Ecosystems & Ecophysiology – Lecture 3

Estuaries

Objectives

1. Compare the pattern of mixing of fresh and sea water in the four main types of estuary.

2. Describe the three main geological types of estuary and their ecological characteristics.

3. Understand why estuaries are dominated by muddy shores, and the physical features of fine sediment substrates.

4. Identify the range of salinity occupied by organisms of freshwater or marine origin, or estuarine specialists.

5. Describe morphological and behavioural adaptations to living in variable salinity and fine sediments.

6. Know the high productivity of estuaries, and the importance of detritus and planktonic and benthic primary production.

Estuaries

Estuaries are where freshwater (fw) and sea water (sw) merge & mix. There are two key features affecting organisms: variable salinity levels from mixing waters, and sediment deposition & movement

Types of estuary
Four types based on salinity profiles – isohalines or contours of equal salinity

1. Salt-wedge. River flow strong, > tidal flows. Fw less dense than sw (1:1.027) so spreads over sea, with a sharp change in salinity (halocline) between the two, close contours (HO 4)

Friction pulls sw into fw at interface, some sw enters wedge to replace this – the residual current (non-tidal). Large rivers - Amazon, Mississippi, Nile

Fine sediment settles from fw, forms delta if sedimentation high. Little marine sediment enters estuary as residual current is low

2. Well-mixed. River flow low, < tidal flows. Tidal flows play the major part in mixing fw and sw

Salinity constant at all depths - vertical contours, no halocline. High turbidity, tidal scouring moves sediment deposits about. Severn, Ganges

3. Partially-mixed. River flow strong, $\cong$ strong tidal flows. Tides force sw upwards, and fw pulled down by turbulence. Thames

Strong residual current so import of marine sediments. Area of high turbidity where fw & sw sediments combine. High suspended sediment at this turbidity maximum, low light & clogs filter feeding

4. Negative. River flow low & high evaporation, only in the tropics. Creates hypersaline water at head of estuary, more dense than sw, sinks and flows seaward along bottom

Replaced by surface flow of sw into estuary. Negative estuarine circulation, e.g. Persian Gulf, Australian rivers, tropical lagoons

Two consequences of estuary mixing pattern:
1. Sediments. Deposition, turbidity, & erosion of sediments in different places & times. May change seasonally - Mekong river is salt-wedge in wet season, partially-mixed in dry season

2. Salinity. Not only mixing to give intermediate salinity, but the position of mixing varies with tides, sw pushed further up estuary at high tide (top)

A benthic organism may thus experience widely fluctuating salinity through a tidal cycle – e.g. crab in diagram from $35 \rightarrow 10$, major physiological stress

Three main types of estuary in terms of geological origin. Most common are drowned river valleys, caused by sinking of the land relative to the sea, gives branching pattern on map

Biological characteristic is flat profile, usually wide expanses of saltmarshes or mudflats fringing the estuary. E.g. Severn, Thames

■ 2. Bar-built or barrier-built estuaries. Form lagoon behind a barrier, as sand accumulates offshore. May form large linked systems, e.g. Wadden Sea in Holland/Germany

Lagoons shallow, usually < 10 m, often < 1 m. Partly isolated from the sea so very variable conditions. Much less tidal disturbance, so macrophytes & high benthic populations present

■ Fluctuating conditions in Caimanero Lagoon, Mexico – can increase in salinity by 2 units/day. Seasonal cycle between hypersalinity (60) & low salinity (10), also large changes in water temperature

Conditions only suitable for *Penaeus* shrimps for part of the year, migrate in as postlarvae, use the high productivity, then leave as adults 5 months later, before hypersaline conditions in summer

■ 3. Fjords, in glaciated valleys. Straight, deep & steep-sided, often with a step or sill at the mouth, left from the glacier, limits entry of sw

Steep sides so no wetlands. Sills prevent mixing of lower water layers, may be depleted of oxygen. Profiles of a Scottish loch show outflow of fw at surface, sill restricts entry of sw

Deep parts of the loch have salinity similar to open sea, but oxygen saturation levels (%) very low. Fjords often with little benthic macrofauna

Salinity

■ Organisms must be adapted to a range of salinity, and rapid change (twice daily). Most species in estuaries are marine, adapted to full sw but tolerant of lower salinity as well (HO 4)

Stenohaline species (narrow salinity range) tolerant down to salinity of 25. Euryhaline species (wide salinity range) are more tolerant – most cope down to 18, some species down to a salinity of 5

Freshwater species usually unable to tolerate salinity > 5, little penetration into the estuary

Salinity range of 7-10 marks a break in faunal composition, neither fw nor sw species can adapt, especially to fluctuations, so few species present

Specialist estuarine (brackish) species occur at salinity of 5-18. Most derived from marine ancestors and can cope with salinity of 35, but restricted by competition or need for fine sediments

Physiological adaptations to salinity in ecophysiology. Animals also show behavioural adaptations to reduce exposure to low and fluctuating salinity

Molluscs can close shells, operculum of gastropods or valves of bivalves, & barnacles shut valves, when exposed to fw. But cannot feed or respire. Similar situation to intertidal species when exposed to air

■ Environmental fluctuations are less marked in the sediment than in the overlying water. Species in burrows are less exposed than epibenthic forms

Some epibenthic fauna (mud snail *Hydrobia*, brown shrimp *Crangon*) burrow during ebb tide to avoid exposure to fw

■ Other species use the estuary just at stages of the life cycle. Seen migratory use of Mexican lagoon to avoid hypersalinity. Eggs & young larvae often the most vulnerable, so many estuarine species breed at sea

Blue crab *Callinectes* migrates from river & estuary to breed in open sea. Larvae carried back in to estuary on the residual current, & young crabs migrate further into estuary to grow

Sediments

The other key characteristic is that estuaries are zones of sedimentation, from fw and possibly also sw

Fine sediments aggregated by flocculation. Clay minerals have –ve charge in fw and repel. The charges are swamped by +ve ions in sw, molecular attraction dominates so particles combine, & deposited

Also biological aggregation. FPOM consumed by filter feeders, lost as faecal pellets of larger size. Inorganic particles bound in mucus & rejected as pseudofaeces before ingestion

Estuaries thus dominated by fine sediments, mud. These are deposited only in areas of low flow, but cohesive once settled. Water velocity to erode >> that to deposit mud

Muds rich in OM and only small spaces between particles. So high bacterial oxygen demand but low oxygen penetration. Leads to anoxic conditions below the surface, often only a few mm down

■ Oxygenated & anoxic layers separated by the redox discontinuity layer (RDL), or redox potential discontinuity (RPD) zone

This is a zone of rapid change in oxygen level and redox conditions. See this in more detail in ecophysiology. Note that:

1. Redox potential goes from positive to negative across the RDL
2. Oxygen decreases to 0, hydrogen sulphide increases from 0, at RDL
3. Sediments pale (brown/yellow) above the RDL, black below

Most infaunal activity is above the RDL where aerobic microorganisms use detritus particles, available to deposit-feeders. Some burrow below the RDL, need to ventilate burrows

Energy inputs

■ **Primary production**. Estuaries are productive, with diverse inputs.

Phytoplankton often higher than fw or the sea, limited by light, not nutrients. Turbidity gives low light penetration, but nutrients often abundant, from fw + sw + recycling within the estuary

Fw often deficient in phosphorus, while sw lacks nitrogen & silica, so mixing increases productivity in estuary

Macrophytes also limited by low light, & macroalgae also by soft sediments. Diatoms & cyanobacteria form mats on surface of mud, also green alga *Ulva*

■ Diatoms live at surface of mud, migrate to surface at low tide to photosynthesise, e.g. *Cylindrotheca*. Extrude mucilage to move, by up to 20 body lengths. Mucilage also increases stability of sediments

Diatoms may make up a large proportion of surface sediments, important productivity. *Hydrobia* snails grow 3 x faster on mud with diatoms than on mud with only bacteria

■ Macrophytes often limited by light in water, but abundant at margins. Difference often described between “American-type” & “European-type” estuaries:

1. American-type estuaries have high primary production by macrophytes, sources of detritus to sea.
2. European-type estuaries have low primary production by macrophytes, sinks for energy.

Cut-down table (HO 3). Original is difficult to compare as different units, millions of kg/estuary *vs* g/m^2. Also shown here as % of energy inputs. Note that input from saltmarshes (macrophytes) much greater in USA

	Europe		USA	
	C[a]	%	C[b]	%
From saltmarshes	0.5	**4.8**	297	**39.6**
Production phytoplankton	0.7	6.7	209	27.9
Production benthic algae	9.3	88.6	244	32.5
Different units:	[a] 10^6 kg C yr^{-1}		[b] g C m^{-2} yr^{-1}	

■ This difference is due to one species of saltmarsh grass *Spartina alterniflora* in America, colonises intertidal mudflats. Other species of *Spartina* confined to upper part of the shore, leaves bare mudflats in Europe

I prefer to view *S. alterniflora* saltmarsh as a wetland (Lecture 5), not as part of the estuary. There is then less difference between estuaries in Europe and America - both have low primary production compared to detritus input

Detritus
In general estuaries are heterotrophic, respiration > production, especially where turbidity limits light. Detritus input as FPOM from rivers & marine sediments. Most fauna are detritivores or their predators

Filterers uncommon despite much suspended FPOM, as inorganic sediment blocks the filtering apparatus. Most macroinvertebrates are collector gatherers. Infaunal, feed on benthic detritus from burrows

■ The lugworm *Arenicola marina* is an estuarine detritivore (see in Practical 5), lives at the bottom of a U-shaped burrow. Keeps tail shaft clear, moves up to defecate at surface

Water current drawn down for respiration – note RDL extends along burrow. Head shaft filled with sediment, kept semi-fluid and oxygenated by water current, sediment ingested

"Gardening" – depression at top of head shaft traps detritus, & oxygenation stimulates bacterial conditioning, increases protein (as in rivers)

■ In other animals appendages gather the surface layer, remove OM and egest mineral particles as pseudofaeces. Annelids use tentacles spread over surface, collect detritus in ciliary-mucous tracts, e.g. Terebellidae

■ Bivalves such as *Macoma* have separate inhalent and exhalent siphons, vacuum up detritus from surface with inhalent siphon

■ Gastropods such as *Hydrobia* rasp up surface of mud, including diatoms

Food webs
■ Estuaries are highly productive, but food webs simple, based on a few tolerant species existing in large numbers

High secondary productivity (of detritivores) supports predators. Also inputs from macrophytes, algae, plankton, & anaerobic food chain (Lecture 13)

"Typical estuary" food web (HO 5) based on clear water American estuary or lagoon. Neglects input of detritus from fw or sw

Shows predation by fish. Some permanent resident predators in estuaries, annelids (*Nereis*), gastropods, but most predators are temporary, feed on detritivores & invertebrate predators

Fish at high tide, birds at low tide, in either case energy is exported from estuary. Wintering birds take up to 44% of prey biomass. Birds on Tagus estuary consume 3 tons dry mass/day in winter

■ Does predation determine estuarine communities, or is the physical environment dominant? Some biotic influences clear. Length of bill determines foraging depth in birds, resource partitioning

Thought that birds do not structure the invertebrate communities, but the opposite – invertebrate availability determines the birds present

Experimental exclusion of predators gives only slight increase in prey biomass. Largely because top predators feed on predatory invertebrates, lowering predation on the detritivores