Ecosystems & Ecophysiology – Lecture 7

Shallow seas

Objectives

1. Understand the causes of permanent, seasonal and daily thermoclines in seas and oceans, and their ecological consequences.

2. Describe the classical pelagic food web and the microbial loop.

3. Know the distribution and structure of kelp beds and forests, and the factors leading to the formation of barren areas by sea urchins.

4. Describe the distribution and growth of coral reefs, and explanations for their high productivity.

5. Compare the productivity and utilization of energy from phytoplankton, kelp, seagrass and coral reefs in shallow seas.

Shallow seas

■ These extend from the sublittoral to the edge of the continental shelf, up to about 200 m deep. Below this the sea floor slopes away steeply as the continental slope, to the ocean floor 4-6 km down (Lecture 8)

Ocean has volcanic mountains, may be underwater, emerge, or subside again below the sea. Form isolated shallow seas, important for corals

Shallow seas may extend up to 750 km from shore. More productive than oceans, 90% of commercial fisheries are on continental shelf. Partly due to sediment, OM & nutrients from land

But also to greater mixing of nutrients into the photic zone. To see why this is we need to look in detail at thermoclines in the oceans

■ Seas & oceans are thermally stratified in the same way as lakes, warm less dense water on top of cold, dense water. Seen this slide in Lecture 4

But there are different thermoclines, confusing if you use separate limnology & marine biology texts. Oceans may have three thermoclines:

1. The major thermocline in oceans is the permanent thermocline (P), at about 500 m. P is present all year round, separates mixed/surface layer from deep water

■ P is the only thermocline present in winter in temperate areas. Generated by solar heating of surface waters in tropics, deep as constant hot conditions & mixed to that depth by storms

This mixed layer then spreads from the tropics by surface currents, generated by wind (Lecture 8), gradually cooling. Internally mixed, but stays separate from deep cold water

2. A seasonal thermocline (S) develops in spring and summer in temperate areas. Shallower, at 10-30 m. S is from the heating effect of the sun on surface waters, which have cooled since they were in the tropics

S is the thermocline equivalent to that seen in temperate lakes, where it is called "the thermocline". In marine biology "the thermocline" means P

3. A daily thermocline (D) may develop in hot calm weather, where hot water at surface is not mixed down by waves during the day, but disperses at night. This is at 1-3 m, and only seen in summer, not important

In autumn daily & seasonal thermoclines break down & oceans are mixed as far down as P. So temperate ocean is similar to a combination of lakes:

P ≡ thermocline in meromictic lake, deep & permanent, never mixed across.
S ≡ thermocline in monomictic lake, one mixing period (without ice cover)

■ Thermocline diagram on HO (16) shows:

1. (A) Seasonal thermocline, in summer but not winter, at 50 m in temperate oceans
2. (B) Permanent thermocline at 500 m, with deep cold water in all areas, & surface water warmest in tropics, & coolest in polar areas (high latitudes)

Both S & P are significant in preventing nutrients reaching the photic zone. P is more important because it is permanent, nutrients only available in few places where deep water comes to the surface (Lecture 8)

So P thermocline responsible for low nutrient availability in oceans. Key feature of shallow seas is that depth less than P, so only S can occur

■ Seas are more productive than oceans as nutrients from sediments are available in photic zone, at least once a year in autumn/winter:

Phytoplankton, tropical oceans	4-40 g C m^{-2} yr^{-1}
Phytoplankton, continental shelf	100-230
Kelp forest	600-2000
Seagrass	1000-4000
Coral reefs	1500-5000
Farmland	500-700
Tropical rain forest	500-1600

Apart from mixing, the main feature of shallow seas is that light may reach the bottom. Primary production by benthic macrophytes (kelp, seagrass) or symbiotic algae (corals) is usually > phytoplankton

Plankton

■ Traditional division was between phytoplankton (photosynthetic unicellular plants, diatoms, dinoflagellates, colonial cyanobacteria), & zooplankton (multicellular animals), giving classical pelagic food web

Small zooplankton grazed the phytoplankton, & larger predatory zooplankton ate those. Finally the swimming nekton (fish) ate the large zooplankton. This scheme covers the "net plankton", literally those caught in nets, > 20 μm

Much of the OM in the sea is DOM, from:

1. Leakage from phytoplankton – 15-25% loss from algal cells.
2. Damage to plankton during predation, & to bacteria by viruses.
3. Chemicals released by organisms, such as mucus.

■ Traditional view was that this energy was lost, not used by organisms. Now known that there is smaller plankton not caught by nets. Incorporation of DOM into the food web by these is known as the microbial loop

Picoplankton (0.2-2 μm), bacteria utilise DOM, also single cyanobacteria cells, photosynthesise. Nanoplankton (2-20 μm), flagellate & ciliate protists, consume picoplankton

Up to 50% of energy flow in pelagic food webs is through the microbial loop

Plankton production reaches the sea floor by falling through the water, as FPOM detritus. Available to benthic filter & deposit feeders

Bed of most shallow seas is soft sediments, sand & mud, no plants if water is deep or turbid, animals mostly infauna.

Similar to soft shores, except no disturbance from waves & less physical stress. No desiccation, constant salinity, smaller temperature fluctuation. So benthos has higher species diversity than on shore

More on plankton & benthos in Lecture 8. Now look at other productivity in shallow seas – macrophytes (kelp & seagrass), & coral reefs

Kelp

■ Very large brown macroalgae, form forests (with floating surface canopy, e.g. giant kelp *Macrocystis*) or beds (without canopy, e.g. *Laminaria*)

Occur on hard subtidal substrates, at depth up to 20-30 m. Need light to reach bottom when young, maximum of 30 m in clear water

■ Distribution is in cold temperate regions (HO 14). Main genera are L=*Laminaria* (N. Atlantic & Japan) & M=*Macrocystis* (rest of world)

Need cool water & high nutrients. All nutrients taken from water despite very large size, depend on water movement to avoid nutrient depletion

Not in warm temperate or tropical seas. Extend further towards equator on west coasts of continents, due to cold currents (Lecture 8). Opposite pattern to coral reefs (later), more on east coasts due to warm currents

Very productive, 1-2 kg C m^{-2} yr^{-1}, several times that of phytoplankton per unit area. Growth rates up to 50 cm day^{-1}

■ Individual plant has holdfast, stipe, pneumatocyst or float, and one or more blades. Float keeps the blade near the surface for photosynthesis. Range of morphology (HO 14)

Perennial, grow from holdfast if damaged in storms, live for up to 7 years. Few herbivores consume them (fish & sea urchins), only 10% grazed, most production consumed as detritus or DOM

■ Form a complex 3-dimensional habitat. Structured in the same way as terrestrial forests in several strata (vertical zones), also horizontal zonation of species away from the shore (HO 15):

1. Small filamentous & coralline algae, tolerate low light
2. Bottom canopy algae

3. Understory kelps, *Laminaria*
4. Midwater & surface canopy kelps, *Macrocystis*

Killed by wave action (storms may destroy 90% of plants), nutrient depletion (especially nitrogen), high temperatures (El Nino). Major biotic influence is grazing by sea urchins, may create barren areas in kelp forests

Caused by change in feeding behaviour of sea urchins, from detritus to living plants, not population explosion

Due to hydrographic conditions (HO 15). Favourable conditions (bottom HO / right slide). Low storms & low temperatures, gives high biomass & recruitment of kelp, & high abundance of drift (detritus)

Urchins eat detritus not living plants (low grazing activity), increasing the recruitment & biomass of kelp. Stable state of kelp area

Kelp may be killed by severe storms or high temperatures, gives low biomass & low recruitment of kelp

Few plants to trap detritus, so urchins consume living plants (high grazing activity), gives low recruitment of kelp & keeps biomass low

Stable state of barren areas. Conversion of barrens to kelp needs high recruitment, swamps grazing ability of urchins, or predators of urchins such as sea otters

Seagrass

Flowering plants (not true grasses) adapted to permanent immersion, pollen dispersed by water. Form dense carpets with up to 40,000 blades m^{-2}, extensive beds in temperate & tropical areas

Long straplike leaves & creeping rhizome (horizontal stem, below surface), from the sublittoral down to 50-60 m in clear water

Stabilise soft sediments. Dampen wave action & increase sedimentation. Higher OM than surrounding sediments, anoxic below a few mm

Occupy a wide temperature range, *Zostera* in Arctic Circle at 2-4^{o}C, up to 28^{o}C. Also tolerant of brackish water, often found in sublittoral of estuaries

High productivity, 1 kg C m^{-2} yr^{-1} for temperate eelgrass *Zostera*, up to 4 kg C m^{-2} yr^{-1} for tropical turtle grass *Thalassia*, > 10 x phytoplankton productivity. Rooted, obtain nutrients from the sediment

Few animals consume while living, some fish & urchins, Green turtle, Canada geese. Most consumed as detritus, within the beds or exported to the seas

Coral reefs

■ Greatest biodiversity per unit area of any aquatic ecosystem, account for 4-5 % of all species. High species diversity of fish on reefs, > anywhere else

Similar biodiversity to tropical rain forests. In both these ecosystems the physical structure is produced by organisms – coral polyps (Cnidaria)

Global significance, half of calcium entering the oceans each year is taken up as calcium carbonate ($CaCO_3$) by reefs. Each Ca combines with one molecule of CO_2 and reefs remove 700 x 10^9 kg of carbon per year

■ Distribution of reefs in shallow tropical seas. Most within 20^{o}C mean surface temperature isotherm, none where annual mean < 18^{o}C

Not on west coasts where there are cold surface currents. Note opposite distribution pattern to kelp (HO 14)

Some corals do occur in temperate & polar waters, but don't form reefs. Reef forming corals have algal symbionts, zooxanthellae, yellow / brown pigments

Therefore limited by light and water depth, as photosynthesis is a major energy source for the coral polyps. Depth maximum 70 m, usually < 25 m. Down to point where light is 1-2 % of surface level

Coral polyps tolerate hypersalinity up to 42. Not low salinity (estuaries break reefs) or sediments which clog feeding mechanism (absent from turbid water). Limited sediments trapped in mucus & removed by cilia

Sensitive to high temperature, often lethal level is only just above usual. Killed by severe El Nino events

■ Form fringing reefs next to land, barrier reefs separated by a water channel, & atolls surround lagoons. Charles Darwin's theory of atoll formation, from fringing reefs around subsiding volcanic mountains

Reef growth matches subsidence, keeping corals in the light. Some submerged mountains 100s-1000s m below the surface have remains of reefs on, subsided too fast

Pacific reefs old, 1,300 m of reef limestone above volcanic rock (proves Darwin's hypothesis) in Marshall Is, 60 million years coral growth. Atlantic reefs young, only 10-15,000 years old, since last ice age

Reefs have very high productivity compared to tropical oceans, 1500-5000 *vs* 20-50 g C m^{-2} yr^{-1}

How can reefs be so productive, when the surrounding waters are not? Especally atolls, isolated in the ocean with no land mass nutrients

■ Many ideas include:

1. External sources such as upwelling – but this is usually of cold water.
2. Tight nutrient recycling within the reef. Internal nutrient cycling between polyps & algae. Macroalgae coralline, so detritus not washed away.
3. Nitrogen fixing cyanobacteria. Free-living *Calothrix* & symbiotic forms in sponges. Reefs have greater N fixation than any other natural community.
4. High extraction efficiency from the water flowing over the reef, even though this is poor in nutrients.
5. Nutrients extracted from POM and DOM consumed by reef organisms - polyps & bacteria.

Bacteria use DOM in water & POM from dead reef organisms. High bacterial populations in lagoon. Total bacterial production on reef may be 0.6-1 x total reef primary production

Utilisation of the reef bacteria not known, may be similar to the microbial loop in plankton

Whole reef is an efficient biofilter, extracting nutrients from the water. Predation by polyps only accounts for 5-10% of reef energy input, most is from zooxanthellae. Corals feed for nutrients rather than for energy?