143SRPP
Stream Revitalization: Principles & Practices

LECTURE 7

Stream Habitat and Ecology

Physical Habitat Classification, Ecohydrology/ Ecohydraulics, Stream Ecology Concepts

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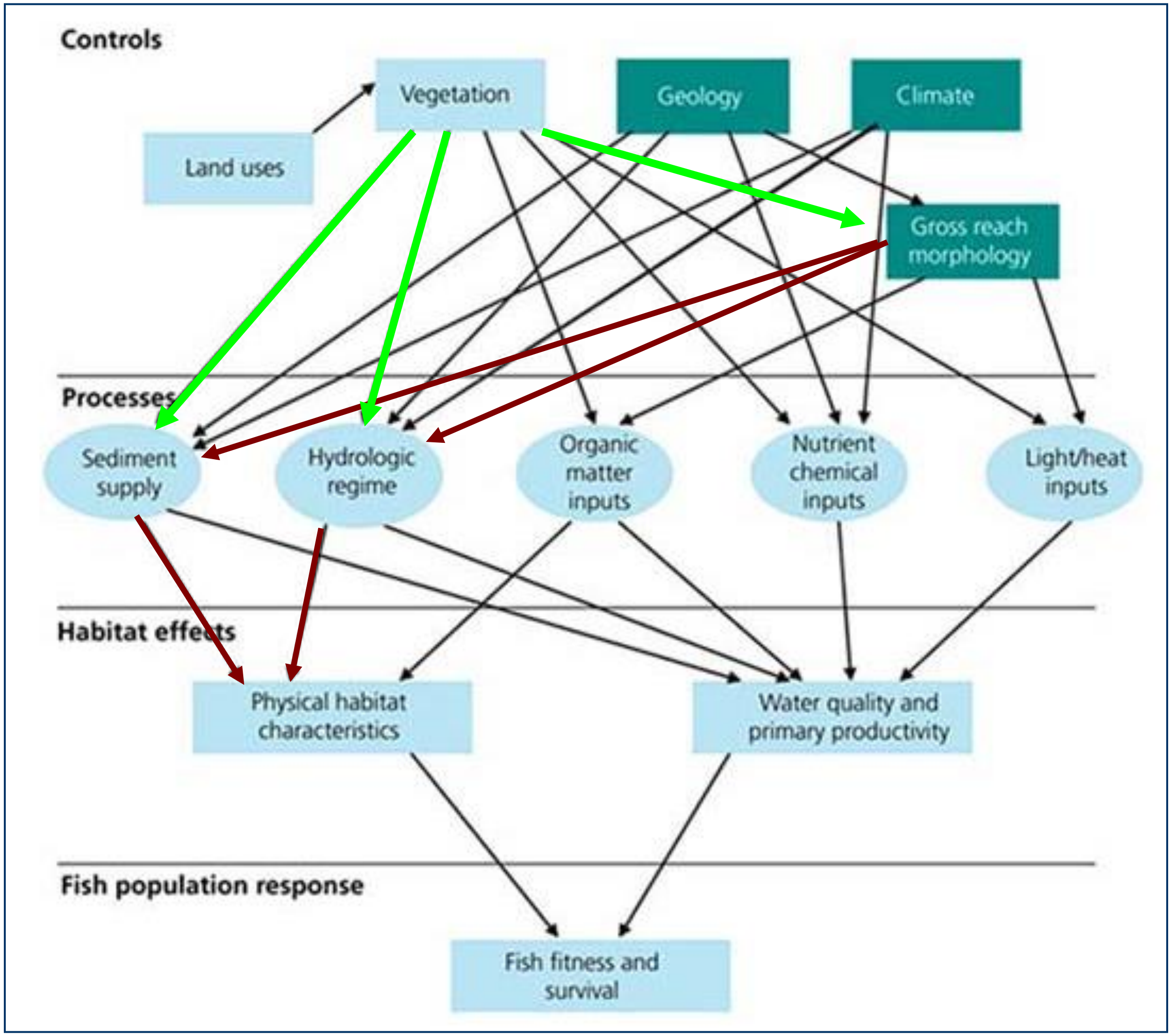
Process Framework for Stream Habitat

Relationships between hydro-geomorphic systems *and* physical stream habitat; in addition to in-stream flows and water quality.

Example for fish



Defining Habitat

Odom (1971) defines habitat as a place where an organism lives, including physical, chemical, and biological features.

Southwick (1976) defines habitat as "…the natural abode ….. of an 'organism' including all features of the environment in an given locality."

- These definitions present a traditional view of habitat:
  1.) habitat is referenced in terms of the organism;
  2.) habitat includes all features of the environment, physical, chemical, and biological; and
  3.) habitat is viewed as definable and quantifiable.

A habitat is where an organism (a plant or animal) lives.
The habitat provides food and shelter for the organisms living there.
Organisms must be adapted (designed) to survive in their habitat.

Defining Habitat

Southwood (1977) defines habitat according to three ecological concepts: duration stability, temporal variability, and spatial heterogeneity.

- ***Duration Stability***:

  Duration stability relates organism generation time with the length of time a habitat will remain favorable.

- ***Temporal Variability***:

  Temporal variability is determined from the time that a site meets specific organism requirements in environments that have seasonal or short-term variations.

- ***Spatial Heterogeneity***:

  Spatial variability recognizes habitat attributes are not constant over space; e.g., bed substrate is highly variable over the stream bed.

Defining Stream Habitat Quality

Habitat complexity – within a designated space and scale in a stream, complexity relates to variety of different types of habitat found there, term most often used to describe local physical characteristics (i.e., pools and riffles, backwaters, root wads, boulders, etc.).

Habitat heterogeneity – refers to the variance in spatial distribution and temporal occurrence of different different types of habitat found in a stream.

Defining Habitat

Southwood's (1977) habitat definition introduces the notion that habitat conditions vary; in terms of favorable and unfavorable locations (space) and periods (time).

In terms of space (*location*), habitat can be:

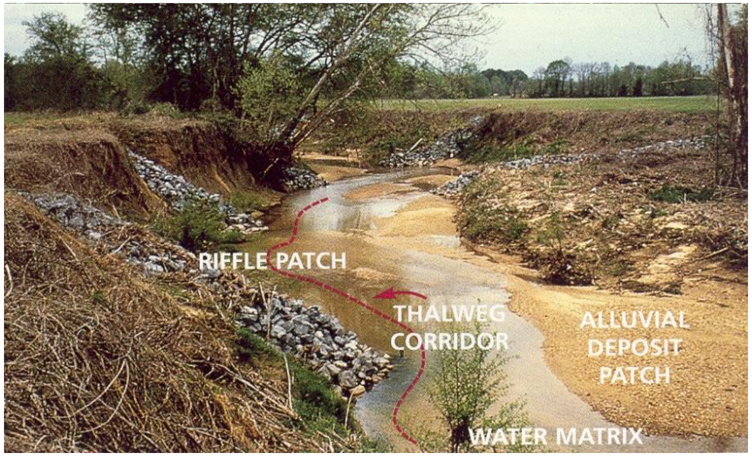
Continuous – favorable area is larger than the organism can cover to meet its biological resource needs;
Patchy – favorable and unfavorable areas are interspersed, but the organism can easily disperse from one favorable area to another; and
Isolated – favorable area is restricted, too far from other favorable areas for an organism to readily disperse between them, except rarely and by chance.

Habitat: Landscape Ecology Terms

Matrix: the land cover is that dominated and interconnected over the majority of the land surface (i.e., forest, agricultural, urban, water, wetland, etc.).

Patch: a non-linear area that is less than abundant than, and different from the matrix.

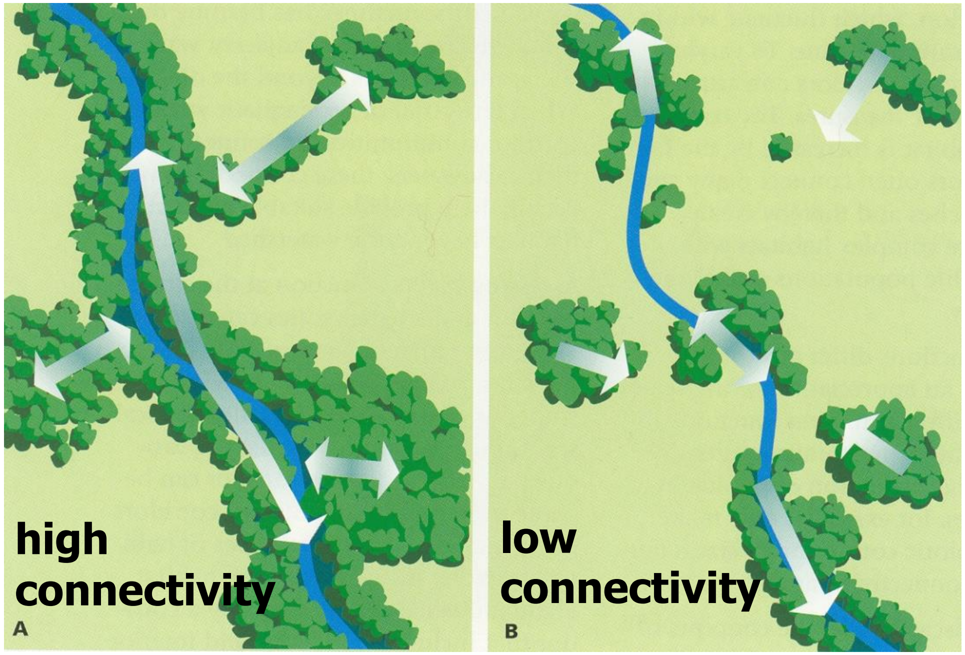
Corridor: a special type of patch that links other patches in the matrix; it is linear and elongated in shape.



Defining Stream Habitat Quality

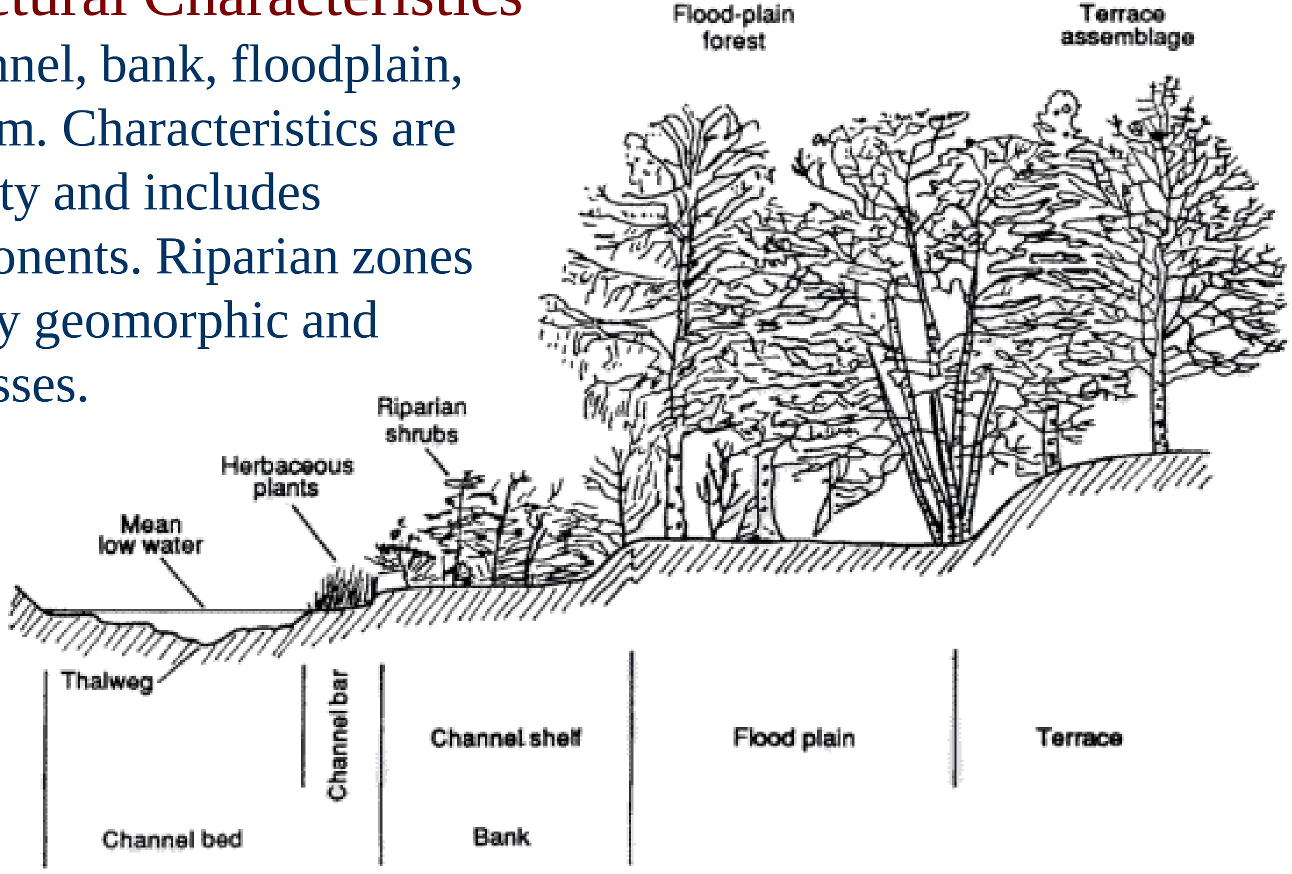
Habitat connectivity – a measure of how spatially continuous a corridor or matrix is, and how well different habitats within are connected in order for free movement of plants and animals, and the transport of materials and energy. In river systems, it is commonly referred to as how well the channel is connected to the floodplain.

Habitat fragmentation – the loss of habitat connectivity; isolation of unique habitat types, thereby reducing ecological function.



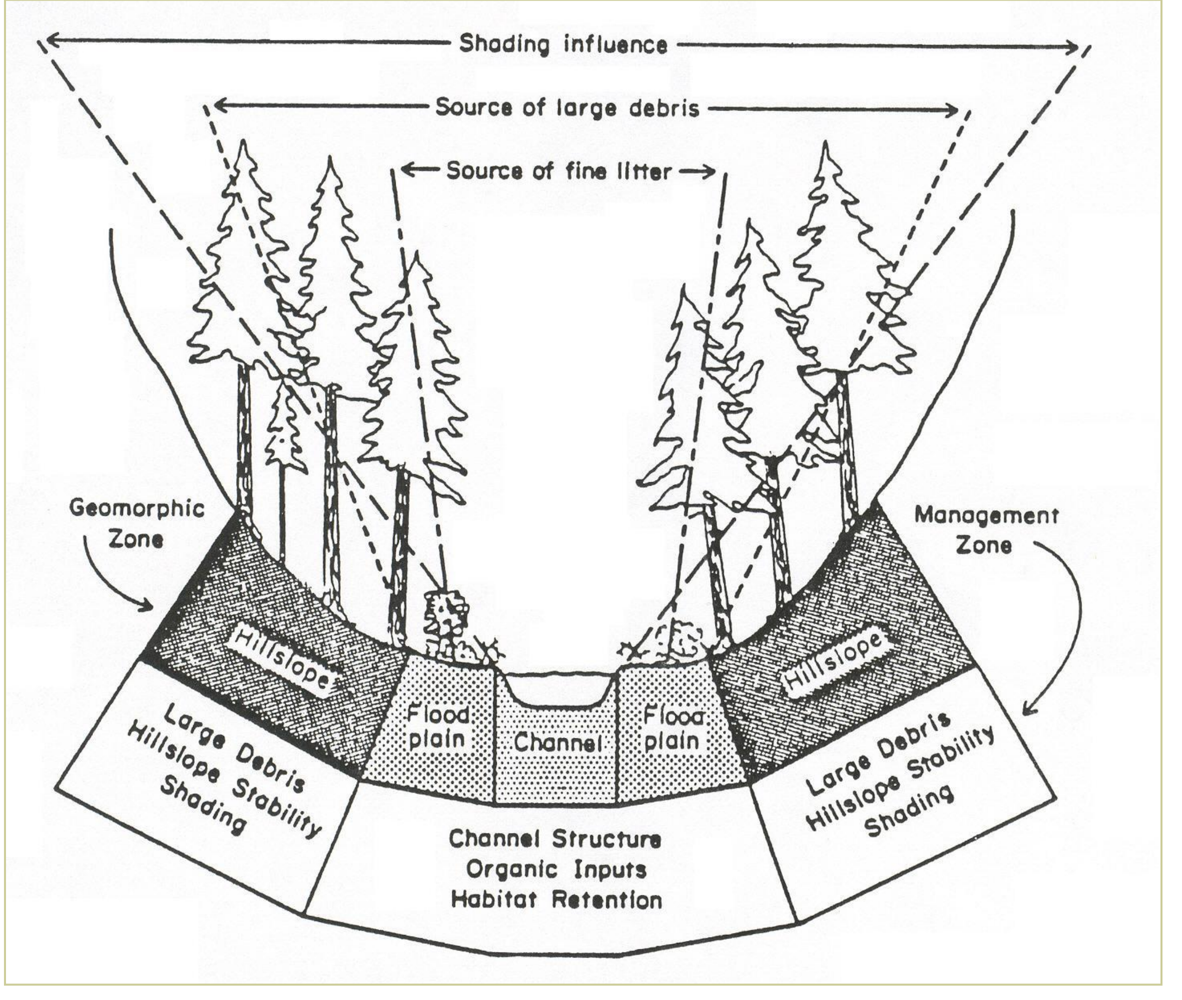
Riparian Structural Characteristics

Riparian Structural Characteristics includes the channel, bank, floodplain, and terrace system. Characteristics are reach-scale quality and includes vegetative components. Riparian zones are maintained by geomorphic and ecological processes.



Riparian Functional Characteristics

Riparian Functional Characteristics includes the ecological relationships to the structural components.

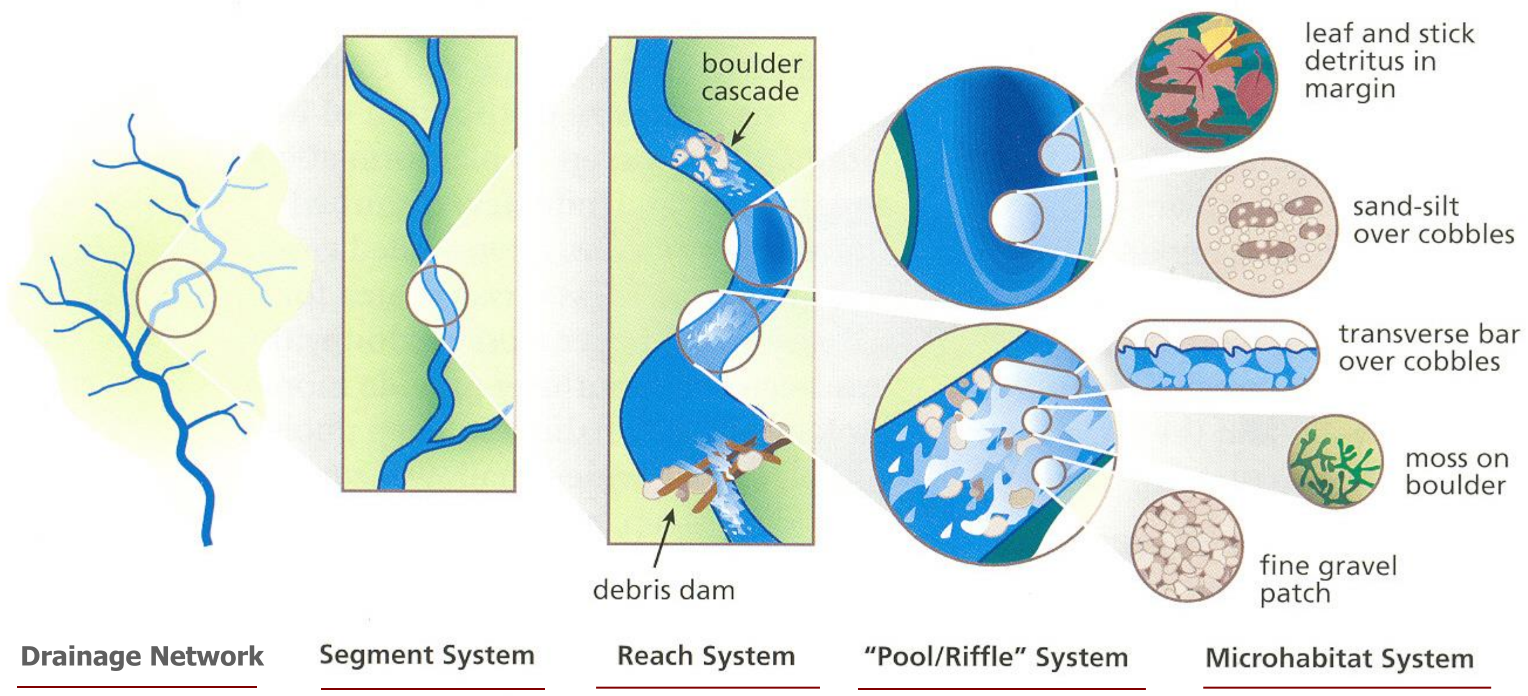


Example:
Pacific NW streams

Stream Habitat Classification

Hierarchical Classification of Stream Habitat:

Frissell *et al*. (1986) identified five major spatiotemporal scales: 1) drainage network, 2) segment, 3) reach, 4) pool-riffle system (channel unit), and 5) microhabitat (channel sub-unit).



Stream Habitat Classification

Hierarchical Classification of Stream Habitat:

Gregory et al. (1991) identifies the same hierarchical scales as Frissell et al. (1986), spatial and time scales for stability (equilibrium) and physical constraints.

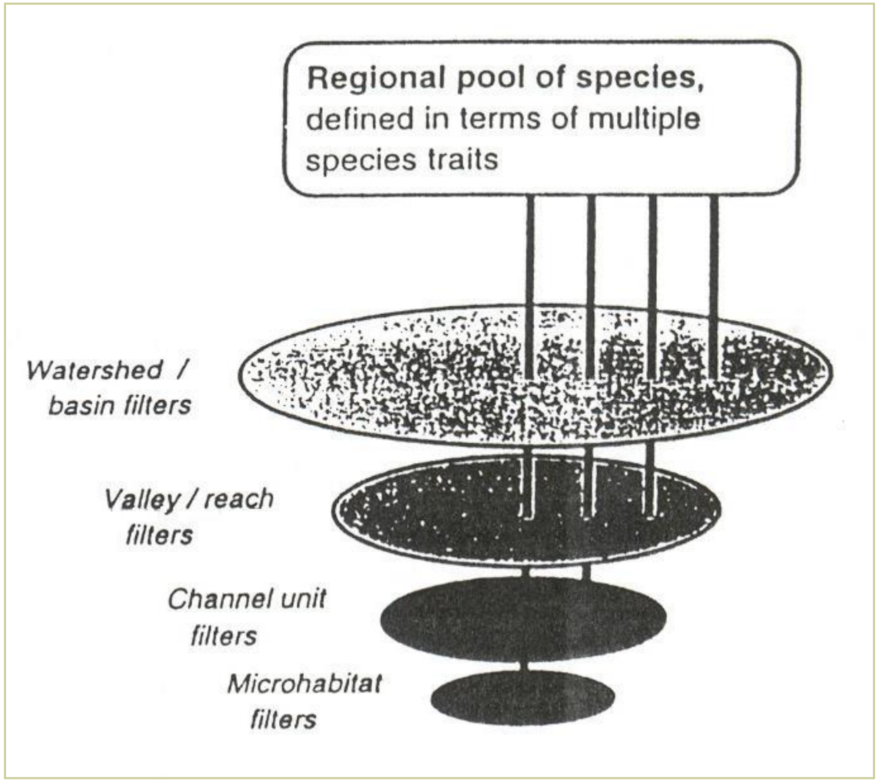
Hierarchical Feature	Spatial Dimensions (channel widths)	Time Scale of Stability (years)	Constraint on Stability and Surface Boundary
Network	$10^{5}+$	$10^{6}+$	Watershed geology
Segment	10^{3} - 10^{4}	10^{4} - 10^{5}	Valley corridor geology
Reach	10^{2} - 10^{3}	10^{3} - 10^{4}	Valley floor and channel aggradation, and degradation
Channel unit	10^{0} - 10^{1}	10^{1} - 10^{2}	Channel hydraulics and roughness elements
Channel sub-unit	10^{-1}	10^{0}	Channel hydraulics, sheer stress, and roughness elements

Stream Habitat Classification

Hierarchical Classification of Stream Habitat:

Habitat classification by Frissell *et al*. (1986) and Gregory *et al*. (1991) rely on a *habitat-centered view* of ecological systems – in that geomorphology is the habitat template that governs the distribution and abundance of organisms.

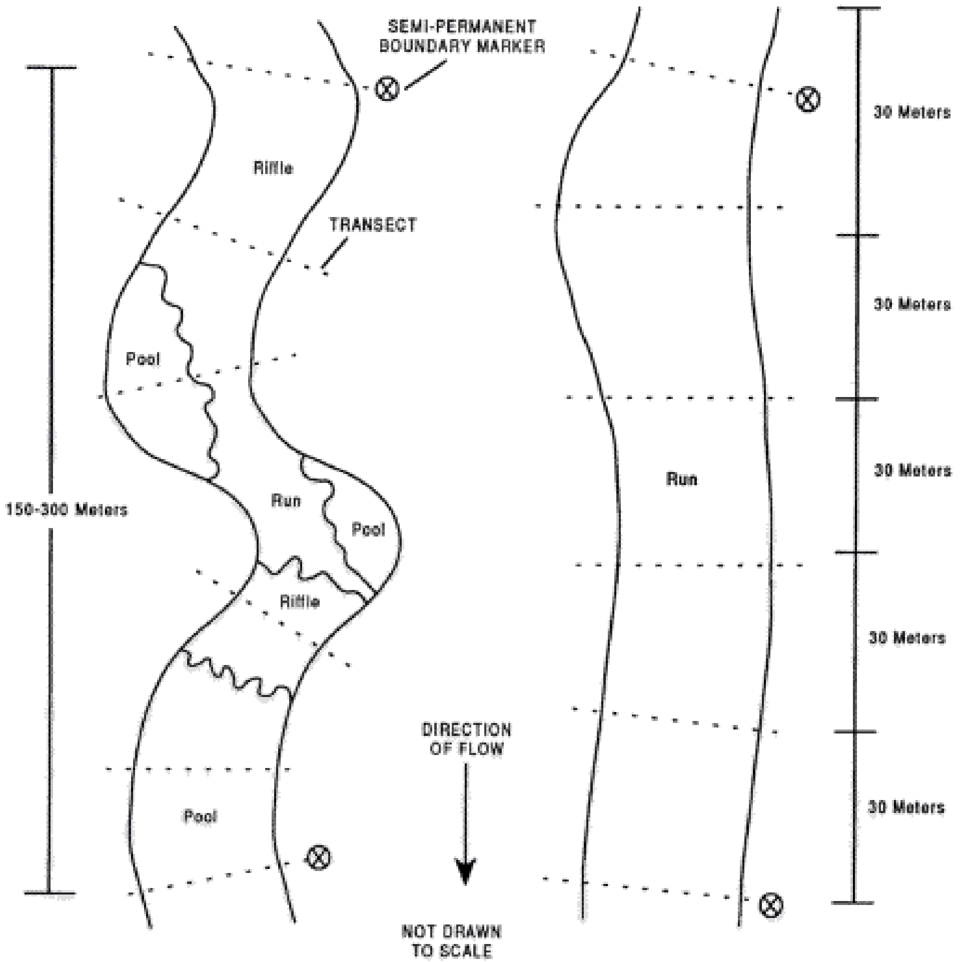
Poff (1997) *adds* a niche perspective, an *organism-view*, to the proposed hierarchical classification systems with different scales acting as a system of "landscape filters" which also governs the distribution and abundance of organisms.



Channel-unit Scale Habitat Classification

Channel-unit Habitat Types commonly include: pools, riffles, glides, runs, rapids, cascades, and steps.

They are identified at a low-flow stage; occur in the wetted area of the stream channel; and distinguished by similar areas of depth, velocity, and substrate.

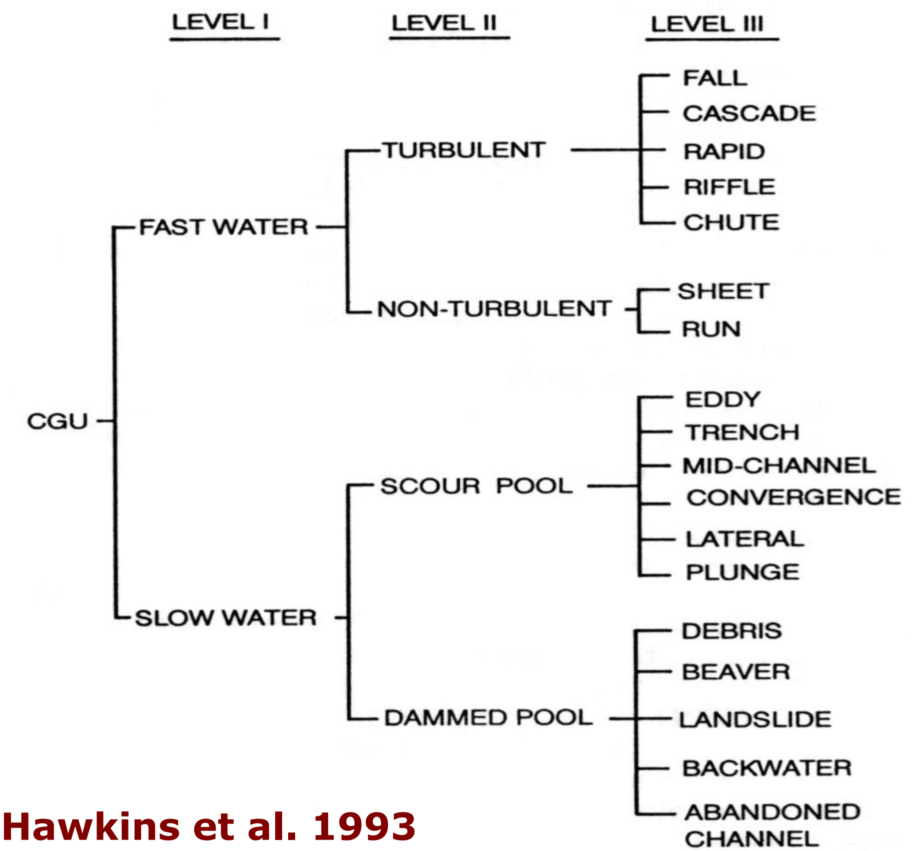


Channel-unit Scale Habitat Classification

CGU = Channel Geomorphic Unit

***Channel-unit scale habitat classification based on*:**

1. **Low-flow stage hydraulics**
2. **One-dimensional hydraulics in downstream direction**
3. **Visual observation of free-surface "turbulence"**
4. **Visual observation of physical-geomorphic characteristics and formative structures**



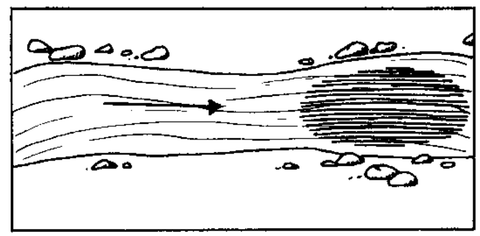
Hawkins et al. 1993

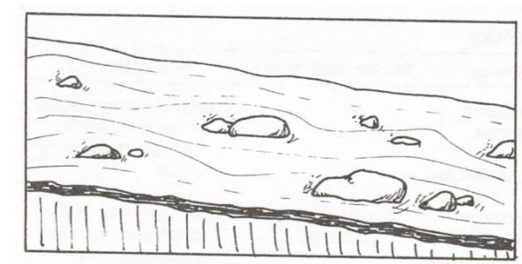
American Fisheries Society; Bain & Stevenson (1999)

Channel-unit Scale Habitat Classification

Channel-unit Habitat Types

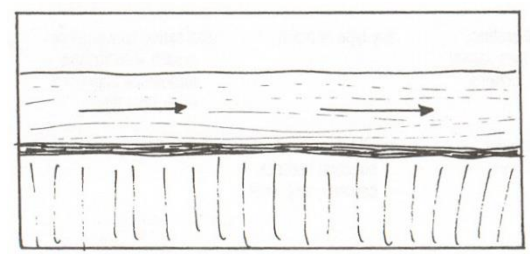
Pool – deeper areas with fine bed substrate; channel slope < 1% ; smooth water surface.


straight scour pool

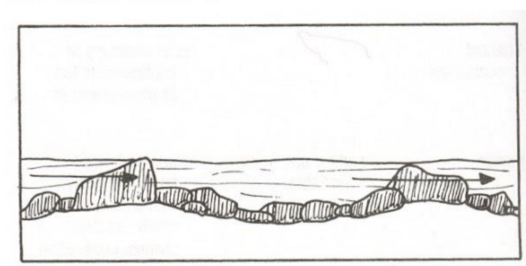

low gradient fast water—riffle

Riffle – shallow areas with course bed material; channel slope <1%; surface waves; fast water.

Glide – shallow areas with fine to course substrate; channel slope < 1%; smooth water surface; water depth uniform throughout.


glide

Run – areas with uniform flow, swift with no surface waves, bed substrate course and variable; bed; channel; slope > 4%.


run

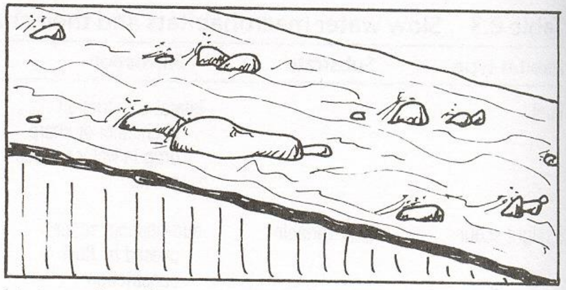
Channel-unit Scale Habitat Classification

Channel-unit Habitat Types

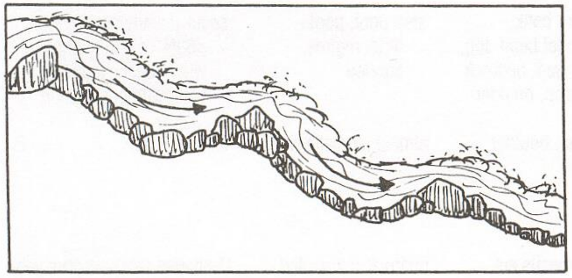
Rapid – shallow areas with course bed material and some cobble/boulders; flow swift with surface waves; channel; slope 4 - 8%.

Cascade – areas with short falls and small plunge pools; bed material consisting of boulders and bedrock; slope > 8%; swift water.

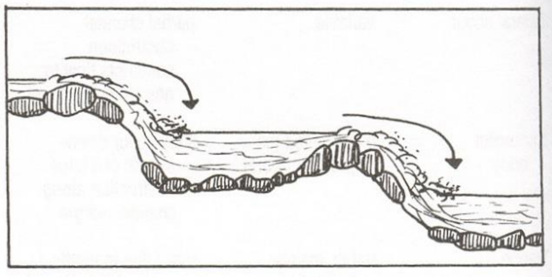
Step – abrupt break in gradient usually shorter than the channel width caused by boulders, logs, or other large roughness elements.



high gradient fast water—rapid



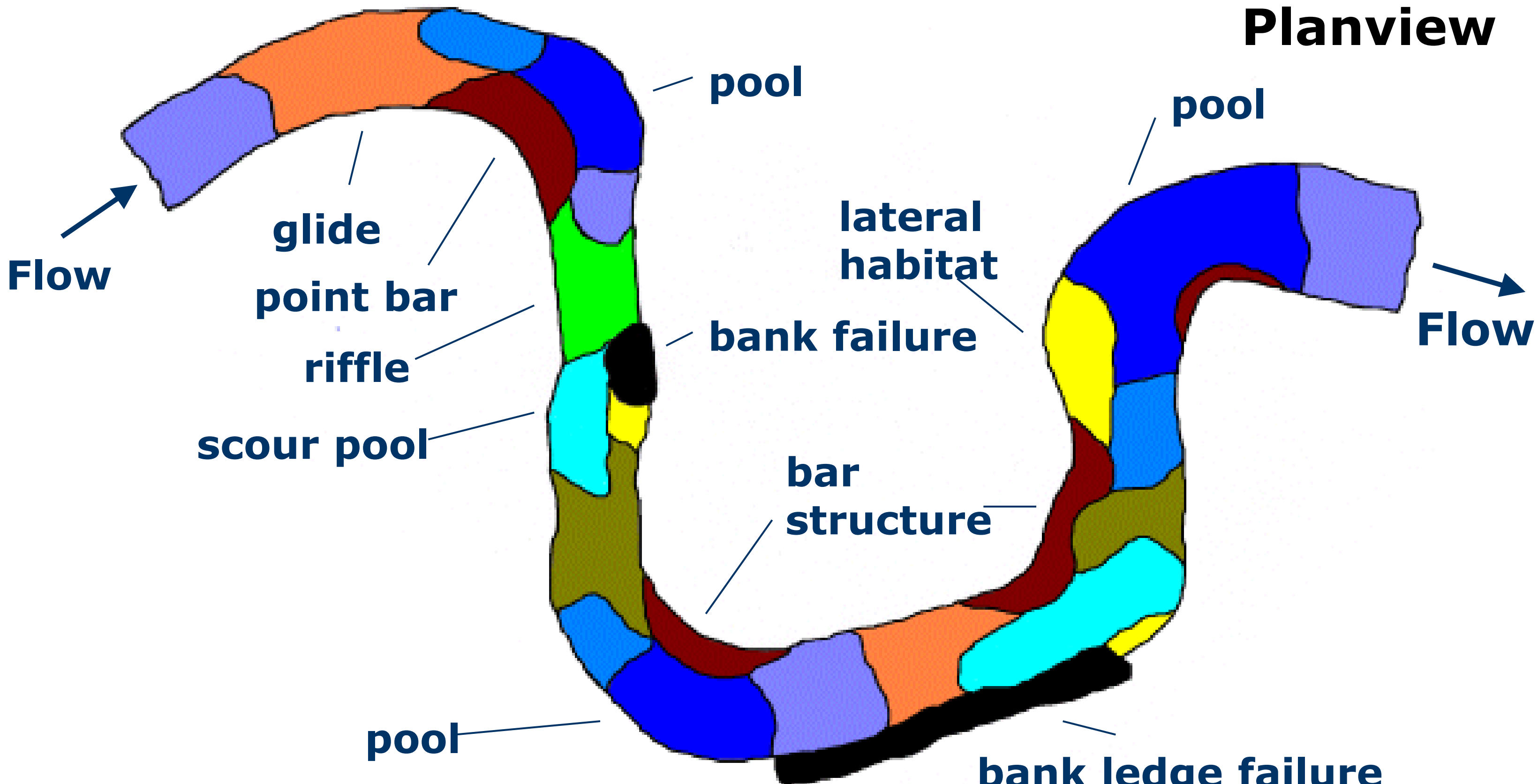
steep gradient fast water—cascade



step run

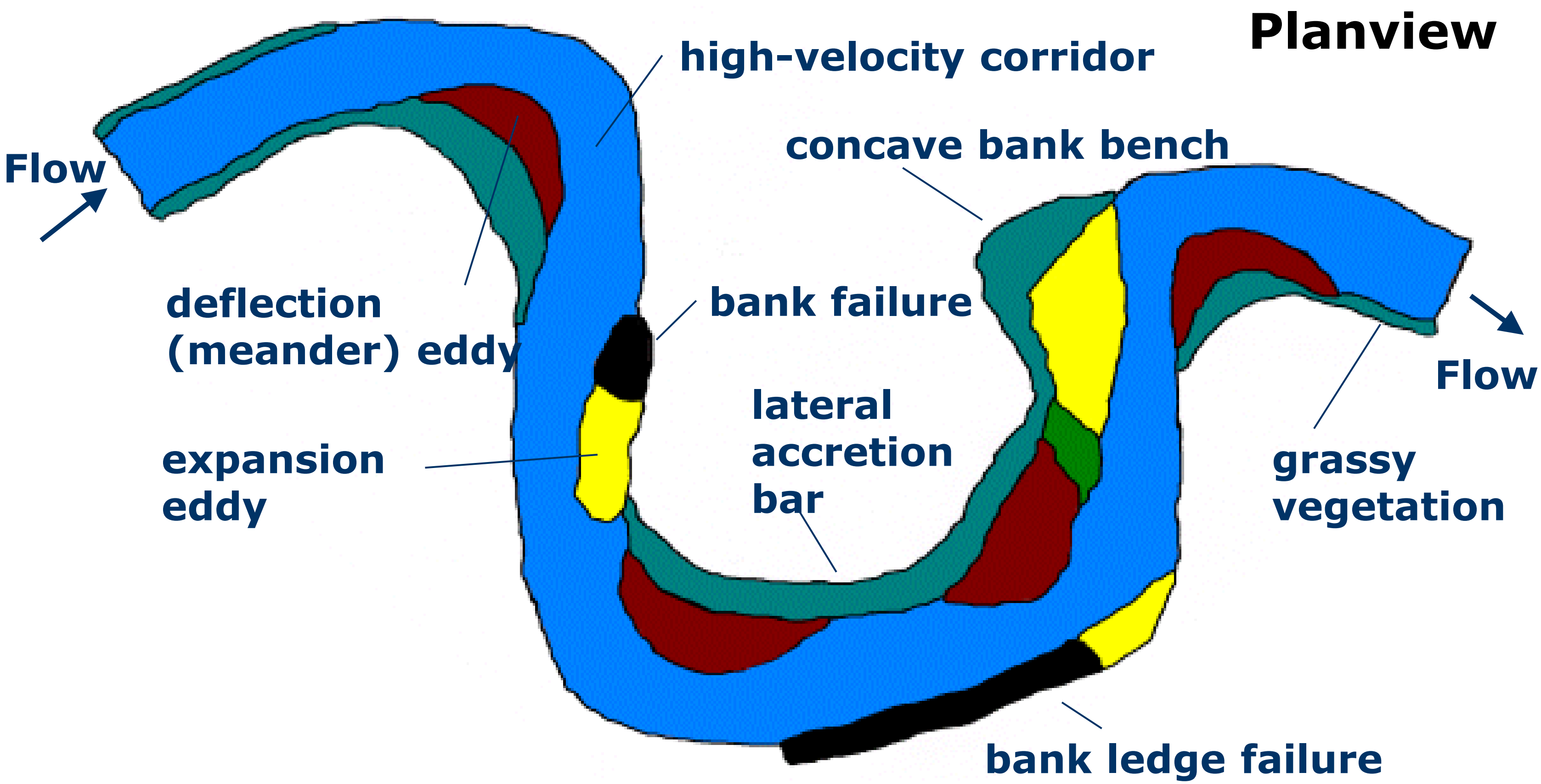
Flow-stage Dependent Habitat Classification

Planview



Low-flow Habitat Units

Flow-stage Dependent Habitat Classification



High-flow Habitat Units

Fish Habitat Use:
expression of biological resource need

Traditional view:

Habitat Structure is the physical conditions of the environment including channel morphology and flow hydraulics.

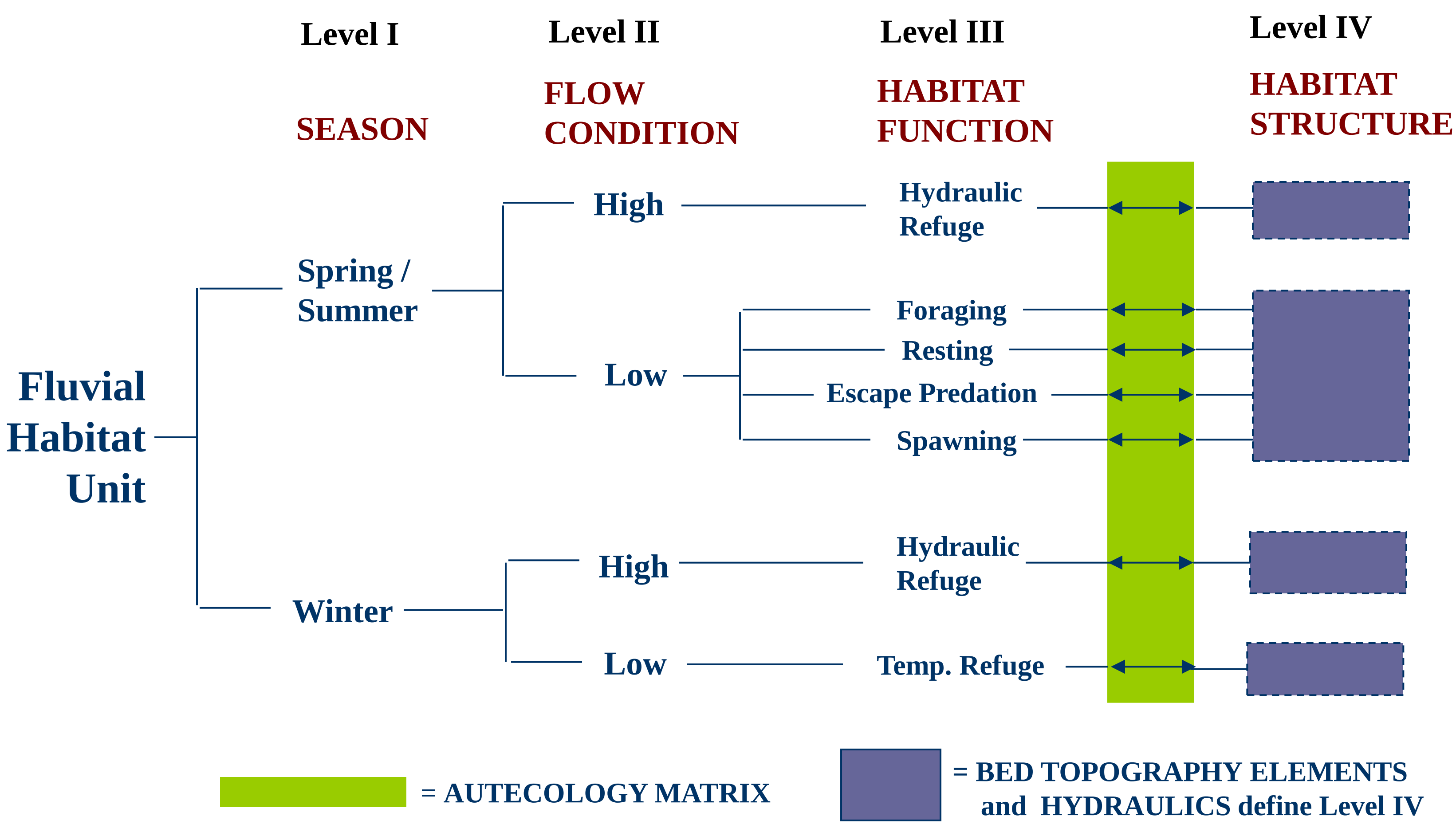
Coupling structure with functional traits:

Habitat Function is how the physical habitat structure meets the biological resource needs of organisms (e.g., feeding, spawning, and flow refuge).

STREAM FLOW CONDITION	SEASON	
	Summer/Fall	Winter
Low and Moderate Base Flows	Spawning Feeding / Resting Escape from Predation	Temperature Refuge
High Storm Flows	Flow Refuge	Flow Refuge

Example framework for Illinois prairie streams

Habitat Structure and Function



Microhabitat Scale Classification

Microhabitat Scale – Unit Characteristics

Physical features that occur within a channel unit that constituent provide an organism some biological resource, and influence their distribution (use of habitat space).

Physical features include:

Substrates (mud, silt, sand, gravel, cobble, boulders).
Large woody debris (debris jams, logs, root wads)
Undercut banks
Macrophytes (aquatic vegetation)
Miscellaneous large roughness elements

Defining Ecohydrology

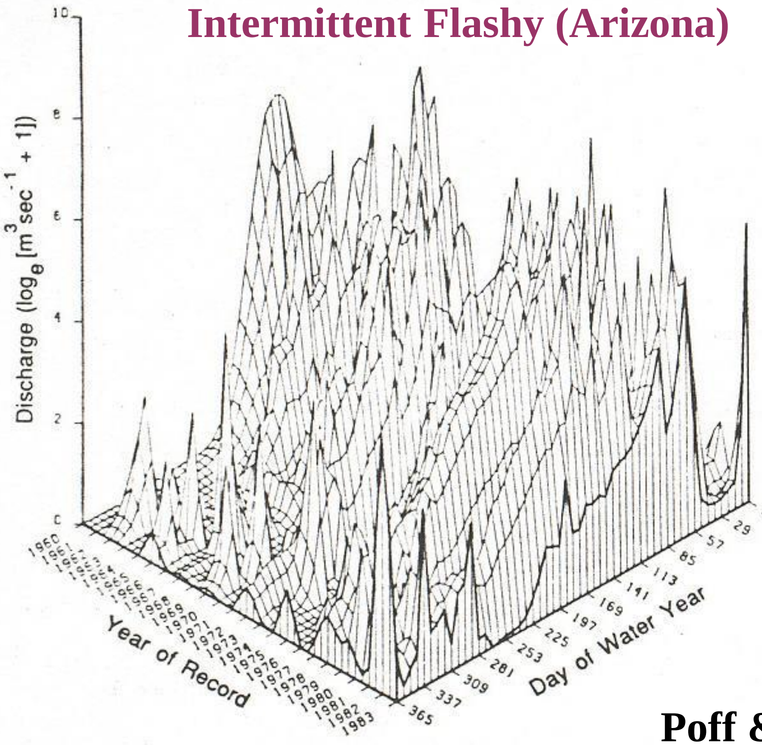
Ecohydrology is the science that studies the mutual interaction between the hydrological cycle and ecosystems, in order to better understand how hydrological processes differ among varying ecosystems, and details how plant and animal communities influence the flow of water and its contents, i.e., nutrients (Zalewski 2000; Hannah et al. 2004).

Ecohydrology is the study of the hydrologic mechanisms underlying the climate-soil-vegetation dynamics and thus controlling the most basic ecological patterns and processes (Rodriguez-Iturbe 2000).

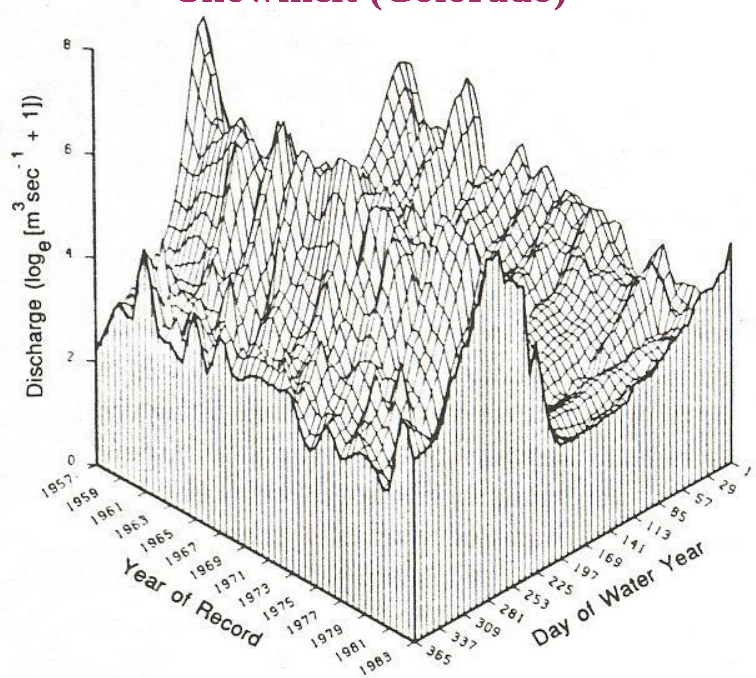
Ecohydrology

Ecohydrology: Linking hydrological patterns in rivers/streams with aquatic ecosystem properties - *regional examples*:

Intermittent Flashy (Arizona)



Snowmelt (Colorado)

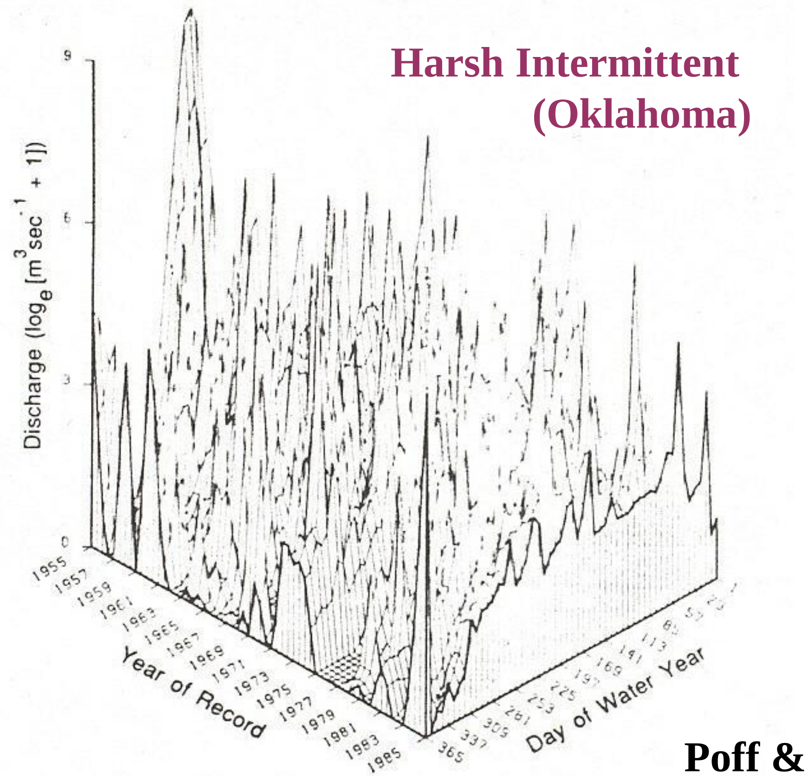


Poff & Ward (1989)

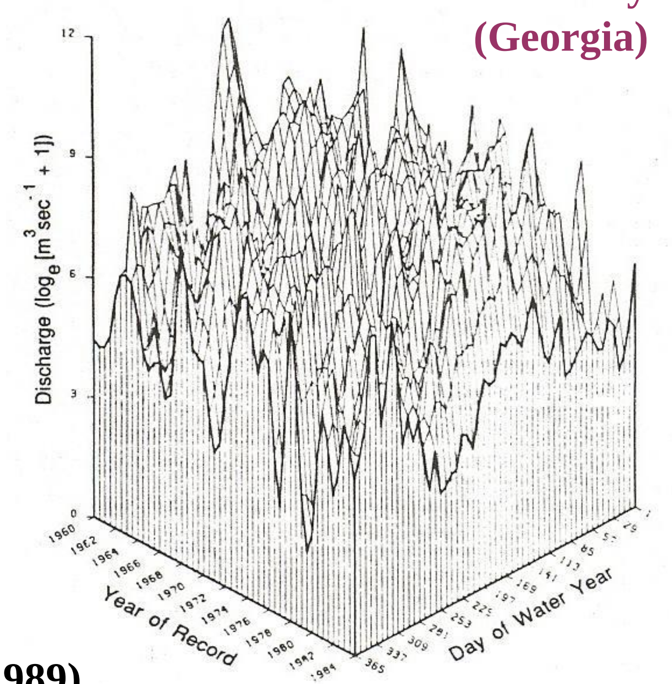
Ecohydrology

Ecohydrology: Linking hydrological patterns in rivers/streams with aquatic ecosystem properties - *regional examples*:

Harsh Intermittent (Oklahoma)



Perennial Flashy (Georgia)

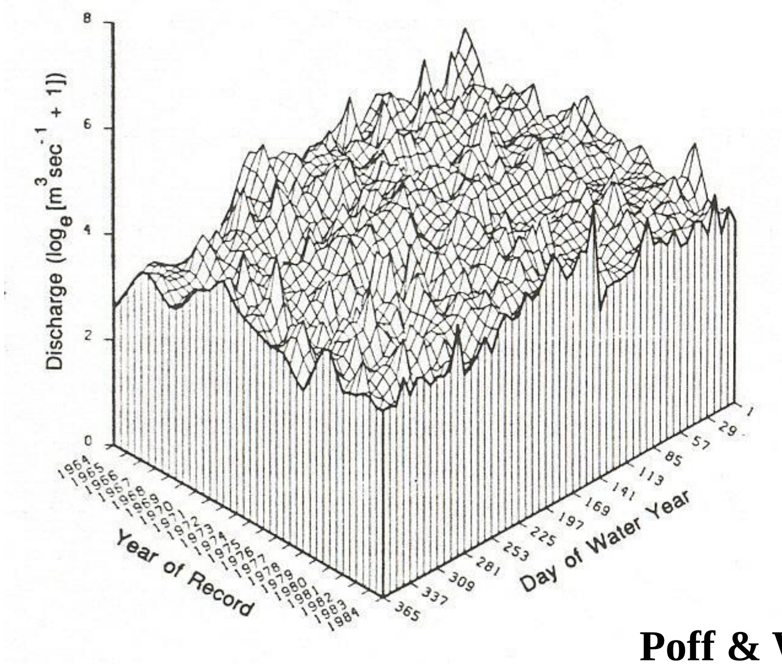


Poff & Ward (1989)

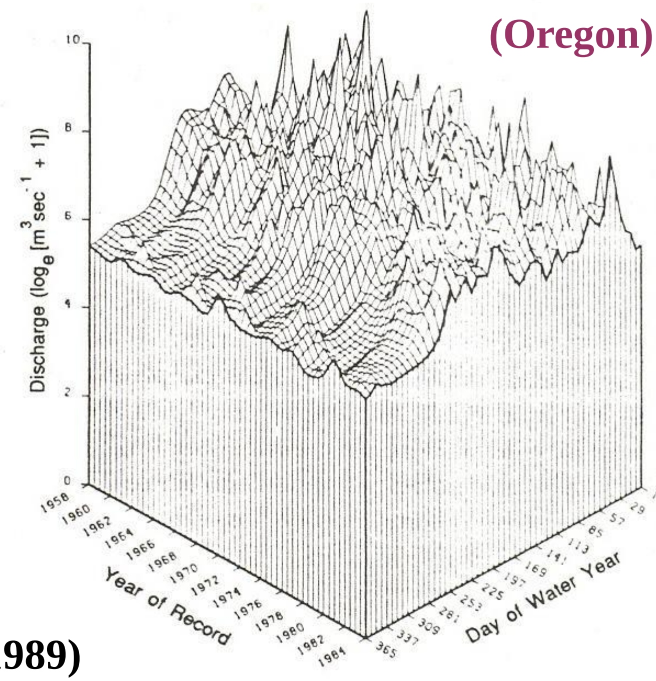
Ecohydrology

Ecohydrology: Linking hydrological patterns in rivers/streams with aquatic ecosystem properties - *regional examples*:

Mesic Groundwater (Missouri)



Winter Rain (Oregon)

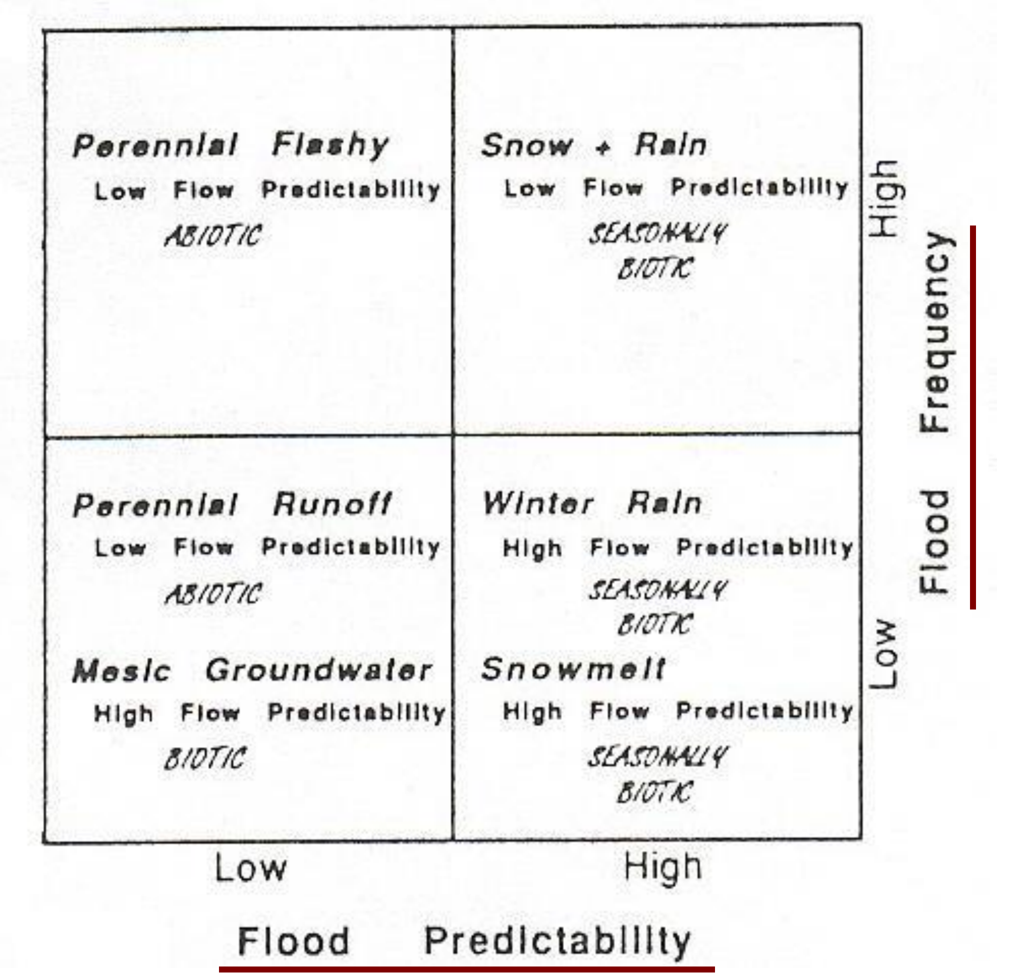


Poff & Ward (1989)

Ecohydrology

Ecohydrology:
Linking hydrological patterns in rivers/ streams with aquatic ecosystem properties – development of a conceptual model (Poff & Ward 1989).

Ecosystem governing factors: abiotic, biotic, and seasonal biotic.



Ecohydrology: Natural Flow Regime

Ecological responses to alterations in components of natural flow regime.

Flow Component	Specific Alteration	**Ecological Response** (examples)
Magnitude and frequency	Increased variation	Wash-out and/or standing; loss of sensitive species; increased algal scour and wash-out of organic matter; life cycle disruptions; altered energy dynamics.
	Flow stabilization	Invasion or establishment of exotic species; reduced water and nutrients to floodplain species; encroachment of vegetation into channels.
Timing	Loss of seasonal flow peaks	Disrupt cues for fish such as spawning, egg hatching and migration; loss of fish access to wetlands or backwaters; modification to food web structure; invasion of exotic riparian species; reduced floodplain plant growth.
Duration	Prolong low flows	Concentration of aquatic species; reduction of floodplain plant cover & growth; diminished plant species diversity.
	Prolonged baseflow “spikes”	Downstream loss of floating eggs; increased access of predators into lateral habitats
	Altered inundation duration	Altered floodplain plant cover types, growth, and physiological stress, mortality.
	Prolonged inundation	Floodplain tree mortality;
Rate of change	Rapid changes in river stage	Wash-out and standing of aquatic species
	Accelerated flood recession	Failure of floodplain seeding establishment

Poff et al. 1997

Ecohydrology:
Indicators of Hydrologic Alteration

Ecohydrology: Linking hydrological patterns in rivers/streams with aquatic ecosystem properties and system alteration:

IHA group	Hydrologic parameters	Ecosystem influences
Magnitude of monthly water conditions	Mean value for each calendar month (12 parameters)	* 1. Availability of habitat for aquatic organisms 2. Availability of soil moisture for plants 3. Availability of water 4. Reliability of water supplies for wildlife * 5. Effects of water temperature and dissolved oxygen
Magnitude and duration of annual extreme water conditions (mean daily flow)	1. Annual 1-day minima 2. Annual 3-day minima 3. Annual 7-day minima 4. Annual 30-day minima 5. Annual 90-day minima 6. Annual 1-day maxima 7. Annual 3-day maxima 8. Annual 7-day maxima 9. Annual 30-day maxima 10. Annual 90-day maxima 11. Number of zero-flow days 12. 7-day minima/mean for year	* 1. Balance of competitive and stress-tolerant organisms 2. Creation of sites for plant colonization 3. Structure of river channel morphology and physical habitat conditions 4. Soil moisture stress in plants 5. Dehydration in wildlife 6. Duration of stressful conditions 7. Distribution of plant communities

Swanson (2002)

Ecohydrology:
Indicators of Hydrologic Alteration

Ecohydrology: Linking hydrological patterns in rivers/streams with aquatic ecosystem properties and system alteration:

IHA group	Hydrologic parameters	Ecosystem influences
Timing of annual extreme water conditions	1. Julian date of each annual 1-day maxima * 2. Julian date of each annual 1-day minima *	1. Predictability and avoidability of stress for organisms 2. Spawning cues for migratory fish
Frequency and duration of high and low pulses **High pulse > 75 percentile** **Low Pulse < 25 percentile**	1. Number of low pulses within each year 2. Mean duration of low pulses each year * 3. Number of high pulses within each year * 4. Mean duration of high pulses each year	1. Frequency and magnitude of soil moisture stress for plants 2. Availability of floodplain habitat for aquatic organisms 3. Effects of bedload transport and channel sediment distribution, and duration of substrate disturbance
Rate and frequency of water condition changes	1. Means of all positive differences between consecutive daily values 2. Means of all negative differences between consecutive daily values 3. Number of hydrologic reversals	1. Drought stress on plants 2. Desiccation stress on low-mobility streamedge organisms

Swanson (2002)

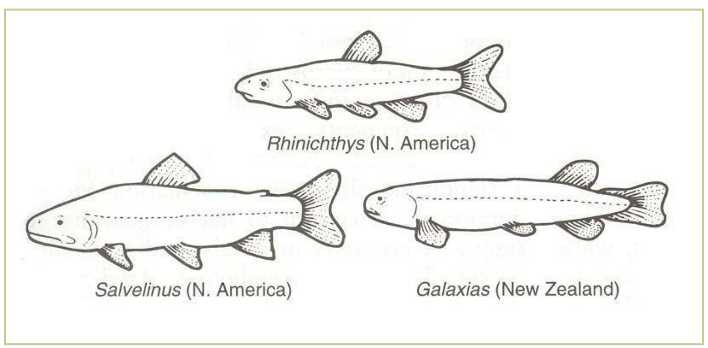
Defining Ecohydraulics

Ecohydraulics is the study of the linkages between the physical (geomorphic and hydraulic) features/processes and ecological responses in rivers, estuaries and wetlands from watershed (system) alterations.

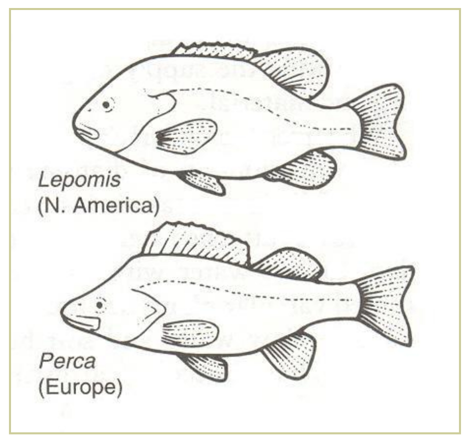
An interdisciplinary approach, crossing the boundaries of science and engineering programs, utilizing *analysis and model simulations* of fluvial environments to better understand the complexities of aquatic systems and their resilience (or lack there of) to anthropogenic disturbances.

Ecohydraulics: Hydraulic Habitats

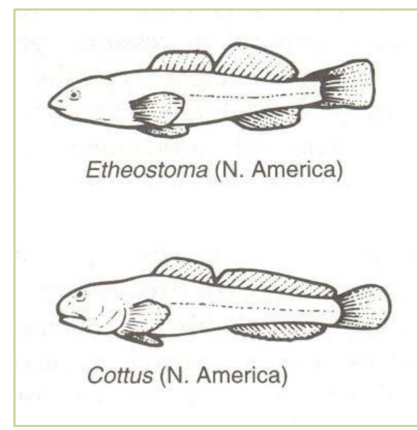
Relationships with velocity, depth, and substrate identify that each species have evolved with an unique body morphology, and behavioral traits to survive, and maintain a vital population (Allan 1995).



Streamlined body:
higher-velocity waters; medium to deep waters; gravel, vegetation spawners



Deep body:
lower-velocity waters; deep waters; gravel to muddy debris spawners



Flatten body lg. pectoral fins:
higher-velocity waters; shallow waters; gravel spawners

Ecohydraulics: Hydraulic Habitats

Ecohydraulics: Hydraulic Habitat Classification

Kemp *et al*. (2000) classifies habitat hydraulics into in-stream flow biotopes.

Biotope (flow type)	Associated river feature
Free fall	Waterfall
Chute	Step (of step-pool cascade)
Broken standing waves	Rapid (whitewater)
Unbroken standing waves	Riffle
Chaotic flow	A mixture of rough flow types
Rippled	Run
Upwelling	Boil
Smooth boundary turbulent	Glide
No perceptible flow	Pool/deadwater

More recent developments recognize the importance of defining 3D habitat hydraulics (*review lecture on habitat*), in which habitat use/preferences change with flow stage, and preferred hydraulics conditions.

Ecohydraulics: Hydraulic Habitats

Ecohydraulics:

Frimpong and Angermeier (2010) relate habitats as a "guild" classes based on geomorphic - physical habitat structure and hydraulics.

Guilds represent common group of organisms (fish in this case) that exploit the same resources based on functional species traits.

Autecology: species relation between habitat function and structure

Guild	Common Name	Species
Microhabitat Framework		
Fast-Riffle	Torrent sucker	*Thoburnia rhothoeca*
	Roanoke darter	*Percina roanoka*
Riffle-Run	Mottled Sculpin	*Cottus bairdi*
	Fantail darter	*Etheostoma flabellare*
	Riverweed darter	*Etheostoma podostemone*
	Central stoneroller	*Campostoma anomalum*
Fast-Generalist	Roanoke hog sucker	*Hypentelium roanokense*
	Margined madtom	*Noturus insignis*
	Black jumprock	*Scartomyzon cervinus*
	Bluehead chub	*Nocomis leptocephalus*
Shallow-Rheophilic	Mt. redbelly dace	*Phoxinus oreas*
	East. blacknose dace	*Rhinichthys atratulus atratulus*
Pool-Run	Crescent shiner	*Luxilus cerasinus*
	White shiner	*Luxilus albeolus*
	White sucker	*Catostomus commersoni*
Pool-Open	Mimic shiner	*Notropis volucellus*
	Swallowtail shiner	*Notropis procne*
Pool-Covered	Bluntnose minnow	*Pimephales notatus*
	Spottail shiner	*Notropis hudsonius*
	Redbreast sunfish	*Lepomis auritus*
	Northern hog sucker	*Hypentelium nigricans*
	Golden redhorse	*Moxostoma erythrurum*
	Silver redhorse	*Moxostoma antiserum*

Ecohydraulics

Ecohydraulics

Habitat Analysis

- Habitat Classification (mesohabitat types, biotopes - flow topologies)
- Habitat Use (trait-based preferences)
- Habitat Modeling (PHABSIM, River2D, MesoHABSIM)

Support Engineering Designs

- Fish Passageways (dams & fish ladders, culverts & FishXing)
- Fish Energetics (migration, passing through hydraulic structures)
- Stream Restoration (habitat maintenance principles)

Rock Ramp Fishway

A nature-like rock ramp fishway in Orrington, Maine becomes the aesthetic center-piece of a local park.

Stream Ecology

Stream Ecology includes ecological **structure** (individuals, populations, and communities) and **function,** where the fluvial ecosystem integrates the biota and biological interactions with all of the interacting physical and chemical processes.

Certain properties characterize the whole system:

- its overall production and metabolism,
- how efficiently nutrients are used,
- the diversity of energy supplies and flux, and
- the number of species and feeding roles represented.

Allan & Castillo (2007)

Stream Ecology

Stream Ecology involves the study of:

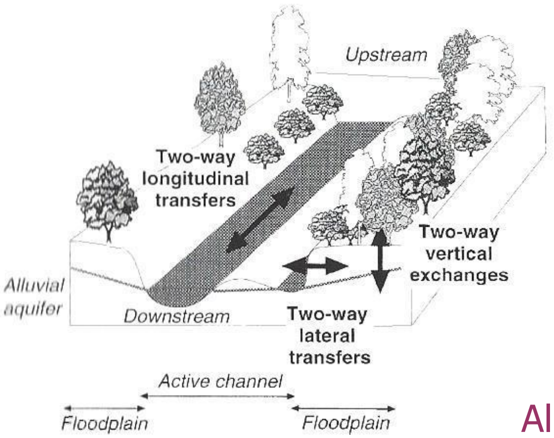
- Channel morphological structure and function (fluvial geomorphology)
- Abiotic environment (stream habitat, water chemistry, flow, temperature)
- Ecological scales (individuals, populations, and communities)
- Nutrient dynamics
- Organic matter budget (energy, metabolism)
- Trophic structure and relationships (food webs, trophic cascade)

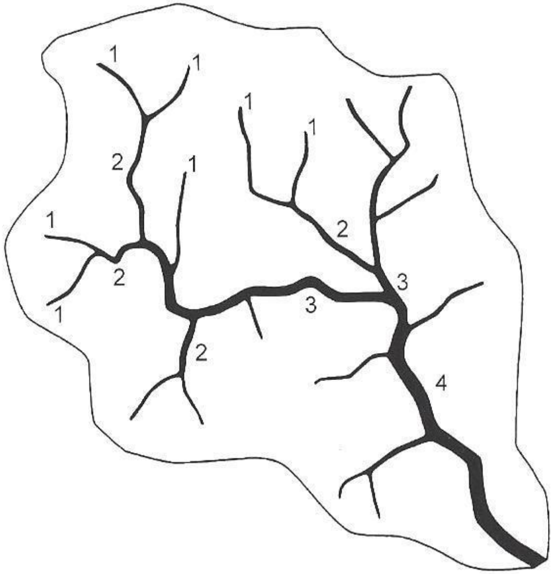
Allan & Castillo (2007)

Stream Ecology

Stream ecosystems have fluxes of energy, nutrients, flow exhibiting high connectivity across three major axes: longitudinal, lateral, and vertical. Spatial space is important to understanding processes, and relates to habitat hierarchical structure.
(*review* Frissell et al. 1986)

Longitudinal: downstream flow of water, ions, organic matter: biota movement up and down
Lateral: flood flows onto floodplains and other lateral surfaces, exchange of nutrients and biota movement
Vertical: water quality transformations in hyporheic zone, and biota habitat and movement.





Allan & Castillo (2007)

Ecological Scales

Ecological scales include:

- Individual, *defined* as a species
- Population, *defined* as a group of species
- Community, *defined* as a group of populations

An ecosystem is comprised of the biological community together it physical environment.

Ecological Scales

Individuals

The ecology of individuals considers:

- the life history of a species, an organisms pattern of growth and size, reproduction (fecundity, the number of eggs produced), migration;
- species behavior (social order and dominance, reproduction); and
- species intraspecific competition.

Governs patterns of resource use for mesohabitat occupancy, survival and reproduction; broadly defined as species traits.

Keystone species are those which exert influences over other members of their ecological community *out of proportion* to their abundances.

Spatial scale typically is at the mesohabitat scale, although the species' population can occupy large areas.

Ecological Scales

Populations

The ecology of population considers:

- collectively, the species home range (distribution and abundance), migration, dispersion and/or colonization;
- Various population characteristics include: numbers of individuals and density within an area, and age class distribution, and sex ratios (when metrics are modeled, it is referred to as population dynamics);
- population growth is density-dependent when the growth of the individual decreases as the population size increases; intraspecific competition for food.
- species interspecific competition (predator-prey interactions, parasitism); and
- The partitioning of resources use per differences in habitat use

Allopatric population = a single species population in a defined area, whereas
Sympatric population = multiple species populations in a defines area.

Spatial scale varies depending on home range, from microhabitat, reaches, to large drainage basins.

Ecological Scales

Populations

The ecology of population considers:

Density-independent Factors: Any **factor** limiting the size of a population whose effect is not dependent on the number of individuals in the population. F**actors are** abiotic for example a flood, pollution, and/or climate change (water temperatures), which will kill all members of the population regardless of whether the population is small or large.

Density-dependent Factors: Any **factor** limiting the size of a population whose effect is **dependent** on the number of individuals in the population. For example, disease will have a greater effect in limiting the growth of a large population, since overcrowding facilitates its spread. Other biotic factors, predation, competition for habitat/food resources, parasitism, and migration (a form of habitat competition).


Schooling vs
non-schooling fish

Ecological Scales

Communities

The ecology of communities, an assemblage of species and their population considers:

- the species richness and/or composition, and biodiversity (diversity indices);
- Interactions among abiotic and biotic factors that influence composition, i.e., competition, productivity and energy fluxes; disturbance caused by natural and anthropogenic environmental conditions.
- community stability in terms of resilience (speed in which a community returns to a former state after disturbance) and resistance (ability of a community to avoid displacement/degradation).

Spatial scale typically is large areas, ecoregions.

Nutrient Dynamics

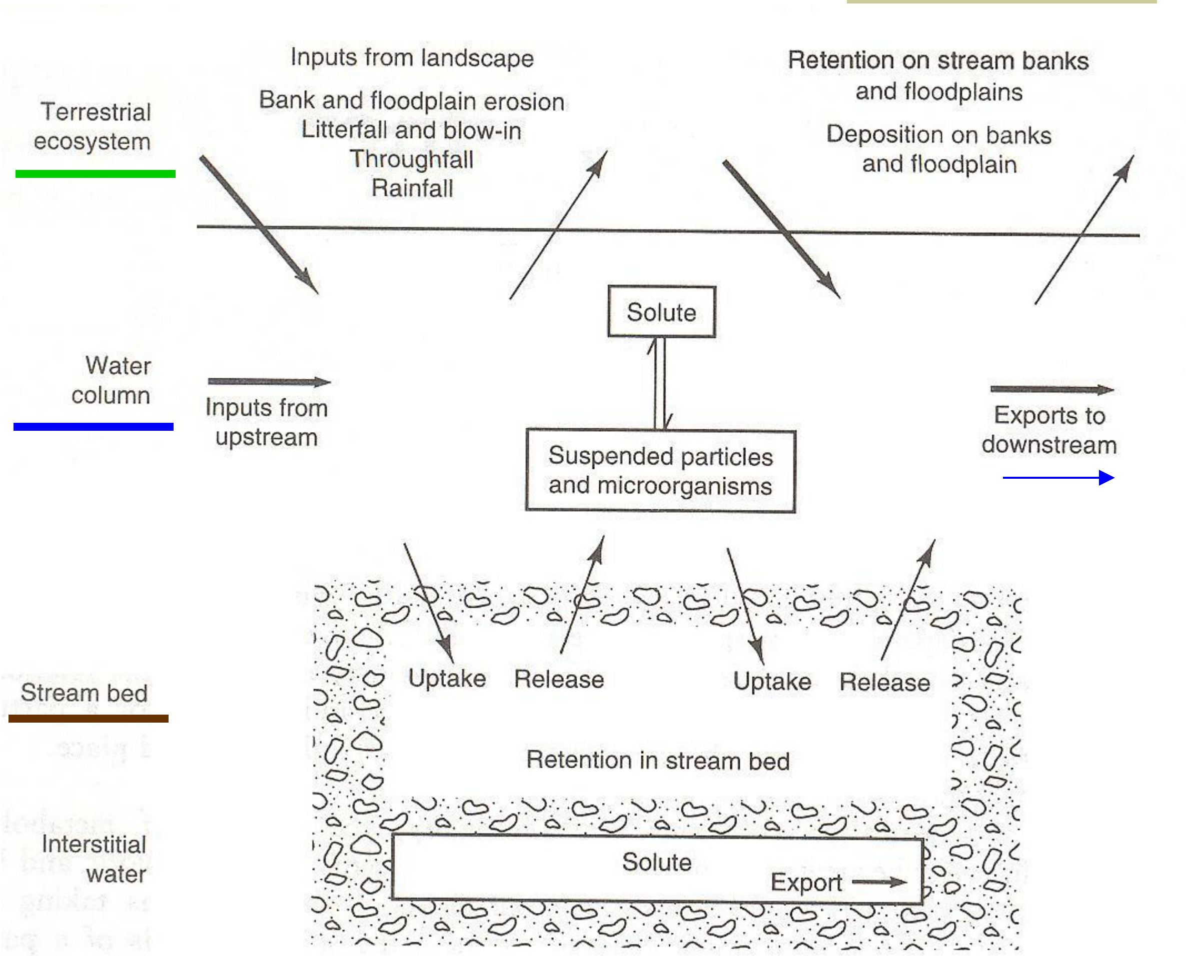
Nutrient Dynamics involves the fate and transport of solutes generating nutrient cycles significantly influenced by both abiotic and biotic processes.

Processes for nutrient cycles include transformations from one chemical to another, chemical precipitation, and physical changes from adsorption and desorption, and biological uptake and release.

Nutrient transport flux is predominantly in the downstream direction; and flux into storage is rapid in streams, typically.

Nutrient Dynamics

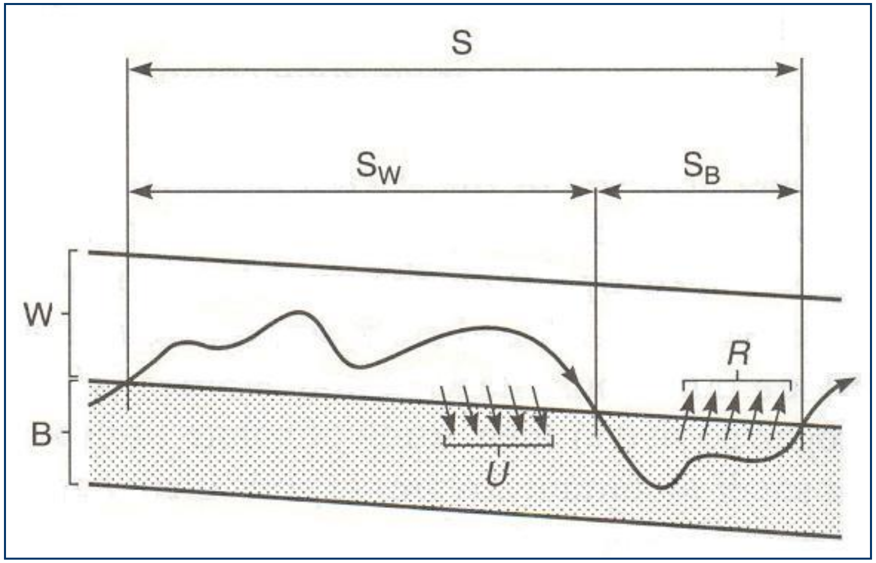
Nutrient Dynamics - conceptual diagram of solute processes in streams.



Allan (1995)

Nutrient Dynamics

Nutrient Spiraling Concept couples nutrient cycling and solute transport, conceptually following an "atom" from entry into the water column and transport, to storage, and then back to entry into the water column. Applying this concept quantifies the distance traveled by an "atom" to complete this process (Allan 1995).



S = spiraling length or distance
S_W = transport distance in water column
S_B = additional transport by biota
U = uptake; R = Release

Nutrient Dynamics

Nutrient Spiraling Concept – Governing factors

Abiotic Controls include physical-chemical process such as precipitation and sorption onto sediments; and hydrologic influences through seasonal variations of flow stage, where velocities and channel complexity greatly influence transport.

Biotic Controls include biological uptake and assimilation mostly by the microbial community, and the animal community by direct consumption.

Organic Matter Budgets

Nutrient Cycling of Carbon – the flux of energy, expressed as organic matter or carbon, can be found in many forms, and the processing of organic material is a key ecosystem function.

Biological processing is dependent of organic matter particle size, including **CPOM** (course particulate organic matter), **FPOM** (fine particulate organic matter), and **DOM** (dissolved organic matter).

Two key organic sources in lotic (*running water*) ecosystems:

1. Autochthonous – material from primary production by periphyton, macrophytes, and phytoplankton inside the stream.
2. Allochthonous – material from production outside the stream such as leaf litter and wood of terrestrial origin.

Organic Matter Budgets

Characteristics / Size Classifications for Organic Matter

Inorganic carbon = dissolved CO_2

Organic Carbon

DOC = dissolved organic carbon, same as DOM
DOM = dissolved organic matter (< 0.5 µm)
FPOM = fine particulate organic matter (> 0.5 µm and < 1 mm)
CPOM = course particulate organic matter (> 1 mm)

LWD = large woody debris (logs, woody debris)

Organic Matter Budgets

Factors influencing **DOC** concentrations

DOC transport varies seasonally due to changes in inputs between growing and dominant seasons, and hydrologically between wet and dry periods.

> DOC concentration increase in the spring season, prior to canopy cover in woodlands streams, from extracellular release of DOC during periphyton (algae) blooms.

> Leaf fall, followed by leaf leachate attributed to increases in DOC concentrations in the autumn period.

> DOC concentrations are increased during high flows as more OM is dislodged from sediment storage and transported.

Organic Matter Budgets

Factors influencing POC concentrations

Similar to DOC, Particulate Organic Carbon (**POC**) transport varies seasonally, but due to changes in biological processes rather than input differences, and also hydrologically between wet and dry periods.

> Accumulation and storage of POC in the streambed can be important to ecosystem function.

> Much of POC in transport during non-storm flows results from biological activity of benthic macroinvertebrates which shred leaves creating CPOM (*shredders*), filter and gather CPOM and FPOM, and consume and release DOC (*collector-gathers*).

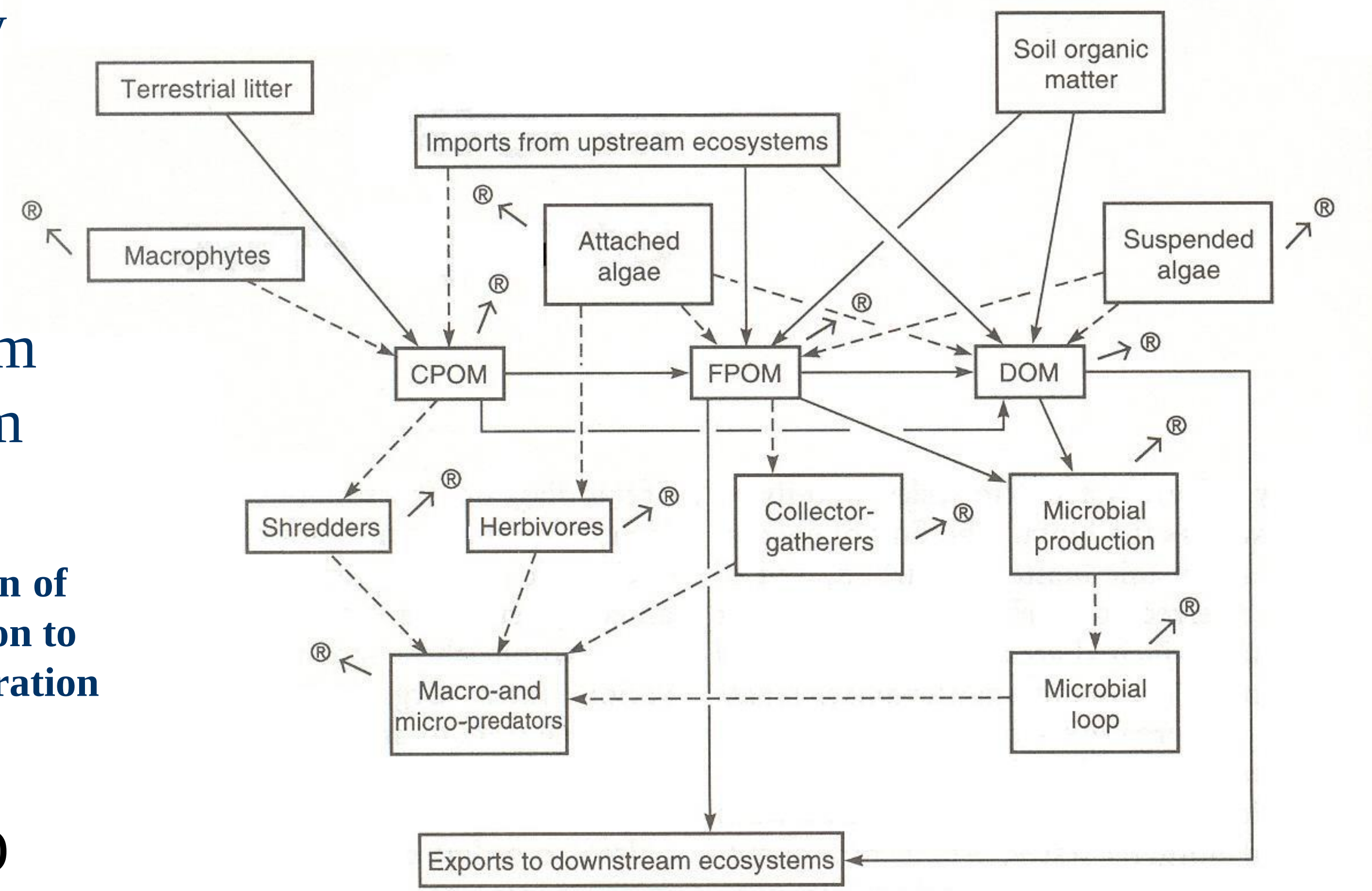
> POC transport is dependent on in-stream hydraulics, transported similarly to suspended sediment during high flows.

Organic Matter Budgets

Summary
Carbon
Fluxes

in a stream
ecosystem

® denotes mineralization of organic carbon to CO_2 by respiration



(Allan 1995)

Organic Matter Budgets

Organic Matter Retention

Retention of organic matter (OM) in streams is critical for the ecosystem, the greater the retention the more the amount of organic matter respired by the consumer community.

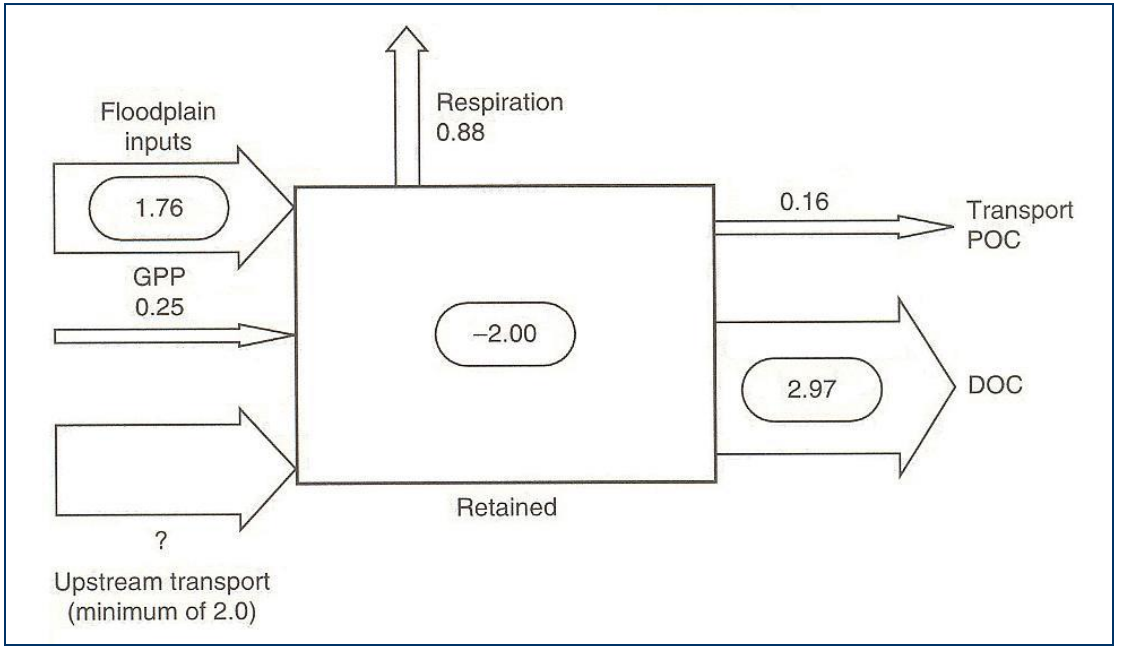
OM Retention is a function of the channel complexity and how its structure traps and accumulates OM as leaf packs on boulders, bank vegetation, and large woody debris.

OM Retention is also a function of local channel hydraulics, channel morphology, and flow stage.

Organic Matter Budgets

Organic Matter Budgets are the mass balance calculations, or budgets, on an accounting of all inputs and outputs from delineated area of a stream ecosystem.

Example
Annual carbon budget for 1.0 m^2 of the Ogeechee River, NC, in units of $kgC/(m^2{\cdot}yr)$, GPP is the gross primary production.



Organic Matter Budgets

Organic Matter Budgets has traditionally been expressed as energy budgets in streams.

Expressed as the ratio of gross primary production (P) to community respiration (R); the **P/R ratio**.

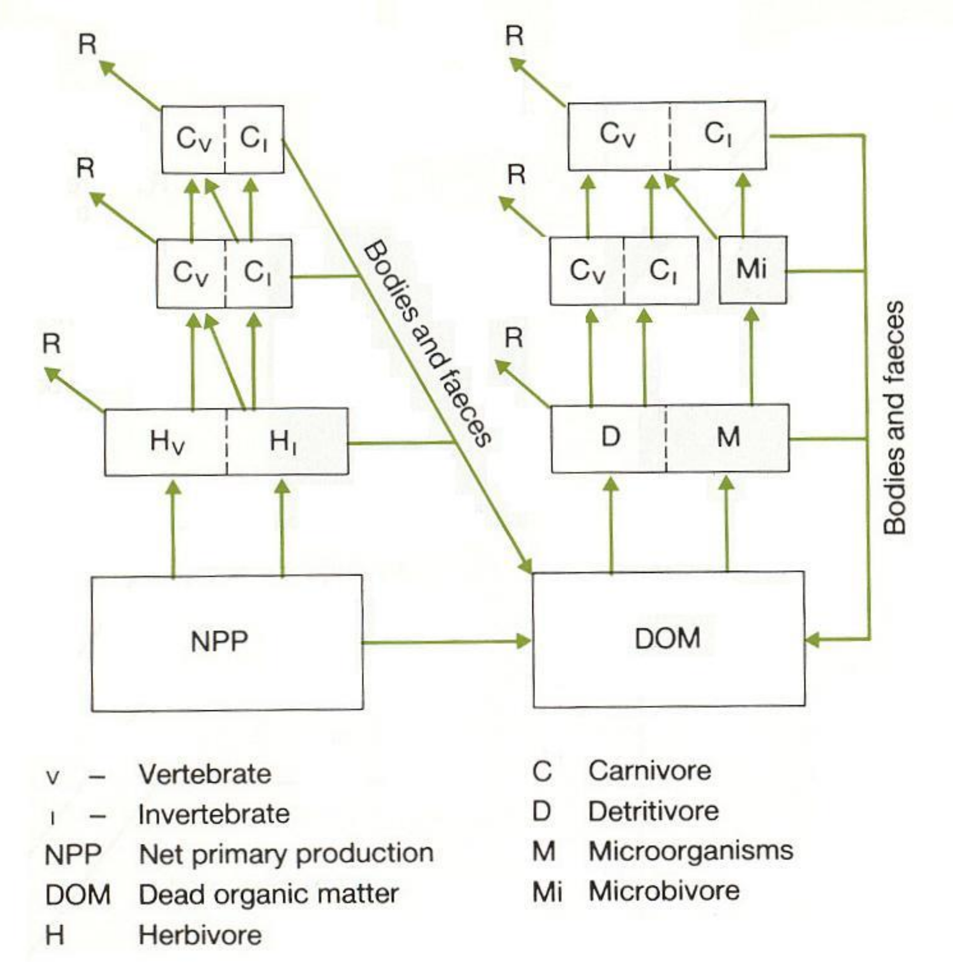
An ecosystem that respires all the energy fixed by its primary producers has a P/R value of one.

> **P/R values greater than one**, export or accrual must be invoked. autotrophic ecosystems, primary production high in contrast to respiration.

> **P/R values less than one**, energy must be imported from elsewhere; heterotrophic ecosystems, respiration high in contrast to primary production.

Trophic Relationships

Trophic structure incorporates the ideas of energy fluxes in an ecosystem, typically as organic matter (OM) budgets, adding the hierarchical pathways-relationships of the food chain (*who eats what or who*), and determining the community structure.



Trophic Relationships

Guild Concept

Guild is a group of species of similar taxonomic affiliation, that exploit the same class of environmental resources in a similar way (e.g., food resources, spawning resources). Guild members may or may not compete for the resources.

Generalist vs Specialist - Species life histories have so evolved to generally exploit environmental resources, or have specialized strategies for exploiting resources. With respect to food resources, diet width is a term used in ecology to distinguish between generalists and specialists.

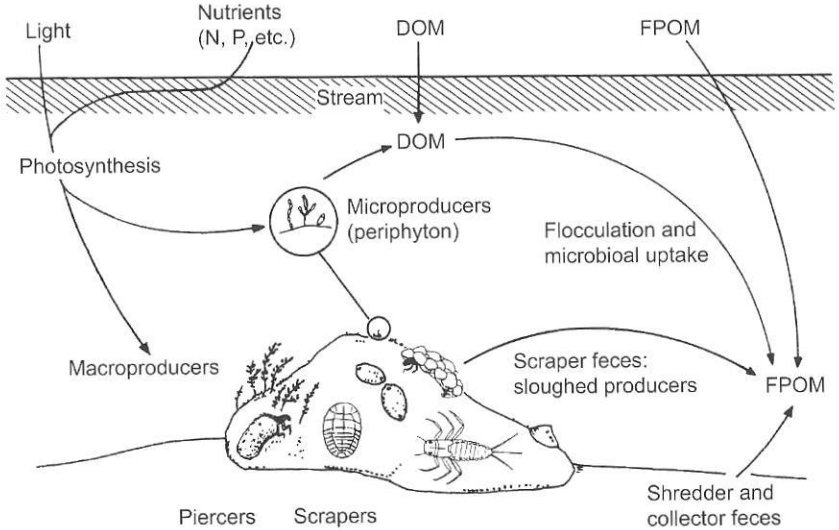
Trophic Relationships

Feeding Guilds: for benthic macroinvertebrates (BMIs) are termed functional groups.

BMIs are important how we organize organic matter processing.

Functional Groups *include*:

- Shredder
- Shredder / Gouger
- Suspension feeder
- Collector-gatherer
- Grazer
- Piercers
- Predator



Allan & Castillo (2007)

Trophic Relationships

Feeding Guilds for benthic macro-invertebrates.

Feeding role	*Food resource*	*Feeding mechanism*	*Examples*
Shredder	Non-woody CPOM, primarily leaves; and associated microbiota, especially fungi	Chewing and mining	Several families of Trichoptera, Plecoptera, and Crustacea; some Diptera, snails
Shredder/gouger	Woody CPOM and microbiota, especially fungi; primarily surficial layers are utilized	As above	Occasional taxa among Diptera, Coleoptera, Trichoptera
Suspension feeder/ filterer-collector	FPOM and microbiota, especially bacteria and sloughed periphyton in water column	Collect particles using setae, specialized filtering apparatus or nets and secretions	Net-spinning Trichoptera, Simuliidae and other Diptera; some Ephemeroptera
Deposit feeder/ collector-gatherer	FPOM and microbiota, especially bacteria, and organic microlayer	Collect surface deposits, browse on amorphous material, burrow in soft sediments	Many Ephemeroptera, Chironomidae and Ceratopogonidae
Grazer	Periphyton, especially diatoms; and organic microlayer	Scraping, rasping and browsing adaptions	Several families of Ephemeroptera and Trichoptera; some Diptera, Lepidoptera and Coleoptera
	Macrophytes	Piercing	Hydroptilid caddis larvae
Predator	Animal prey	Biting and piercing	Odonata, Megaloptera, some Plecoptera, Trichoptera, Diptera and Coleoptera

Allan (1995)

Trophic Relationships

Feeding Guilds for fish.

Guild classifications applies similarly to the concept as with benthic macro-invertebrates.

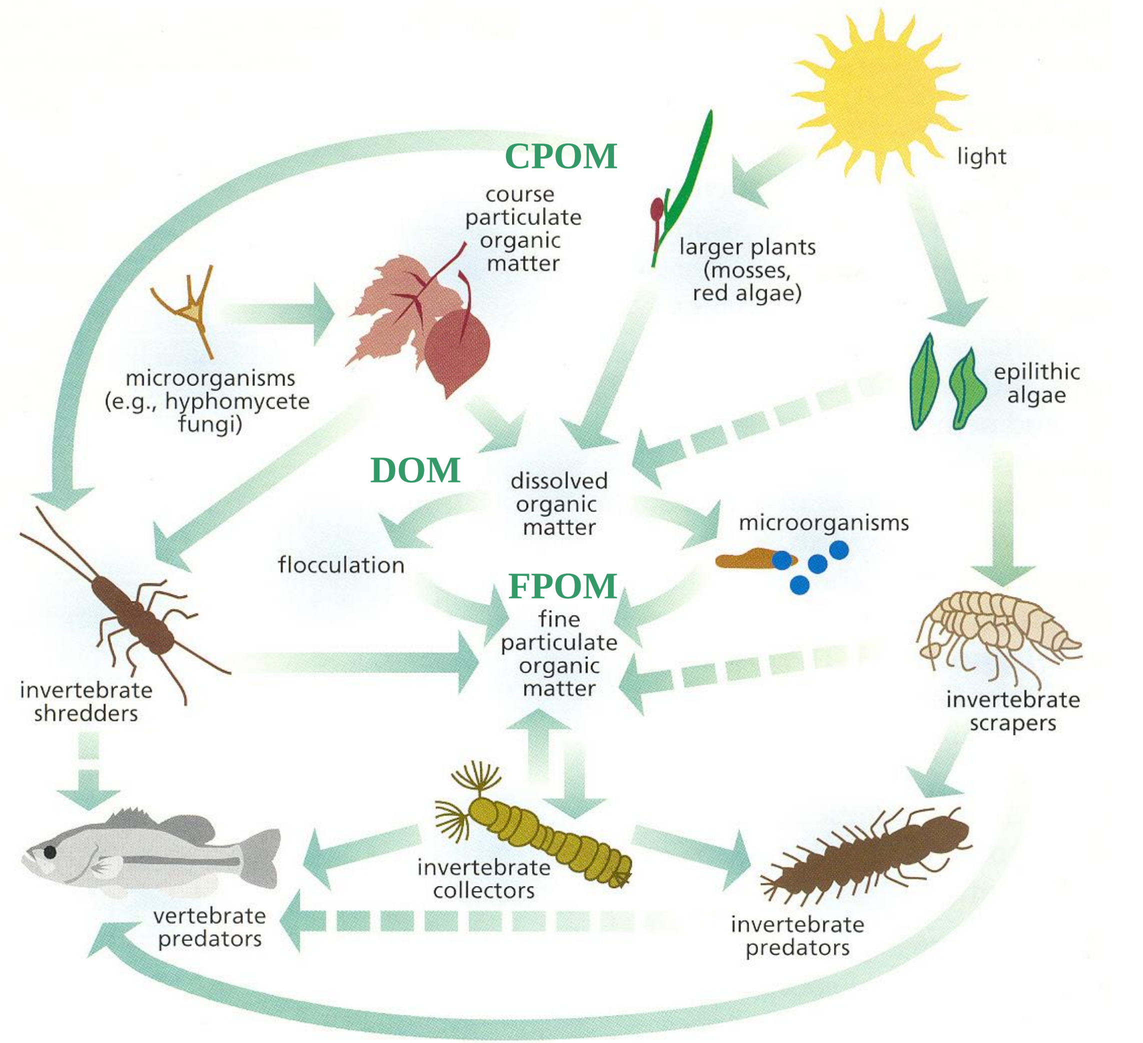
Guild	*Description for temperate streams*	*Occurence by species (%)*
Piscivore	Consumes primarily fish and/or large invertebrates, but includes smaller invertebrates	16
Benthic invertebrate feeder	Feeds on benthic invertebrates, primarily immature insects	33
Surface and water column feeder	Consumes surface prey (mainly terrestrial and emerging insects) and drift (zooplankton and invertebrates of benthic origin)	11
Generalized invertebrate feeder	Feeds at all depths	11
Planktivore	Midwater specialist on phyto- and zooplankton	3
Herbivore–detritivore	Bottom feeder ingesting periphyton and detritus; includes mud feeders with long intestinal tracts	7
Omnivore	Ingests a wide range of animal and plant foods, and detritus	6
Parasite	Ectoparasite (e.g. lampreys)	3

Allan (1995)

Trophic Relationships

Food Webs

generalized lotic food web *relevant to* stream restoration



FISRWG (1998)

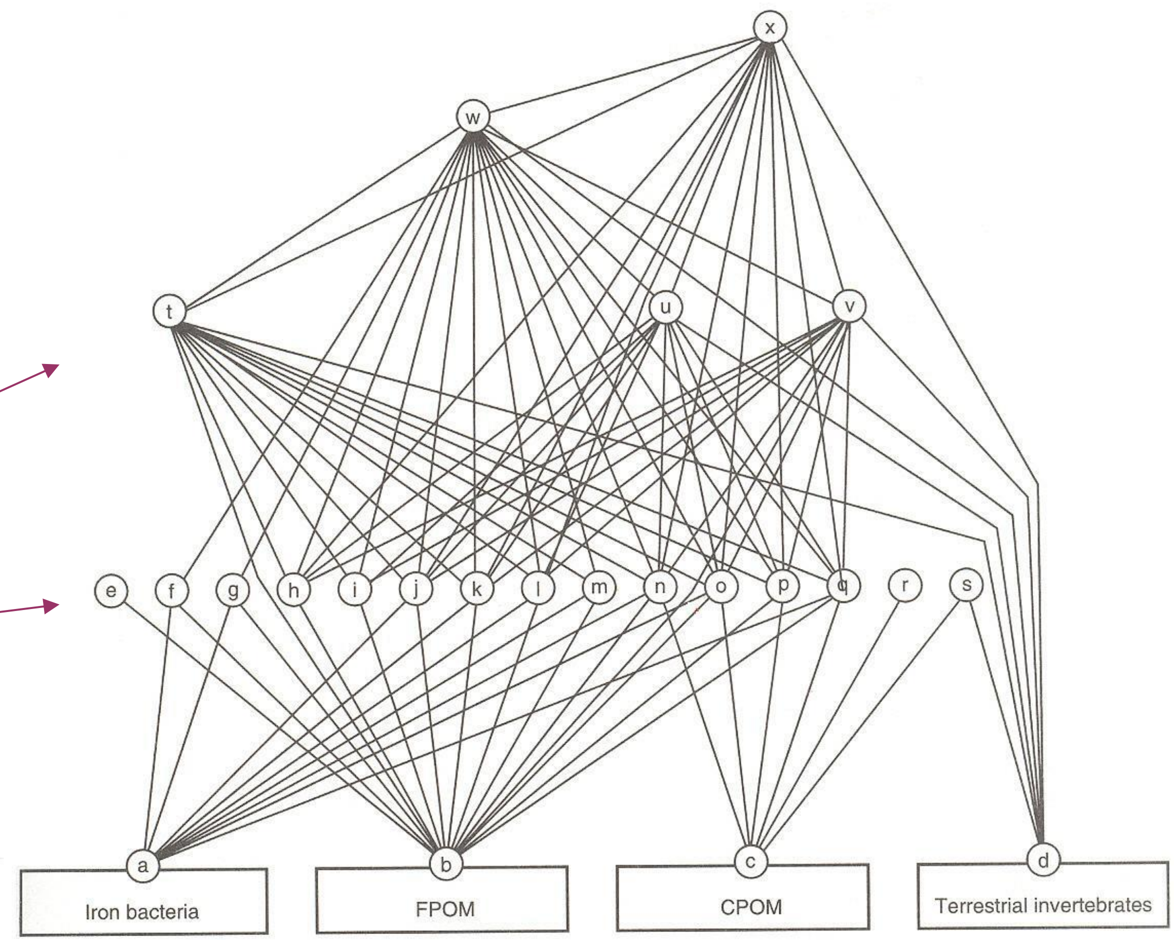
Trophic Relationships

Food Webs

Species-specific lotic food web

Predators

Primary consumers: herbivore & debris feeders



Allan (1995)

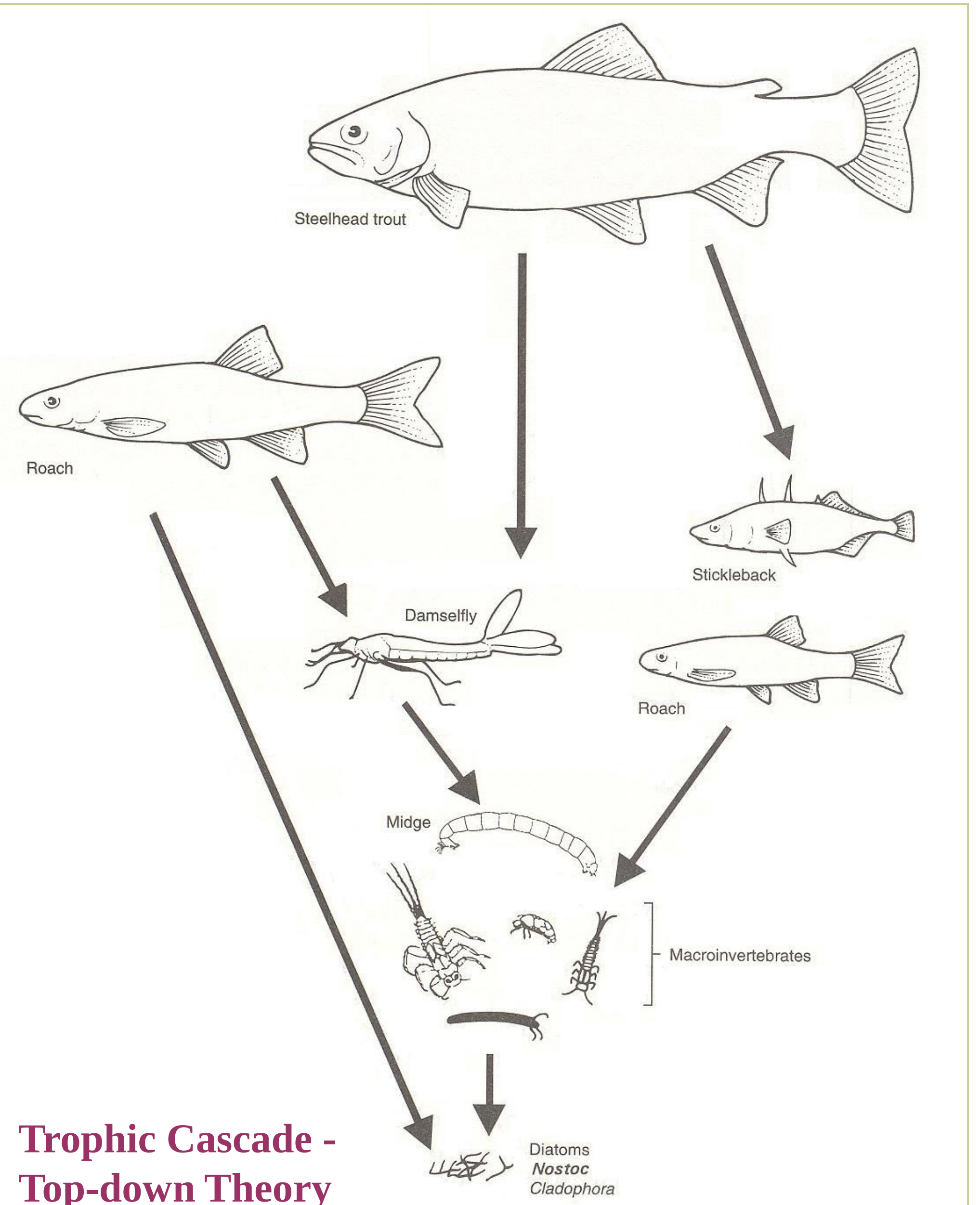
Trophic Relationships

Trophic Cascade
in stream food webs

Top-down Theory: Idea that top predators in the food web control ecosystem community structure.

In contrast, other argue, **Bottom-up Theory:** Idea that availability of prey controls ecosystem community structure.

Allan (1995)



Trophic Cascade - Top-down Theory

River Continuum Concept

River Continuum Concept is a framework for integrating predictable and observable biological adjustments of lotic systems with the continuous gradient of physical conditions (abiotic factors) from headwaters to mouth.

Changes in the community structure of aquatic biota are related to the ecological function of processing organic matter, in which ecological function relates to:

1) a product of the physical changes in habitat structure along the longitudinal profile, and
2) the corresponding changes in organic inputs to the system (allochthonous / autochthonous sources).

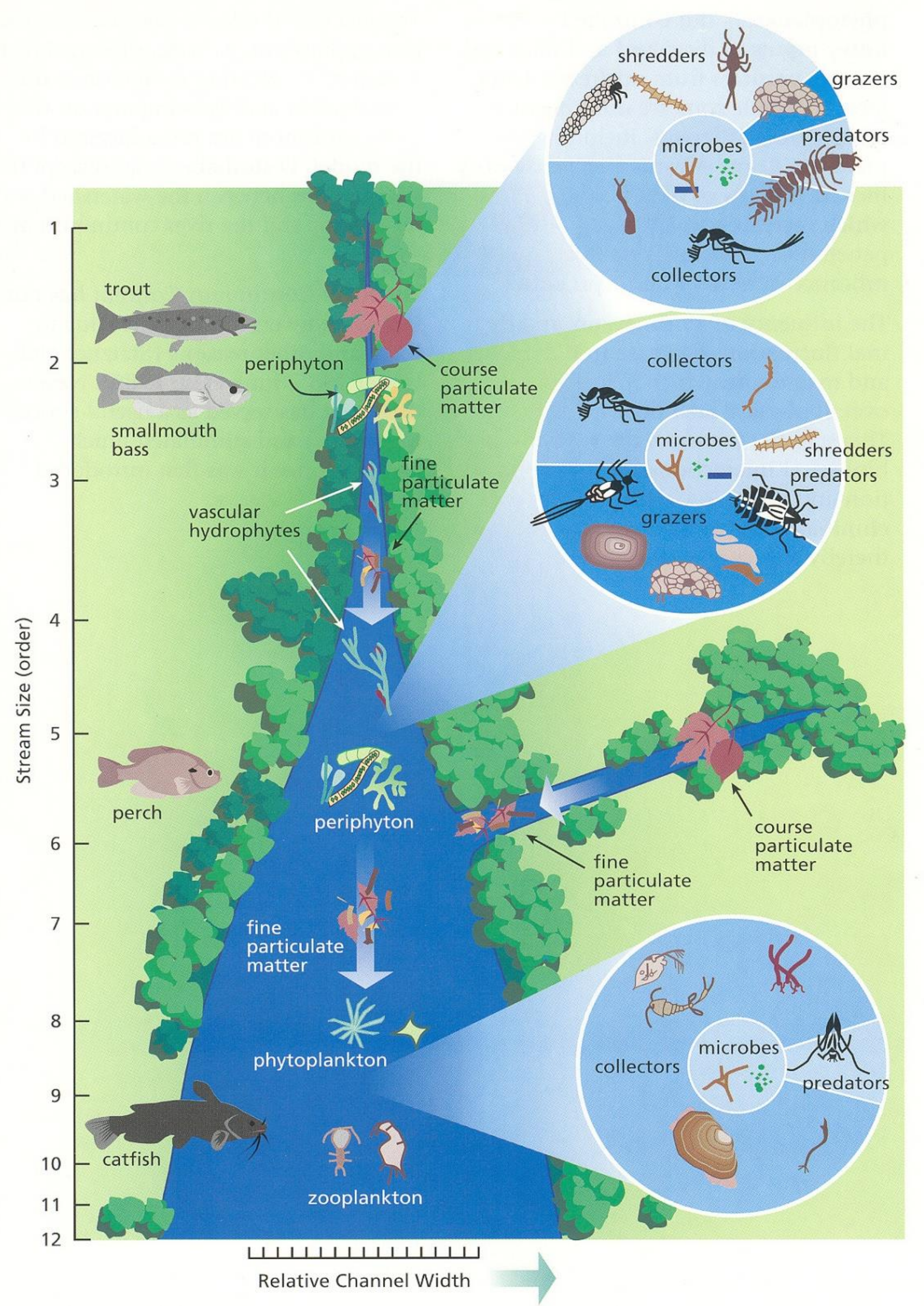
River Continuum Concept

Stream order versus relative channel width

Headwaters

Longitudinal gradient

Mouth



FISRWG (1998)
from Vannote *et al*. (1980)

Flood Pulse Concept

Flood Pulse Concept summarizes the dynamic interactions between water and land in the riparian floodplain corridor, and how aquatic biota have adapted (evolved) to exploit the floodplain resources during flood cycles.

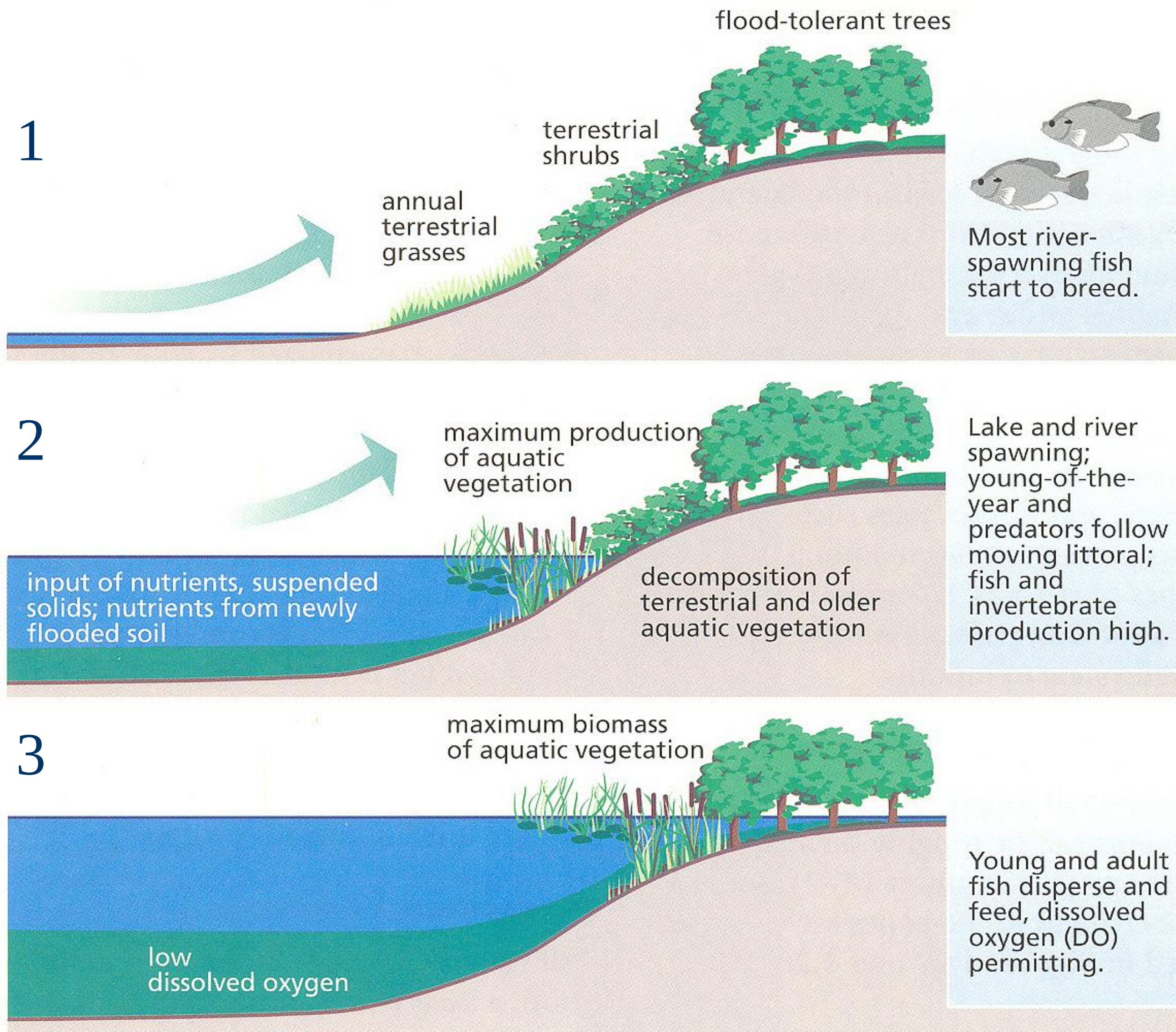
Applicable mainly to **large rivers** with relatively (seasonal) regular floods, the concept demonstrates that the predictable advance and retraction of water on the floodplain enhances biological productivity and maintain biodiversity (Bayley 1995).

Large river aquatic biota exploit floodplain resources during flood cycles to spawn (rapid emergence), and obtain food (terrestrial sources not acceptable during low flows).

Flood Pulse Concept

Flood Pulse:

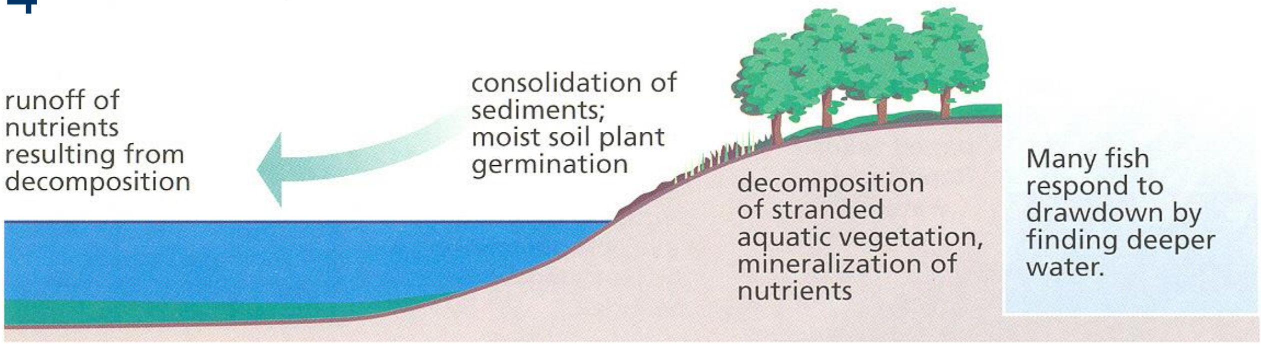
Rising limb of hydrograph to peak



Flood Pulse Concept

Flood Pulse: **Falling limb** of hydrograph

4



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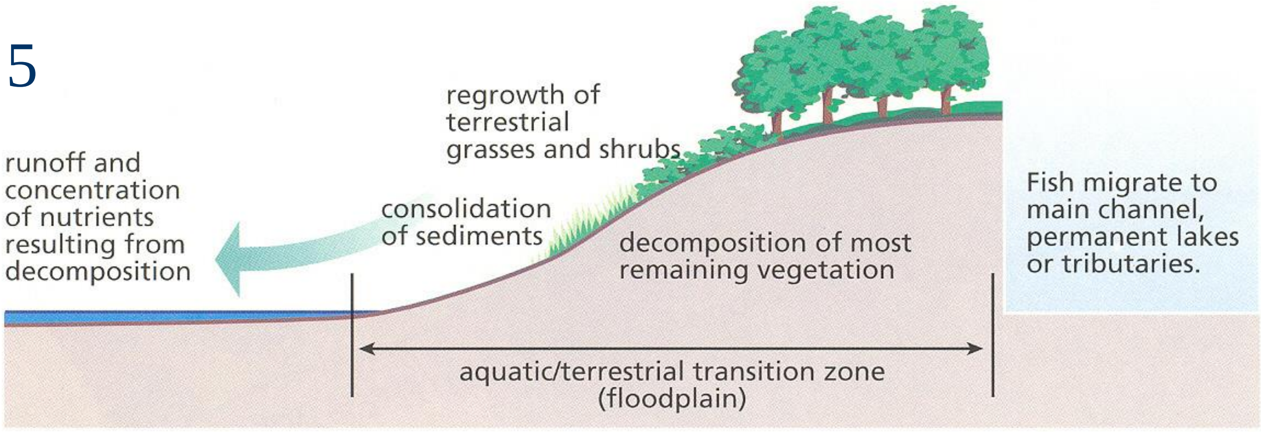


Community Structure: Abiotic & Biotic Factors

Interplay between Abiotic and Biotic Factors in Lotic (*running waters*) Communities:

Opposing Arguments

1. Lotic communities constitute a tightly interwoven network of strongly interacting species. Biotic factors dominant to maintain communities and tropic structure near an ecological equilibrium.

2. Lotic communities are merely loose assemblages that persist in an area because the individual species are adapted to the particular environment. Variable and unpredictable abiotic factors are pre-eminent, and species that are found together are simply those that happen to be favored by the environmental conditions of the moment.

Community Structure: Abiotic & Biotic Factors

Interplay between Abiotic and Biotic Factors:

How the *interaction* between abiotic and biotic factors influences lotic communities has been formulated into a number of similar, but subtly different conceptual frameworks.

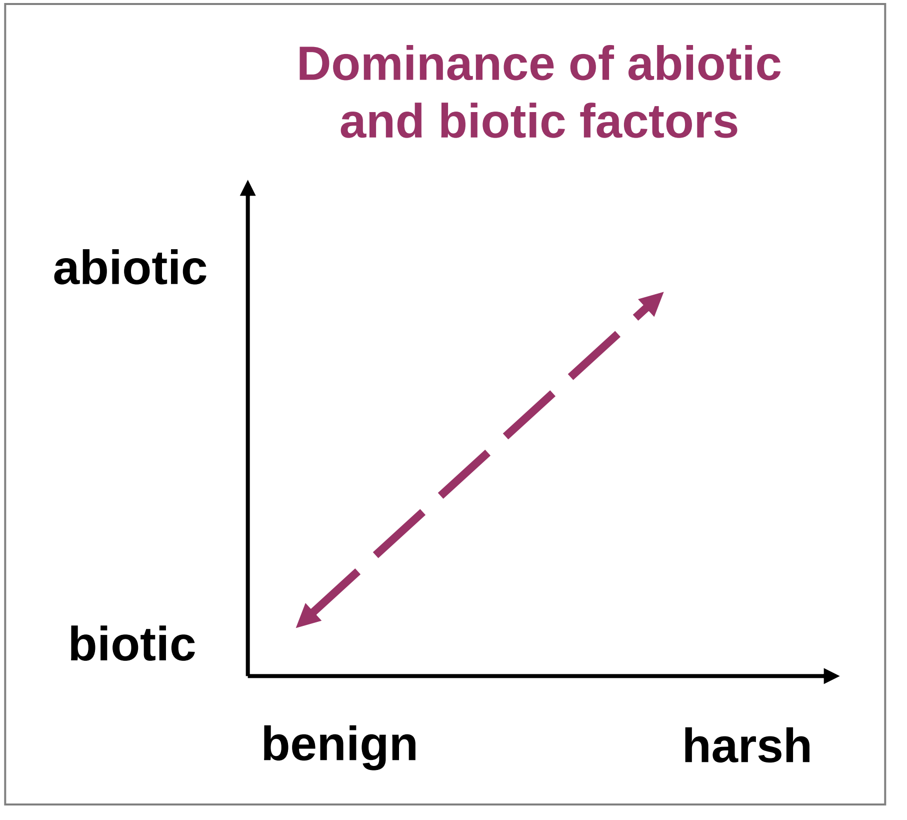
The frameworks for lotic communities are**:**

1. Harsh-benign concept
2. Intermediate disturbance hypothesis
3. Patch dynamics concept

Harsh-Benign Concept

Harsh-Benign Concept

Local environments vary from harsh to benign, with a corresponding shift in the relative importance of abiotic and biotic factors.



Intermediate Disturbance Hypothesis

Intermediate Disturbance Hypothesis

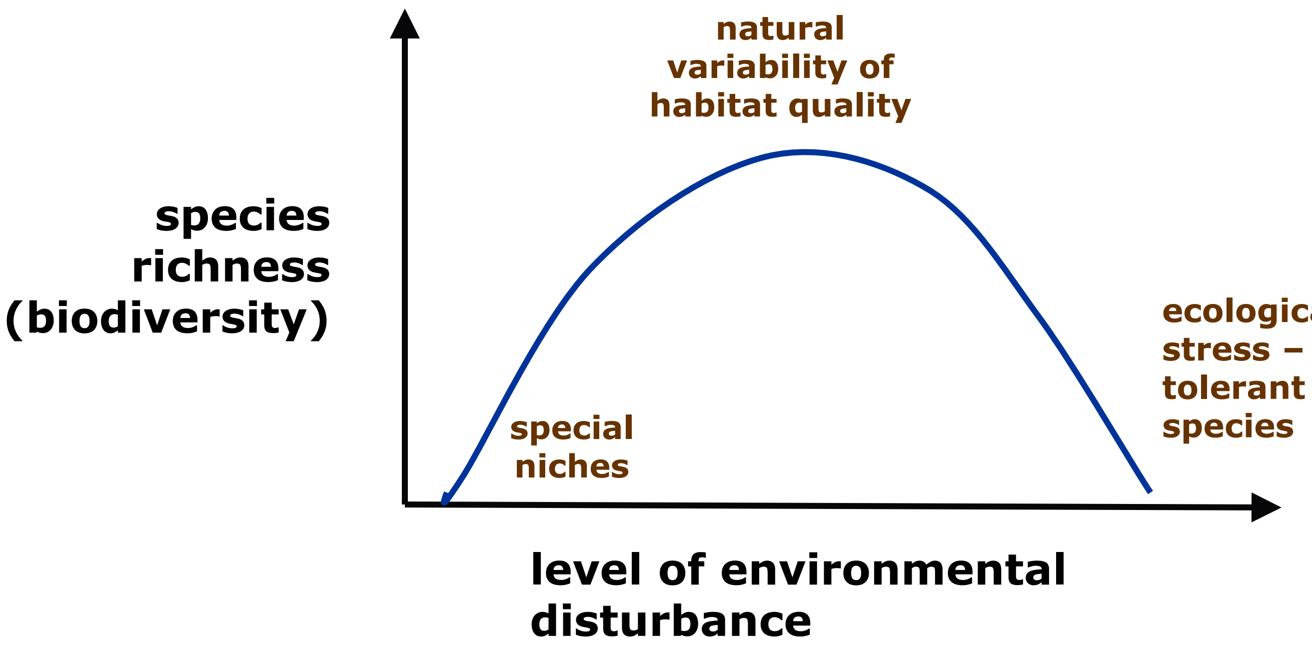
Intermediate disturbance hypothesis emphasizes the importance of biological interactions, and especially competition among species, in structuring lotic communities.

Similar to the Harsh-benign Concept, in very environmentally constant (benign) habitats strong biological forces permit only a few biologically superior species to maintain populations, and in harsh environments only species with highly-specialized adaptations can survive.

Some moderate level of natural physical disturbance prevents dominance by a small number of the most specialized and effective competitors, allowing other species including those that are rapid colonizers, but easily displaced, to coexist - **maximizing biodiversity.**

Intermediate Disturbance Hypothesis

Intermediate Disturbance Hypothesis -



Patch Dynamics Concept

Patch Dynamics Concept shares some aspects of the harsh-benign concept and the intermediate disturbance hypothesis frameworks, but places more emphasis on dispersal ability of organisms and a shifting mosaic of environmental conditions.

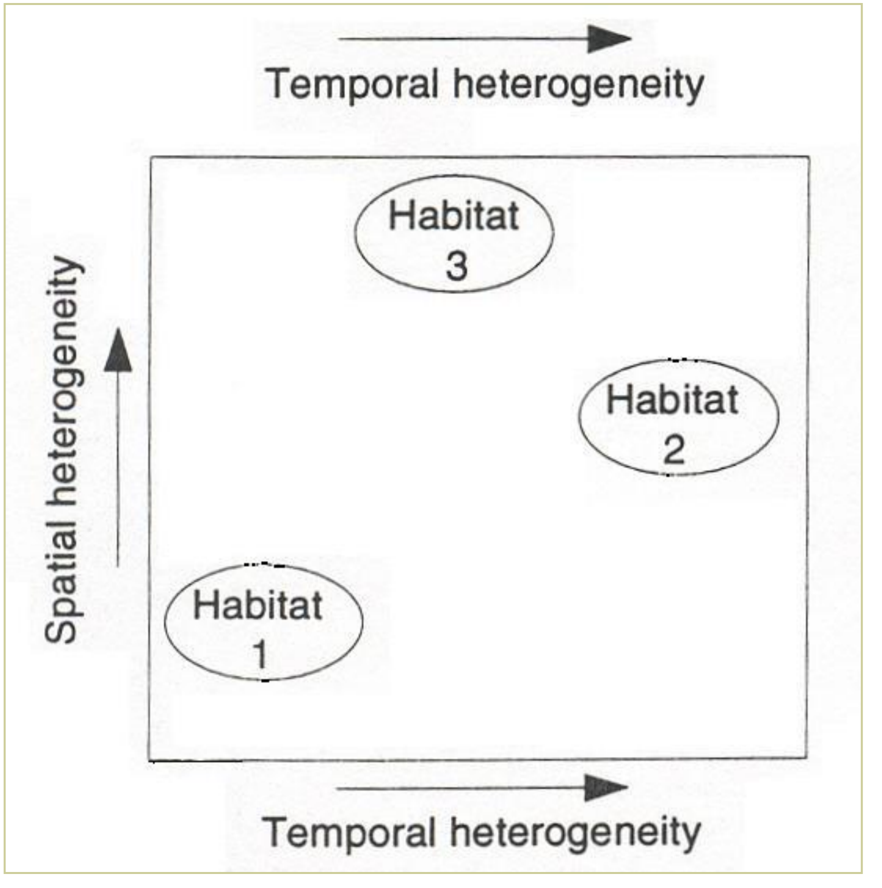
The Patch Dynamics Concept considers:

1) habitat spatial and temporal heterogeneity (variability);
2) some regularity to patterns in environmental conditions, in a broad sense, seasonally; and
3) ability of stream organisms adapted to fluctuating environmental conditions of running waters, to colonize and rapidly reproduce, where by more species are allowed to co-occur than would be true if environmental conditions were more consistent.

Patch Dynamics Concept

Patch Dynamics Concept

Mosaic of habitat patches: a function of spatial and temporal heterogeneity



Townsend & Hildrew (1994)

Patch Dynamics Concept

Patch Dynamics Concept

Applications of patch dynamics to problems in lotic ecology must consider patch characteristics and how they affect abiotic and biotic processes over various habitat spaces.

Key habitat patch characteristics include (Pringle et al. 1988):

1. size and size distribution
2. density (number of units per longitudinal distance): complexity
3. juxtaposition
4. diversity: spatial heterogeneity
5. duration
6. mechanisms affecting formation and/or maintenance

Patch Dynamics Concept

Patch Dynamics Concept

Habitat patch geometry:

The shape of habitat patches can cause similar effects as those due to patch size, however shape effects the length of the "edge" between patches.

The **edge effect** is known to increase biodiversity. Species have the ability to better exploit resources between two patch habitat conditions.

Disturbance and Patches

Disturbance plays a central role in determining the structure of aquatic communities -

Intermediate Disturbance Hypothesis links conceptually disturbances and diversity, and the Patch Dynamics Concept added the idea of spatial and temporal patchiness.

In lotic systems, flow-generated disturbances (high- and low-flow events) create "patches" or habitat refugia.

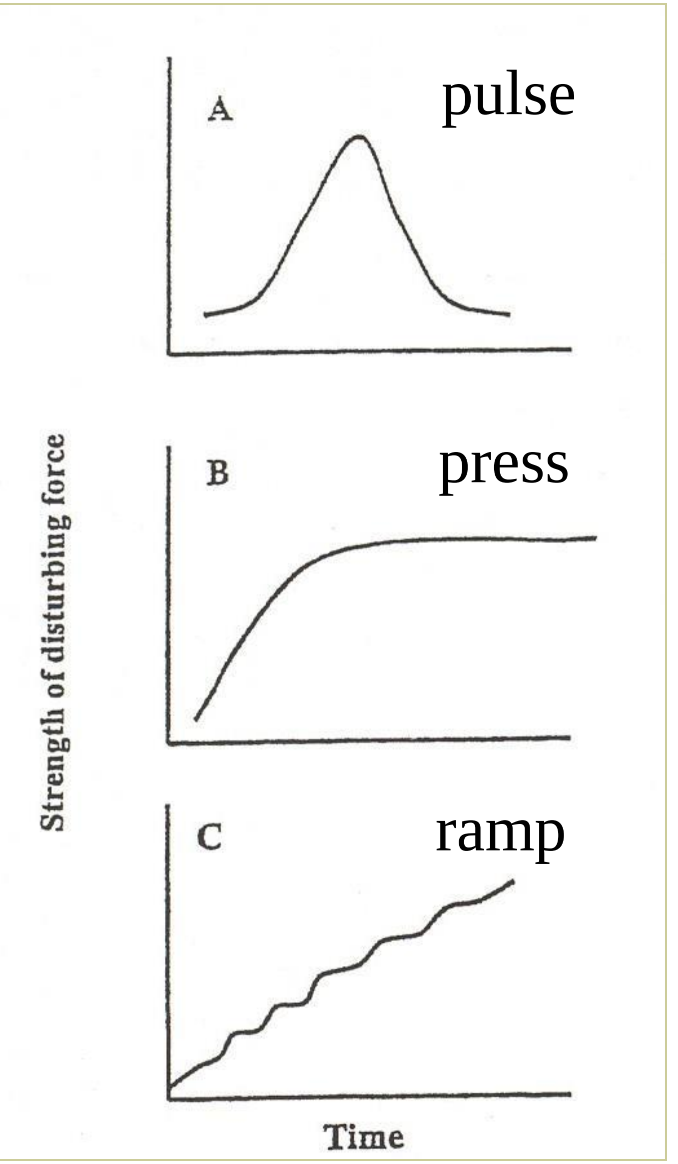
Patches scale to the river size and channel (habitat) complexity, in addition the scale depends on the biological expression (behavior, home-range) of individuals to meet time-dependent ecological needs (species traits).

Characterizing Disturbance

Disturbance can be characterized by:
intensity, season of occurrence, extent and patchiness, frequency, and type.

Temporal patterns:
Pulses (e.g., floods)
Presses (e.g.,, channelization, bank failures landslides)
Ramps (e.g., urbanization)

Lake (2000)

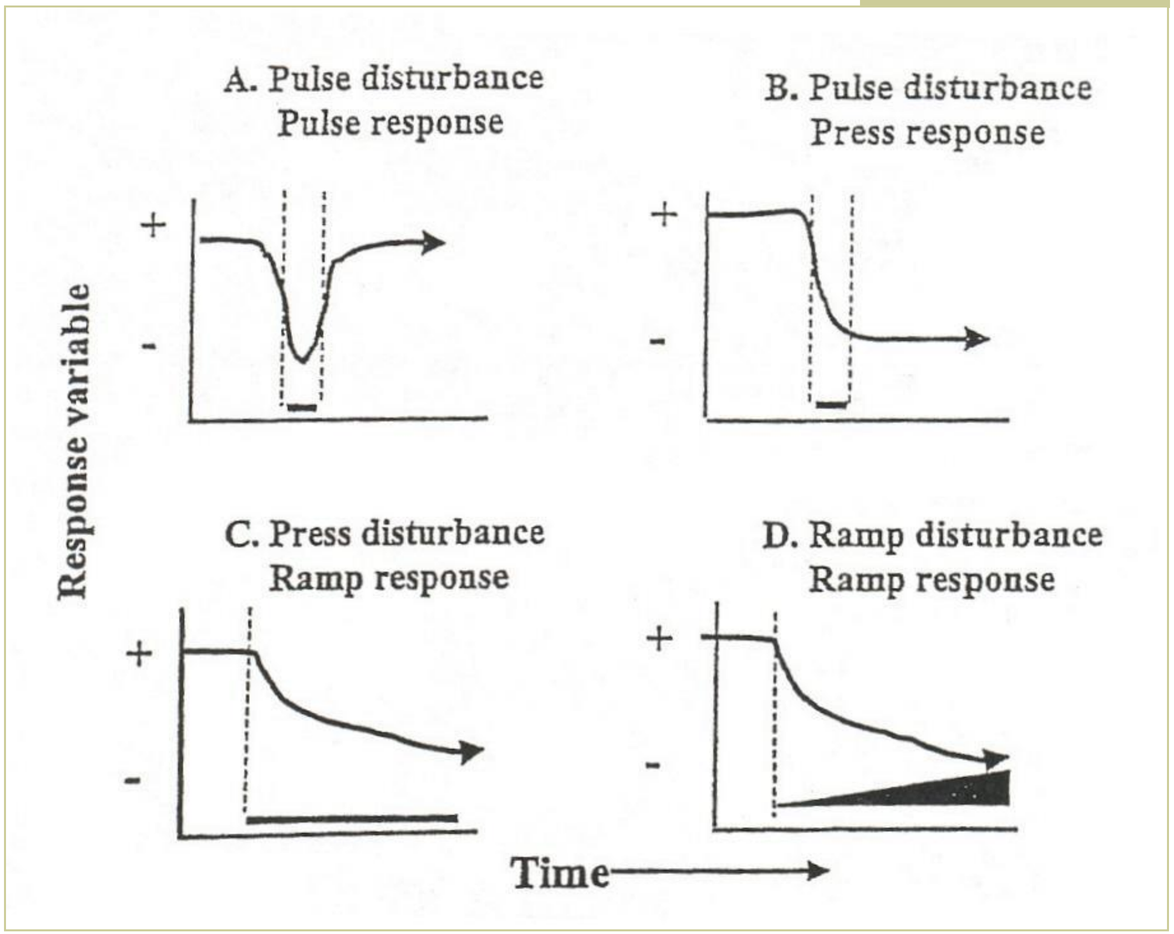


Perturbations

Perturbation is the stressor(s) and the disturbance-response relationship.

Duration of the disturbance is indicated by the solid bar

Lake (2000)



Ecosystem Disturbance-related Terms

Resistance is a measure of the ecosystem capacity to recover from a disturbance; also noted as the system's capacity to resist stressors (stressor-response magnitude).

Resilience is the speed of recovery from a disturbance (response rate); dependent on recolonization rate, number of survivors after applied stress (recolonization potential), and distance between refuge patches.

Ecological Succession is when physical habitat conditions do not change greatly from a disturbance, and over time distinct communities tend to replace others after the disturbance in a predictable way, generally.

Stability has been referred to the lack of perturbations, and highly resistant ecological community.

(NRC 1986)