Ecosystems & Ecophysiology – Lecture 9

Extreme aquatic environments

Objectives

1. Understand the concentration of salts in endorheic basins to form saline (high chlorinity) or soda (high alkalinity) lakes.

2. Describe the ecology of saline and soda lakes, including examples of their simple community structure, and the relationship between salinity and species diversity.

3. Know the physical and ecological characteristics of shallow equatorial lakes, and their diurnal rather than seasonal variation.

4. Understand the causes of El Nino – Southern Oscillation events and their consequences in aquatic environments.

5. Describe the ecological characteristics of the Arctic and Antarctic Oceans, and polar lakes.

Extreme aquatic environments

■ Seen all the major aquatic environments. Now look at some extreme cases of these as preparation for ecophysiology

Most extreme aquatic environment is where water absent, temporary pools & rivers. Seen emersion on the coast, which is short duration & predictable. Droughts are long & unpredictable

Temporary water is similar to floodplain, any anaerobic sediments are oxygenated when dry, increases nutrient availability when water returns

Many small pools & rivers in hot arid areas are dry most of the time. Large areas also dry up, example Lake Chad in W Africa, edge of the Sahara. 20,000 km^2 but area & water level fluctuate greatly

Inflow from several rivers but no outflow = endorheic or closed basin. 92% inflow evaporates (evaporation > 2 m yr^{-1}), rest seeps away

Whole lake almost dry every 25 years, as inflow varies. Great variation in extent, with high or low rainfall for a few successive years. Unshaded = Greater Chad, black = Lesser Chad

Unusual as water is not saline. Salts are concentrated in most endorehic lakes as water evaporates. Lake Chad has very dilute inputs, and salts remain in the dry zone, geochemical precipitation, not dissolved when lake expands

Saline lakes

■ Large global volume of saline lakes ≡ fw lakes, but > 70% is the Caspian Sea. With the Aral sea, was part of former Tethys Sea, cut off from Mediterranean by tectonic activity

Main salts in saline lakes are NaCl or $MgCl_2$ – chloride dominated. Soda lakes are dominated by carbonates (high alkalinity), usually in volcanic areas, salts often directly from hot springs

Caspian sea has a salinity gradient from fw at northern end where R. Volga enters, to about 13 at the southern end. This is a stable gradient, unlike estuaries, where it moves with the tides

Caspian has normal fw fauna in north, brackish water fauna in south, unlike more saline lakes which have specialised organisms.

Saline lakes are often hypersaline (> 35), marine species cannot tolerate these conditions, so organisms usually evolved from fw species

Also stable salinity gradient in the Baltic. Marine species e.g. *Fucus* seaweed tolerate salinity down to 5-6 there, compared to 10 in estuaries. Variability increases physiological stress

Saline & hypersaline lakes often show great natural variation in water level and so salinity (inversely). Mar Chiquita in Argentina varies from 2000-5000 km^2 depending on rainfall, salinity 30-300

Many saline lakes now increasing in salinity as inputs are diverted. Aral Sea has 2 rivers, now used for irrigation, volume decreasedby 2/3 from 1960-1990, salinity increased from 10 to 29

Lower species diversity with increasing average salinity. Table (HO 24) shows data for saline lakes in Australia:

Salinity (ppt)	1-10	10-100	100-200	200-300	>300
No. of species	71	36	8	1	0

■ **Great Salt Lake**. Composition mostly NaCl like sw but 10 x as concentrated (simplified from HO 24):

	Na^+	Mg^{2+}	Cl^-	CO_3^{2-}/HCO_3^-
Ocean	11	1	19	0.01
Great Salt Lake	101	6	113	0.2
Dead Sea	25	31	150	trace
Lake Nakuru	3	0.001	1	7
Lake Bogoria	28	0.002	6	58

■ Area of 2,500-6,500 km^2, remains of L. Bonneville 50,000 km^2 in rainfall maximum of 14-16,000 years ago. Map shows minimum area in 1963 (black) & maximum in 1873 (shaded)

Now forms salt flats (speed records). Left salt deposits on land, now being washed into lake. Mean depth 4-7 m, fluctuates by > 5 m. Lake Bonneville had depth of 335 m

■ Algae *Dunaliella salina* & bacteria *Halobacterium halobium* live under salt crust, photosynthesise, give pink colour from carotenoid pigments. These species have worldwide distribution in saline lakes, characteristic colour

Dunaliella has widest range of salt tolerance known, 20-350 (saturated NaCl), optimum is 120

Few other species are present, but abundant individuals. Larvae of the brine fly *Ephydra*. Also one species of fungus and a ciliate protist

Food web based on algae & bacteria. Eaten by brine shrimp *Artemia salina*, filter feeder (Practical 4), tolerates salinity of 10-220. Also worldwide distribution in saline lakes dominated by NaCl

Anostracan crustacean, most other species are found in temporary fw pools that dry or freeze soon after formation, in deserts or polar conditions. Key to success is resistant eggs, hatch after dehydration

■ **Dead Sea**. Most concentrated natural salt lake, high MgCl (HO 24) at salinity of 350 (g l^{-1} so its water is 1/4 solids). Lowest point on earth, –392 m, in Syrian branch of African Rift Valley

■ Connected to Mediterranean in Pliocene 2-5 million years ago, when sea level higher. Main inflow is R. Jordan, high chloride levels, also salt from hot springs. Most salts are from rock salt of the former sea

Rainfall < 100 mm yr^{-1} but evaporation 2 m yr^{-1}. Almost nothing lives in the dead sea, just a few microorganisms including *Halobacterium*

Soda lakes

■ Commonest in Eastern Rift Valley of Africa, where many lakes have high carbonates. Lake Nakuru has high Na_2CO_3, but L. Bogoria (also E Africa) has 10 x higher concentration (HO 24)

■ L. Nakuru fed by 2 permanent & several temporary rivers, plus alkaline springs along shores. Area 36-50 km^2 varies with rainfall, mean depth <0.5 to 3.5 m. Salinity 10-165, organisms have to tolerate wide fluctuations

No macrophytes, phytoplankton dominated by 1 species of cyanobacteria *Spirulina platensis* (found in many soda lakes)

Eaten by copepod *Lovenula africana* & lesser flamingo. Also 5 spp rotifers in zooplankton, & 2 midge larvae in mud. Very simple community

■ Productive, 1.5 million lesser flamingos, also greater flamingos which eat copepods & midge larvae, coarser straining mechanism in beak

Spirulina is spiral filament of cells, 0.2 mm long (HO 24). Flamingos filter for 12 h to obtain sufficient food, 30 l h^{-1}. In mid 1970s fw input increased, lower salinity, *Spirulina platensis* replaced by a smaller species

Too small for lesser flamingo, flew away. Copepods also disappeared, phytoplankton replaced by benthic algae & greater flamingos ate those. Unstable community, sensitive to small changes in physical conditions

Lake Magadi another soda lake, has input from hot alkaline springs at 45°C and pH 10.5. Cyanobacteria on rocks near springs in hot water (HO 24)

Grazed by cichlid *Oreochromis alcalicus*, tolerates up to 41°C. Clear browse line of cyanobacteria shows limit of fish temperature tolerance

High temperature

■ Move on to hot fw lakes. Lake George in Uganda, spans the equator. Non-seasonal river flow from mountains, outflow so not saline, shallow (2.4 m deep) but little variation in depth as stabilised by outflow

■ Temperatures non-seasonal as on the equator. Phytoplankton & zooplankton also constant throughout the year (HO 23)

■ Compare pattern of zooplankton in seasonal lake. *Cyclops* in Loch Leven in Scotland varies greatly compared to *Thermocyclops* in L. George (HO 23)

■ Instead of seasonal variation, L. George is dominated by diurnal cycle. Polymictic lake, shallow thermocline forms each day, overturns at night

Hot water at surface from 10-18 h (HO 22, top). Overturns at 18 h (vertical isotherms) until 10 h the next day

Constant warm conditions allow cyanobacteria *Microcystis* to dominate, forms > 70% of phytoplankton. Cyanobacteria typical of late summer bloom in temperate lake, but continuous throughout the year in L. George

High photosynthetic activity so water becomes supersaturated with oxygen (HO 22, middle), > 200% of saturation level at surface, 70% at lake bed

High rate of photosynthesis by *Microcystis*, cells sink later in the day as they accumulate sugars, avoid strong UV radiation on equator. Chlorophyll a mixed in morning, 180 contour steep, then high values at lake bed (HO 22, lower)

Most herbivores cannot digest cyanobacteria cell walls, pass through gut. Copepod *Thermocyclops hyalinus* is one, dominates the zooplankton

Also 2 species of fish, *Oreochromis niloticus* & *Haplochromis* sp, form 60% of total fish biomass in lake. Secrete very strong stomach acids to break down mucilage (HO 23, see in ecophysiology)

Most nitrogen input in L. George is from fixation by cyanobacteria, more than streams & hippo faeces, important as N is deficient overall (HO 22)

Supersaturation of oxygen in L. George is of no ecological significance. Seen many examples of low oxygen aquatic environments, in muddy shores & estuaries, permanent wetlands, deep lakes

■ The sea is generally well oxygenated by currents. Only anoxic deep water where sills prevent circulation, in the Black Sea and in some deep trenches

Seas & oceans buffered against temperature change by high heat capacity of water. But this constancy means that organisms often have only low tolerance of variation, i.e. lethal levels just above normal maximum temperature

Abnormally high temperatures can cause mortality in the sea, e.g. of kelps & corals by El Nino events

El Nino or Southern Oscillation (ENSO) is an irregular change every 2-10 years, named for appearance of warm water off Peru after Christmas. Due to changes in air & water circulation in the Pacific, but worldwide consequences

Normally hot air rises over Indonesia (equator), the low pressure pulls air west from high pressure in the southern Pacific (SE trade winds)

The south equatorial surface current produced (deflected to the left in S) pushes water to the west, so sea level & the thickness of the permanent thermocline is greater there (HO 20)

Permanent thermocline thinner in the east, allows coastal upwelling of cool water off west coast of S. America

During an ENSO event high pressure over Indonesia stops the trade winds. The sea surface slope of the Pacific disappears as the water flows back east

The permanent thermocline becomes horizontal, & meets the coast of S America. This stops the upwelling of cold water, so nutrient levels decline

■ Warmer water causes mortality of kelp & coral reefs. Low nutrients cause decreased productivity of fish

Fishery of Peruvian anchovies in these waters, declines in El Nino years. Also decline in population size of guano birds that feed on them (HO 21)

Low temperatures

■ Arctic Ocean is mostly enclosed by land, has input of fw from rivers, stratified low salinity surface layer. Shallowest ocean at 1300 m, surrounded by shallow seas, & mostly ice covered

Mediterranean type enclosed system, further towards pole than Antarctic (> 70°N compared to 50-70°N), so less light available. Rarely disturbed by waves as ice cover, so nutrient depletion in summer

■ Antarctic or Southern Ocean is open to other oceans, around a central landmass. Narrow continental shelf, so upwelling of nutrient rich deep water

■ Antarctic has higher productivity, biomass 10 -100 x greater at same depth. Phytoplankton productivity of Antarctic ≡ temperate oceans, as cold but high nutrients. Arctic phytoplankton productivity only 1% as high:

Arctic Ocean	< 1 g C m^{-2} yr^{-1}
Tropical Oceans	4-40
Temperate Oceans	70-120
Antarctic Ocean	100
Continental shelf	100-230

■ Thousands of lakes in the Arctic, as many glacial depressions. Freeze in winter. Lake ice is 2 m thick, but snow is the main block to light, 20 cm snow absorbs or reflects 99% of light

Example is Char Lake, in northern Canada. Mean air temperature –15°C. Free of ice for only 5-6 weeks per year

Ice 1-2 m thick, takes up 20% of lake volume. Water temperature varies from 1-5^{o}C, always well oxygenated, but low nutrients

Mosses dominate photosynthesis, use low light levels & nutrients from sediments (as in low order shaded streams). Low phytoplankton. Zooplankton dominated by one spp of copepod *Limnocalanus macrurus*

45 spp benthic animals + 1 fish arctic char. Productivity < 1% of that of many temperate & tropical lakes

Sunlight under ice is low until snow melts in June, but still sufficient for some photosynthesis by phytoplankton

Antarctic lakes – winters longer & summers colder than Arctic as nearer pole. Cyanobacteria form benthic mats, some green algae, diatoms & mosses. Light levels, photosynthesis & productivity are very low

Only microscopic benthic animals, some tolerate nightly freezing. Zooplankton of anostracan crustaceans, same group as in temporary desert & saline pools, tolerant. Same adaptation, resistant eggs (here to winter)

Conclusion. Organisms can tolerate extreme conditions in aquatic environments. But species diversity low in such areas, simple communities & food webs. Few species can adapt - mechanisms in ecophysiology