Ecosystems & Ecophysiology – Lecture 1

Introduction to aquatic systems

Objectives

1. Understand the terms ecosystem and ecophysiology.

2. Know the chemical and physical characteristics of water that are important for life and aquatic ecosystems.

3. Describe the hydrological cycle and know the approximate size of water compartments and movements on the earth.

4. Know the common measures of salinity, and the major constituents of sea water.

5. Understand the concepts of acidity, alkalinity, solubility, and light penetration, and typical values for natural waters.

6. Describe the major niches and energy sources in aquatic systems.

References

Page *n* in the book of handouts is referred to as (HO *n*). Some of the handouts are complex - the best way to use them is to make simplified versions in your notes

PowerPoint slides are referred to in sequence as ■. These are available on Blackboard at <u>`http://www.bbd.bris.ac.uk/`</u>

The recommended book for the first half of the course is:
Dobson, M. & Frid, C. (1998). Ecology of Aquatic Systems. Harlow: Prentice Hall

Introduction to aquatic systems

Ecosystems & Ecophysiology course deals with the interactions between organisms and the physical environment. Two halves, ecology and physiology

Ecology – "the interactions between organisms and their environment and each other". May be familiar with interactions between organisms in other ecology courses. These are biotic factors – competition & predation

The ecosystem concept (Sir Arthur Tansley, 1935) was developed to include both organisms and their physical environment. The ecosystem is "the integration of organisms and the physical world they share"

The ecological part of this course concentrates on interactions between organisms and the physical environment – abiotic factors

Physiology – study of the functioning of organisms – how they work

Ecophysiology – function in relation to particular environments or niches

Focus on aquatic ecosystems, both marine (sw) & freshwater (fw). These combine a high level of diversity but with common features based on the physical properties of water

Biotic processes can be important locally or in the short term, but the physical environment is the dominant factor in structuring aquatic systems

The hydrogen atoms in water (H_2O) are covalently bonded to the oxygen by shared electrons. Oxygen is more electronegative than hydrogen so the electrons are positioned on average closer to the oxygen nucleus

The water molecule is asymmetric, with an angle of 105^o between the two hydrogens. The molecule is therefore polar, with a slightly negative charge on the side of the oxygen, and a slightly positive charge on the other side

Water molecules form relatively weak hydrogen bonds between each other in liquid water, and as a regular lattice in solid ice. H bonds are 6% as strong as the covalent bond between O–H

Properties of water and similar compounds

		Molecular Weight	Boiling point (^oC)	Specific heat capacity (J kg^{-1} $^oC^{-1}$)
Ammonia	NH_3	17	-33	-
Water	H_2O	18	100	4190
Hydrogen sulphide	H_2S	34	-62	-
Carbon disulphide	CS_2	76	46	1000

Several consequences:

1. Water is a <u>liquid</u>. Similar compounds such as ammonia & hydrogen sulphide are gases at environmental temperatures (low B.P.)
2. Water is a good <u>solvent</u>, forms hydrogen bonds with polar organic molecules and with charged ions
3. High <u>surface tension</u> – organisms can be supported on top or beneath the surface film
4. Regular lattice in ice fills more space, so <u>ice is less dense</u> and floats on water, insulates the surface from further heat loss

Another feature of water is its high <u>specific heat capacity</u>, takes a large amount of heat for a given temperature change. High thermal inertia, temperature fluctuations much lower than in air

■ There are about <u>1.5 billion km^3</u> of water on earth (1.5×10^9), mostly in the oceans which cover 71% of the surface and have a mean depth of 3.7 km

Oceans	96.5%
Glacial ice	1.8%
Groundwater	1.7%
Freshwater lakes	0.008%
Saline lakes	0.006%
Wetlands	0.001%
Atmosphere	0.001%
Rivers	0.0001%

The atmosphere and rivers hold negligible proportions, but are very important for transport in the <u>hydrological cycle</u>

■ Water movements in 1000 $km^3\ yr^{-1}$. Evaporation from the ocean (430) exceeds precipitation (390), E > P. The excess 40 moves to land in the <u>atmosphere</u>, mean duration 9 days

Precipitation on land made up by this 40 plus 70 from <u>evapotranspiration</u> from land (ET = evaporation + transpiration from plants)

Precipitation on land (110) exceeds evapotranspiration (70), P > ET. The excess 40 returns to the ocean through <u>rivers</u>. Mean duration in rivers 18 days

Water movement on land is due to <u>gravity</u>. Three types of water movement in oceans, with different causes: waves, currents & tides

See in later lectures in systems where each is most important. For now, just note that they have different features, especially periodicity & predictability, and can be <u>independent</u> - any combination of them is possible

■ Water composition

Water in the environment has suspended & dissolved materials. Dissolved matter as mg l^{-1} (= ppm, parts per million, for fresh water) or g l^{-1} (= ppt, parts per thousand, ‰, for sea water)

Total amount of dissolved material is the salinity. Practical salinity unit (psu, dimensionless number) = ppt. Can be measured by evaporation, but difficult as some components lost on heating

Or measured as conductivity, as it is the dissolved ions that conduct electricity through water. Siemens (S) cm^{-1}. Fortuitously, $\mu S\ cm^{-1} \cong$ ppm and $mS\ cm^{-1} \cong$ ppt

■ Salinity of the sea usually 34-37, varies with evaporation, or dilution with rain or rivers. Up to 40 in the Red Sea & Persian Gulf

Salinity values

	ppm	
Distilled water	2-4	
Tap water	60-100	
Clean river	<300	
Dirty river	>500	
Sea water	35 000	(= 35 ‰ or 35 g l^{-1} or salinity of 35)

■ Composition of major ions in sw is very constant even if the salinity does vary. 8 most abundant ions make up 99.9% of salinity (by mass)

		ppm	% (by mass)
Chloride	Cl^-	19350	55
Sodium	Na^+	10760	31
Sulphate	SO_4^{2-}	2710	7.7
Magnesium	Mg^{2+}	1290	3.7
Calcium	Ca^{2+}	410	1.2
Potassium	K^+	390	1.1
Bicarbonate	HCO_3^-	140	0.40
Bromide	Br^-	60	0.19
Total			99.9

[ppm for comparison, Cl^- = 19,350]. Sea salt is 86% NaCl but still substantial amounts of other ions, especially $MgSO_4$, Ca^{2+} & K^+

Most elements found in sw, in trace amounts. Nitrate NO_3^- & phosphate PO_4^{3-} are scarce in sw, not in constant ratio with other ions, vary with biological activity

Values are much lower and more variable in fw, defined as salinity < 3. Saline lakes have salinity > 3, in some cases > 35, and may have very different ionic composition

Dissolved gases. O_2 & CO_2 come from the atmosphere, at the water surface, and from biological activity (photosynthesis & respiration). Slow diffusion in water, needs mixing to reach depths

Saturation of O_2 depends on temperature & solutes. In equilibrium with air:

0^oC	14.6 ppm	10.4 ml l^{-1}	(air has 210 ml l^{-1})
10	11.3	8.1	
20	9.1	6.5	
30	7.6	5.4	
40	6.5	4.6	

[ppm given for comparison, 0^oC = 14.6]. Note solubility falls by half from 0-30^oC

The saturation level is the maximum concentration under normal conditions. A lower amount is present if used by organisms, especially bacteria decomposing organic matter. Often show oxygen concentration as a % of saturation

Water can be supersaturated, from photosynthesis – bubbles of O_2 form. Saturation level in sw is 20% less than in fw at the same temperature as solutes lower the solubility of gases

CO_2 is 30 times more soluble than O_2 as a gas (dissolved), and also combines with water molecules to form ions:

$$CO_2 + H_2O \leftrightarrow \underset{\text{Carbonic acid}}{H_2CO_3} \leftrightarrow \underset{\text{Bicarbonate}}{H^+ + HCO_3^-} \leftrightarrow \underset{\text{Carbonate}}{2H^+ + CO_3^{2-}}$$

Most CO_2 in sw is present as bicarbonate ions, replaces dissolved CO_2 removed by photosynthesis as reactions go to the left. So CO_2 much more available than on land (makes up only 0.03 % of air)

Acidity. A measure of the hydrogen ion (H^+) concentration. $pH = -\log [H^+]$. Some molecules in pure water dissociate to H^+ and OH^-, with $[H^+] = 10^{-7}$ mol l^{-1} so pH = 7

Alkalinity is a measure of buffering, the capacity to neutralise excess H^+, usually from bicarbonate & carbonate in solution

Alkalinity does not refer to how alkaline a solution is – even acid water with low pH can have a high alkalinity

Circum-neutral pH range of 5.5 - 8.5 covers most natural water bodies. SW has pH of 8.0 ± 0.2, little variation, strongly buffered by bicarbonate & carbonate

Now acidification by pollution, but some aquatic habitats are naturally acidic. Volcanic crater lakes have pH < 2. Some fw has humic acids from decomposition

High pH is uncommon. Soda lakes can have pH > 11, due to high sodium carbonate (Na_2CO_3) & sodium bicarbonate ($NaHCO_3$) from lava

Energy sources

Photosynthesis. Needs light & CO_2, plus nitrate & phosphate for protein synthesis. CO_2 is not usually limiting in aquatic systems. Plant growth is primary production, by:

1. Flowering plants need soft sediments for roots (seagrass), often not dominant in aquatic systems. More common in wetlands (mangroves). Roots take up nutrients

2. Algae - Macroalgae usually need hard substrate (kelp forest). Microalgae (green algae, diatoms) may be in water (*Chlorella* - green) or on bottom. Take up nutrients from water

3. Cyanobacteria (blue-green algae) in water or on bottom (mats in Shark Bay). Some fix nitrogen, independent of nitrates in water

Light is always less available in water than in the air above. 20-98.5% of light is reflected from the surface, depending on the angle of incidence. Much reflected at low angles, important at high latitudes where light scarce anyway

The rest is absorbed or scattered by the water, dissolved organic matter & particles, or by organisms themselves. In water with dense algal bloom light may penetrate only a few cm

Penetration depends on wavelength, even in clear water all red absorbed within a few m of surface, 70% of blue light penetrates as far as 70 m (HO 1)

The penetration can be calculated as: $L_d = L_0 e^{-kd}$
Where L is light at depth d or at the surface 0, and k is the extinction coefficient. Either wavelength-specific, or for all visible light

K can be measured with a light meter, or estimated as 1.7 $\times$ the Secchi depth. Secchi disk – 20 cm diameter, black & white quadrants, lowered until no longer visible

Light attenuation is exponential, so transformed to a straight line relationship on a logarithmic light intensity scale. This is useful to calculate the depth where light intensity falls to 1% of the surface value (HO 1)

Above this depth is the photic zone, below it is the aphotic zone. The Secchi depth is a surprisingly good guide to the depth of the photic zone for biology

■ **Detritus** (dead organic material) is the other main energy input - the dominant source of energy in many aquatic systems

Primary production is often not grazed as living material in water, but consumed after death as detritus

Autochthonous = detritus from primary production within the ecosystem
Allochthonous = imported detritus, from other aquatic or terrestrial ecosystems

Particulate organic matter (POM) or carbon (POC, depending whether mass or carbon is measured) is dead particulate matter in the water

1. Coarse (CPOM) is > 1mm diameter, plant fragments, animal carcases, up to whole trees. Often heavy, usually sinks

2. Fine (FPOM) is < 1mm diameter, settles only in still water, often remains suspended

Dissolved organic matter (DOM) /carbon (DOC) passes through a 0.45 μm mesh. Leakage from living cells (15-25% of algal photosynthesis is lost), or from decomposition (humic substances, of low nutritional quality)

■ **Niches**
Multicellular life evolved in the sea, which still has more diverse animal life in terms of number of major taxa. 30/33 animal phyla in the sea, 16 solely marine

Sw and fw organisms are taxonomically distinct, but ecological similarities:

Pelagic – in the water column

1. Plankton – weak or non-swimmers. Algae, cyanobacteria, small animals. Phytoplankton & zooplankton, defined by ability to photosynthesise

2. Nekton – active swimmers. Fish, marine mammals

Benthic – on the bottom (benthos)

1. Epifauna – on the surface, attached (sessile) or free moving

2. Infauna – burrowed into the substrate (usually soft sediments)