Ecosystems & Ecophysiology – Lecture 8

Oceans

Objectives

1. Understand the generation of surface water currents by prevailing winds, deflection of winds and currents by the Coriolis force, and the formation of oceanic gyres.

2. Know how deep ocean currents are generated, and the location and significance of upwelling zones.

3. Understand what is meant by the “paradox of the plankton”, and describe some explanations of this paradox.

4. Describe the physical conditions and sources of energy in deep water, and adaptations of some pelagic and benthic animals.

5. Know the distribution, characteristics and faunas of hydrothermal vents and other reducing environments on the ocean floor.

Oceans

■ Continental shelf is on seismically passive margin of continental plates. Slide over oceanic plates where they collide from continental drift, less dense

Continental slope down to abyssal plain, depth of 4-6 km. On the active (seismic) margin there is no continental shelf, & a deep ocean trench, maximum 11 km in Marianas Trench

Three major environments in the oceans:

1. Surface layer, above the permanent thermocline, top 500 m.
2. Deep water, below the thermocline, cold & dark.
3. Benthos.

Properties of surface & deep water depend on ocean circulation. Water currents caused by prevailing winds, over long periods, not short-term like waves. Pattern depends on atmospheric circulation

■ Solar energy is maximal at the equator, warms air which rises and diverges towards the poles. Causes winds at surface moving towards the equator to replace the rising air

■ Opposite happens at poles, coldest region, air sinks and moves towards equator as surface winds. Air circulation is completed by downwelling at 30^{o} latitude (N & S), and upwelling at 60^{o} latitude - Hadley cells

■ Surface winds are deflected by the rotation of the earth, the Coriolis force. Imagine sitting at the north pole & throwing a ball to a target on the equator. By the time the ball arrives, the target has moved to your left

So the ball appears to be deflected to the right along a curved path, relative to the thrower and to the ground

Coriolis force is an imaginary force that affects any freely moving body on a rotating object. Deflected to the right in the N & to the left in the S

■ So surface winds don't approach the equator from the N & S, but deflected right (NE trade winds) or left (SE trade winds)

From $30\text{-}60^{o}$ latitude surface winds are away from the equator, deflected right or left to form the westerlies

■ Surface water currents produced by friction of the prevailing winds on the sea. Coriolis force also acts on the water, the surface is deflected at 45^{o} to the wind, to the right in the N & to the left in the S

■ Deeper water layers also move due to friction with those above, & each is deflected, forming a spiral. Overall result is that the layer of water affected by the wind (Ekman layer) moves at 90^{o} to the wind

■ Surface water currents therefore form a clockwise pattern (gyre) between equator & 60^{o}N, and anticlockwise gyre between equator & 60^{o}S

Causes warm currents on E coasts of continents & cold currents on W coasts, already seen importance for distribution of kelps & coral reefs

■ Surface water is warmed at equator, this is the source of the permanent thermocline. The surface water cools as it moves towards the poles, eventually density difference lost

■ So permanent thermocline overturns at poles, surface water sinks to bottom, spreads along the ocean floor as deep current

Deep water is Antarctic bottom water (AABW) from Weddell Sea, or North Atlantic deep water (NADW), not as cold so overlies AABW

These deep currents very slow, water molecule spends 250-500 years in deep before rejoining the surface circulation

Some deep water comes to surface at poles to replace sinking surface water. This has many nutrients from decomposition, gives high productivity

■ Deep water also upwells in 2 other areas:

1. Along the equator. N and S equatorial surface currents diverge due to Coriolis effect. Replaced by equatorial upwelling of deep water

■ 2. Where surface current diverges from coast next to deep water, gives coastal upwelling. Occurs on the west coasts of N & S America & Africa. Needs a wind towards the equator

■ Map shows these zones of upwelling of deep water, equatorial & coastal

■ Upwelling zones have high productivity, seen in satellite measurements of global primary production (HO 18). Note high values in high latitudes, along W coasts, & equator. Log scale, blue $\rightarrow$ green = $\times$ 100

Open ocean at centres of gyres has very low productivity, as nutrients fall below the permanent thermocline & are not replaced

Apart from nutrient distributions, the other major consequence of ocean circulation is that deep water is very cold & well oxygenated. Comes from the poles, oxygenated at surface, & high saturation level as cold

So unlike deep lakes (anoxic), the deep sea is well oxygenated. Oxygen is used by benthic organisms, but they are few so not depleted substantially

Surface layer - plankton

■ Nitrogen is the main limiting nutrient in sw, diffuses only slowly across the thermocline, so used up where no upwelling. Phosphate also at low levels, also depleted at the surface

Phytoplankton not necessarily concentrated at the surface for maximum light. May be maximum chlorophyll concentration in slightly deeper water to intercept nutrients lower down

■ Many different species of phytoplankton, 40-50 diatoms in oceans & lakes, plus other groups. An ecological puzzle is how phytoplankton can be so diverse. Hutchinson (1961) classic paper, “the paradox of the plankton”

Autotrophic plankton all use light and compete for the same nutrients, in a featureless medium, no microhabitats. How can they coexist?

Competition theory predicts that a few species would outcompete the others. Two types of explanation possible:

Equilibrium explanations:
1: Symbiotic relationships, dominant competitors need accessory nutrients from others so cannot exclude them

Three B group vitamins needed by phytoplankton, thiamine, biotin & B_{12}. But 3 vitamins cannot explain coextistence of 50 species

2: Every species is limited by a different nutrient. Could explain up to about 6 species. This explanation does predict greater diversity in oligotrophic areas, as more nutrients potentially limiting, as observed

Non-equilibrium explanations:
3: Continual reversals of competition as conditions change - of light, temperature, nutrient levels, water chemistry

4: Complete competitive exclusion would take too long, with the vast population sizes of phytoplankton

5: Biotic interactions with grazing zooplankton of different types

6: (In fw). Plankton are doomed descendants of benthic species, e.g. diatoms & cyanobacteria, the real competition occurs on solid substrates which are diverse & allow coexistence

Probable solution is a combination of factors rather than one dominant process. Species can coexist as long as their optimum conditions occur with sufficient frequency & duration

■ Can see some of these factors in seasonal succession of phytoplankton, as in lakes (HO 19). Properties of different groups in HO 17

One or a few species dominate for a while, then replaced, same pattern repeated annually. Successions differ from those on land, no climax community (as in hydrosere), & not due to organisms modifying environment

Not simply due to temperature as species may recur at different temperatures. Also, temperature & nutrient levels in sea change more slowly than phytoplankton species

■ Partly due to different light requirements. Dinoflagellates photosynthesise best at high light levels, green algae at lower light levels, & diatoms between

■ Another factor is biological conditioning of sw by metabolites, either positive (vitamins, above) or toxins. Toxins produced by dinoflagellates inhibit other phytoplankton, e.g. in red tides

Water turns brown/red from cells, toxin levels high enough to kill other phytoplankton, dangerous to humans when concentrated by filter feeders (mussels). Up to 20,000 deaths yr^{-1}, similar to snakes

Red tides known for a long time, bible describes waters of the Nile turned to blood. Red Sea named for frequent red tides

Grazing by zooplankton recycles some nutrients in surface water, but eventually lost as OM falls through the permanent thermocline

Deep water
Conditions very constant, no diurnal variation. Little seasonal or geographic variation, so inhabitants widely distributed. High pressure, completely dark below 2 km, salinity constant (34.8), cold –2 to +2 ^{o}C

Main energy input in deep ocean is the rain of detritus, “marine snow”, faeces, carcases & larval skins

Supports a low density of fish in deep waters. Large eyes & silver to reflect light at higher levels, enough light to see but not photosynthesise

Reduced or absent eyes & black colour in very deep water. Crustaceans red, as bioluminescent light is blue, not reflected by red animals

Other familiar adaptations, bioluminescent organs, to camouflage against dim light from above, or to startle predators, illuminate prey, or signal. Large mouths & recurved teeth to consume anything they encounter, prey scarce

Benthos
■ Ocean floor is soft sediments, of terrestrial origin near land, otherwise biological origin (oozes), calcium carbonate or silica from plankton shells. Animals often have long legs / stalks to elevate above the ooze

Most marine animal groups found there (no plants). Most are small & fragile, smaller than shallow water relatives. But some show gigantism, e.g. 42 cm isopod. Due to high longevity & slow growth as in cold seas?

80% are deposit feeders, also scavengers & predators. Filter feeders scarce as little FPOM in water & very slow currents, active filtering is uneconomical

Diverse community as many rare species, compared to shallow water dominated by fewer abundant species. Three hypotheses for high diversity, probably a combination of all three:

1: Stability-time hypothesis. Stable environment, persisted for long time, so evolution of narrow niches

2: Disturbance hypothesis. No competition as animals are all scarce, limited by generalist predators (as predation maintains diversity on rocky shores)

3: Area hypothesis. Species diversity is related to area. Deep sea benthos diverse as it is the most widespread habitat, 42% of earth

Hydrothermal vents

Discovery over last 30 years exciting, as it breaks the rule that all life on earth derives its energy from the sun through photosynthesis. (Including detritus falling to the ocean floor)

■ Hydrothermal vents areas where hot water emerges. Mineral content supports chemoautotrophs, bacteria that generate energy from reduced chemicals

1. Black smokers, > 350^{o}C, water black from metal sulphides. (High pressure prevents boiling).
2. White smokers, 30-350^{o}C, white from barium sulphate.
3. Warm seeps, 4-30^{o}C.

Other benthic reducing environments are:

4. Cold seeps, water takes up chemicals but not heated.
5. Whale carcases.

■ Hydrothermal vents associated with sea floor spreading, at centres where new crust being formed. Distribution around tectonic plates

Sea water enters cracks in rock, heated by new crust above magma chamber, the rises by convection, draws more water in.

Limited lifespan (15-25 years?) as magma chamber is cooled by the water. Inactive vents found, surrounded by remains of vent animals. Also changes in fauna at vents revisited after 5 years, due to changing conditions?

Chimney formed as sulphides precipitate out of water where it cools on meeting cold ocean, up to 10 m high. Warm seeps where hot water is diluted by cold ocean water before emerging

Cold seeps don’t always correspond to edges of tectonic plates. Where reducing chemicals such as methane given off

Whale carcases on ocean floor recently discovered as another reducing environment. Significant as possible stepping stones between vents

Calculate from whale populations & decomposition times that if randomly distributed, there would be whale carcases at intervals of 10-25 km. Animals can disperse between vent fields 100s km apart

■ Dominant animals at vents are clams, mussels, or vestimentiferan worms e.g. *Riftia* (polychaete family, formerly Phylum Pogonophora, no mouth or gut). 443 species found so far, 82% endemic to vents

Seeps have different fauna, 211 species, 13 shared with vents. Greater diversity per seep than per vent, perhaps because they persist longer?

Food web has 5 pathways:

1. Bacteria in plume water, 10^6 l^{-1}, their productivity > surface waters. Abundant plankton in plume feed on bacteria.
2. Filter feeders consume bacteria & plankton.
3. Grazing on bacterial mats.
4. Symbiotic bacteria in dominant animals, worms, clams & mussels.
5. Scavengers & predators of the others.