Environmental Studies 30 -- The Global Ecosystem

LECTURE 18. Estuaries

Introduction

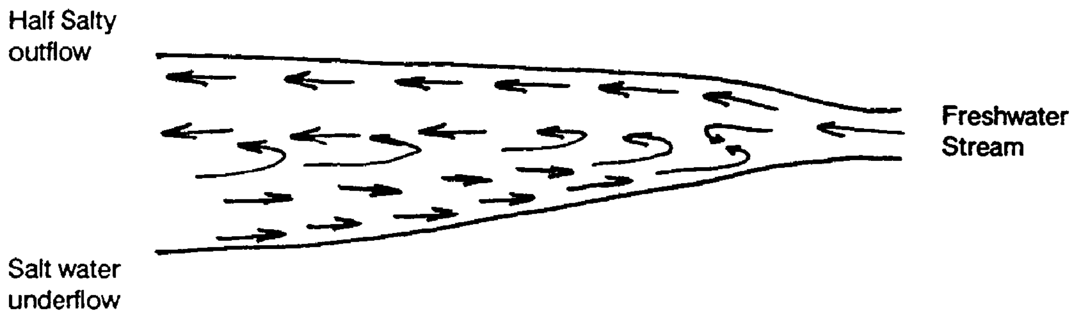
Estuaries are indentations of the coast where fresh and salt water mix over some fairly considerable area. Most estuaries have formed as a result of changes in sea level during the Pleistocene. When sea levels are low, rivers or glaciers cross the continental shelf, carving deep river valleys. When the glaciers melt and sea level rises, these river valleys are flooded to form estuaries and fjords (the deep estuaries of glacially carved valleys). Estuaries are relatively recent and short-lived features by geological standards. In some places estuaries are formed from tectonic activities (e.g. San Francisco Bay) or when sand bars are deposited across the mouths of rivers. The deltas of rivers like the Mississippi which extend into the coastal ocean, have very small estuarine regions.

Most estuaries are filled in by sedimentation very rapidly, perhaps 2-4 m of sediment per 1000 years is average. They are very near to filling as fast as sea level rises, hence the idea that most will be geologically short-lived. Sediments come from the river itself, from sea-sand dropped in the mouth of the estuary, and from biogenic sediments, mostly old carbonate shells of clams and the like. Peat may also fill in some areas, as in the upper parts of the Sacramento-San Joaquin "Delta." In fairly short order, geologically speaking, most estuaries will become projecting deltas, like the tiny Mississippi estuary, unless sea level continues to fluctuate. Sea leavel rise from climate change will drown larger areas and increase the size of estuaries.

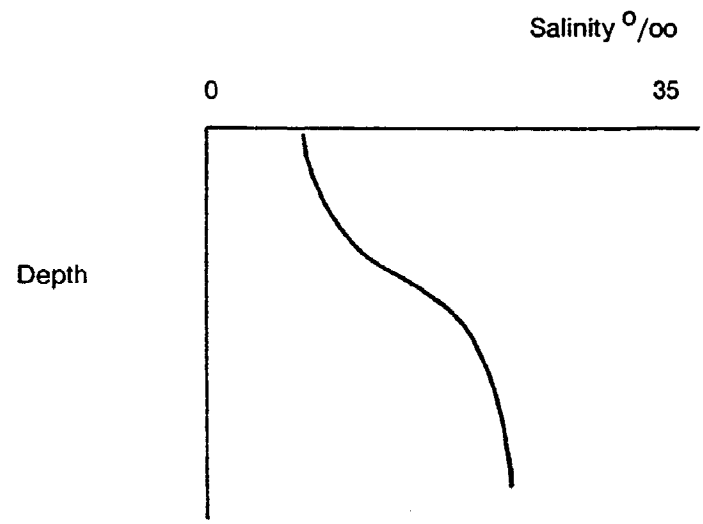
Hydro-climate of Estuaries

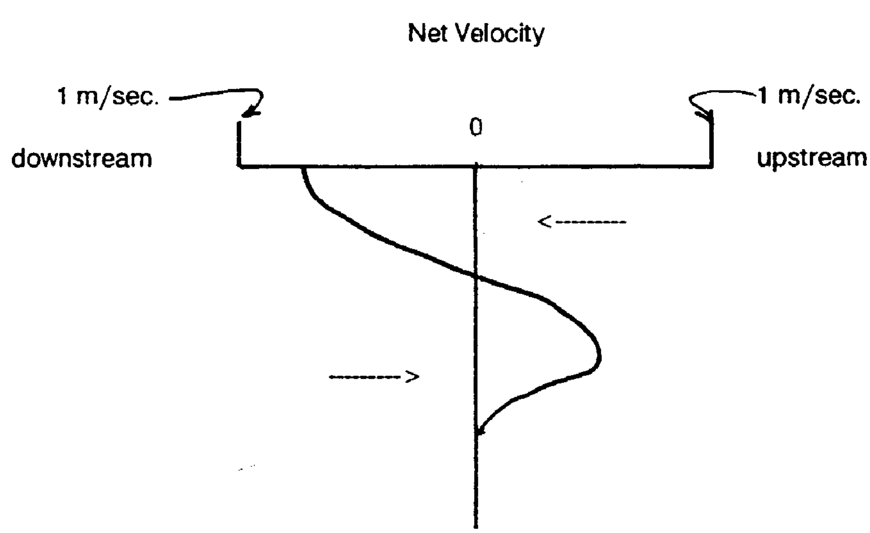
The hydro-climate of estuaries is dominated by salinity gradients generated by the mixing of fresh and salt water. The mixing itself is complex, depending upon the shape of the estuary, the amount of tidal flow and the amount of freshwater runoff. The pattern of mixing currents also plays an important role in the nutrient economy of estuaries. The most common type of estuarine circulation is called two layer flow: Freshwater, lacking much dissolved salt, is lighter than seawater. The seawater thus pushes under the inflowing fresh water and the fresh water pours out at the surface. In the simplest cases, that is all that happens until the fresh water exits the estuary and the turbulence of the open ocean mixes the fresh water with the sea. Generally, however, the inflow and outflow of the tide sets up considerable currents in the estuary itself, which generates enough turbulence to partly, but not entirely, mix the water column. As the deeper salt water mixes with the overlying fresher layer, the rate of outflow increases there, inducing a net upstream current (averaged over the tidal cycle) in the deeper, saltier layer.

Diagrams



Vertical profiles of salinity and velocity at the estuary midpoint:



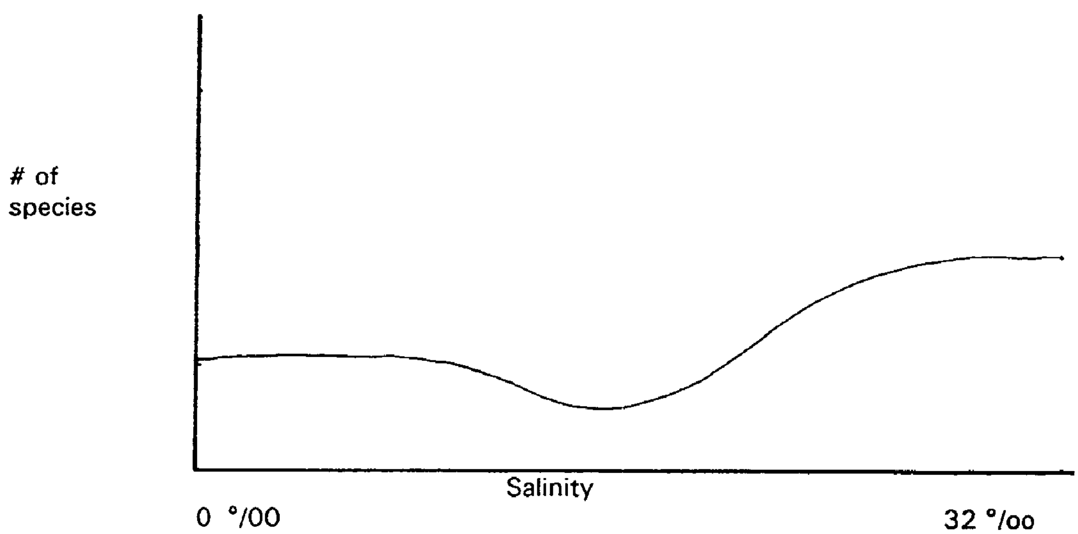


The flow downstream in the upper layer in the middle of the estuary is usually much greater than the river flow alone, because the salt water mixed from depth must flow out at the surface as well.

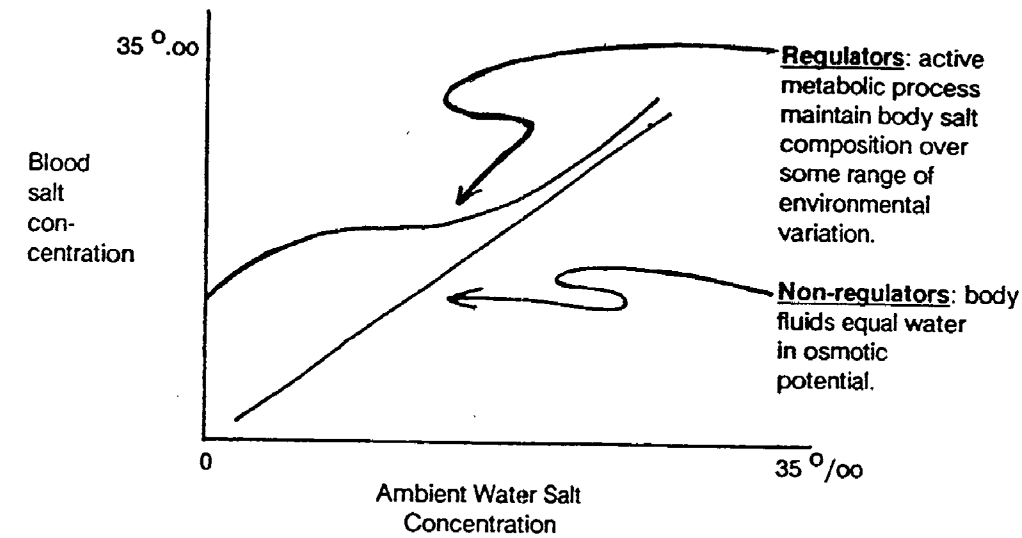
The influence of this circulation on nutrient regimes is that the upsteam flow at depth carries nutrient mineralized on the bottom back up into the estuary. Particles growing in the surface water also tend to be carried back upstream when they sink. Thus, estuaries tend to recycle nutrients effectively and are generally very productive.

<u>Biological Processes in Estuaries</u>

Aside from high production, estuaries are harsh environments. One of the classical subjects is physiological ecology in how estuarine organisms tolerate the extreme ranges of salinity to which they are subjected. During each tidal cycle the salinity of the water changes. During high runoff periods fresh water dominates far seaward, while in droughts saline water reaches deep toward the back of the estuary. Thus the typical estuarine organism is subjected to rather severe osmotic stress. This is particularly true in the middle reaches of the estuary. As a consequence of the difficulty of adapting to these fluctuations, diversity in the middle reaches of estuaries is quite low. In addition estuaries have large temperature fluctuations and often have large volumes of mobile sediment (most especially if channel dredges are at work).



Adaptation to fluctuating salinities can be achieved in two ways. First, animals or plants can be active regulators of their internal salt concentrations. Many estuarine species have this capability, but most ocean animals do not. The following figure illustrates the differences:



Second, animals can regulate their exposure to water of unfavorable salinity by behavior or habitat selection. Oysters do this by closing their valves tightly when floods bathe them in fresh water. Similarly, living in sediment partly insulates an animal from short-term salinity fluctuations because exchange of pore water with the overlying water is relatively slow. Thus the infaunal environment is relatively well buffered with respect to salinity compared to the epifaunal.

Interestingly enough, most of the animals of estuaries have mainly marine affinities. As soon as the salt concentration rises above 3-4 o/oo most of the species with mainly fresh water relatives drop out. Many of the salt marsh plants like cordgrass and pickleweed, on the other hand, have terrestrial ancestry.

Estuaries have large amounts of littoral and benthic habitat in comparison with plankton. Plankton probably accounts for the bulk of primary production in most estuaries but littoral areas are important as well. Salt marshes are particularly productive and often export large amounts of detritus. Zooplankton consumers are generally less important in the economy of estuaries than in the open sea (or most lakes for that matter). The large benthic community of suspension feeders competes quite effectively with the zooplankton due to shallow depths and strong mixing.

Negative Estuaries

In some arid and semi-arid regions, large semi-enclosed water bodies which open to the sea have very little freshwater inflow. When evaporation dominates over freshwater inflow, heavier, saltier water is formed at the back of the estuary, and the usual pattern of two-layer flow is reversed. The Mediterranean and Black Seas are examples of this phenomenon on a very large scale. Not surprisingly, the Mediterranean is a relatively unproductive body of water. Nutrient rich water is carried out of the estuary instead of back into it.

Human Uses

Estuaries are among the most intensely and multiply used "biomes" in the aquatic realm. Cities tend to grow up on estuaries because they form transportation nodes, harbors for maritime traffic and rivers for inland movement of heavy cargo. The biological resources are also important. Many fish and shellfish either live exclusively in estuaries (oysters) or spend a significant amount of time in them (some commercial crabs, salmon, sturgeon, stripped bass and many others). The high productivity of estuaries and proximity to markets makes these fisheries especially valuable.

Pollution absorption capacity is another biological/physical resource in estuaries. The engineers dictum "the answer to pollution is dilution" has been widely applied in estuaries. The relatively high mixing and high natural organic matter and nutrient loads in estuaries makes them fairly effective in this role. Unfortunately, few estuaries can dilute or biologically process the waters of huge urban areas without significant detriment to other uses.

Recreation is a major use of many estuaries because they form the major open space resource of a large fraction of the world's industrial cities. Boating, fishing, and scenic enjoyment are difficult resources to measure, but they are important.

Because of the intensity of multiple uses, estuaries in urban areas require difficult and controversial management decisions. Sports fishermen conflict with commercial fishermen, jobs and profits conflict with scenic enjoyment and so forth. Regular newspaper readers in California, especially from the Bay Area, can add to this list almost endlessly. If you ever have the job of managing an estuary, put a cardiologist and a psychiatrist on retainer!

E.S. 30 Peter J. Richerson

Lecture 18: Discussion Questions

1. How would you expect the depth of an estuary to affect the degree of mixing of salt and fresh water, holding tidal fluctuations, surface shape, freshwater inflow, and so forth, constant?

2. Most estuarine animals have marine rather than fresh water ancestry. How might some marine organisms get an adaptive head start on freshwater ones as regards invading estuaries?

3. One of the sewage treatment options for San Francisco Bay and similar estuaries is to pump primary treated (that is, nearly raw) sewage into the ocean via long pipes sunk on the ocean floor, rather than to put better treated wastes into the Bay itself. Assuming the costs are similar, what are the other trade-offs involved?