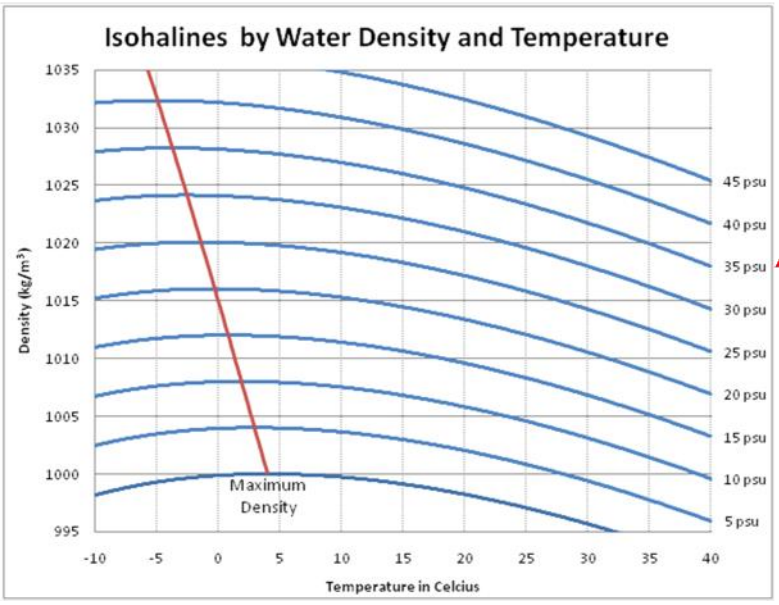
The **CHANGE** in ρ (in parts per 1000) from S = 0 and T = 0°C

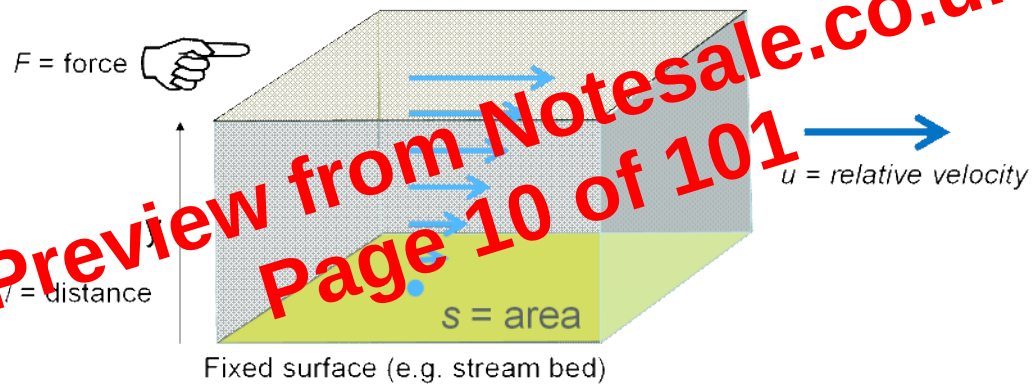


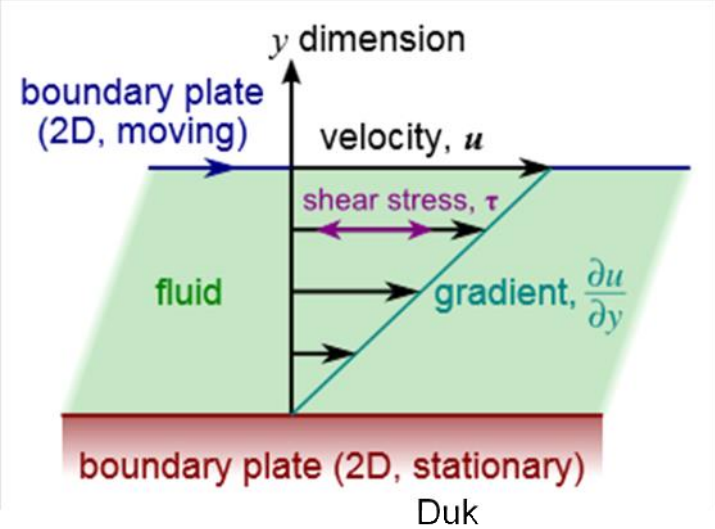
Sea Water 31-39 ($^{0}/_{00}$)

- Density is important for buoyancy

Viscosity

- Resistance to flow



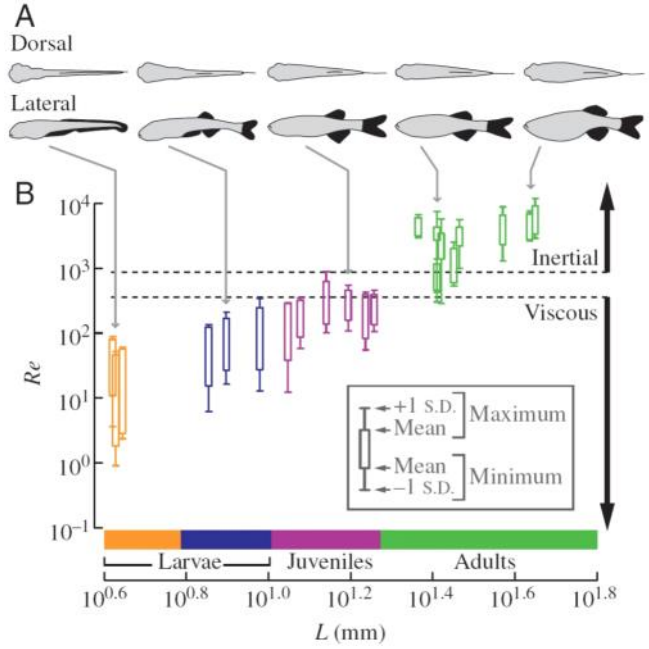


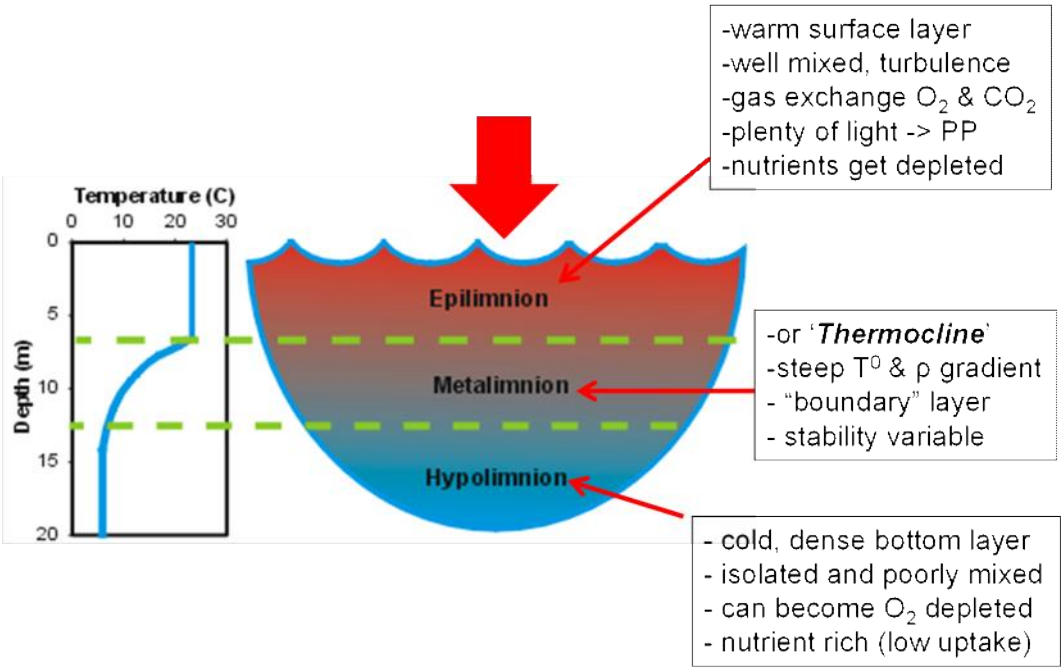
Duk

- Lower velocity with increased depth
- Dynamic viscosity

- Inertia
- Faster
- Bigger
- Drag an issue

○ Changes through life cycle





Wind

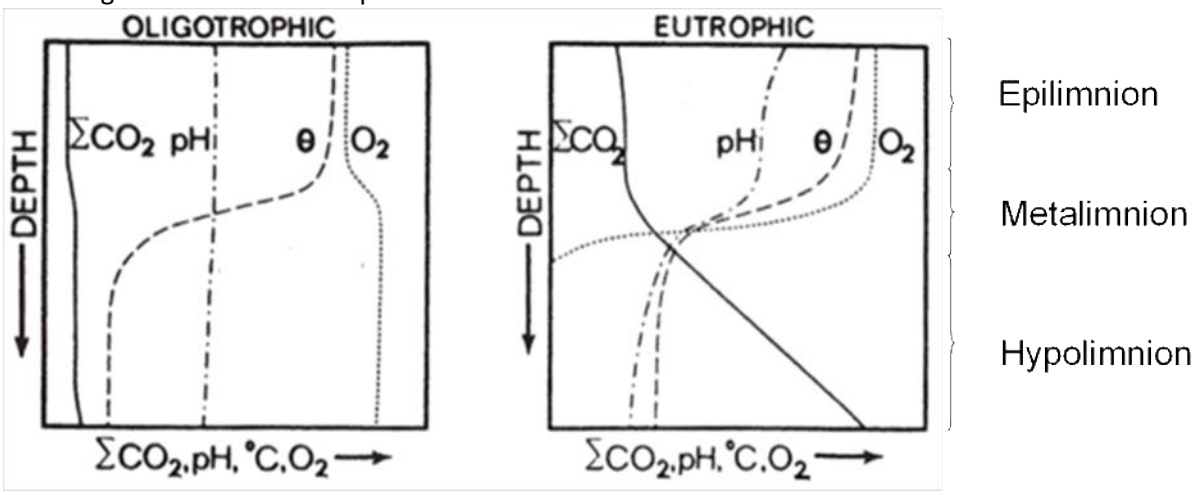
- Mixing of epilimnion
- Density gradient in metalimnion prevents mixing
  - High Richardson's Number (R_i)
- Autumn - less solar energy, more wind
- Surface waves - piles and thickens epilimnion on leeward shore
- Subsurface waves
  - Pushing thermocline up in autumn
- Standing waves when wind stops
  - Long shallow
  - 5m high in Lake Erie

Mixing

- Dimictic
  - Winter stratified
  - Summer stratified
  - Spring and autumn more wind, overturning
- Warm monomictic
  - Common in UK
  - Stratified in summer
  - Mixed all winter - no ice
  - Temperate maritime
- Cold monomictic
  - Inverse stratification most of year
  - No summer stratification
  - High altitude/latitude
- Polymictic
  - Frequent/daily mixing
  - Too shallow to stratify
- Discontinuous polymictic
  - Frequent mixing
  - Stratify for parts of year
  - Typically deeper

Oxygen

- Eutrophic
    - Less CO_2 at top - photic zone
    - High at bottom - decomposition



Limnic Eruptions

- Rare
- CO_2 build up
- Mass casualties - Lake Nyos, Cameroon
- Stratification with cool lower layer
- Disturbance to boundary
- High input of C rich sediment
    - Broken down by bacteria

Humic Substances

- High molecular weight
- Decomposition of organic matter, especially terrestrial plants
- Lack chemical definition
- Humic and fulvic acids
    - 40-60% DOM
- Yellow to black
- Strong UV absorbance
- Humics and Lake Function
    - Hugh humics ---> low diversity and productivity
    - Low light levels
    - Acidic
    - Low O_2
    - C not available to plants
        - Is available to bacteria - buffer against anthropogenic interference

Light and Organics

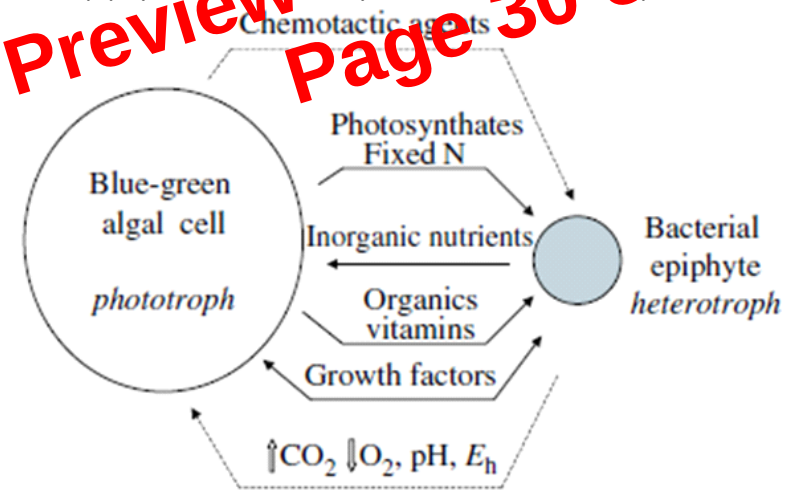
- Recent studies show <10-25%
- Closely linked with phytoplankton productivity
    - In photic ~20%
    - Below photic zone is linked to C content of sediment
- Bacterial productivity is higher in eutrophic lakes

Out of Control Bacteria

- Cyanobacteria
- Cyanotoxins
- Efficient light harvesting
- High CO_2, low pH
- Resistant to radiation
- Extreme temperatures
- Some fix N, can grow in low nutrient conditions
- Buoyancy mechanisms
- Resistant to removal by filter feeding zooplankton

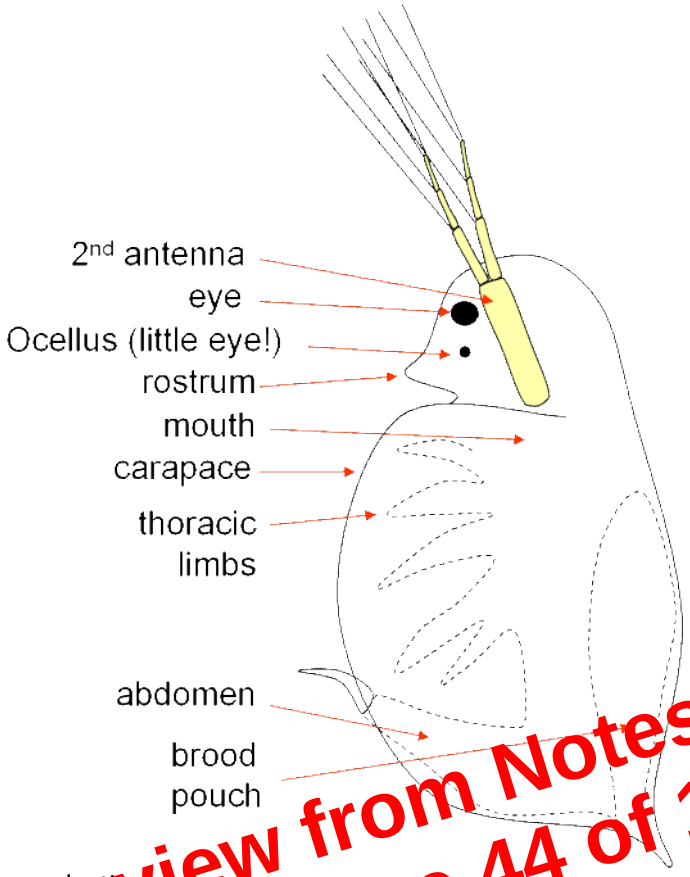
Phytoplankton and Bacteria

- Antagonistic interaction
    - Phytoplankton
        - Production of acrylic acid
        - Antibiotic production
    - Bacteria
        - Algal lysing by antimicrobial compounds
        - Parasitic/predators
        - Epiphytic effects
    - Bacterial competition is most limiting when nutrients are limited, but C is not
        - Allochthonous
- Bacteria breakdown DOM, make N and P available to phytoplankton
- Phytoplankton increase DOC available to bacteria
- Cooperation?
    - Epiphyte interaction may be beneficial to both parties

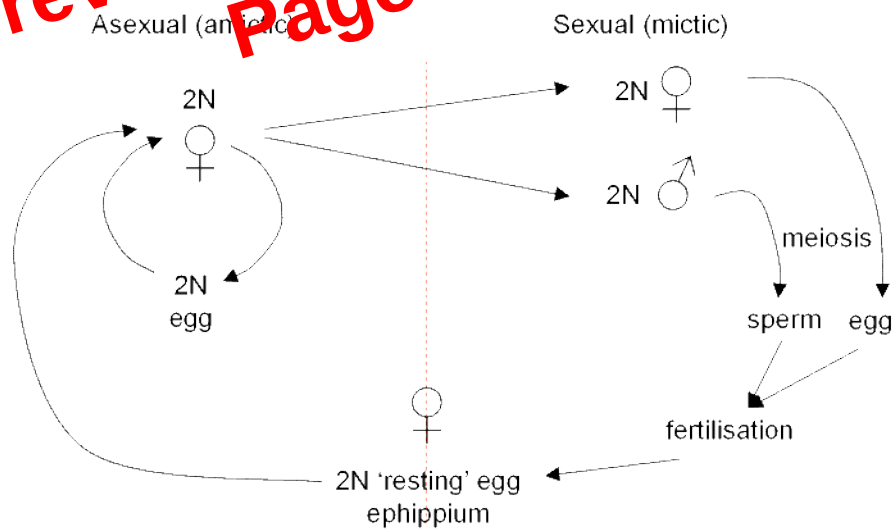


Planktonic Cladocera

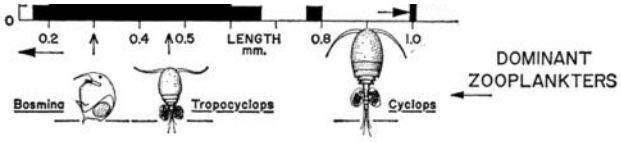
- Characteristics
  - 0.2-2mm
  - Bivalved carapace
  - Compound eye and ocellus
  - Enclosed thoracic limbs
  - Abdomen with hook
  - Broad pouch



- Reproduction



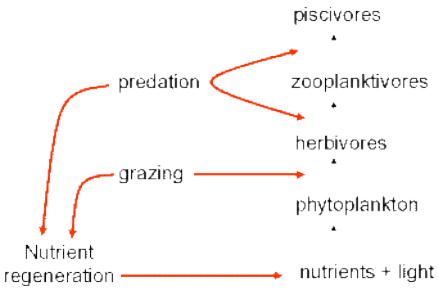
- Feeding
  - Water drawn between valves
  - Particles collected on setae
    - 1-50mm
  - Some predatory
    - *Leptodora*
- Locomotion
  - 2nd antennae



Brooks & Dodson, Science. Vol. 150. No. 3692 (1965), pp. 28-35

- Size efficiency hypothesis
  - Brooks and Dodson
  - Large grazers outcompete small
    - Food particle size range
    - Collection efficiency
    - Metabolic efficiency
  - Vertebrate predators size selective
    - Detection
    - Energy return

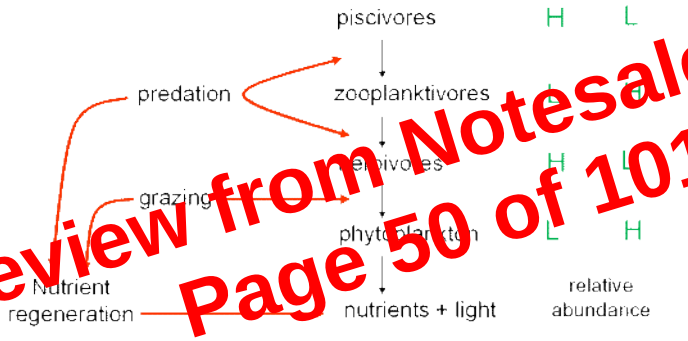
Control of open water communities



Bottom-up

- Algal productivity nutrient & light limited
- Nutrient limited growth
- Light availability
- Sinking/turbulence

Bottom-up or top-down?



Top-down

- Planktivores control herbivore composition & abundance
- Clearance rates to100% d^{-1}
- Trophic cascade?

Lake Macroinvertebrates

01 March 2016 10:39

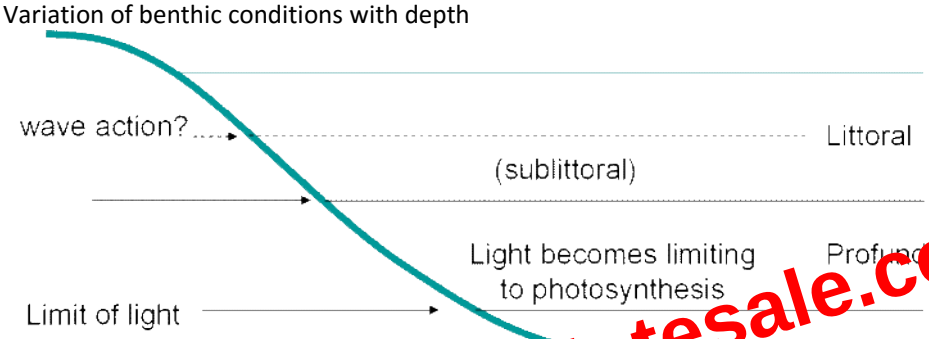
- Benthic environment is variable

Exposure

- Eroding
  - Rock/coarse substrate
  - No macrophytes
- Depositing
  - Mud/silt
  - Macrophyte beds
- Conditions depend upon
  - Catchment
  - Lake dimension (fetch)
  - Orientation to prevailing wind

Zonation

- Variation of benthic conditions with depth



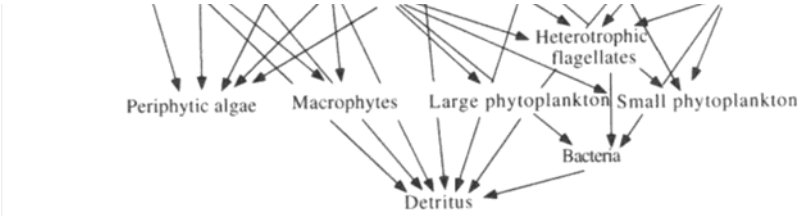
- Littoral conditions
  - Spatial variation in exposure - habitat diversity
  - Epilimnial water
    - Well mixed (O_2)
    - Close to surface
    - High light - high primary productivity
    - Temporal variation mainly in temperature
- Profundal conditions
  - Deposition
    - Fine sediment
    - Organic
  - Little spatial variation
  - Hypolimnial water
    - Poorly mixed
    - Isolated during stratification
  - Little temporal variation in T - low
  - O_2 may vary strongly in eutrophic lakes
    - Severely hypoxic (bacterial respiration)

Benthic Diversity

- Species diversity declines with depth
  - Habitat diversity
  - Need for surface access
    - Emergence
    - Respiration
  - Environmental rigour

Benthic Abundance

- Declines with depth
- Increases with productivity

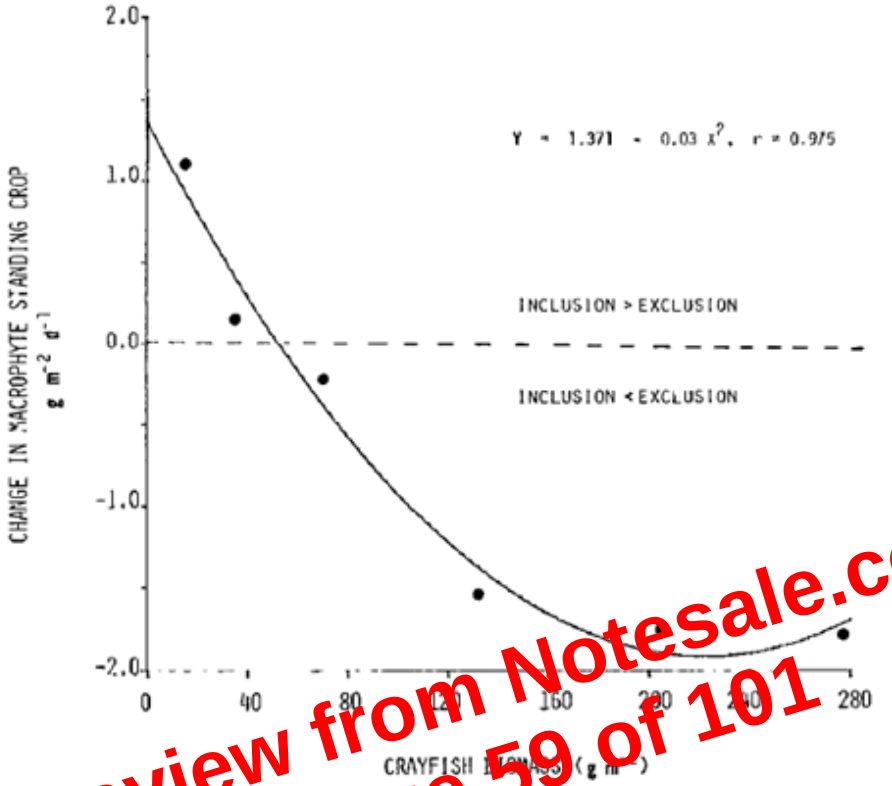


important link between phyto/zooplankton and many predatory fish species

Brönmark & Hansson, The Biology of Lakes & Ponds, 2005

Benthic Grazers

- High abundance of crayfish grazers can reduce macrophyte biomass

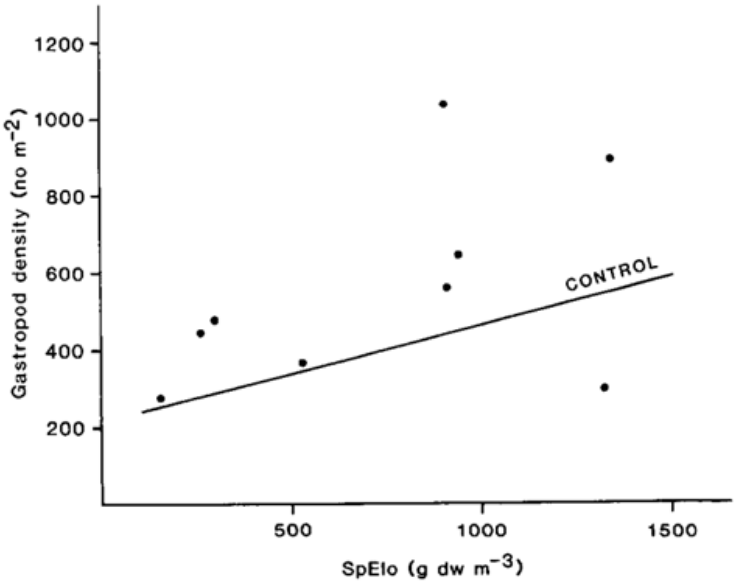


Detritivores

- High input of nutrients is often detrimental to macroinvertebrates
  - Switched lakes from clear to turbid
- Particulate organic matter from outside the lake can provide a lot of food

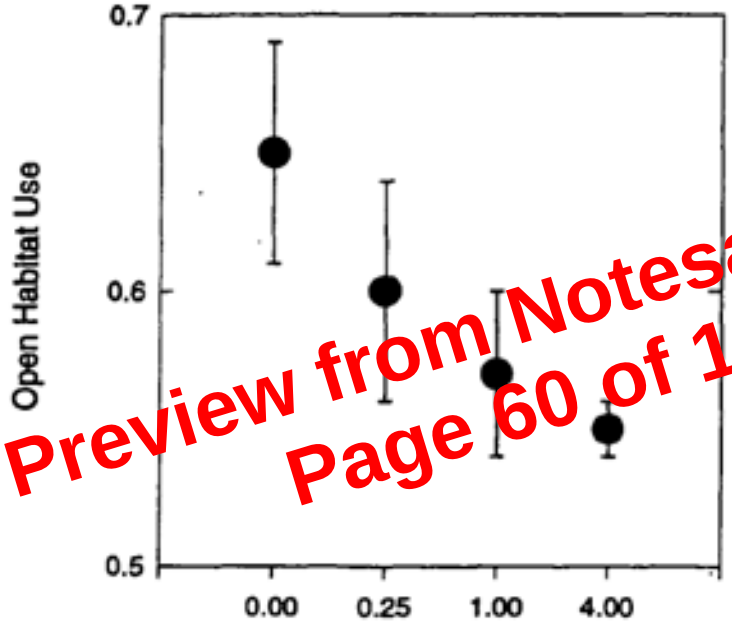
Invertebrates as Prey

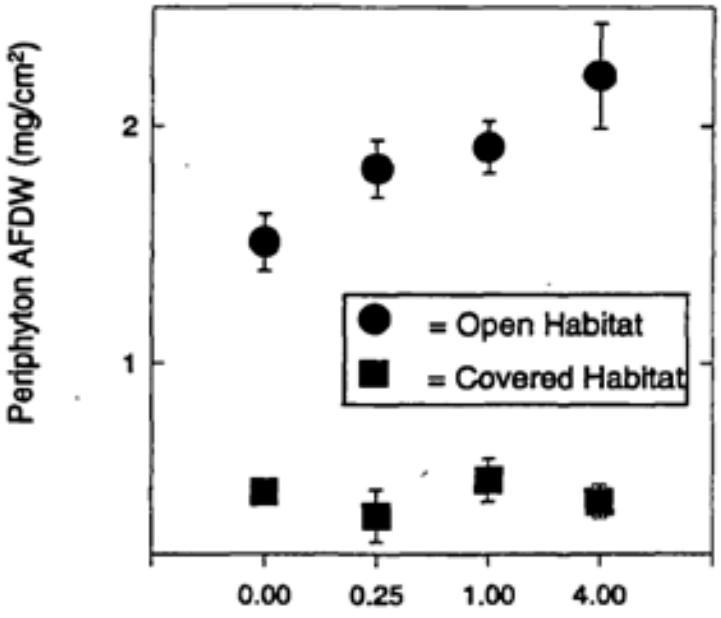
- Control with predators
- Test without predators
- Breakdown of relationship



Tri-Trophic Interactions

- Risky conditions significantly altered habitat use and periphyton diversity

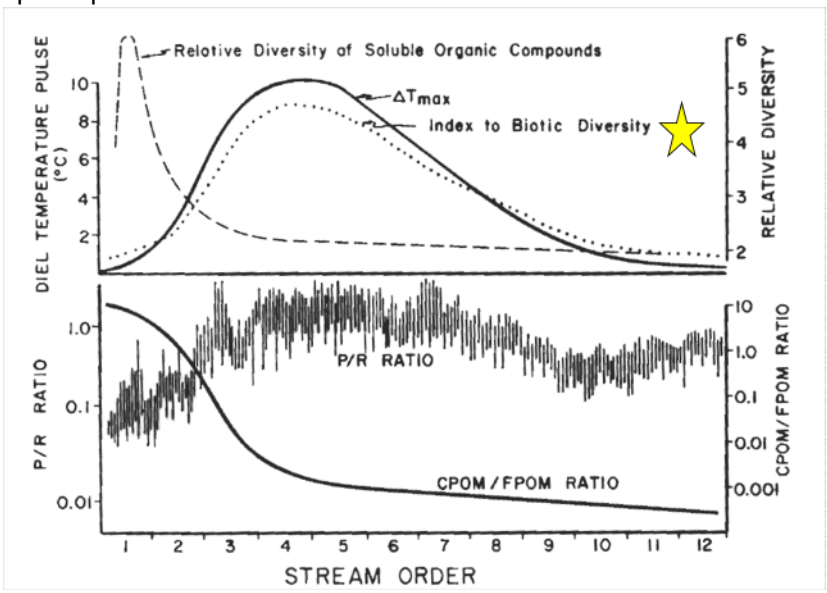




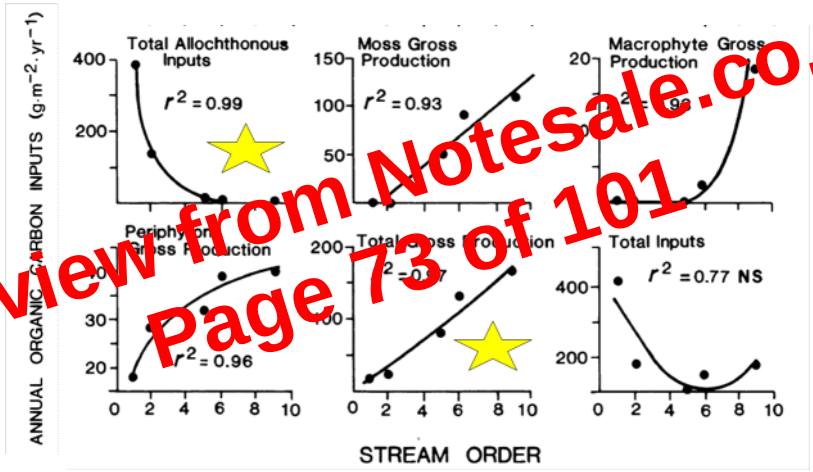
Stream Communities

08 March 2016 11:34

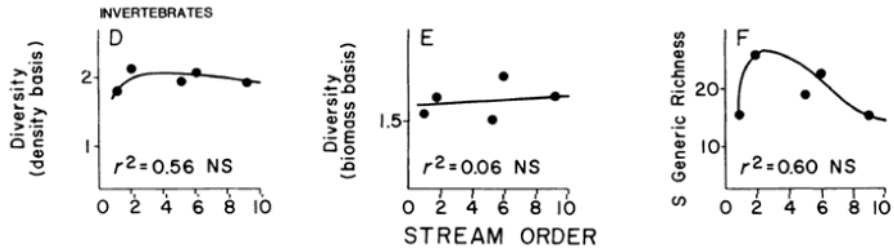
- Spatial pattern



  - Compared across stream orders (1-9) in Quebecoise systems
  - Primary productivity



    - Follows predictions of River Continuum Concept
    - Low order streams autochthonous
  - RCC predicts highest diversity in 4-6 order streams - max habitat diversity



    - No particular pattern
    - Most genera in 2nd order
  - Small scale variables count
    - Pools and riffles
    - Patterns differ by stream order - pools and riffles give more different

The impact of dipper, Cinclus mexicanus, predation on stream benthos

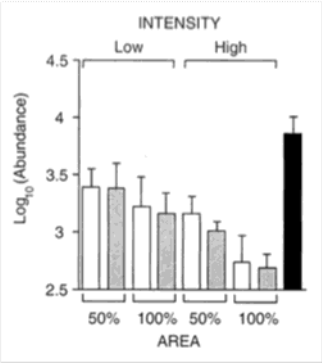
Bret C. Harvey and Carl D. Marti

- Steep 2nd order stream
- 3.5m wide
- 615m reach
- Trout only, low density
- 3x3 treatments
  - Dipper enclosure 15x8
  - Exclosure control - roof no sides
  - Open - flagging tape
- Dippers reduced density of large preferred prey -
- Small *Baetis* mayflies less abundant at depth, *Heptas* more abundant

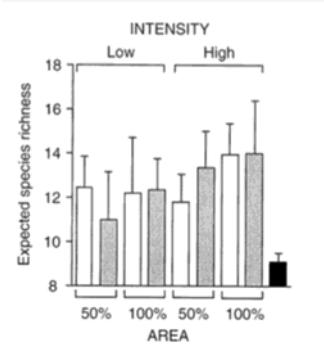
- Disturbance
  - Are communities controlled by biotic or abiotic factors?
  - Harsh - benign spectrum
    - Harsh (extreme variation in temp., flow, O_2)
      - Densities periodically reduces - abiotic dominated
    - Benign (relatively constant conditions)
      - Competition and predation control
  - Patch dynamics view
    - Shifting mosaic of conditions
    - Dispersal of benthic organisms between patches
    - Local variation but predictability at larger scales
  - Declan J. McCabe · Nicholas J. Gotelli

    Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates
    - Garden paving stones
    - 3x2 design (and control)
    - 7 blocks
    - N=63
    - Intensity high/low
    - Area 50/100%
    - Frequency 1/2 per week
    - Disturbance reduced invertebrate abundance at high and low frequency
    - Disturbance increases invertebrate diversity at high and low frequency

Disturbance REDUCES invertebrates abundance at HIGH and LOW frequency



Disturbance INCREASES Invertebrates diversity at HIGH and LOW frequency



Stream-Terrestrial Linkages

STREAM ORDER

Lower order streams- less stable and low number of 'generalist species'

- •Increase in number of habitat types
- •Increased pools, backwaters and slack currents (nursery areas)
- •Increase in the volume of living space
- •Increase in the energy base- more primary productivity further down the river
- •Increase in the stability of environment- e.g. productivity and temperature.

High order streams- more stable and higher diversity. More generalist species

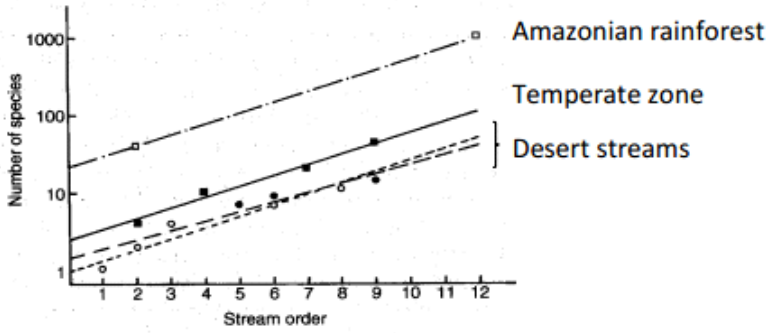
- Environmental harshness ad stream order effects on species diversity (Wooton, 1998)
  - 

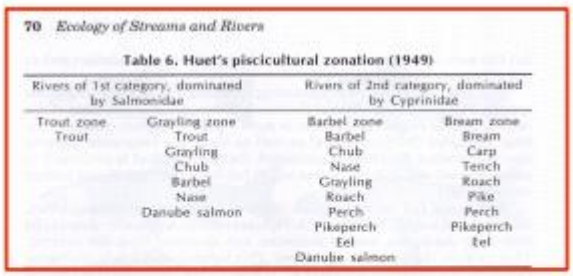
Fig. 12.5 Comparison of species richness (log scale) in rivers from different climatic regions according to stream order (see page 301). Symbols: ○, tropical rain forest – Amazon (South America); ■ temperate zone – [illegible] (central Europe); ○ (short dashes) desert streams – Nevada (south-western USA); ● (long dashes) boreal zone – [illegible] River (Labrador, Canada). Redrawn from Lewski and Neiman (1978).

98)

- Chemical Factors
  - pH, O_2, DOM, all define chemical fingerprint
  - Different species have preferences for water chemistry
    - Some very narrow (salmon)
    - Some very tolerant (bream, eels)

Longitudinal Zonation of Fish Assemblages in Temperate Rivers

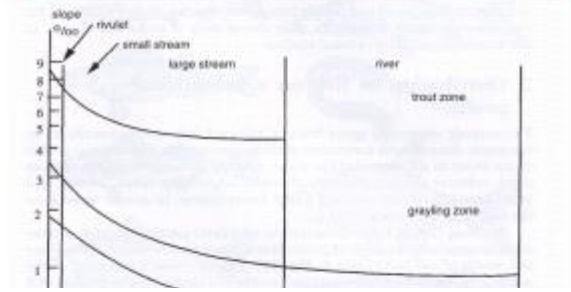
- Huet 1949 - topology of piscicultural zones as functions of slope and width

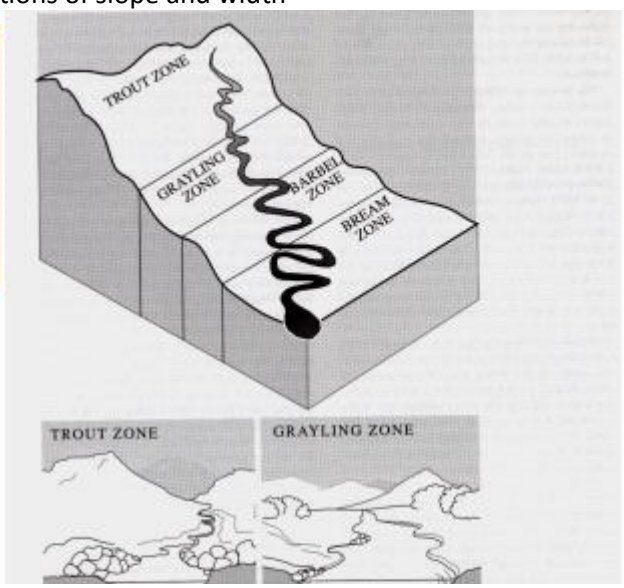


70 *Ecology of Streams and Rivers*

Table 6. Huet's piscicultural zonation (1949)

Rivers of 1st category, dominated by Salmonidae		Rivers of 2nd category, dominated by Cyprinidae	
Trout zone	Grayling zone	Barbel zone	Bream zone
Trout	Trout	Barbel	Bream
	Grayling	Chub	Carp
	Chub	Nase	Tench
	Barbel	Grayling	Roach
	Nase	Roach	Pike
	Danube salmon	Perch	Perch
		Pikeperch	Pikeperch
		Eel	Eel
		Danube salmon	





Threats to Freshwaters

14 April 2016 11:39

- Freshwaters under greatest threat - high human activity, relatively low area
  - Living Planet Index shows 76% decline in FW populations of birds, fish, and amphibians
  - 39% in terrestrial and marine
- Ecology warning for European water
  - 70% of UK waters "less than good"

Pollution

- Man-made harmful addition of substances or energy
- Most uses alter water quality
- Removal and alteration an also be a problem e.g. deforestation, changes to course
- Acidification
  - Source: acid rain from sulphur and nitrogen oxides from burning fossil fuel, run-off from mines
  - Effect: acidified freshwater, leaches ions from soils
- Thermal pollution
  - Source: slowing water flow via damming, release of warm water from power plants
  - Effects: lowered oxygen, increased decomposition of organic matter
- Silt
  - Source: agricultural run-off, deforestation, construction, concrete/smooth surfaces
  - Effect: reduce light penetration, disrupt feeding, may bury spawning grounds
- Salinisation
  - Source: leached from alkaline soils by over-irrigation
  - Effect: many species are intolerant of saline conditions, disrupts osmotic balance (stenohaline (cannot control) or high energy cost)
- Nutrients (N+P)
  - Source: primarily from agriculture
  - Effect: eutrophication, excessive algal and bacterial growth , lowers oxygen levels
- Organic matter
  - Source: sewage, run-off, industrial waste, farming
  - Effect: increased decomposition and bacterial growth lowers oxygen, increased turbidity
- Metals
  - Source: mining, industry
  - Effect: toxic, persistent, bioaccumulation
- Organic toxins
  - Source: industrial, sewage, farming etc.
  - Effect: varied, including pesticides, endocrine disruptors, pharmaceuticals, anti-fouling agents
- Radioactivity
  - Source: nuclear power and weapons
  - Effect: toxicity (chromosome damage), chronic toxicity (cancer, genetic abnormalities)
- Oil
  - Source: oil spills, industry leakage, motor vehicles
  - Effect: physical (suffocation, blocking light, clogged limbs), water soluble components toxic

Changes To River Courses

- Longitudinal fragmentation (dams)
- Lateral fragmentation (connection with surrounding flood plain)
- Changes to riparian zone
- Flow modification

Tackling

- Catchments important
- Land use strongly influences lakes and river
- Very interconnected
    - Pollution from factory in one area will prevent salmon spawning upriver, less nutrient input from salmon corpses
- Human population increasing, land use will change

- Policy for Protection: The Water Framework Directive101 1992
    - Natura 2000 meeting
    - Habitats maintained or, where appropriate, restored at a favourable conservation status
    - Maintenance of biodiversity
    - "water is not a commercial product, … but a heritage which must be protected"
    - Delivered at water body scale
        - Coherent subunit
    - The "good status" challenge
        - Good surface water chemical status - meet environmental objectives
        - Ecological status expression of quality and functioning of aquatic ecosystem
    - "One out all out"
        - Lowest classified element = final classification
    - ~1000 surface water bodies in Wales
        - 67% below "good status"
        - Reasons: rural agriculture, barriers, mining, forestry, pH, sewage, reservoirs

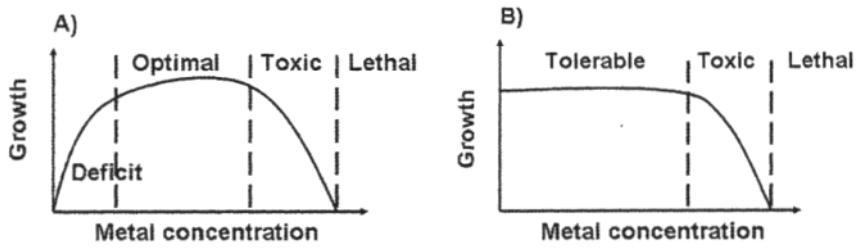


FIGURE 3. Model of deficiency and oversupply of a) essential and b) non-essential metals (after Förstner & Wittmann, 1981).

- Optimal range of light metals
  - Up to toxic down to deficit
- Heavy metals tolerable
  - Toxic
  - Lethal at highest

Measuring

- LC_{50}
  - Lethal concentration
  - 50% dead within time
- LT_{50}
  - Lethal time
  - 50% dead at concentration
- EC_{50}
  - Sub-lethal effect seen
  - 50% show effect at concentration
- HC_{50}
  - Any environmental impact
  - 50% show at concentration

Factors

- Species highly variable
- Population variability (adaptation)
- Size (SA:V) and developmental stage
- Environment (temp., pH, Ca/Mg)
- Bioaccumulation (life history and longevity)
- Bioconcentration/biomagnification (trophic level)

Impact on Upland Streams in Wales and Cornwall Hirst et al. 2002

- Water hardness effecs toxicity and bioavailability of some metals
  - Criteria for Ce, Cu, Pb, Zn modified