Ecosystems & Ecophysiology – Lecture 4

Lakes & Ponds

Objectives

1. Know the geological origin of major lake types.

2. Understand the cause and consequences of thermal stratification, and the patterns of mixing in lakes of different depth and latitude.

3. Compare the nutrient levels and biological features of oligotrophic and eutrophic lakes.

4. Understand how photosynthesis by phytoplankton is measured, and the seasonal patterns in temperate lakes.

5. Know that lakes have a lifespan limited by succession, and the relationship between lake longevity and the endemicity of its biota.

6. Describe the importance of biotic interactions in lakes, especially predation.

Lakes & Ponds

■ Defined as water encircled by land, outflow (if present) small compared to volume. Saline lakes (salinity > 3) & other extreme forms in Lecture 9

Largest lakes are > Wales. Separation of lakes & ponds attempted by penetration of light to bottom, or development of thermal stratification. Best is that a pond could sensibly be waded across

1% of surface in UK is lakes, approx. 60,000 in total, 5500 of them > 4 ha. Major feature is still water, lentic systems, compared to flow of lotic systems

Lake needs a source of water & a depression. Geology is the key, Africa has 20 times greater volume of lakes than S. America, but lower rainfall. Geologically three types:

1. Depressions in bedrock:
    a) Glacial – Northern Europe & North America. Great Lakes of the USA. Low nutrients at first, scoured by glacier
    b) Volcanic – crater lakes, often large inorganic inputs
    c) Tectonic – Rift lakes, where sections of crust sink or rise along faults. Lake Baikal, Russia 1.6 km deep, 1/5 of the worlds fw

■ Often deep. Western Rift Valley, L. Tanganyika, 1.5 km deep. L. Victoria shallow lake (80 m) between raised edges of central section. Eastern Rift Valley has soda lakes with volcanic inputs (Lecture 9)

2. Depressions in sediment, more nutrients available:
    a) Glacial sediments – meres in Lake District
    b) Fluvial sediments – oxbow lakes, isolated bends of river

3. Barrier lakes, usually less permanent:
    a) Inland – landslides, lava flows, ice barriers, glacial moraine
    b) Coastal sand bars – lagoons with fw inflow (i.e. estuaries) eventually become fw if connection to the sea is closed

Most lakes fill depression to lowest point on rim then flow out. Depression only part full in arid areas, forms saline lake due to evaporation

Level in most lakes constant, regulated by outflow. Doubled water flow into L. Victoria in the 1960s raised level by only 2.5 m

■ **Thermal stratification**
The key physical characteristic of lakes, also occurs in the sea. All except very shallow lakes are stratified by temperature

Surface water warmed by absorbing sunlight, density decreases therefore remains at surface (like fw on sw in estuary)

Any more warming also occurs at surface so stratification stable. Warm layer at surface is the epilimnion (fw) or mixed layer / surface layer (sw). Mixed internally by wave action

Then layer of rapid temperature change, the thermocline or metalimnion (fw) with a lower layer of cold water, the hypolimnion (fw) or deep water (sw)

Depth of thermocline depends on:

a) Wave size - waves transfer heat down
b) Water clarity - opaque water absorbs heat in upper layers
c) Duration of calm conditions - gets deeper through the summer

This diagram from the sea, deep thermocline (500 m), usually much shallower in lakes. Temperature difference varies, may be 20 ^{o}C in the sea, or only a few degrees in lakes. L. Victoria 25 ^{o}C on 23 ^{o}C

■ Biological importance is not the temperature difference, but that there is little mixing of water across the thermocline

So may be depletion of nutrients by photosynthesis of phytoplankton in upper layer, and of oxygen by bacterial decomposition of detritus in lower layer

■ Seasonal pattern is dimictic in cool temperate areas, two mixing periods per year (spring & autumn):

a) In spring no temperature difference, vertical isotherm, water well mixed throughout lake. Nutrients & oxygen evenly mixed with depth
b) Thermocline develops in summer, solar heating and low winds. Winds mix upper layer only
c) Thermocline breaks down in autumn as surface water cools and winds increase. Lake mixed again, the overturn
d) In winter reverse thermocline as ice forms at surface, insulates the warmer water below. No mixing as ice shields water from wind

In warm temperate areas pattern is monomictic, single season of mixing as no ice in winter. Thermocline in summer, mixed for rest of the year

Shallow tropical lakes are polymictic, a shallow thermocline develops in day & mixed at night. Deeper tropical lakes are oligomictic, usually stratified, mixed rarely by storms

Some deep tropical lakes are meromictic, bottom waters are never mixed. Permanent thermocline at 200 m in L. Tanganyika not mixed for 10,000 years

■ **Conditions for plant growth**

Light. Little sediment or turbidity in lakes, light restricted by humic solutes or phytoplankton. Dense algal bloom can limit light to top few cm. If light reaches bottom then macrophytes & benthic algae grow

Nutrient status determines productivity in lakes:

1. Oligotrophic lakes have low nutrients, low phytoplankton, clear water, well oxygenated as little detritus to decompose
2. Eutrophic lakes have high nutrients, high phytoplankton or macrophytes, reduced oxygen (even anoxia) if deep

Nutrient status may be assessed by:
1. Nutrient concentrations. Phosphorus is usually limiting so total phosphorus (TP) is the best measure. Includes any organisms in the water
2. Phytoplankton biomass, estimated as chlorophyll a (Chl a), related to total photosynthesis
3. Water transparency, as the Secchi depth D_s (inverse measure, large depth = low productivity)

Measures 1 & 2 lower if macrophytes dominant, 3 varies with inorganic sediments or humic acids. No universally applicable definitions, typical values:

	TP ($\mu g\ l^{-1}$)	mean Chl a ($\mu g\ l^{-1}$)	D_s (m)
Oligotrophic	10	2.5	6
Eutrophic (x 10)	100	25	1.5

Thermocline prevents nutrients in deep water from reaching phytoplankton in epilimnion. Nutrients depleted by phytoplankton until availability becomes limiting, then their populations crash

■ Phytoplankton need N:P ratio of 16:1 by moles (the Redfield Ratio), so either one or the other may be limiting, not both simultaneously. Usually P in fw, although silicate may be more limiting to diatoms

Limitation by phosphorus is shown by availability/demand ratio. Typical values in lakes relative to P=1, e.g. N is twice as available in relation to need as P

P	1	Cu	8
N	2	Mg	16
K	3	Na	64
Ca	5	Fe	900

Schindler (1974) added phosphorus & nitrogen to one basin of a lake, caused algal bloom. Just nitrogen to another basin, no bloom, therefore P limiting. Classic expt suggested P in detergents was a cause of eutrophication

■ Phytoplankton photosynthesis measured by light & dark bottles, water enclosed & suspended at collection depth (same temperature). Bottles suspended for 1-4 hours, not longer else conditions inside change

Light bottle has increase of oxygen from photosynthesis, but also decrease from respiration. Gives primary production or net photosynthesis

Dark bottle has decrease of oxygen from respiration. Difference between change in light & dark bottles is photosynthesis alone (gross photosynthesis)

Energy inputs
Mostly from phytoplankton in deep lakes. Attached macrophytes restricted to shallow water, at edges. Also energy input as FPOM from river

Grazing by zooplankton can consume 30% of phytoplankton per day in summer. Gives nutrient cycling in epilimnion. Then zooplankton numbers fall through low food supply

Benthic organisms mostly detritivores, FPOM input from above as phytoplankton dies, & from river. Chironomid larvae, oligochaetes & filter feeding bivalves. Only anaerobic bacteria in anoxic depths

Typical seasonal pattern of phytoplankton in temperate areas. Limited by low light & temperature in winter

Peak in spring as light & temperature increase, nutrients available from mixing. First (usually highest) peak due to diatoms, decline as they deplete nutrients above the thermocline, especially silica for cell walls

Graph shows bloom of *Asterionella* diatoms (log scale), reduced nitrates but especially silica. This is the limiting factor, causes population decline

Decline of diatoms often leaves reasonable levels of other nutrients, so a second, usually lower, peak of green algae, remove nitrate & phosphate until they too crash

Low phytoplankton in summer, some nutrients from zooplankton. Late summer peak of cyanobacteria, nitrogen fixing so not limited by nitrates, but require high temperatures & decline in autumn

Final peak of diatoms again in autumn as nutrients from the overturn. Decline in winter as light & temperature lower, despite high nutrients

Succession and evolution
Lakes have measurable life spans. Always being infilled, as rivers carry sediments, deposited as flow reduced

Also filled by ecological succession, the hydrosere. Plants lead to accumulation of detritus, as peat. May be fast, East Anglian fens lost their open water a few thousand years after formation

Successional order same as lake littoral (edge):
1. Submerged macrophytes – restricted by light penetration
2. Floating-leaved macrophytes – restricted depth range, by stems
3. Emergent macrophytes
4. Terrestrial herbaceous plants

Then
5. Trees - willow & alder adapted to wet soils. Accumulation of sediments & peat from plants eventually fills the lake depression, covered by trees

6. Final succession may be diverted to *Sphagnum* bog, if precipitation high & drainage very slow. Water table above ground (Lecture 5)

Deep oligotrophic lakes last longest (slow peat accumulation), but even so most are lost in 10^4 or 10^5 years. Lake biota is isolated, destroyed with the lake. Most lake organisms therefore have good dispersal

Resistant eggs, spores & cysts dispersed by wind or birds. Insects are strong fliers (beetles), unlike rivers (mayflies)

Only some tectonic lakes persist, as basins subside. L. Baikal & African Rift Valley lakes ≈ 20 million years old. L. Baikal has bottom sediments 8 km deep, enough to have filled in several times over without subsidence

Therefore high endemicity of organisms with poor dispersal. 1000+ species of gammarid shrimps in L. Baikal, compared to *G. pulex* in UK (Practical 1)

■ Best example is cichlid fish in African rift lakes. Table (simplified from HO 10) shows high level of endemism in lakes compared to rivers in Africa, although the rivers are much older (Mesozoic or earlier *vs* Cenozoic)

	% endemic	Age
R. Zaire	65	Mesozoic or earlier
R. Niger	20	"
R. Nile	20	"
R. Zambezi	0	"
L. Malawi	99	Cenozoic
L. Victoria	99	"
L. Tanganyika	99	"
L. Kivu	73	"

500+ species of cichlids in L. Malawi, all but 4 endemic. Adaptive radiation of mouthparts (HO 9), to very specialised niches. L. Kivu (Rwanda) also ancient, but volcanic disturbance so lower endemicity

Biotic interactions
Lakes (& shallow seas, Lecture 7) are least physically stressful aquatic environments, so biotic interactions important. Best evidence comes from lakes, as discrete systems changed by experiment or accident

■ Depends on lake size - model for snails. Ultimate limitation is calcium content of water, required for shells. Always has high relative importance, no snails where < 5 μg Ca l^{-1}

1. Small ponds limited by disturbance, from drying up or complete freezing. Only support tolerant species, and those best adapted for dispersal
2. Medium ponds determined by competition, as large numbers of snails build up, consume available plant food

3. Lakes determined by predation, large enough to support predators such as fish & crayfish

■ Introduced fish can completely restructure food webs, not just lower numbers of prey. Nile perch *Lates niloticus* (50+ kg) introduced into L. Victoria for fisheries, after large cichlids overfished in 1950s

Introduced in early 1960s, numbers exploded in early 1980s. Biomass curves show increase of *Lates* & decline of cichlids. There were 300 species of endemic cichlids, 200 now extinct or severely endangered

■ 90% of fish biomass in L. Victoria is now *Lates*. Original detritivores & grazers replaced by a crustacean *Caridina* and pelagic cyprinid fish. Original inhabitants, but numbers greatly increased

Original food web complex, native cichlids shown in black, also other types of fish important: lungfish, catfish, mormyrids (elephant's trunk)

■ Now much simplified. *Lates* feeds on *Caridina*, cyprinid & its own young. Introduced species in grey - note no native cichlids important

Successful commercial fishery, 3-4 times greater yield than before, but conservation disaster. E. African fish greatest extinction of vertebrates in 20th century

Conclusion is that biotic interactions can be important in lakes, with predation the dominant factor in structuring communities