Ecosystems & Ecophysiology – Lecture 6

Coasts

Objectives

1. Describe the generation of waves by the wind on open water, and their action at the coast.

2. Understand the generation of tides by the moon and sun, and the periodicity of high & low, and spring & neap, tides

3. Know the properties of soft shores of different particle size, and the discontinuity of faunas between soft and hard shores.

4. Describe the pattern of zonation of a typical temperate rocky shore, including the levels occupied by some common organisms.

5. Understand that the upper limit of each zone is determined by physiological tolerance, while the lower limit is determined by biotic interactions.

6. Know the major physical stresses on rocky shores, and the effects of wave exposure on zonation.

Coasts

■ Coastline or intertidal, between high & low tide levels. Periodically covered by sea (immersed) or exposed to air (emersed)

Small extent but important for biological study & harvesting as easy access. Not as productive as shallow seas as periodically emersed, but often high biomass, as many predators excluded by exposure

■ Most important determinants of community structure on coasts are substrate type, and water movement by waves & especially tides. Physics complex, not expected to know more than in lectures

Waves caused by friction between wind & sea, size proportional to wind speed, distance over which wind acts (fetch), & duration of wind

Water molecules move in a circular orbit as a wave passes, wider near the surface. No movement below L/2 where L is the wavelength, distance between crests. Waves in deep water transfer energy, not matter

In shallow water (< L/2) orbits become elliptical and slowed near the substrate. Wave height (H) increases, wavelength decreases

When H/L is > 1/7 the wave breaks, exerts drag force on substrate. Velocity of water hitting shore is 7.7 m s^{-1} for 3 m high wave. Compared to tidal velocity up to 5 m s^{-1}, similar to a fast river

■ **Tides** caused by the gravitational attraction of moon & sun. Moon pulls water towards it, creates bulge on earth facing moon

But earth-moon system is itself rotating around its common centre of gravity, creates apparent centrifugal force away from the centre of gravity. So also bulge of water on the earth facing away from the moon

The earth rotates once in 24 hours, so these two bulges (high tides) would move around the earth with 12 hours between, if the moon had a constant position relative to earth

■ But the moon is orbiting the earth, with a period of about 29 days. Moon moves in the same direction as the earth's rotation, so this delays high tide experienced at any point on earth – it has to catch up with the moon

So tidal cycle has period of 24.8 hours, high tides 12.4 hours apart

■ The sun also has a similar effect. Much larger but also much further away, net effect is a force 46% as large as that of the moon. Height of high tides varies, depending on positions of sun & moon

When sun, moon & earth in line (new moon, dark), pull of sun & moon added together, gives large tidal variation of spring tides (spring up, not season)

When sun, earth & moon perpendicular, sun & moon act in opposition, small tidal variation or neap tides (moon has larger effect so still some tide)

When moon in line on far side of earth (full moon, bright), gravitational pull of sun added to centrifugal force from earth/moon system, spring tides again

■ So two spring tides in the lunar month of 29.5 days, about 15 days apart. Note that Dobson & Frid use a different lunar month of 27.3 days

Because there are two lunar months, & they chose the wrong one. For astronomy, the orbit of the moon around the earth in relation to the fixed stars is 27.3 days, the sidereal lunar month

See return of moon to original position in relation to universe (fixed stars), the dashed line. But the earth has itself moved around the sun in those 27 days

Takes a further 2.2 days for the moon to return to a position between earth & sun. This is the synodic lunar month, of 29.5 days. This is the one relevant to tidal cycles, which involve lining up the earth, moon & sun

Height of tides also varies with topography. Lower in the Mediterranean as surrounded by land. Higher on coasts which have a funnel effect

■ Importance for coastal organisms is that they are exposed about twice a day, and the level of exposure varies over about 2 weeks

Extreme high water springs (EHWS) is only immersed at high water of maximum spring tides. Extreme low water springs (ELWS) only exposed at low water of maximum spring tides

Above EHWS is the supralittoral, littoral fringe, or splash zone, affected only by spray. Below ELWS is the sublittoral, never exposed

Variation of exposure between these two levels, in the intertidal, eulittoral, or midlittoral. The lowest part of this is the infralittoral fringe. Only neap tide range is both immersed and exposed in every tidal cycle

Substrates

■ The water velocity needed to carry sediments is directly related to particle size. Fine particles of muds are deposited only by slow currents - stones & boulders are carried only by fast currents:

	Size (cm)	Velocity (m s^{-1})
Boulders	> 25	> 3
Stones	6-25	2-3
Shingle	1.5-6	1-2
Gravel	0.2-1.5	0.5-1
Sand	0.01-0.2	0.1-0.5
Mud	< 0.01	< 0.1

■ Already seen mud shores in estuaries & wetlands. There is a continuum of particle size from mud, sand, shingle, boulder & rock

But an ecological discontinuity between soft shores (sand & mud) and hard shores (boulders & rock). Intermediate shingle & stones form a very harsh environment, large particles only deposited in very high energy locations

Drain quickly & detritus carried away so no infauna, and stones moved so no attached eipfauna. So shingle & stones form an ecological desert, giving a discontinuity between communities of soft & hard shores

■ Sandy shores similar to mudflats, no new principles. Main differences are:

1. Larger particles, deposited in higher energy areas (high wave action)
2. Steeper slope, and low stability as particles loose
3. Larger spaces between particles so water drains out at low tide, water table below the surface
4. Larger spaces allow greater permeability, anoxic layers absent or redox discontinuity layer RDL much deeper than in mud
5. Lower organic content so dominant organisms are filterer collectors rather than gatherer collectors

■ There is a zonation on sandy shores, with increasing tolerance of exposure in organisms higher up the shore. 3 zones. High shore zone of amphipod crustaceans (beach hoppers), burrowing detritus feeders

Mid shore has isopods, polychaetes, molluscs, mostly filter feeders. Low shore or surf zone has greatest diversity, including echinoderms & permanent burrows. Animals need to burrow rapidly, or deeply, as sand unstable

Low primary productivity, no macrophytes or macroalgae as sand unstable, moved with every tide. Few benthic diatoms, in sheltered areas, migrate to reach the light. No herbivorous macrofauna

Zonation of animals less distinct than on rocky shores, as:

1. Protected from exposure by sand, and water table, so less sharply defined environmental variation
2. Mobile, not attached, so zonation varies through the tidal cycle

Rocky shores

Bedrock - boulders similar, but turned so often at earlier successional stages

■ Typical pattern on a rocky shore (HO 11). Most intertidal species are of marine origin, so fewer at higher levels, more stress from drying (desiccation). Also variable salinity, low from rain, high from evaporation

Typical on temperate shores is upper littoral fringe of black lichens (*Verrucaria*), fungal part stores water. Also cyanobacterial mats (*Calothrix*), mucilage lowers desiccation. Grazed by winkles (*Littorina*), breathe air

Eulittoral zone with barnacles, mussels, limpets & fucoid algae. Infralittoral fringe usually immersed so many predators, dominated by algae. Then sublittoral zone, dominated by kelps (*Laminaria*)

■ Zones extend higher up shore in areas exposed to strong wave action. Waves reach parts that tides alone cannot reach (HO 11)

Other effects of strong wave action: animals have smaller size, thicker stronger shells, simpler shapes with less spines, greater aperture in gastropods for large foot to hold rock when active under water

■ Macroalgae have smaller fronds, without air bladders. (Air bladders float the fronds closer to the light when under water). Wave action limits size of intertidal algae, large ones more likely to be dislodged

Drag force larger in large fronds, but force / area constant. Not the drag that washes them off, but the sudden acceleration as waves hit. Total force (drag + acceleration) increases with frond area, so survival lower for large algae

Zones caused by physiological tolerance & biotic interactions. Also behavioural adaptations to reduce stress

Selection of favourable microenvironment, crevice or under algae. Closing of valves or operculum, or clamp down tightly on to rock, to reduce water loss

■ General model is that upper limit of zone set by tolerance of physiological stress, lower limit set by biotic factors, competition or predation

Stress from high light & solar heating, or cold & freezing, desiccation (& high salinity), exposure to low salinity in rainfall, lower feeding time. These all increase up the shore. Physical stress from waves peaks in mid shore

Biotic interactions from grazing by herbivores, predation, & competition for space among sessile animals & for light among plants

Well studied on rocky shores as experiments possible, removing competitors, excluding predators with cages, transplanting sessile animals above or below their typical zone. Very difficult on sandy shores

■ Classic example is zonation of barnacles, studied by Connell (1961) at Millport, Scotland (field course). *Chthamalus* found higher on shore than *Semibalanus* as adults (on right)

Larvae of *Chthamalus* can settle lower on shore, & larvae of *Semibalanus* at all levels, so zones not due to settlement of larvae (on left)

Chthamalus normally crowded out by *Semibalanus*, but grow to adults if alone. *Chthamalus* moved lower on the shore were overgrown by *Semibalanus*
So lower limit of *Chthamalus* set by competition for space. *Semibalanus* grows faster & overgrows, undercuts or crushes *Chthamalus*

Semibalanus moved to above their normal zone died, so upper limit set by physiological tolerance, desiccation (also of *Chthamalus*). Lower limit by predation by whelks *Nucella,* or competition by mussels

Zonation of plants
■ Similar pattern for algae, *Fucus* spp highest. Then *Chondrus crispus*, Lower limit set by grazing of sublittoral sea urchin *Strongylocentrotus*

Macroalgae are only susceptible to herbivores when small. Once of large size, limited by competition & physical abrasion. Competition among algae shown by weeding expts, also at Millport.

Parts of *Fucus spiralis* zone cleared, colonised by *Pelvetia*, normally from higher zone (HO 11), & *Fucus* sporelings removed. *Pelvetia* grew in cleared areas, but slower than *Fucus* (HO 12); poor competitor, normally excluded

■ Succession in bare areas, e.g. after the pollution by oil and toxic dispersal agents after the Torrey Canyon in 1967 (HO 13). Most shore animals killed, including the herbivores (limpets)

First stage is biofilm of diatoms, microalgae, bacteria, as in rivers. Settlement of algal spores & animal larvae greater on rocks with biofilm than ones without

First macoorganisms were green algae *Enteromorpha* (stippling), then rapid colonisation by *Fucus vesiculosus*, filled circles

Returned to community dominated by barnacles & grazing limpets (open circles, *Patella*) by 1977. Final community controlled by herbivores

Energy inputs
Most energy from grazing on microalgae (including epiphytes) and filter feeding. Suspended food is phytoplankton, most abundant in spring bloom, also zooplankton, & some FPOM from the sea

Microalgae have faster rates of production than macroalgae even though less obvious. Macroalgae enter detritus food chain, not grazed when living

Macroalgae have C:N ratios higher than the 17:1 needed by animals, also chemical toxins. Microalgae have C:N ratios of 6-10:1

Rocky shores accumulate little detritus, swept away & consumed by sublittoral communities, energy exported