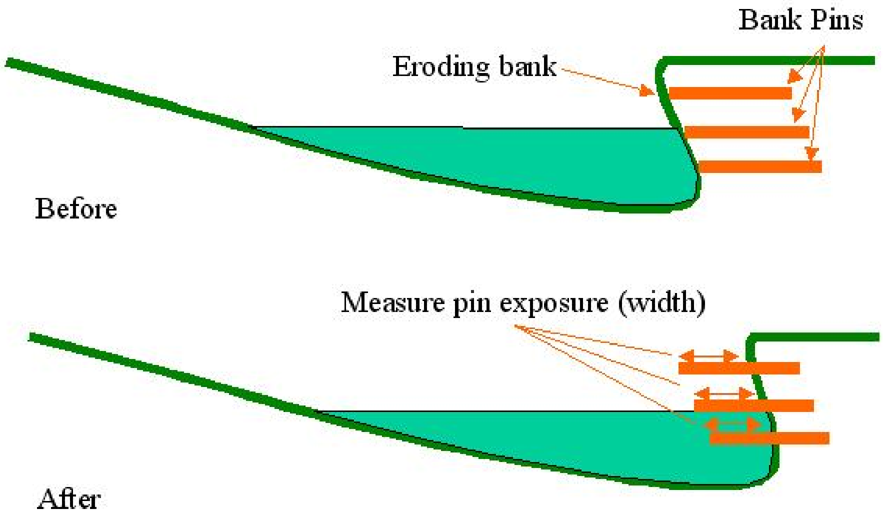
Erosion

- bank and bed erosion - stabilizing role of plant root systems
- **critical erosion capacity**

  = the lowest velocity needed for a transport of a particle of a given size

  - lowest for sand (ca 20 cm s^{-1})



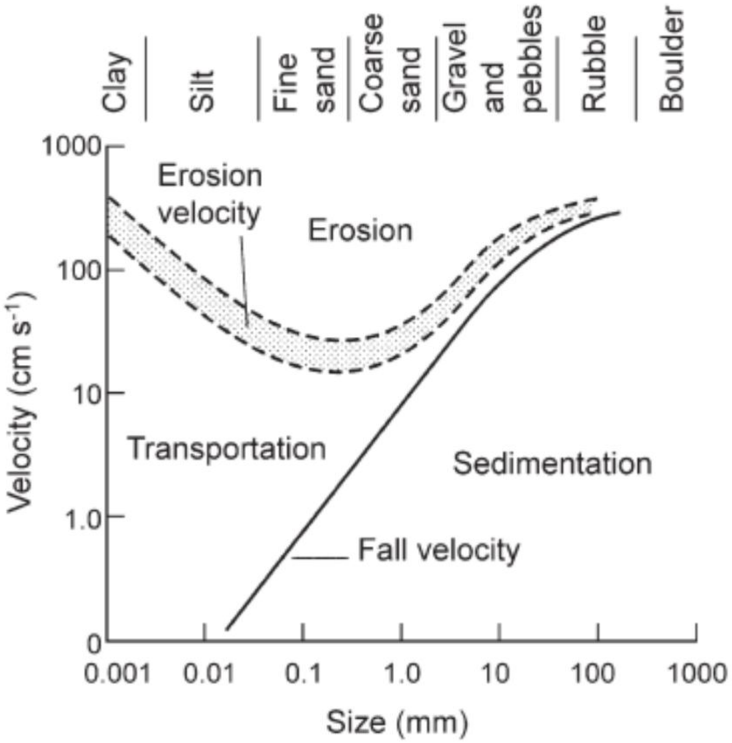
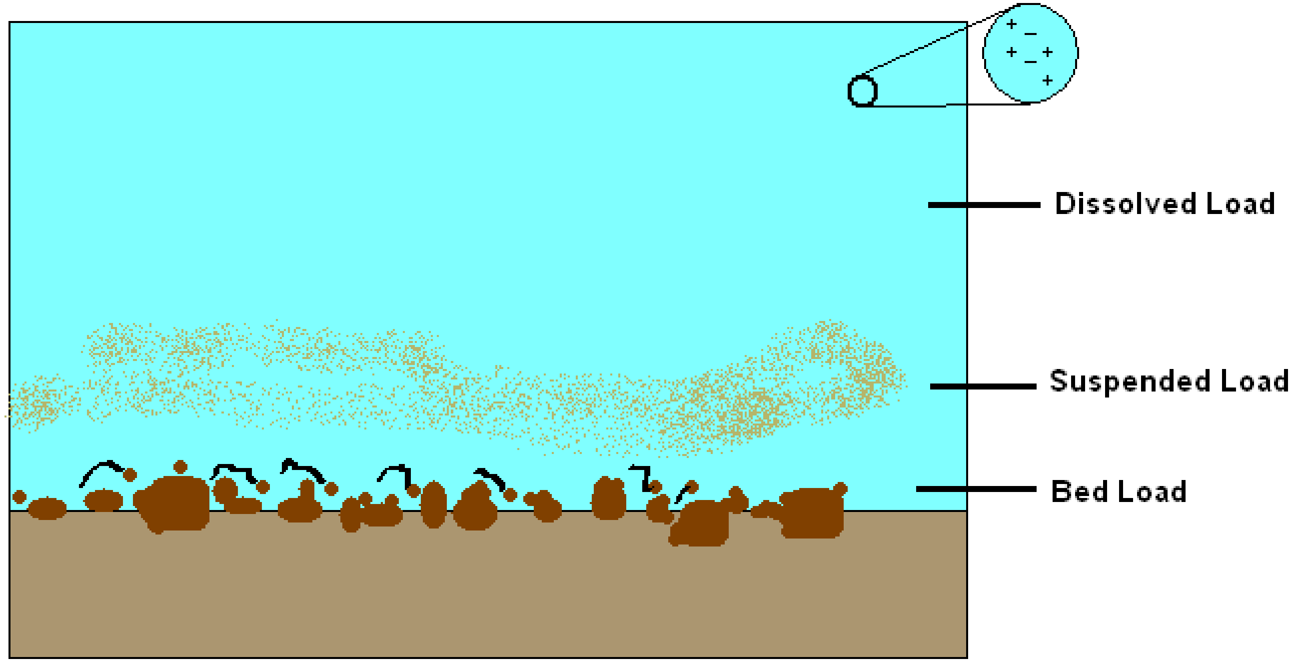


FIGURE 3.8 Relation of mean current velocity in water at least 1 m deep to the size of mineral grains that can be eroded from a bed of material of similar size. Below the velocity sufficient for erosion of grains of a given size (shown as a band), grains can continue to be transported. Deposition occurs at lower velocities than required for erosion of a particle of a given size. (Reproduced from Morisawa 1968.)

Sediment load

- Suspended load (plaveniny) – usually majority of the total load (5-50 × more than bedload), increases turbidity
- Bedload (splaveniny) – <5-10% of the total load but strong impact on the channel shape



Sediment load

- Washload – 0.5 µm-0.625 mm, clay, silt and very fine sand, may never settle out

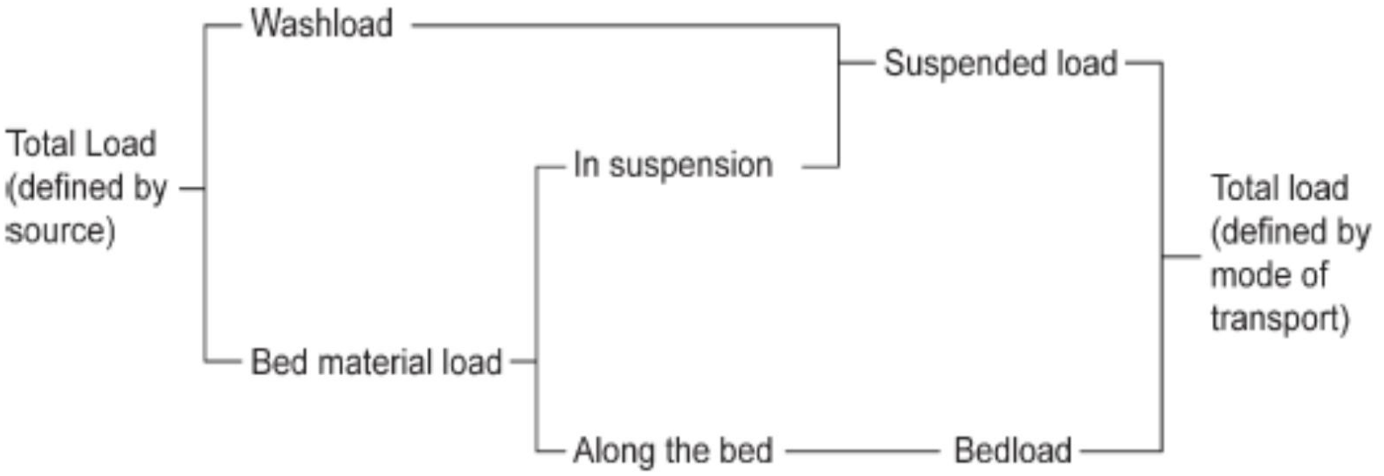


FIGURE 3.9 The components of stream sediment load shown in terms of sediment source and mode of transport. (Reproduced from Hicks and Gomez 2003.)

Effect of discharge on sediment transport

- stream capacity = total load of sediment the stream can carry

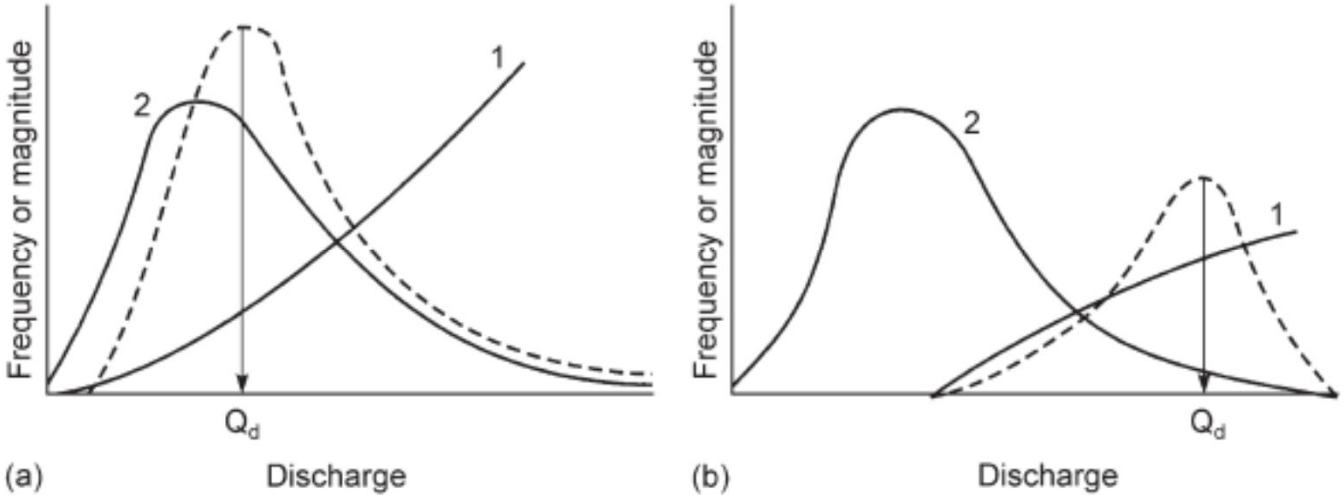
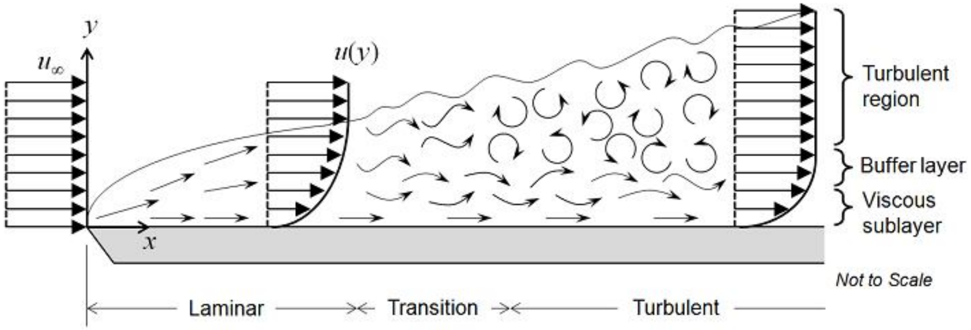


FIGURE 3.10 The relationship between frequency and magnitude of discharge events responsible for sediment transport: (a) suspended load, (b) bedload. Curve 1 depicts the increase in sediment transport rate with increasing magnitude of discharge, and curve 2 describes the frequency of discharge events of a given magnitude. Their product (dashed line) is the discharge that transports the most sediment, referred to as Q_d, the dominant or effective discharge. Q_d is approximately Q_{bkf} for suspended sediments, and is in the range $Q_{1.5}-Q_{10}$ for bedload. (Reproduced from Richards 1982.)

Abiotic environment: Current

- boundary layer theory (Davis 1986, Vogel 1994)
- laminar (viscous) sublayer



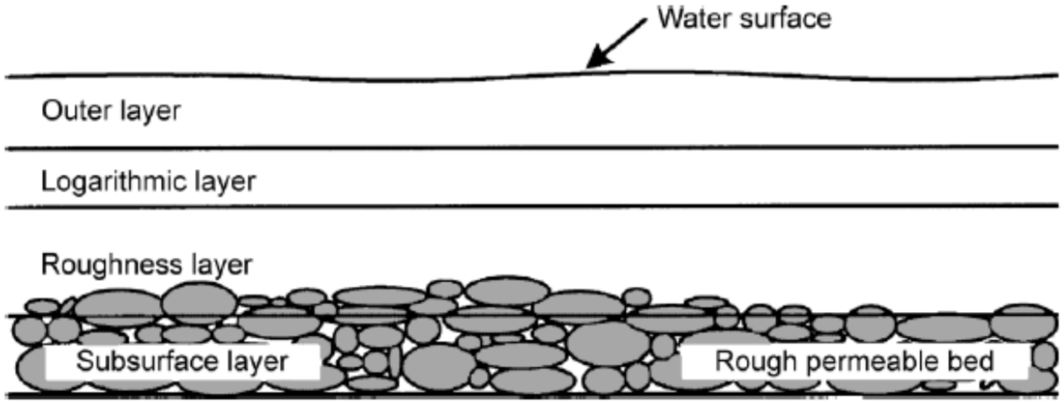
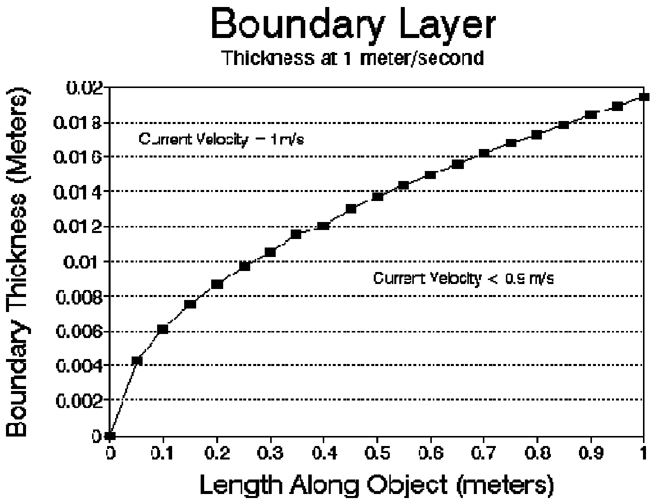
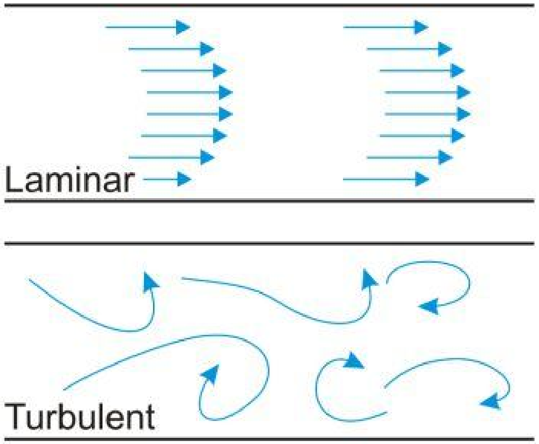


FIGURE 5.3 Subdivision of hydraulically rough open-channel flow into horizontal layers. Flow velocities within the "roughness layer" are unpredictable based solely on knowledge of flow in the logarithmic layer. This figure is not drawn to scale. (Reproduced from Hart and Finelli 1999.)



Hydraulic variables



Reynolds number

$Re = U\,D/v$

$Re < 500 \rightarrow$ laminar flow

$500 < Re < 10^3 - 10^4 \rightarrow$ transitional flow

$Re > 10^3 - 10^4 \rightarrow$ turbulent flow

Froude number

$Fr = U(gD)^{-0.5}$

$Fr < 1 \rightarrow$ subcritical flow

$Fr = 1 \rightarrow$ critical flow

$Fr > 1 \rightarrow$ super-critical flow

U	Mean velocity	cm s^{-1}	Measured at 0.4 depth from bottom or from open-channel
D	Water depth	cm	Total depth, surface to bed
g	Acceleration due to gravity		$9.8\ m\ s^{-2}$
v	Kinematic viscosity		$1.004 \times 10^{-6}\ m^2\ s^{-1}$ at 20°C

Influence of substrate roughness on the stream flow

- low relative height of roughness elements to channel depth → very komplex turbulent flow
- the role of wood and vegetation

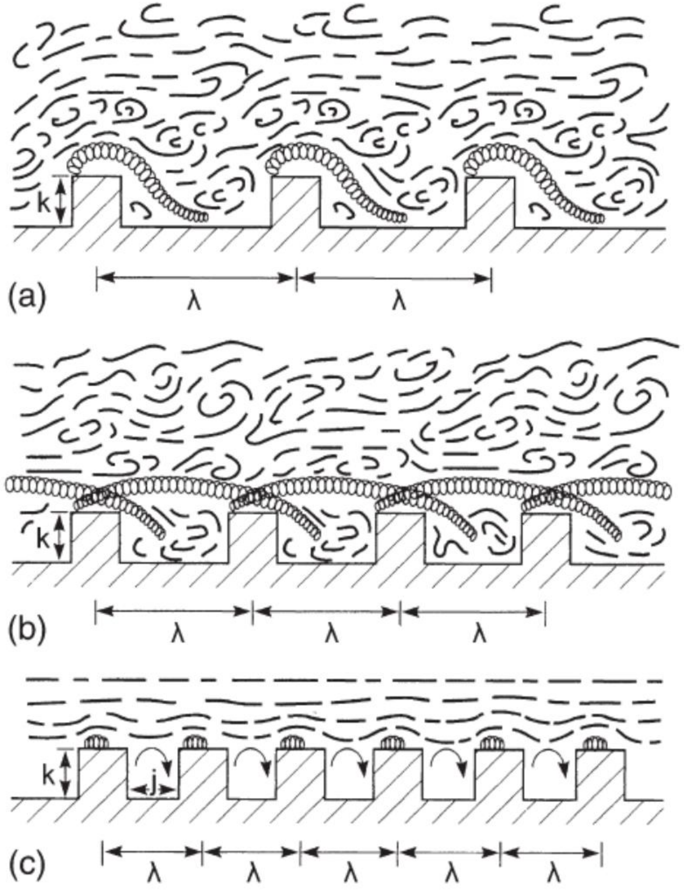


FIGURE 5.7 Conceptualization of three types of flow occurring over a rough surface, depending upon differences in relative roughness and longitudinal spacing between roughness elements. (a) Isolated roughness flow, (b) wake interference flow, (c) quasi-smooth flow. (Reproduced from Davis and Barmuta 1989, after Chow 1981.)

Hydraulic variables II

Boundary Reynolds number

$Re^* < 5 \rightarrow$ hydraulically smooth flow

$5 < Re^* < 70 \rightarrow$ transitional flow

$Re^* > 70 \rightarrow$ hydraulically rough flow

$$Re^* = U^* k / v$$

U^*	Shear velocity	cm s^{-1}
k	Substrate roughness	cm

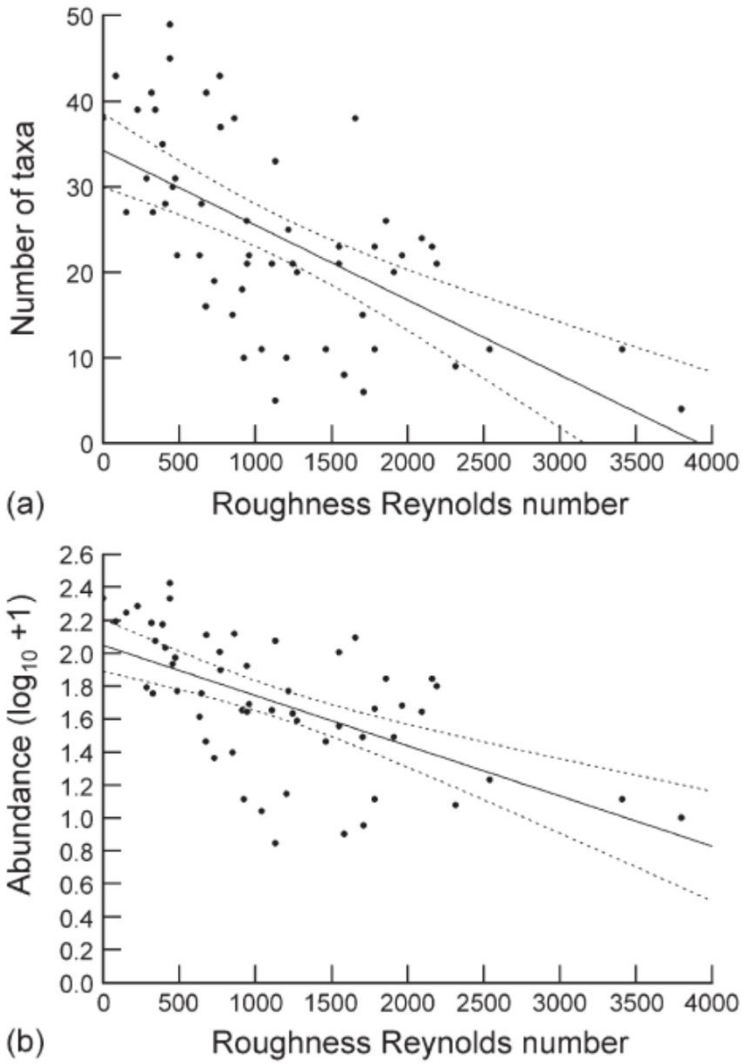


FIGURE 5.6 Relationship between roughness Reynolds number and (a) number of invertebrate taxa and (b) macroinvertebrate abundance in sampled areas of 0.07 m^2 within three riffles in the Kangaroo River, New South Wales, Australia. Dotted lines indicate 95% confidence intervals. (Reproduced from Brooks et al. 2005.)

Near-bottom flow conditions

- very variable
- **FST – hemisphere method**

  Statzner B. & Müller R. (1989) : Standard hemispheres as indicators of flow characteristics in lotic benthos research. *Freshwater Biology* 21, 445 - 459.
- **shear stress** (tractive force, smykové napětí) τ

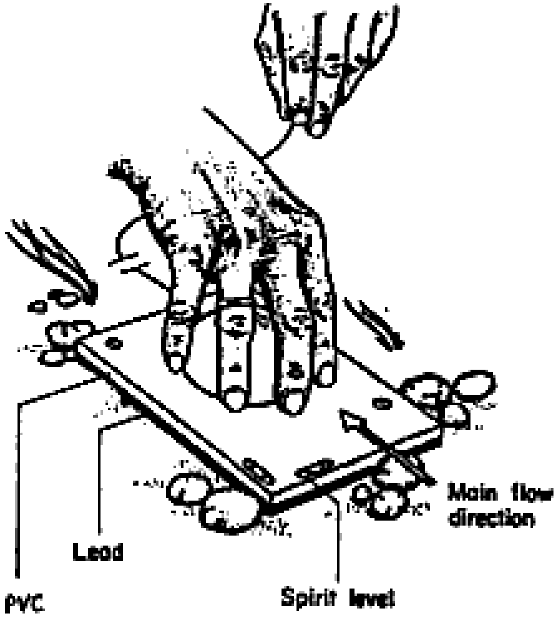
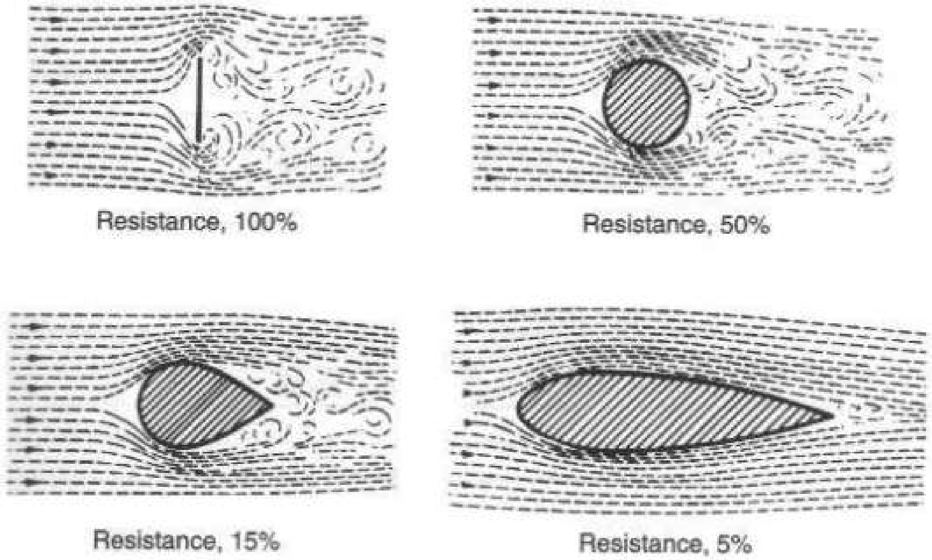


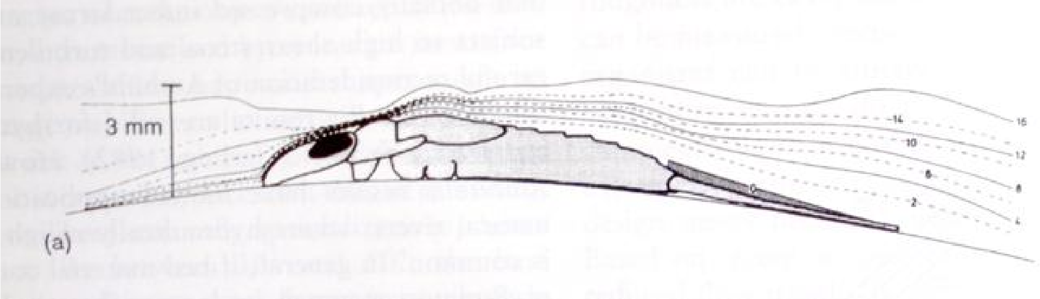
FIG. 2. Placing a hemisphere on the plane in a stream.

Adaptations of biota to current

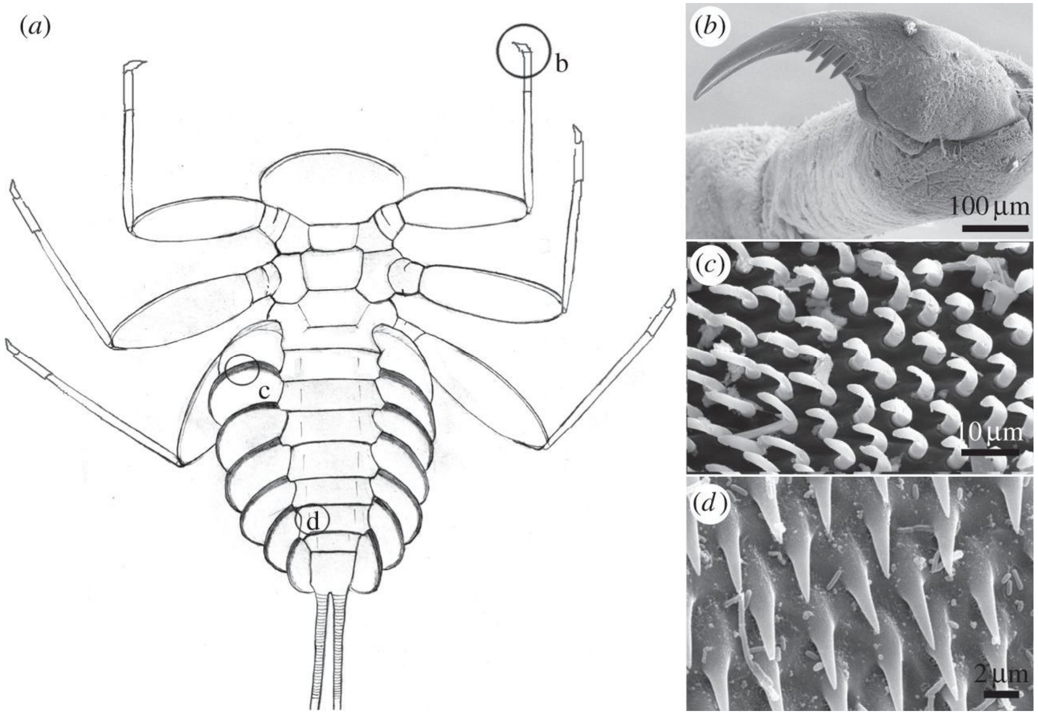
Baetidae

Heptagenidae





Adaptations of biota to current II



Ditsche et al. 2013: *Epeorus* - on smooth substrate biofilm significantly increases the friction force of claws

Simuliidae

Response of biota to current

Edington (1968)

Plectrocnemia conspersa (Polycentropodidae): v ~ 0-20 cm/s

Hydropsyche instabilis (Hydropsychidae): v ~ 15-100 cm/s

Infuence of current on biota

- drag cost, dislocation
- increases food, nutrient and gas supply
- increases difusion rate on microbe membranes
- active and passive colonization: drift, refugee (debris dams, zones of transition, channel edges, hyporheic zone)

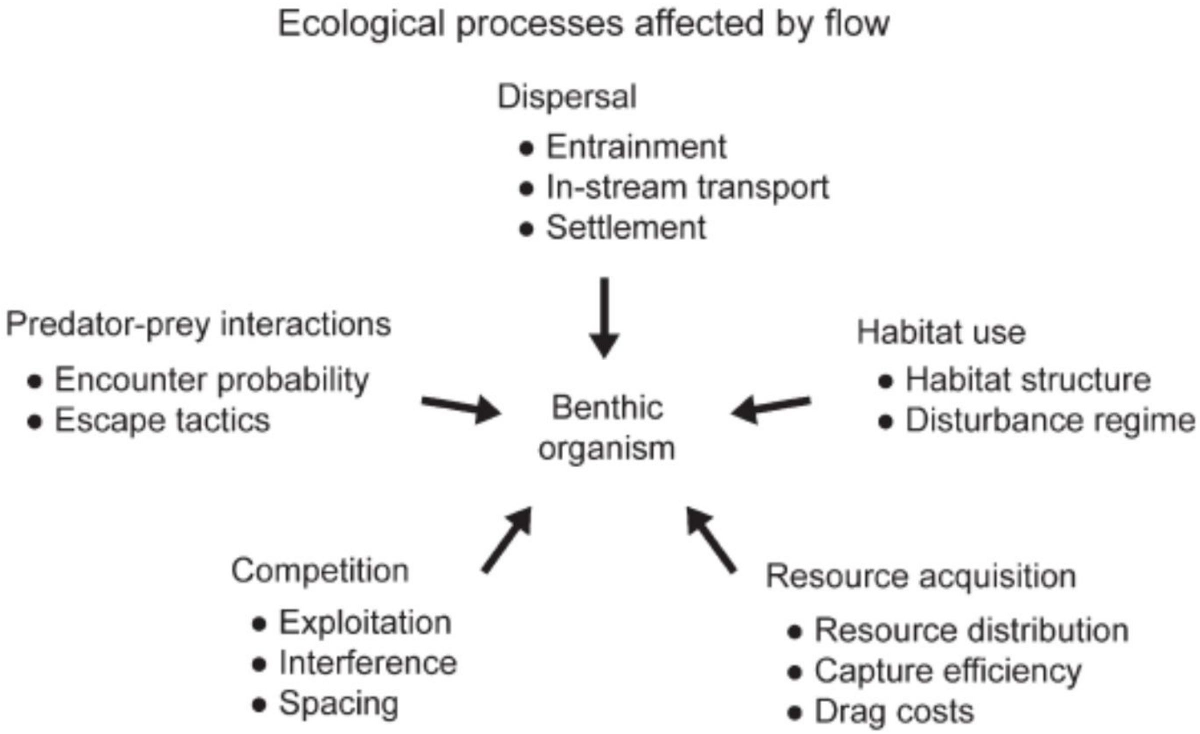


FIGURE 5.2 Multiple causal pathways by which flow can affect organisms. Potential interactions among pathways are not shown. (Reproduced from Hart and Finelli 1999.)

Temperature

- influences physic-chemical processes
- influences biological processes - methabolic rate, distribution of organisms along river's length and in different geographic regions, leaf breakdown, nutrient uptake, production
- **seasonal variation**

  Amazon river ~ 29±1 °C

  temperate streams: 0-25 °C

  high altitude and latitude: max. ~ 15°C
- cumulative temperature

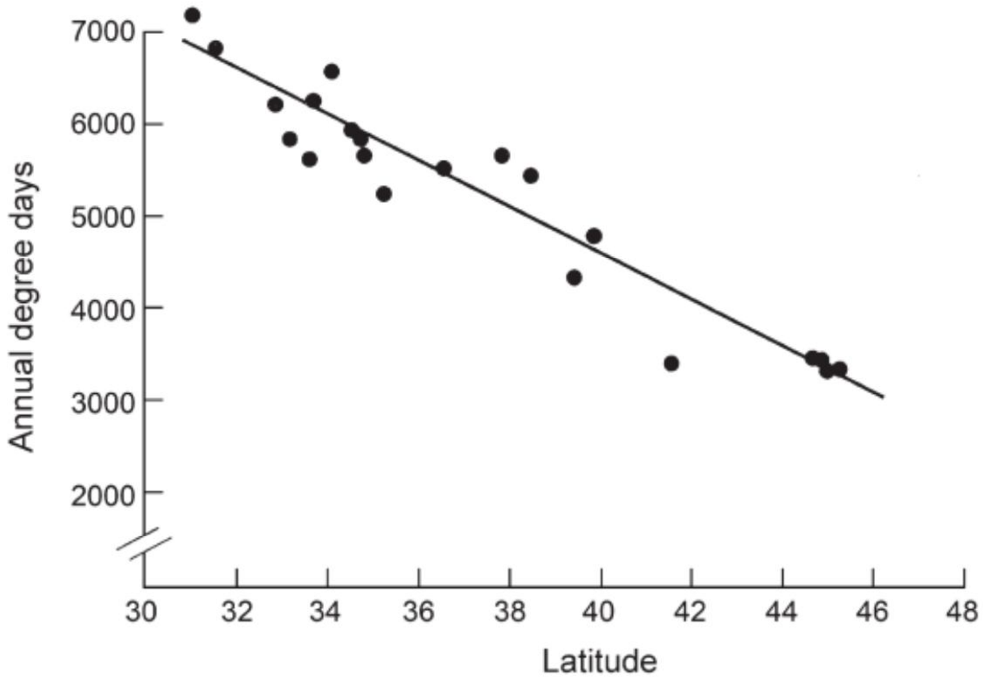


FIGURE 5.11 Total annual degree-day accumulation (>0°C) as a function of latitude for various rivers of the eastern United States. (Reproduced from Vannote and Sweeney 1980.)

Variability in water temperature

- at the source – T close to that one of groundwater
- max. **diel variability** in wide but shallow rivers (~ 4th order)
- **spatial variability**

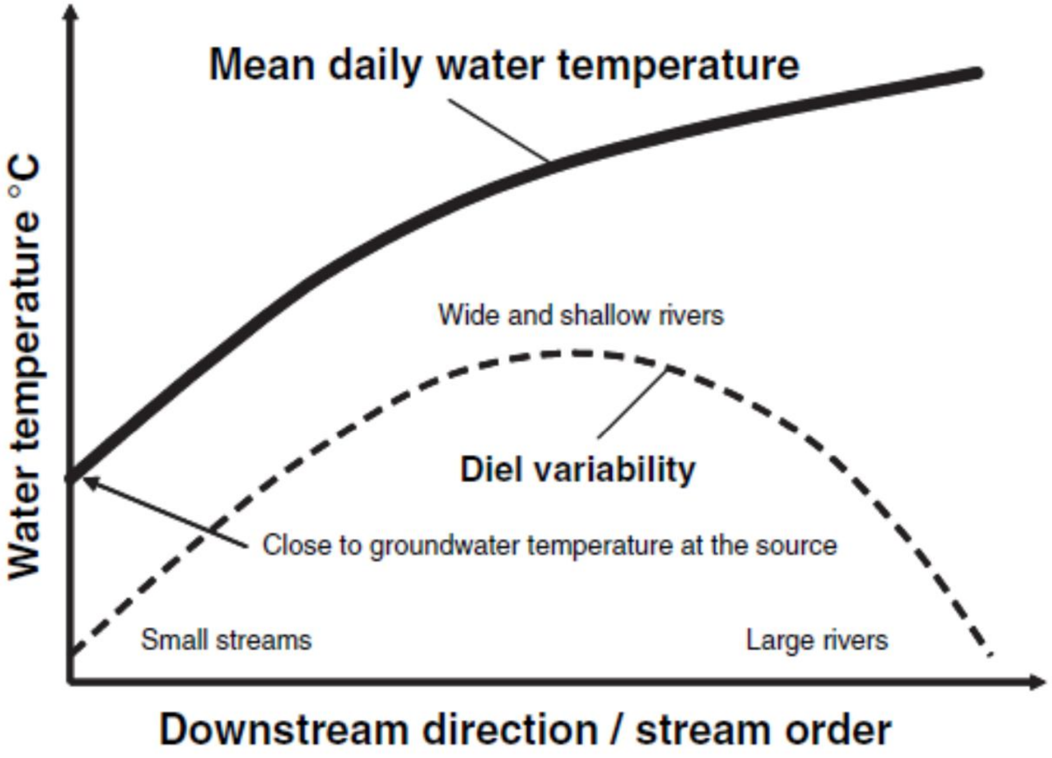


Fig. 2 Mean daily and diel variability of water temperatures as a function of stream order/downstream direction.

The effect of impoundment on water temperature

- increase residence time and surface area exposed to solar radiation
- surface-released dams
- deep bottom-released dams

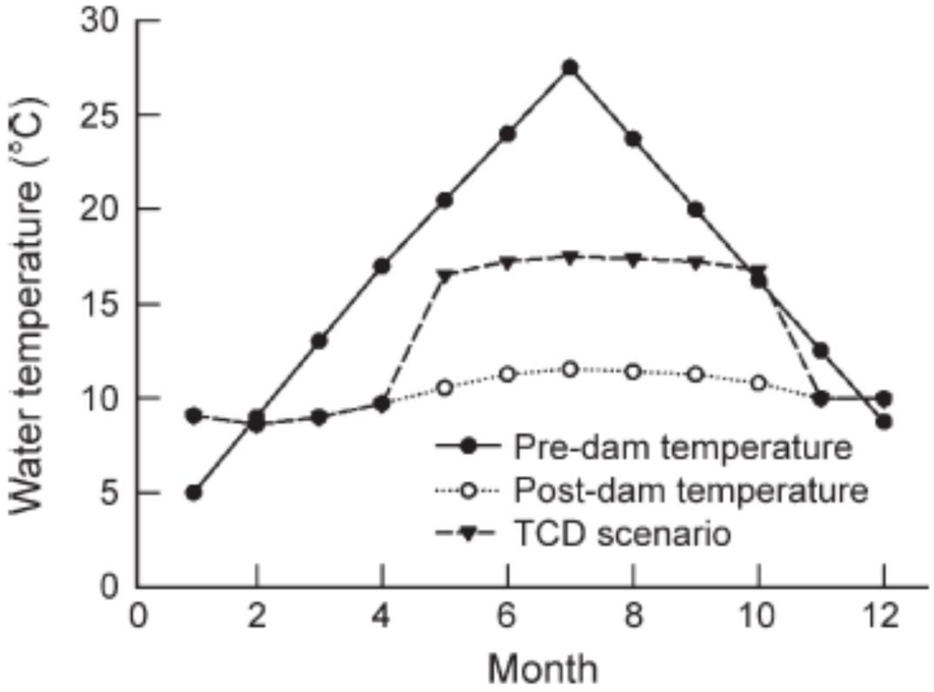


FIGURE 5.13 Average monthly water temperatures in the Grand Canyon of the lower Colorado River before and after the construction of Glen Canyon Dam, and for a potential temperature management scenario using a temperature control device (TCD). Temperature data are from the US Geological Survey at river mile 61 near the confluence with the Little Colorado River. (Reproduced from Petersen and Paukert 2005.)

Temperature requirements of organisms

- stenothermal vs. eurythermal
- cold-water fishes – max. 25°C
- warm-water fishes – Esocidae, Cyprinidae – max. ~ 30 °C
- specialized taxa – desert fish (up to 40°C), some invertebrates (up to 50°C), some Cyanobacteria (up to 75°C)
- importance of phylogenetic origin - Plecoptera (Hynes 1988), Odonata (Corbet 1980)
- cue, regulation and synchronization of insect life cycles – food availability and competition vs. predation risk
- high altitudes – short period of fast growth, long periods of dormance
- higher temperature → smaller adults → smaller fecundity
- temperature optimum – max. fecundity

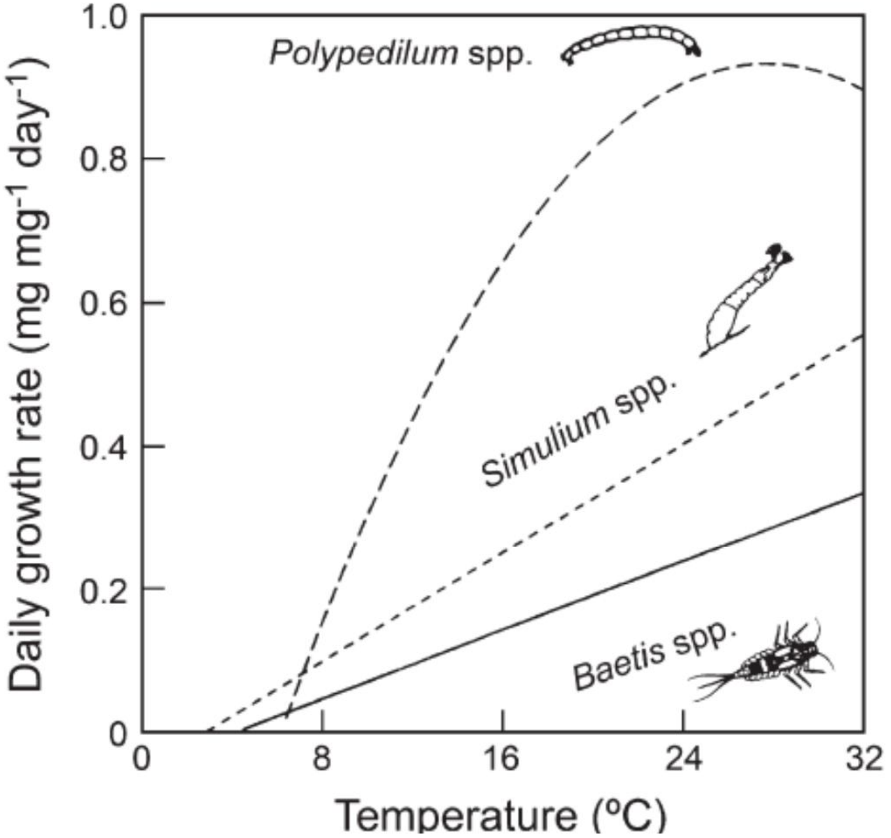


FIGURE 5.18 Daily growth rates (mg mg^{-1} day^{-1}) as a function of temperature for three aquatic insects found on snag habitat in the Ogeechee River, Georgia, and reared in stream-side artificial channels. Insects include the midge *Polypedilum*, the black fly *Simulium*, and the mayfly *Baetis*. (Reproduced from Benke 1993.)

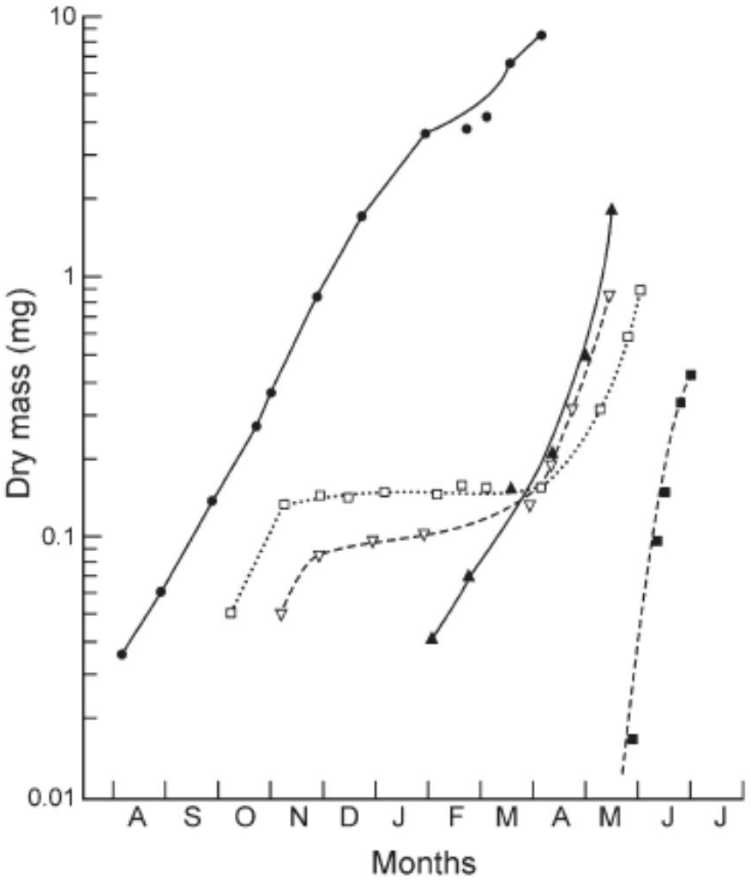
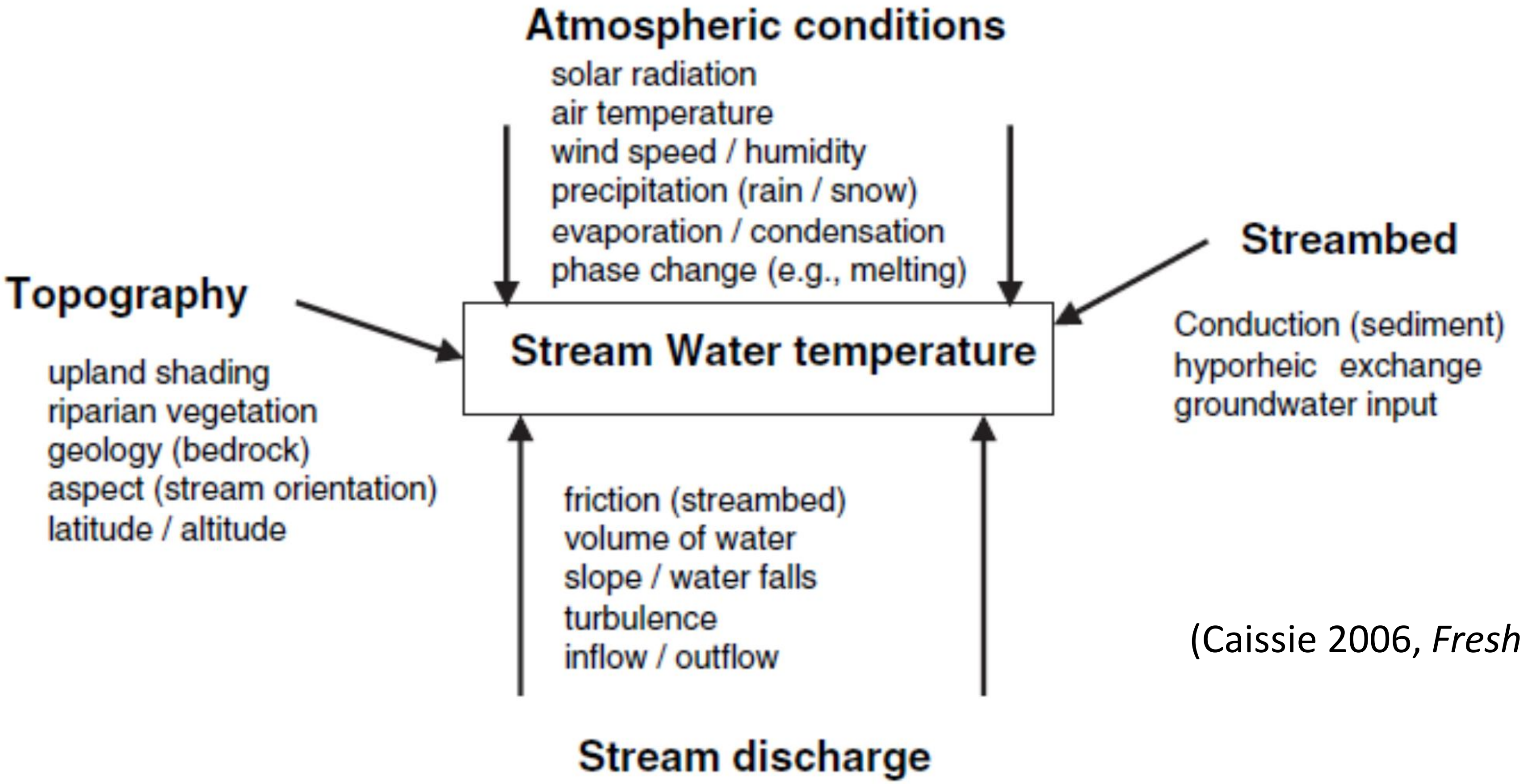


FIGURE 5.14 Larval growth period for five species of riffle-inhabiting ephemerellid mayflies in White Clay Creek, Pennsylvania. (●) *Ephemerella subvaria*; (▲) *E. dorothea*; (□) *Seratella deficiens*; (■) *S. serrata*; (inverted open triangle) *Euryophella verisimilis*. (Reproduced from Sweeney and Vannote 1981.)

Factors influencing water temperature in streams



Atmospheric conditions

solar radiation
air temperature
wind speed / humidity
precipitation (rain / snow)
evaporation / condensation
phase change (e.g., melting)

Topography

upland shading
riparian vegetation
geology (bedrock)
aspect (stream orientation)
latitude / altitude

Stream Water temperature

Streambed

Conduction (sediment)
hyporheic exchange
groundwater input

friction (streambed)
volume of water
slope / water falls
turbulence
inflow / outflow

Stream discharge

(Caissie 2006, *Freshwat. Biol.*)

Primary producers

- benthic algae, vascular plants, bacteria, protists
- macrophytes – angiosperms, bryophytes (mosses, liverworts), filamentous growth forms of algae
- periphyton, phytoplankton
- epilithon
- epipelon
- epipsammon
- epixylon
- epiphyton

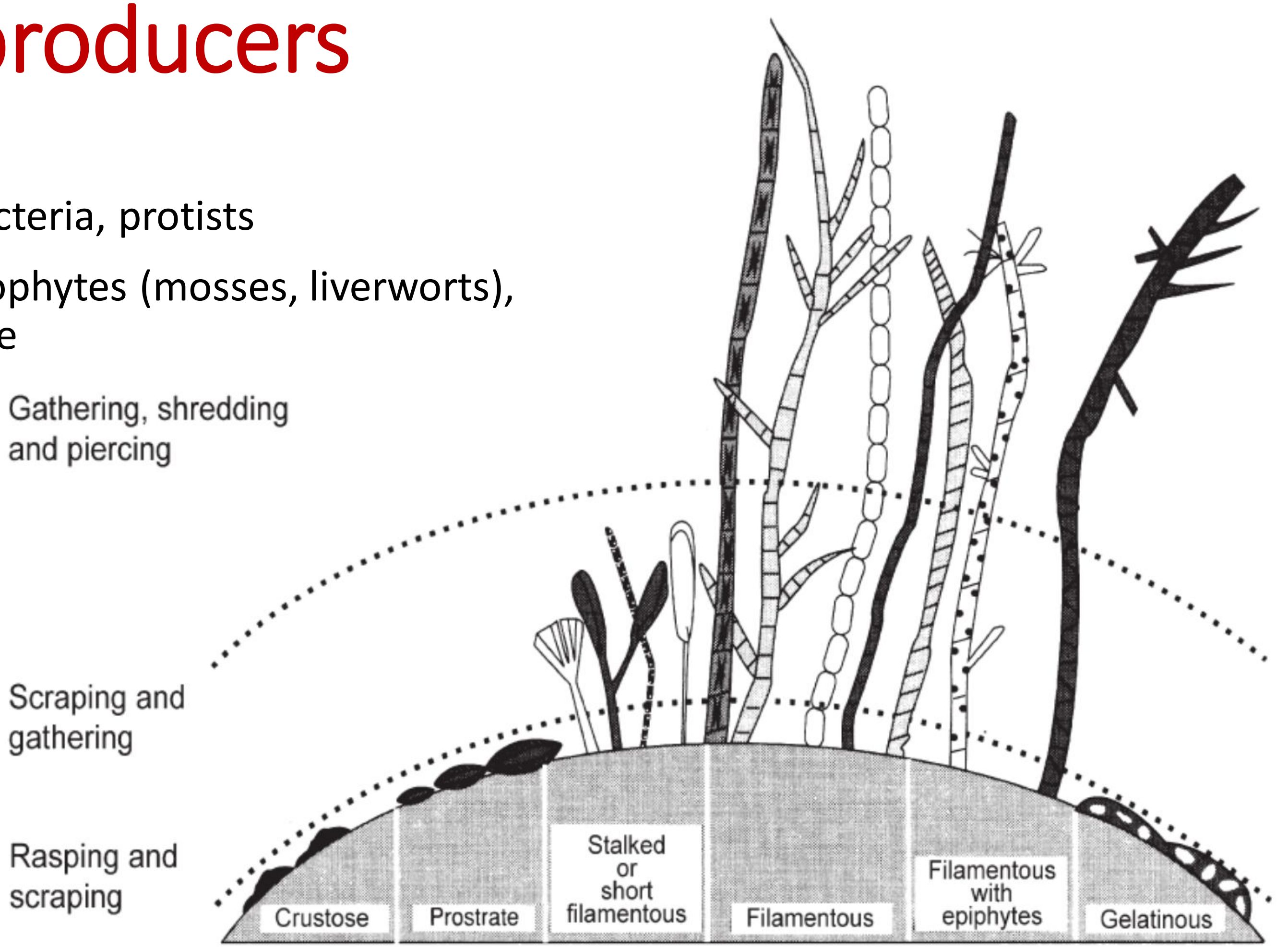


FIGURE 6.1 Hypothetical representations of major growth forms of periphyton assemblages. Different modes of herbivory are expected to be most effective with particular growth forms. (Reproduced from Steinman 1996.)

Benthic algae

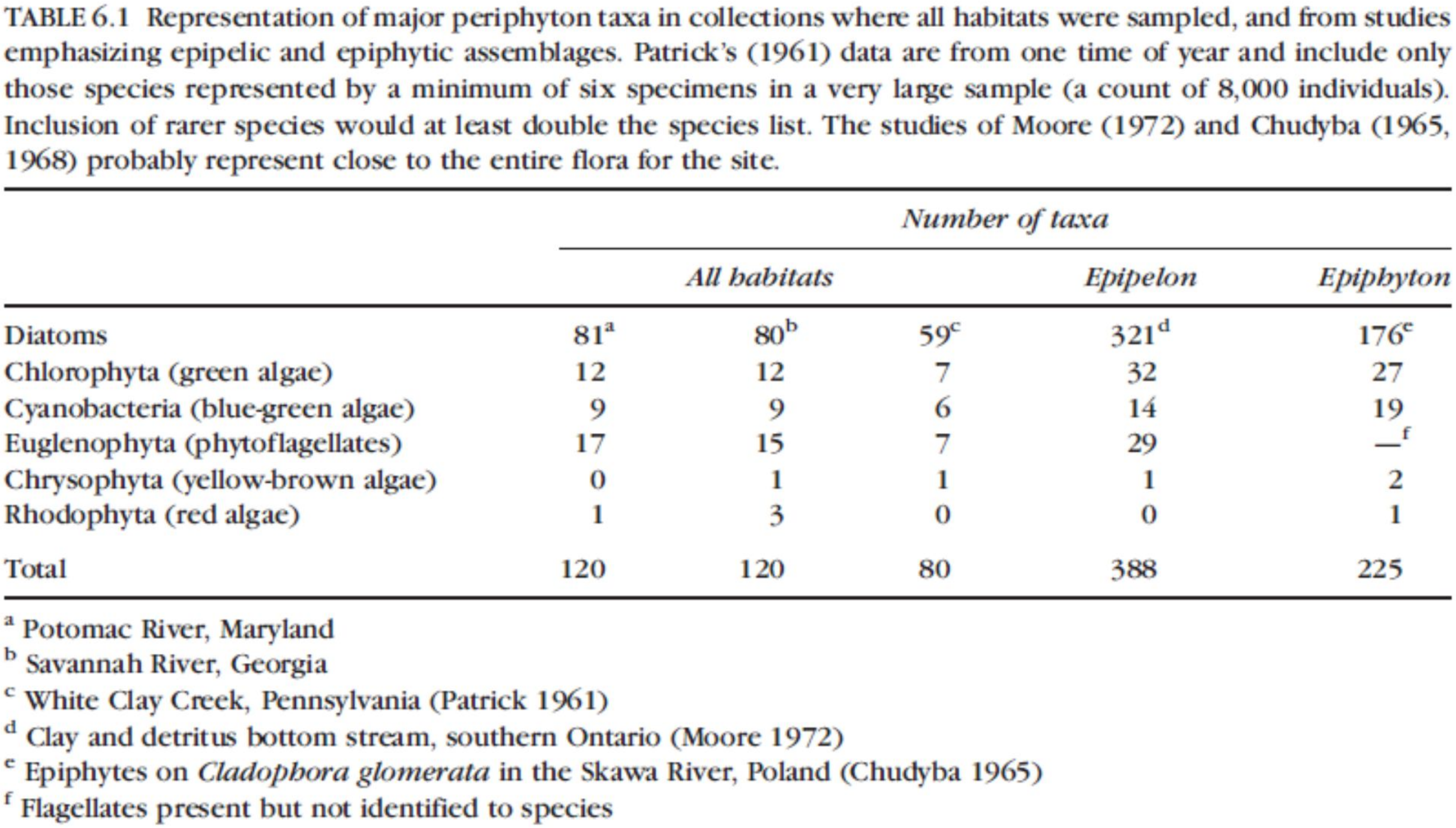


TABLE 6.1 Representation of major periphyton taxa in collections where all habitats were sampled, and from studies emphasizing epipelic and epiphytic assemblages. Patrick's (1961) data are from one time of year and include only those species represented by a minimum of six specimens in a very large sample (a count of 8,000 individuals). Inclusion of rarer species would at least double the species list. The studies of Moore (1972) and Chudyba (1965, 1968) probably represent close to the entire flora for the site.

	Number of taxa				
	All habitats			*Epipelon*	*Epiphyton*
Diatoms	81[a]	80[b]	59[c]	321[d]	176[e]
Chlorophyta (green algae)	12	12	7	32	27
Cyanobacteria (blue-green algae)	9	9	6	14	19
Euglenophyta (phytoflagellates)	17	15	7	29	—[f]
Chrysophyta (yellow-brown algae)	0	1	1	1	2
Rhodophyta (red algae)	1	3	0	0	1
Total	120	120	80	388	225

[a] Potomac River, Maryland

[b] Savannah River, Georgia

[c] White Clay Creek, Pennsylvania (Patrick 1961)

[d] Clay and detritus bottom stream, southern Ontario (Moore 1972)

[e] Epiphytes on *Cladophora glomerata* in the Skawa River, Poland (Chudyba 1965)

[f] Flagellates present but not identified to species

Primary production

- gross vs. net promary production
- biomass accrual per time for macrophytes
- small autotrophs – open stream gas exchange, light and dark bottle (chamber) exposure, radiotracer uptake
- max. 1-6 g C m^{-2}d^{-1}
- in shaded stream of temperate zone – 0.01-0.1 g C m^{-2}d^{-1}
- after elimination of grazers, biomass significanly increases
- scour, export and burial
- release of DOC

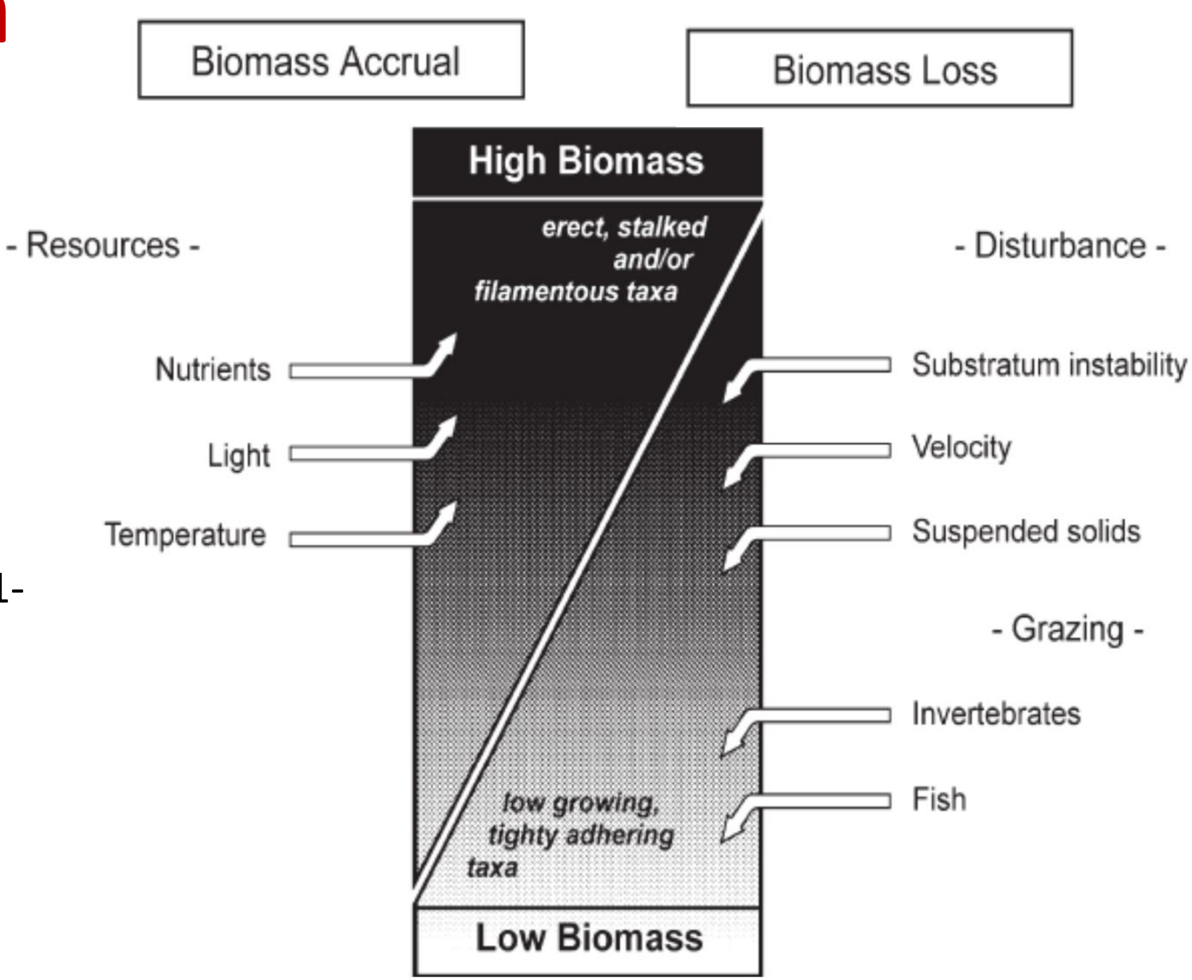
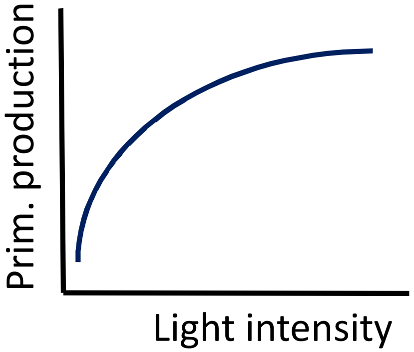


FIGURE 6.2 Factors controlling the biomass and physical structure of periphyton in streams. (Reproduced from Biggs 1996.)

Influence of light and seasonal variation

- high light – filamentous algae
- low light – diatoms, cyanobacteria
- limiting factor in small streams in forested areas
- seasonal variation
- studies: shaded vs. unshaded sites, effects of experimental clear-cutting
- masking effect of herbivory or limiting concentrations of nutrients



Influence of nutrients

- limiting factors generally in freshwaters: 1) P –, 2) N:P < 16:1 (10-30:1) → N becomes limiting, 3) Si and trace metals
- constant supply of nutients in running waters – relative „physiological enrichment“
- thickness of periphyton mats
- colimitation by N+P

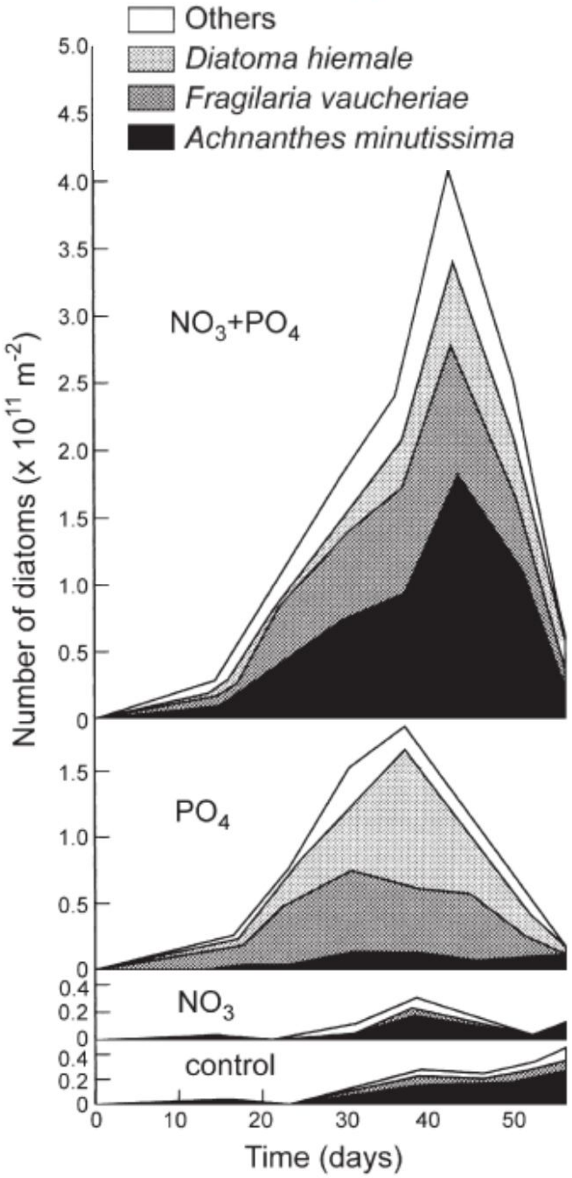


FIGURE 6.6 Changes in the numbers of the dominant diatom species in troughs enriched with NO_3-N, PO_4-P, or both in combination. Troughs were placed in Carnation Creek, Vancouver Island, allowed 4 weeks to colonize, and then fertilized for 52 days. Note that periphyton populations peaked after 30–40 days, and then declined sharply prior to termination of the fertilization experiment. (Reproduced from Stockner and Shortreed 1978.)

Influence of flow

- high streamflow – scouring and abrasion
- different community composition in different flow conditions (diatoms, *Cladophora*)
- different growth form in different flow conditions

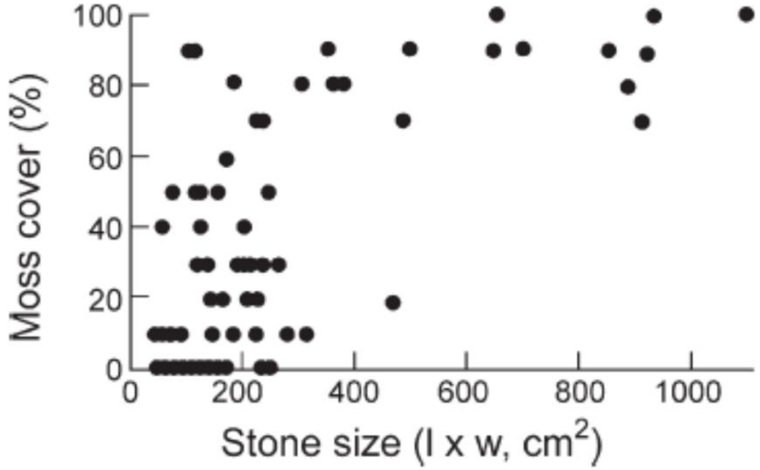


FIGURE 6.12 Amount of stone surface covered by the moss *Hygrohypnum* as a function of stone size in a mountain stream. (Reproduced from McAuliffe 1983.)

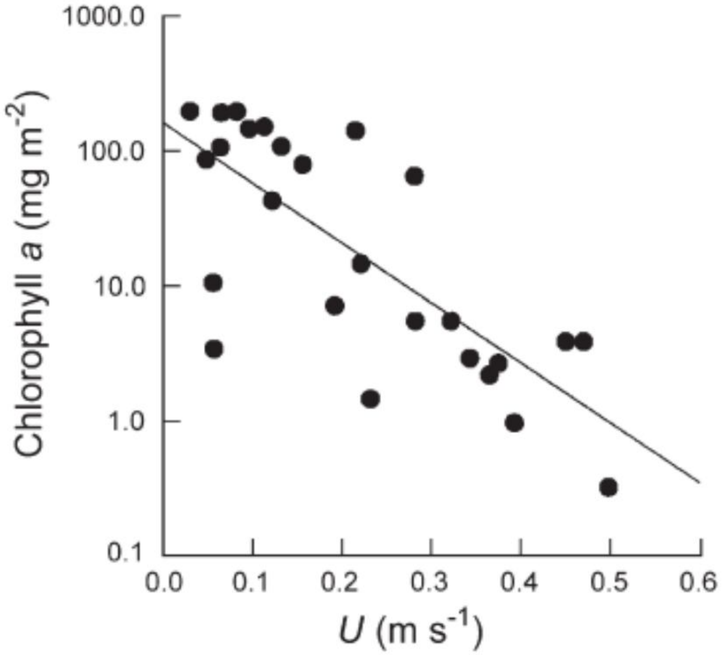


FIGURE 6.11 Chlorophyll *a* responses to variation in water column velocities (*U*) in long filamentous green algal communities in the Waiau River, New Zealand. (Reproduced from Biggs et al. 1998.)

Phytoplankton

- potamoplankton, displaced cells from benthos, backwaters and impoundments
- diatoms, cyanobacteria, Chlorophycae
- large lowland rivers, slow water current
- export up to hundreds km
- residence: tens of days
- 1-2 doubling per day

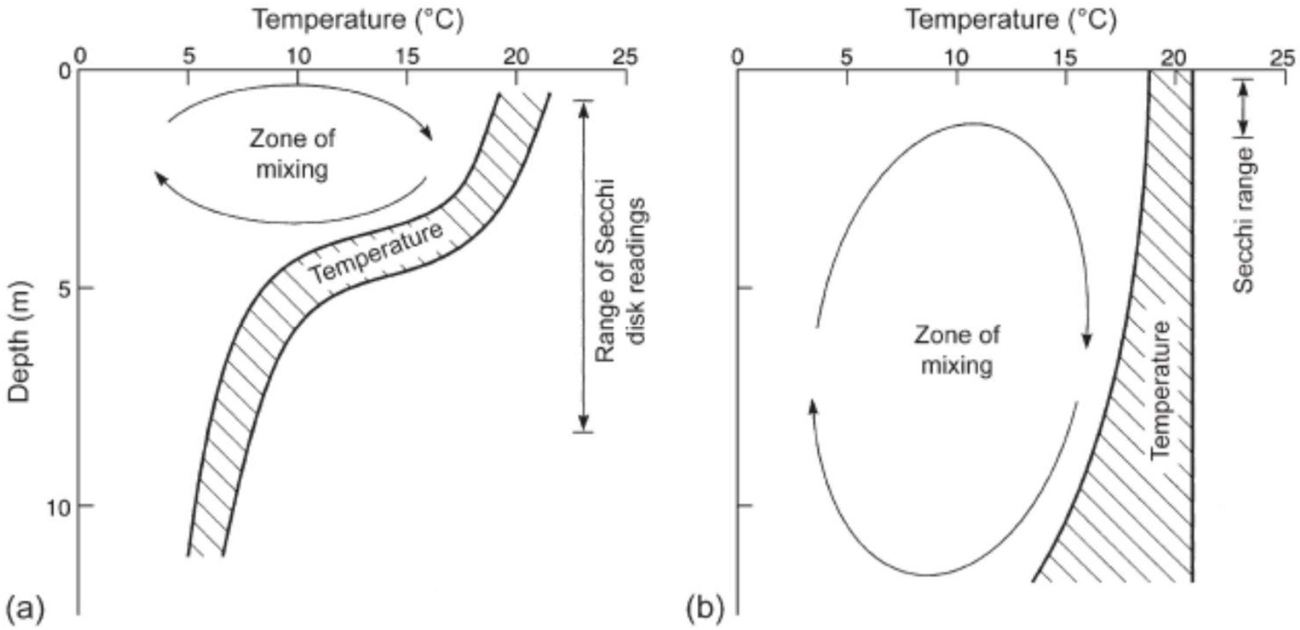
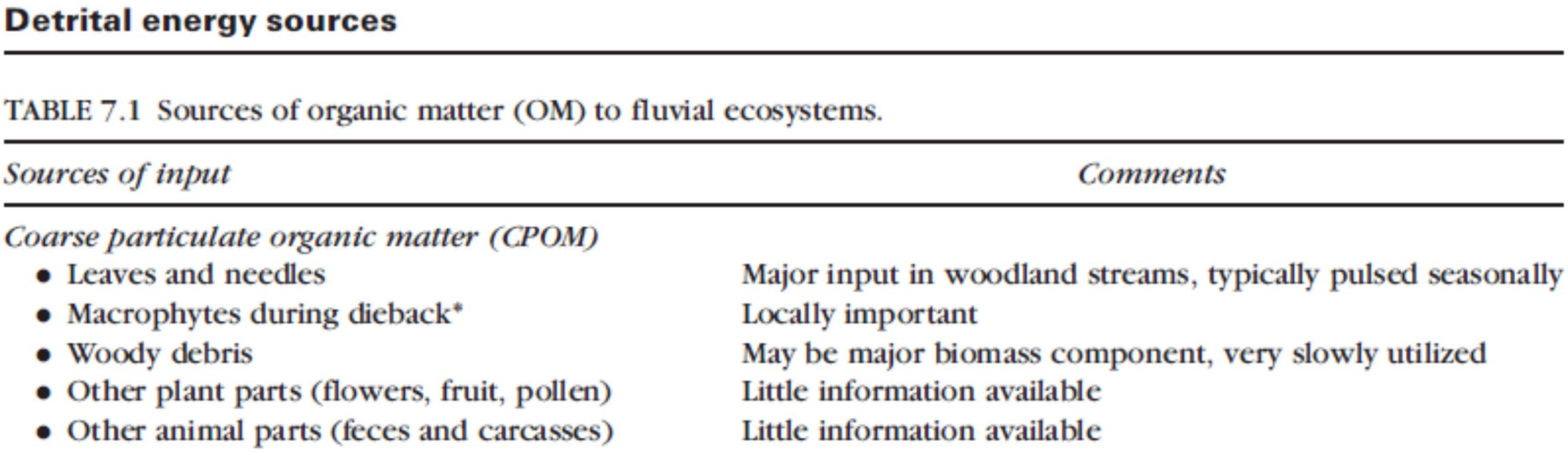


FIGURE 6.15 Schematic diagram comparing effect of depth of mixing on primary production in phytoplankton of a lake versus a river. In a lake (a), establishment of a temperature barrier between surface and deep waters restricts mixing to the upper few meters. In a river (b), temperature stratification is impeded by turbulence of flow, and the water column typically mixes from top to bottom. Depths of 5–20 m are common in large rivers. Rivers often carry substantial sediment loads, restricting light penetration to, at best, the upper 1–2 m.

Heterotrophic energy sources

- allochtonous sources usually dominate the photosynthetic ones
- mineralization, storage or export



Detrital energy sources

TABLE 7.1 Sources of organic matter (OM) to fluvial ecosystems.

Sources of input	*Comments*
Coarse particulate organic matter (CPOM)	
• Leaves and needles	Major input in woodland streams, typically pulsed seasonally
• Macrophytes during dieback*	Locally important
• Woody debris	May be major biomass component, very slowly utilized
• Other plant parts (flowers, fruit, pollen)	Little information available
• Other animal parts (feces and carcasses)	Little information available

Leaf breakdown

- the loss of leaf mass is loglinear
- $W_t = W_i \times e^{-kt}$ (Webster & Benfield 1986)

  W_t ... dry mass at time t

  W_i ... initial dry mass

  k (days^{-1}) ... measure of breakdown rate
- breakdown rate depends on tempetarure, N availability, pH, hydrological regime
- autumn-shed, the loss in april is ca 85%

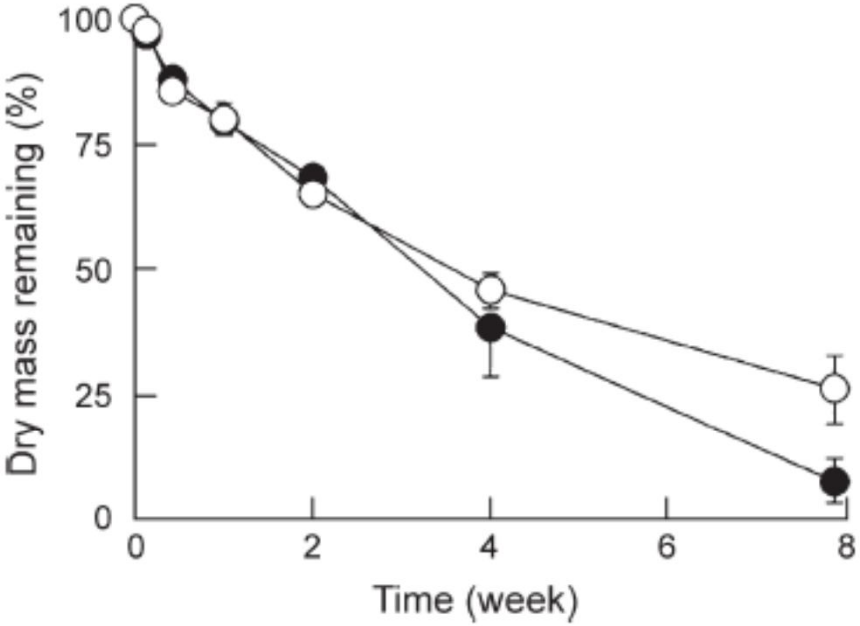
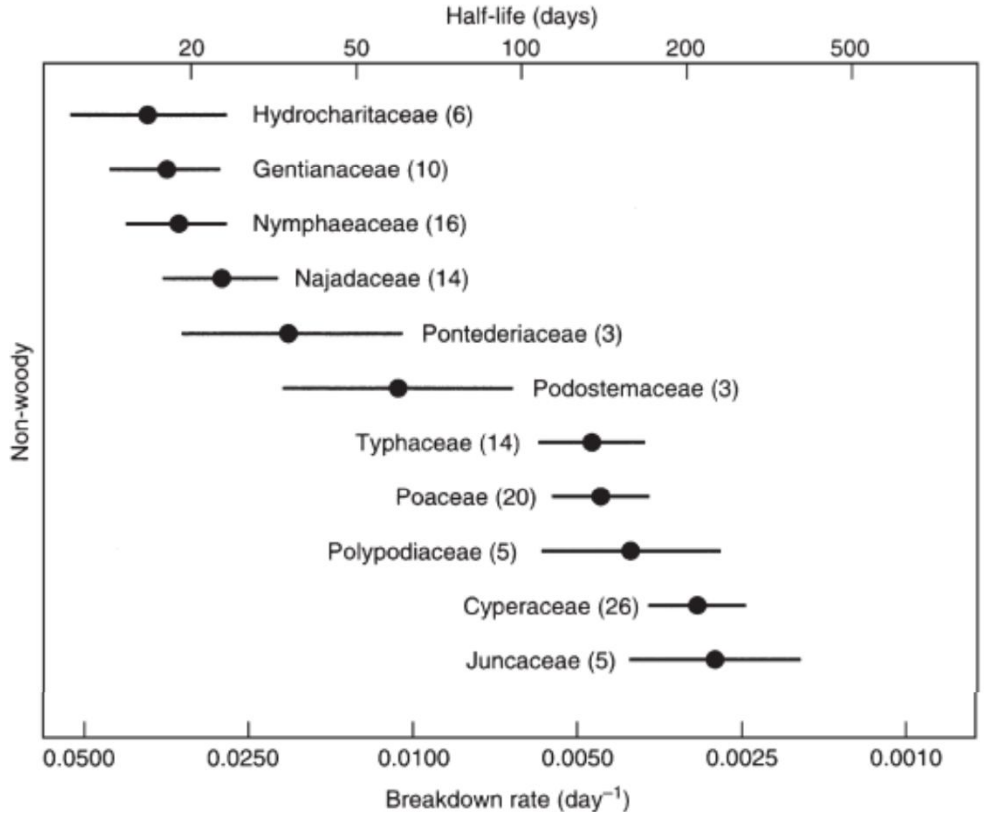
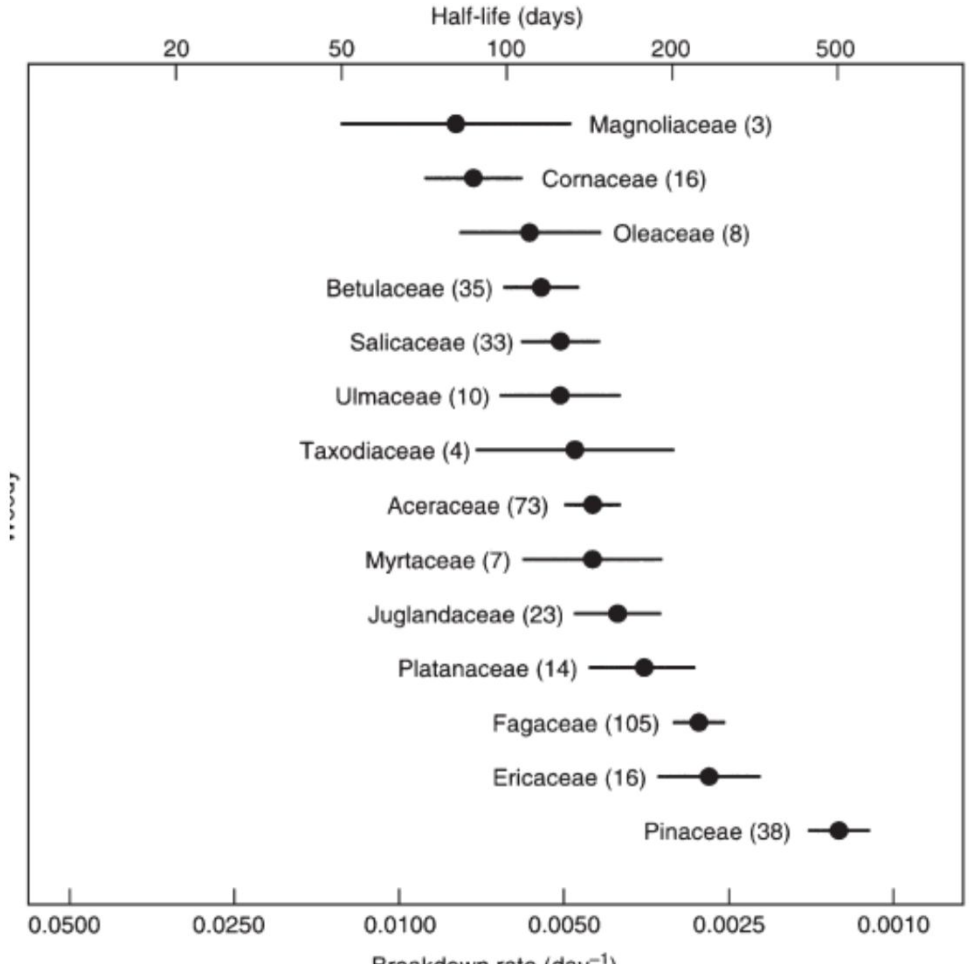


FIGURE 7.1 Leaf dry mass remaining (as %) from alder (●) and willow (○) leaf packs in an experiment conducted in a Black Forest stream, Germany. Error bars represent 95% confidence intervals. (Reproduced from Hieber and Gessner 2002.)

Brakedown rate

- high N concentration – fast breakdown
- lignin and celulose – slow breakdown





Leaf breakdown

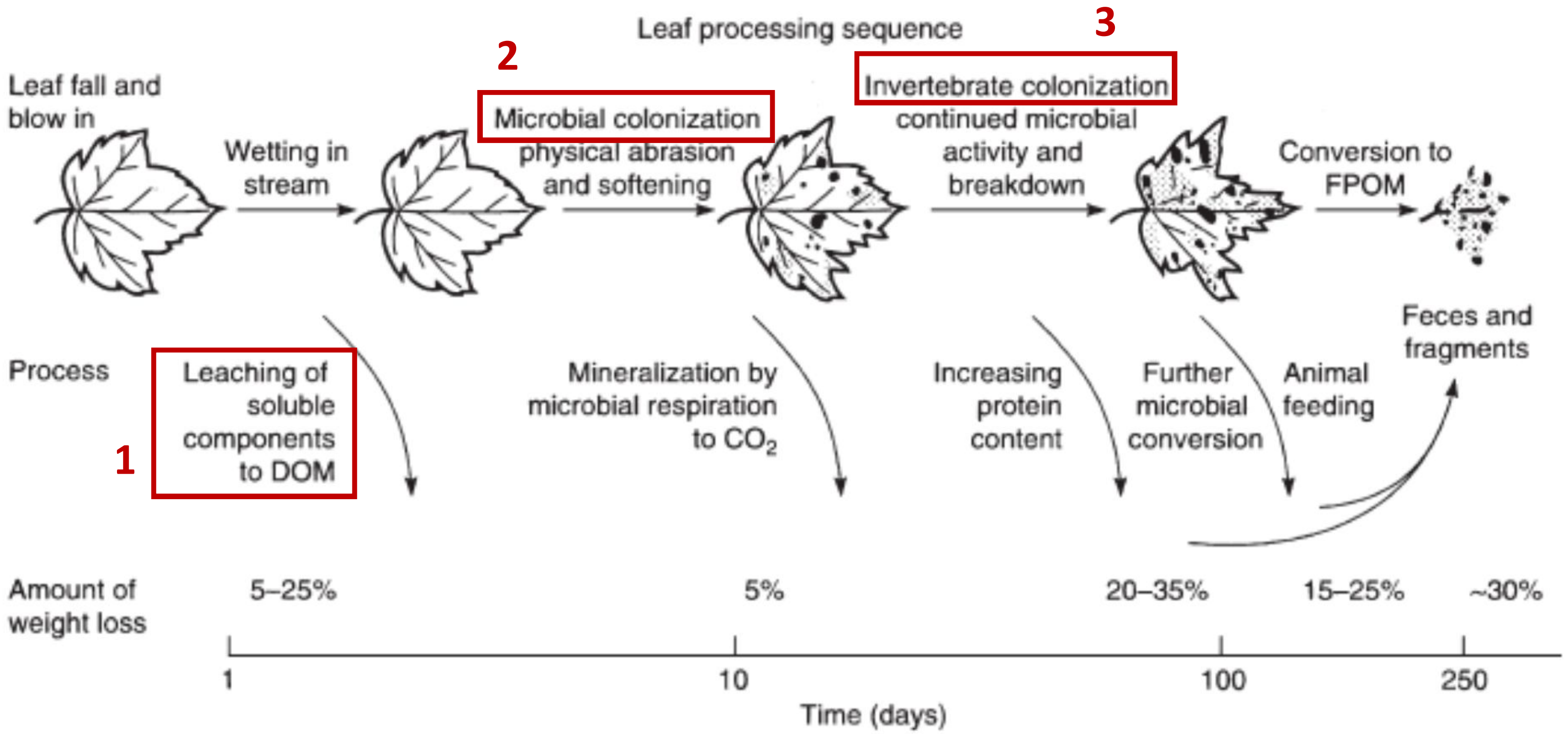


FIGURE 7.3 The processing or "conditioning" sequence for a medium-fast deciduous tree leaf in a temperate stream. Leached DOM is thought to be rapidly transferred into biofilms by microbial uptake.

Microbial decomposition

- aquatic hyphomycetes dominate during 12-18 weeks, up to 30 species, only 2 dominant, nearly no succession
- bacteria dominate terminal stage
- synergic and antagonistic interaction

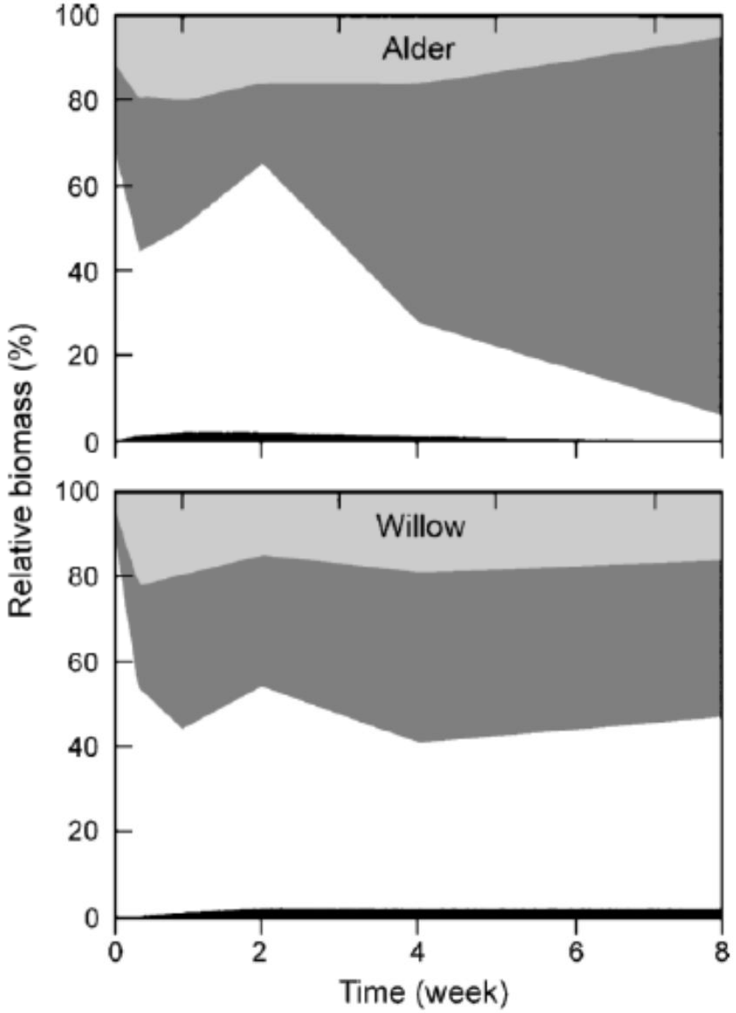


FIGURE 7.6 Proportions of biomass of bacteria, fungi, shredders, and other macroinvertebrates during alder and willow leaf decomposition in a Black Forest stream, Germany. (Reproduced from Hieber and Gessner 2002.)

Invertebrate shredders

- aquatic insects (e.g., *Tipula*) and crustaceans
- detritovores significantly accelerate decomposition

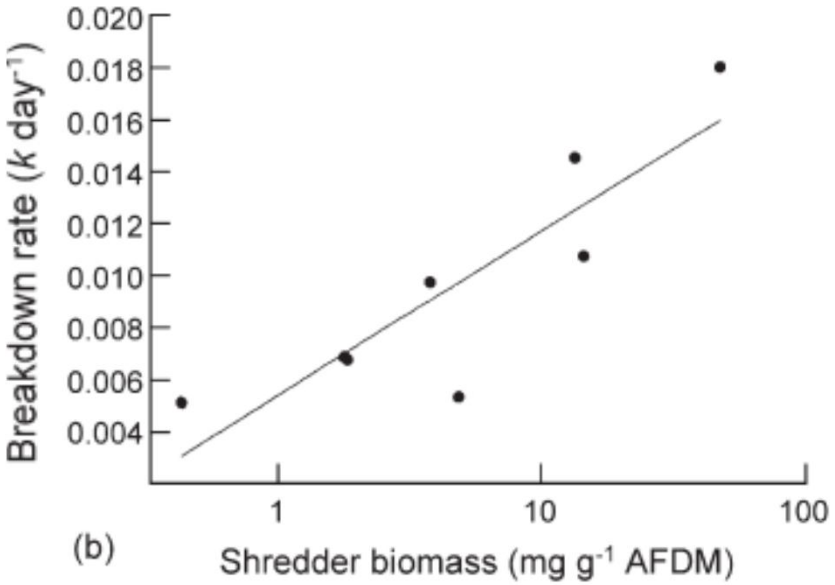


FIGURE 7.10 Correlations between leaf breakdown rates and ~~(a) density and~~ (b) biomass of shredders expressed per gram of leaf AFDM. (Reproduced from Sponseller and Benfield 2001.)

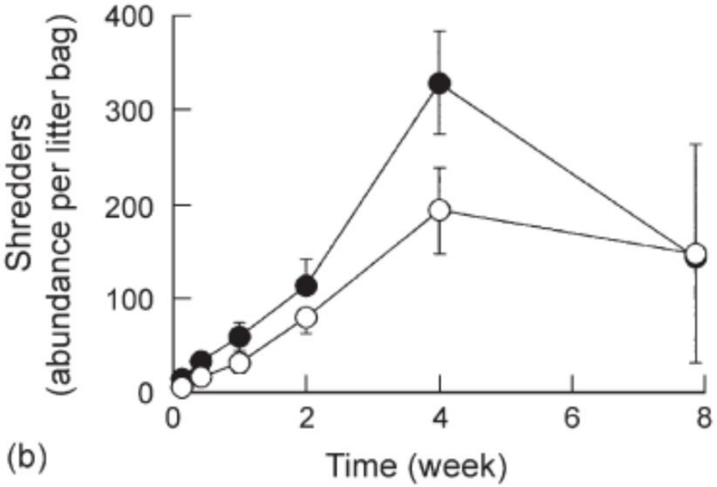


FIGURE 7.9 Colonization of alder (●) and willow (○) leaf packs by ~~(a) macroinvertebrates and~~ (b) shredders in a Black Forest stream, Germany. Error bars represent 95% confidence intervals. (Reproduced from Hieber and Gessner 2002.)