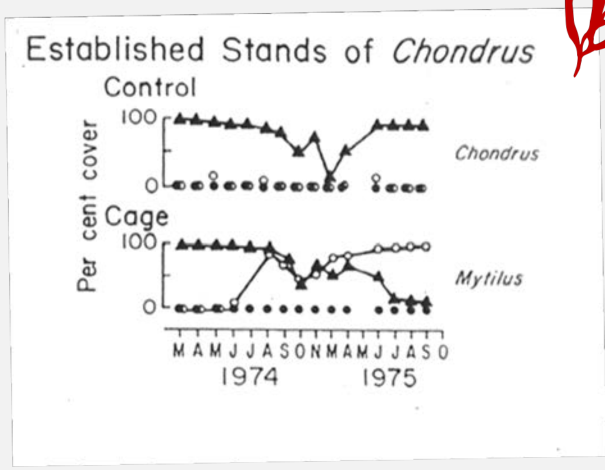
- Sheltered shores: predators present
  - ➢ Algae dominant
- Exposed shores: predators absent (washed away)
  - ➢ Barnacles and mussels dominant

Mytilus > Balanus > Chondrus

○ *Mytilus*
● *Semibalanus*
▲ *Chondrus*







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BIOTIC INTERACTIONS

Rocky shores

tide pools on rocky shores of New England

giant kelp forest

Sandy/muddy shores

Corophium vs Nereis

Fish & crabs

Main sea urchin predators: sea otter *Enhydra lutris*

https://www.climate.gov/sites/default/files/otter_urchin_lrg.jpg

Enhydra lutris

- Historical distribution: Aleutian Is - S California
- Quasi extinction beginning of 20th century (hunting)

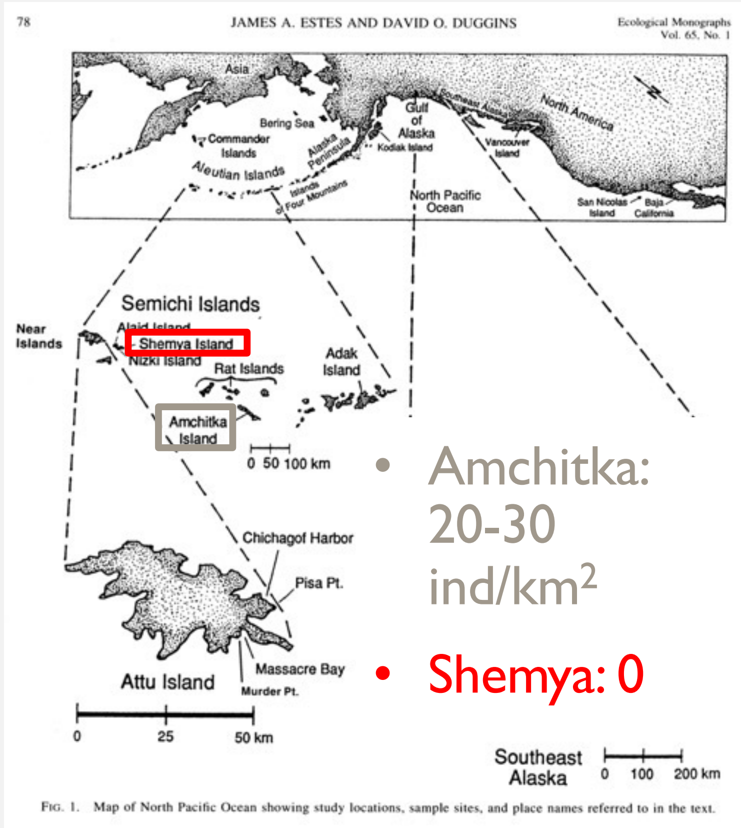


FIG. 1. Map of North Pacific Ocean showing study locations, sample sites, and place names referred to in the text.

- Amchitka: 20-30 ind/km^2
- Shemya: 0

- Amchitka: Otters present:
  - Sea urchin density low
  - % cover kelp high
- Shemya: Otters absent:
  - Sea urchin density high
  - % cover kelp = 0
  - Higher biomass
  - Bimodal size distribution

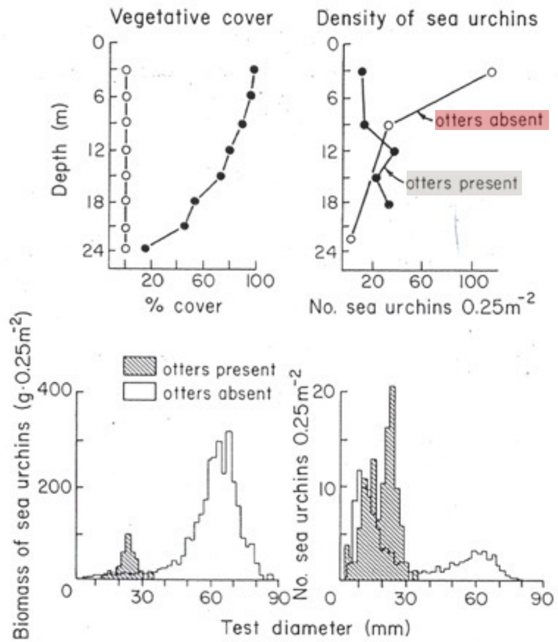


Figure 9-1. Interactions among sea otters, sea urchins, and vegetative cover in kelp beds off the Alaskan coast. Sea otters are present in Amchitka Island and absent in Shemya Island. Symbols on top left are the same as top right. Size of sea urchins is shown as the diameter of the test not including spines. Adapted from Estes and Palmisano (1974). © AAAS, reprinted by permission.

- Otters present:
  - Necessary for high kelp cover
- Otters absent:
  - Kelp cover always low

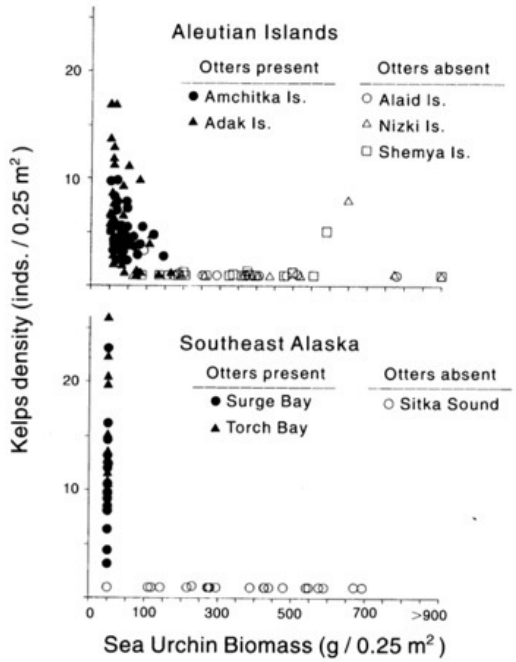
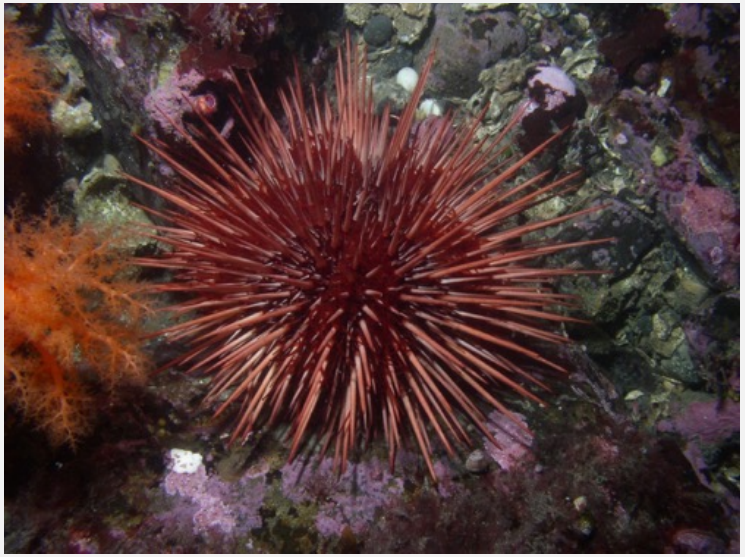
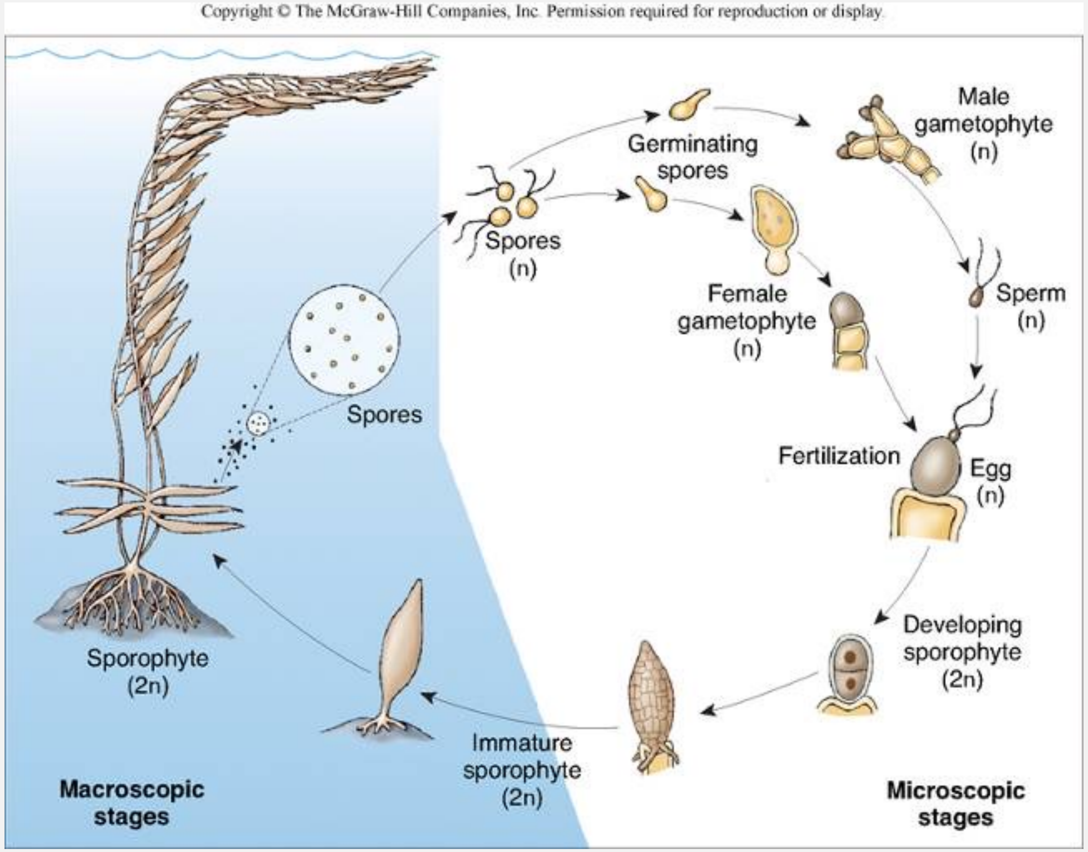


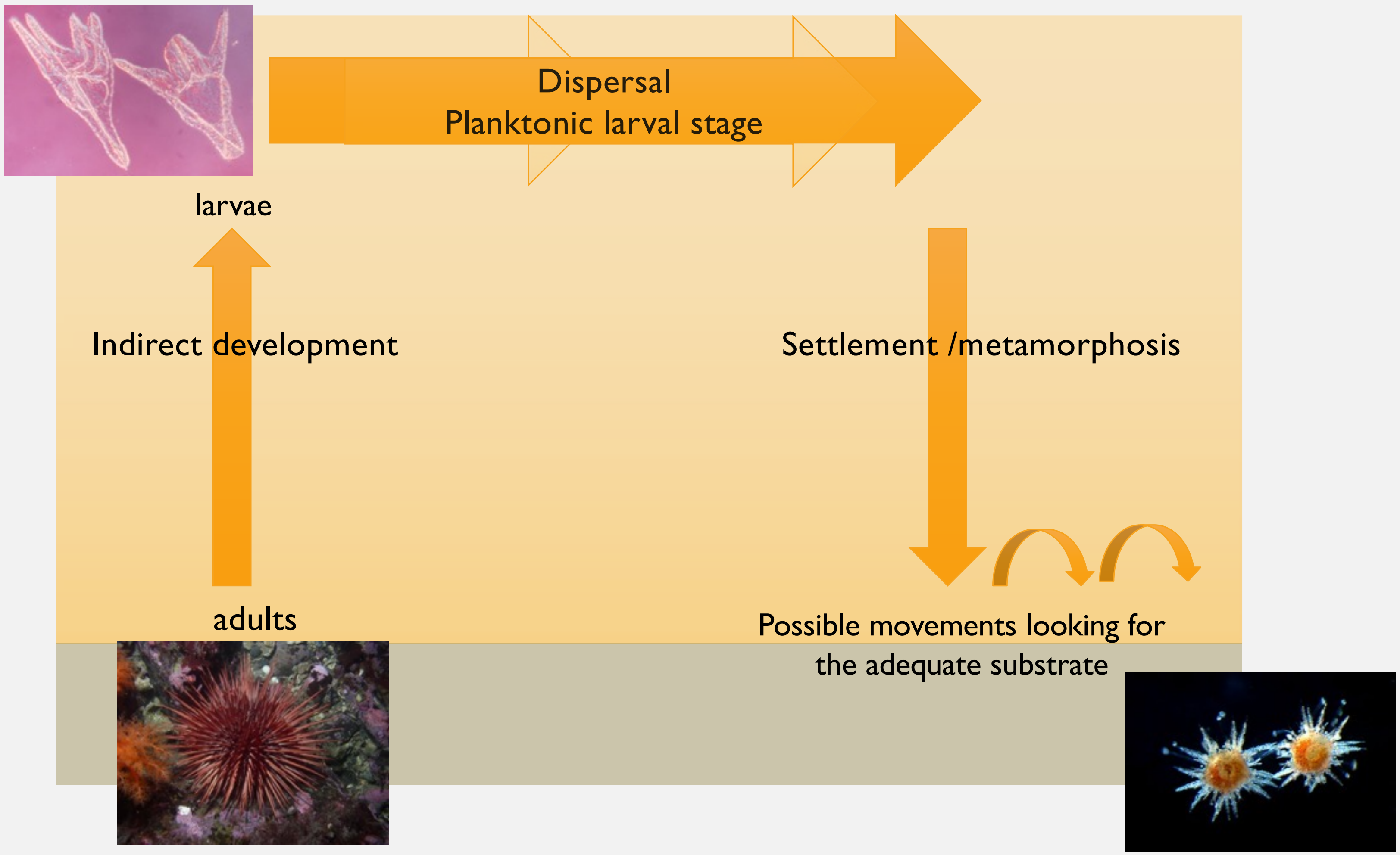
FIG. 7. Epibenthic kelp density (inds./0.25 m²) plotted against estimated sea urchin biomass (g/0.25 m²) for the Aleutian Islands and southeast Alaska. Points represent averages for sites within locations. Sea urchin biomass was estimated from samples of population density, size–frequency distribution, and the functional relation between test diameter and wet mass.



Kelp and sea urchins have an indirect development:
Presence/absence also depends on recruitement of propagules or larvae

Planktonic stages

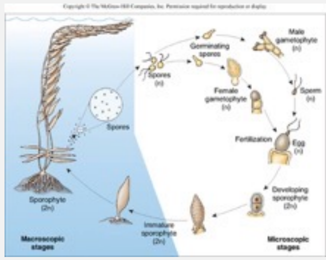


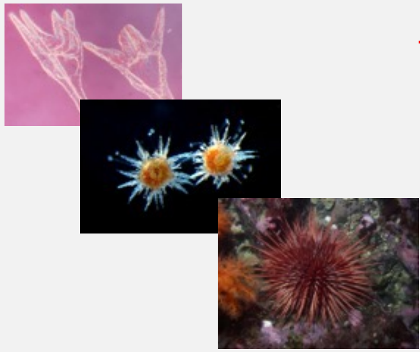

Dispersal
Planktonic larval stage
larvae
Indirect development
Settlement /metamorphosis
adults
Possible movements looking for
the adequate substrate

Top-down controls

- Otters → sea urchins
- Sea urchins → kelp

= trophic cascade





Recruitment of juveniles

- Depends on the advection of competent larvae by hydrographic processes

BIOTIC INTERACTIONS

Rocky shores

tide pools on rocky shores of New England

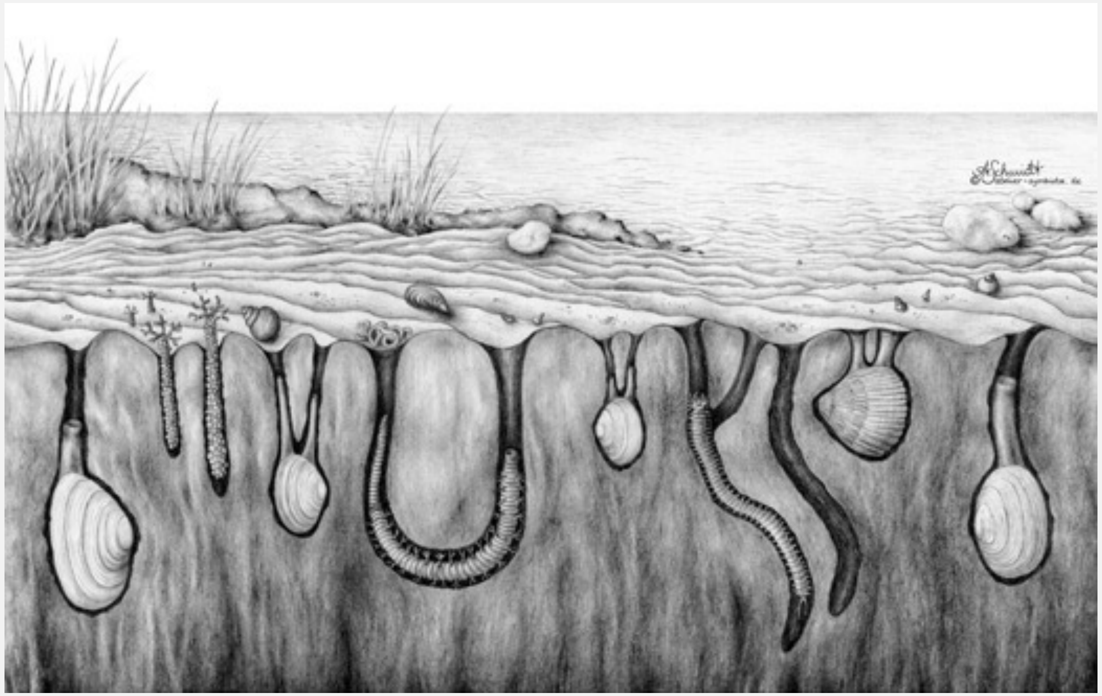
giant kelp forest

Sandy/muddy shores

Corophium vs Nereis

Fish & crabs

- Effects much more variable than on rocky shores:
  - 3D environnement ➔ escape possibilities higher



Olafsson & Persson 1986

Corophium volutator

- filter-feeder & detrivore
- burrows at sediment-water interface
- U-shaped

Nereis diversicolor

- filter-feeder & detrivore
- predator/scavenger
- burrows at sediment-water interface

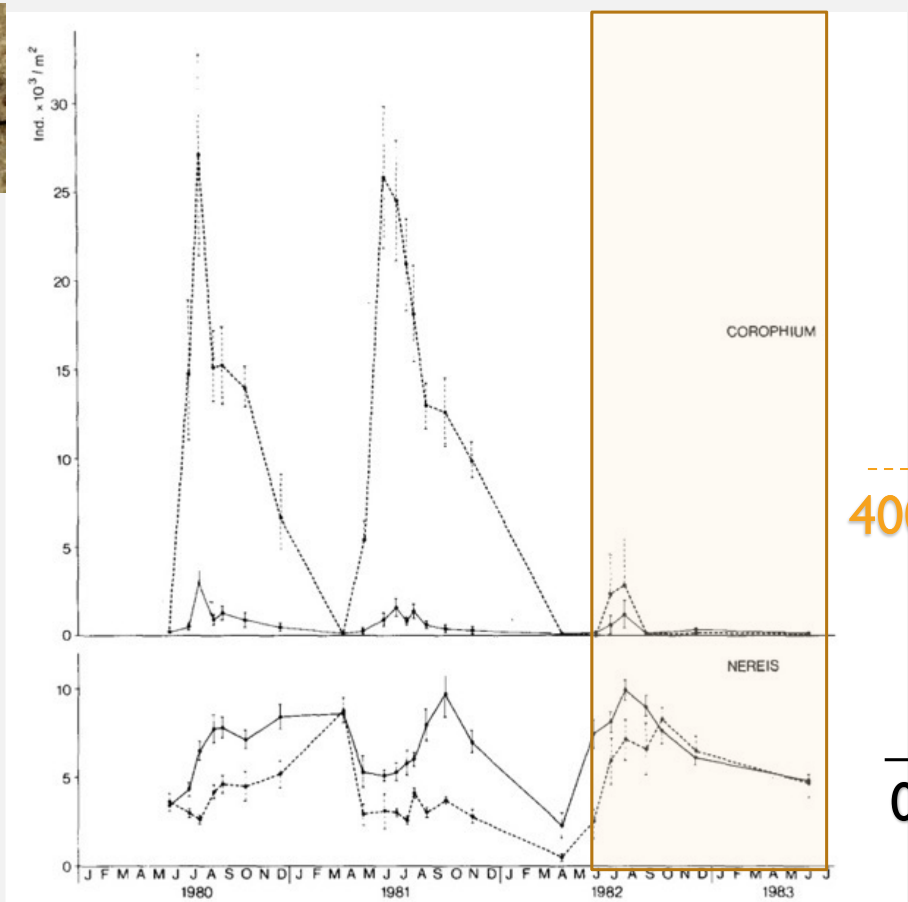


Fig. 2. Mean densities (± SE) of *Corophium volutator* (1980–1983) and *Nereis diversicolor* in the two sub-areas; solid line, 0–400 m (n = 15); broken line, 400–500 m (n = 5).

Olafsson & Persson 1986

400-500 m

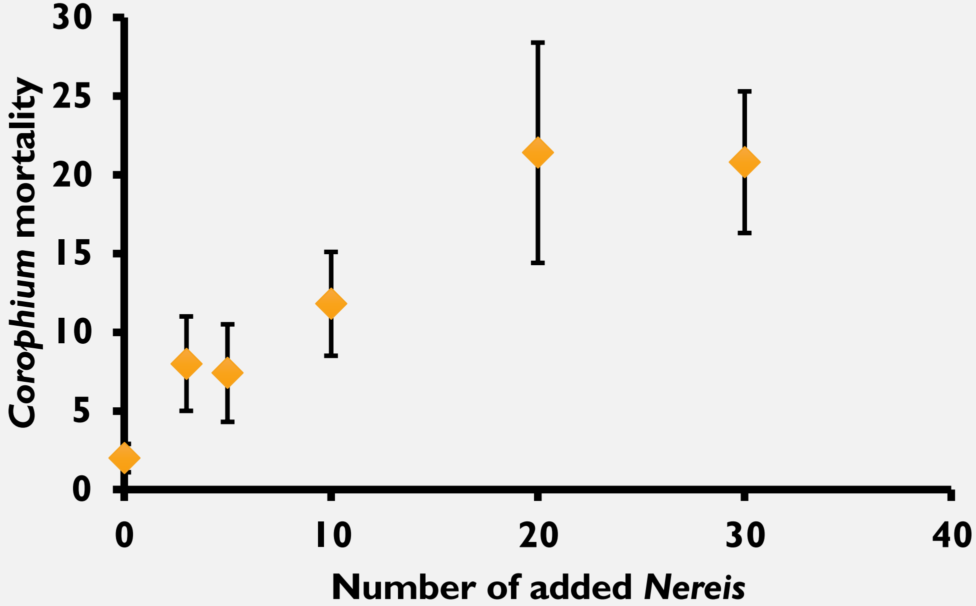
0-400 m

Corophium
Seasonal peaks
400-500m > 0-400m
82 population crash
Overall low densities

Nereis
Seasonal peaks
0-400m > 400-500m
82 population crash
High densities overall

- Competition for space and exclusion: first come, first served <-> importance of recruitment

- An experiment
- Competition for space and exclusion: first come, first served <-> importance of recruitment



Olafsson & Persson 1986

BIOTIC INTERACTIONS

Rocky shores	tide pools on rocky shores of New England
	giant kelp forest
Sandy/muddy shores	*Corophium vs Nereis*
	Fish & crabs

- Predation: effects much more varied than on rocky shores:
  - More complex trophic networks ➔ mutiple trophic interactions mitigating the effects of excluding one predator
  - Ex: salt marsh NE USA

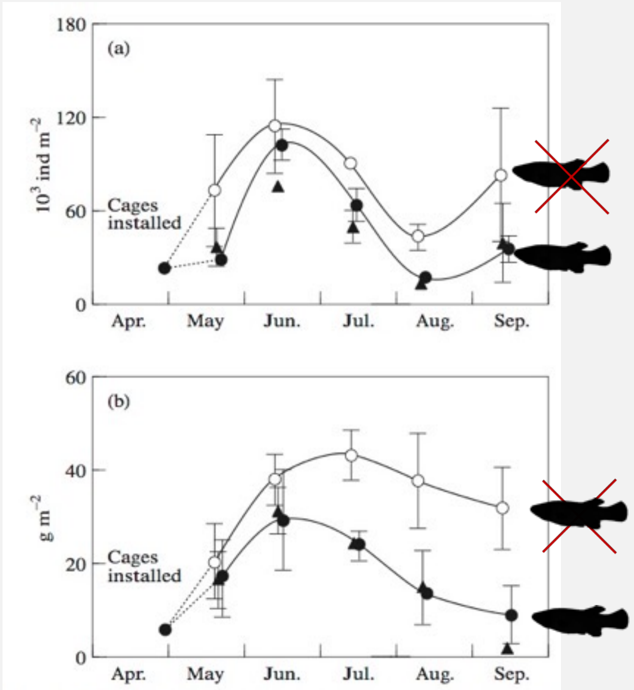


FIGURE 1. Monthly average density of macroinfauna inside complete cages (○), ambient sediments (●) and in partial cages (▲) (a) and the corresponding mean biomass (b). Vertical bars are standard errors of the mean.

Sarda et al 1998

🡅 density and biomass of infauna

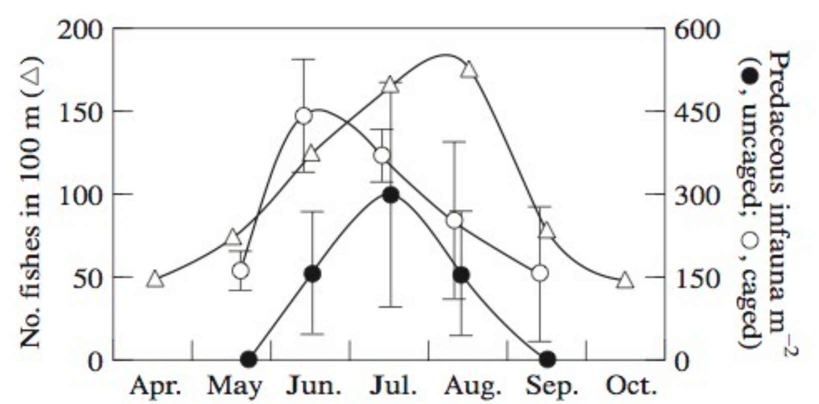


FIGURE 4. Density of predaceous infauna in complete cages and ambient sediments, and number of total fishes in a transect of 100 m in the tidal sandy channels of the marsh.

Sarda et al 1998

↑ predaceous infauna density

- Effects much more varied than on rocky shores:
  - Ex: salt marsh NE USA

- Competition
  - Recruitment: first come, first served
  - Exclusion:
    - Modification of habitat (bioturbation)
    - Eradication of post-larvae
- Top-down control possible but:
  - More complex effects than on rocky shores
  - Not general: refuges
    - Burrowing
    - Protection by phanerogams (seagrass beds and mangroves)