BIOLOGICAL CHARACTERISTICS OF RIVERS

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Contents

Summary

This article introduces the biotic members of running waters: microbes, algae, macrophytes, invertebrates and fishes. Periphytic algae are major producers in rivers, and diatoms, green algae, and cyanobacteria (blue-green algae) are dominant. Aquatic insects are predominant in zoobenthos. The Orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies), and the family Chironomidae are rich in species number and biomass. Odonata (dragonflies and damselflies) are aquatic insects, but they are less abundant than in lentic waters. Of other benthic animals, shrimps and crabs (Crustacea), aquatic worms (Naididae and Tubificidae; Oligochaeta), and snails (Gastropoda) and bivalves (Bivalvia) are important groups. Life history patterns, feeding strategies and other ecological characteristics of stream insects are provided. Undirectional flows and gradual changes from upstream to downstream determine the ecological framework of rivers and streams. This article also reviews the river continuum concept (RCC) and ecological spiralling, along with food web characteristics of stream benthos.

1. Introduction

Streams and rivers have two essential characters that contribute to determine their biota and biological characteristics. These are running waters and unidirectional flow from upstream to downstream. Thus, the flowing water carries inorganic debris, organic matter, and nutrients only in one direction. Normal level water carries nutrients, suspended and floating organic matter. Floods carry inorganic and organic sediment of larger and variable sizes, wash load, boulders, leaves and coarse woody logs.

This unidirectional flow determines the fundamental structure of river ecosystems. The ecological processes occurring in upper stream reaches affect the ecosystems in lower reaches, i.e. biotic communities in upper reaches reduce food resources but produce nutrients and particulate organic matters as faeces and fragments. They become the basic resources and foods for downstream biota.

A variety of intensities of floods and spates occur in streams and rivers. River ecosystems encounter more frequent disturbances than other aquatic ecosystems. This situation favors r-strategists becoming more numerous in stream ecosystems than k-strategists. Some plant species on sand bars recede when bars become stable, since they are adapted to unstable environment but they are weak in competition with other plants. In benthic animal communities, most members are omnivorous and can feed both on vegetative and animal matter. These omnivorous feeding trends of stream benthos may be an adaptation to highly unstable and unpredictable environments, thus making their food webs more complicated.

Stream water originates from rainfall and groundwater, and collects both organic and inorganic matter, the latter through dissolution of rocks and soils. In contrast to lakes and oceans, stream water is transported rapidly and is less concentrated by evaporation. Nutrients and ion concentrations in river water are often lower than those in other aquatic ecosystems, but both are rapidly and constantly replaced by the steady flow. Therefore, river organisms are effectively living in nutrient-rich systems.

The volume of water running through each stream section exceeds the volume that exists at any moment in time in the section. Thus, the amount of organic matter and nutrients carried by water exceed those existing in each stream section. The flow greatly overwhelms the stock. Biotic communities in a river section serve as effective storage systems to retain organic matter and nutrients in flowing water. To enhance sound river ecosystems, these biotic storage systems should perform effectively. The biodiversity, especially species richness, is the principal requisite. Stagnant waters, such as bankside pools, peripheral areas of channels, and sub-surface runs have functions of abiotic storage.

2. Biota of streams and rivers

There is a large variety of organisms in running waters, from microbes and fungi to higher plants, and from protozoans to vertebrates, such as fishes and mammals. In lentic waters, planktonic organisms are predominant, especially in open water. Benthic organisms are confined to lake bottoms and littoral zones, and the biomass is less abundant than the planktonic. In river and stream channels, however, planktonic organisms appear only in lower reaches where channels become wide and deep; this is known as potamoplankton. In the upper to middle reaches, planktonic organisms are unable to complete their life cycles in fast flowing waters, but they sometimes appear in bank side pools or stagnant areas. Stream plankton is exceedingly rare compared with other aquatic systems. The river biota is composed mostly of benthic organisms on river bottoms and shores. Benthic organisms comprise a range of taxa of variable sizes, and use a variety of habitats. The nekton is mostly confined to fish and a few crustaceans.

Meiobenthos, defined as intermediate in size between the microscopic and macroscopic, live mostly in the hyporheic zone or interstices in the river bottom. Protozoans, Rotifers, and Oligochaetes (Tubificidae and Naididae) are predominant. Young larvae of aquatic insects and micro-crustacea (e.g. Harpapticoida) often appear in hyporheic zones. The number of species is high but the biomass is small compared with macrobenthic organisms. We are lacking in ecological and taxonomic information on meiofauna and microbes in running waters.

3. Autotrophic organisms

Macrophytes, algae, protista with chloroplasts, and cyanobacteria (blue-green algae) are component autotrophs in running waters. Macrophytes include vascular plants and bryophytes. Chlorophyta (green algae) and Rhodophyta (red algae) also belong to the plant kingdom. Diatoms, yellow-brown algae and euglenophyta are protista. Cyanobacteria also sometimes become dominant in algal communities. Most microscopic autotrophs exist as periphytic or attached algae; i.e. epilithic or epiphytic life forms. Some become potamoplankton in lower reaches and stagnant waters.

Autotrophs play important roles in nutrient cycles and gas metabolism in lotic ecosystems. In midstream reaches, dissolved oxygen exceeds saturation during daytime as a result of photosynthetic activity of autotrophic periphytons: diatoms, chlorophyta, and cyanobacteria. They are important primary producers and become the food of grazers and chewers. They then become detritus and are used by detritus feeders and collectors.

Recent scanning macroscopic work has revealed that periphytic algae form microscopic forests on stone surfaces: filamentous, stalked, epiphytous, and creeping algae (Allan, 1995). The species composition of periphytic algae changes spatially and seasonally. In temperate streams and rivers, diatoms are predominant from winter through early summer, but cyanobacteria and green algae become dominant in summer. The species composition of periphyton communities was reported in a wide range of rivers and streams (Allan, 1995). A total of 100 to 400 species were recorded from a single site and diatoms comprise about 70 to 80% of the total number of species. Chlorophyta and Euglenophyta follow. Cyanobacteria are poor in species number but sometimes abundant in biomass.

Nitrate and phosphate are critical nutrients for stream autotrophs and diatoms need silica to construct their frustules (shells). Some species of cyanobacteria can utilize atmospheric nitrogen and become abundant in waters poor in nitrate-nitrogen. Phosphate often becomes a limiting nutrient in lakes. In rivers, however, flowing water carries nutrients and delivers them to algal communities continually. It is more complicated to estimate the limiting supply of nutrients in flowing waters compared with standing waters.

Macrophytes are relatively poor in running waters compared with standing waters. A selection of flowering plants, mosses, and liverworts constitute the macrophyte vegetation in lotic waters. From their growth forms, macrophytes are classified into 4 groups: emergent, submerged, attached and free-floating plants. Emergent plants have roots under or close to water level, and aerial stems and leaves; these are often found on banks or shores. Attached plants have creeping forms and attach firmly to river bottoms, these include some angiosperms, mosses and lichens. In attached plants, peculiar flowering plants of Podostemonaceae (*Cladopus*) and mosses of Fontinaliceae (*Fontinalis*) become dominant and cover rock faces of cool and fast running streams. Submerged plants also attach to rock or other substrata by roots, and extend their stems and leaves into the water. *Ranunculus spp*. (Ranunculaceae) appear in cool running streams. In slow flowing or stagnant area, submerged flowering plants become more diverse and abundant, especially in tropical rivers and their flood plains. *Potamogeton spp*. (Potamogetonaceae) contains many species in slow flowing streams and creeks in temperate and subtropical areas. Free-floating plants, such as *Lemna* and *Azolla*, live in the margins of lower reaches and in pools of ephemeral streams and are generally more abundant in stagnant waters. Water hyacinth, *Eichhornia crassipes* (Potederiaceae), originated in the Neotropical region, but has become common or dominant in most tropical and subtropical rivers.

4. Microbes and protista

Fungi play important roles in decomposing organic matter, especially by breaking down leaf litter in two ways. One is direct decomposing activity by fungi and the other is that microbes enhance the nitrogen content of leaves; these are then preferred by macroinvertebrates, especially shredders. The fungi in running water include Matigomycotina, Deuteromycotina, Ascomycotina, and Zygomycotina (Maltby, 1996). The term “aquatic hyphomycetes” is traditionally and commonly used, but some members do not fit it taxonomically. Microbial activities to process leaf litter is measured in several ways: by comparing sterilized leaf litters with native ones (Petersen et al., 1989), and measuring oxygen consumption by microbes (Petersen et al., 1989) etc. In one study of a fungal community on leaves in a stream, 55 species were identified and 29 species were of terrestrial origin (Barlocher and Kendrick, 1974). A similar number of species was reported on a woody substratum (Maltby, 1996). Most fungi are difficult to find with the naked eye, but Saproleganiaceae (Saprolegnia and Achlya) are commonly found in polluted waters and form huge visible colonies.

Bacteria also play important roles as decomposers, but little is known of their species composition and ecological roles. Direct microscopic observations can reveal the diversity and abundance of mycoflora in natural streams.

Heterotrophic protozoans are widely found in freshwaters, and have high species richness in plankton communities in lakes, but little is known about them in running waters. In epilithic protozoan communities in streams, Mastigophora appeared predominantly and Bodo was the most abundant genus. Sarcodina and Ciliophora also occurred (Hori and Morikawa, 2000).

5. Macroinvertebrates

Macroinvertebrates are dominant and diverse in river benthic communities. These animals have received much attention in the ecology and biology of running waters. They form important links between micro-organims and larger animals. Among invertebrates, insects are abundant both in species number and biomass. Aquatic insects became members of the freshwater fauna from terrestrial lifestyles. Some insect species spend their whole lives in water, but most species spend their aquatic lives as larvae and/or pupae, and the adults have a terrestrial phase for reproduction. Among insect orders, Ephemeroptera (mayflies), Odonata (damselflies and dragonflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) have aquatic stages in all species, except for some exceptional terrestrial species. Other insect orders also have species classified as aquatic insects. The families Chironomidae (Diptera), Tipulidae (Diptera), and some Coleopteran ones (Elmidae, Psephenidae, etc.) are specialized for aquatic lifestyles. Chironomidae are rich both in species number and abundance, in running and standing waters, and play a key role in food webs of the zoobenthos.

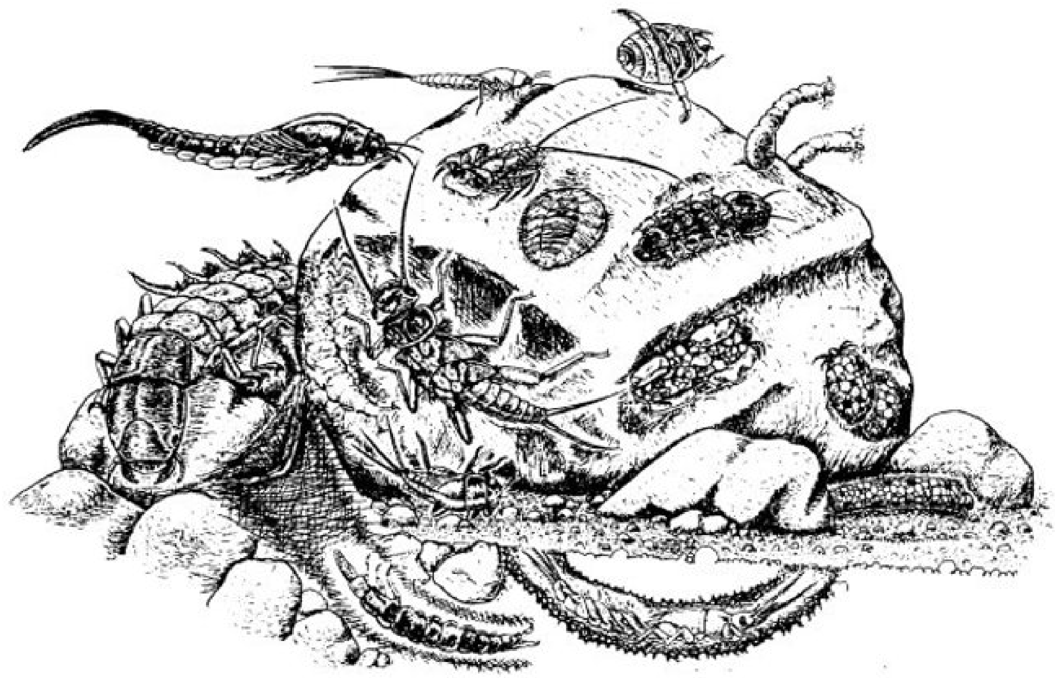

Figure 1. Major taxa of stream insects on a boulder. (Line drawings by K. Inada). Ephemeroptera: (1) *Ameletus* (Leptophlebidae), (2) *Baetis* (Baetidae), (5) *Epeorus* (Heptagenidae), (11) *Ephemera* (Ephemeridae). Trichoptera: (8) *Goera* (Goeridae), (9) *Glossosoma* (Glossosomatidae), (10) *Gumaga* (Sericostomatidae), (12) *Stenopsyche* (Stenopsychidae). Megaloptera: (14) *Protohermes* (Corydalidae). Hemiptera: (3) *Aphelochirus* (Aphelocheiridae). Plecoptera: (13) *Kamimuria* (Perlidae). Coleoptera: (6) *Eubrianax* (Psephenidae). Diptera: (4) *Simulium* (Simulidae), (7) *Bibiocephala* (Blepharoceridae).

In rivers and streams, Ephemeroptera, Plecoptera, Trichoptera and Chironomidae are rich in species number and abundant in biomass (see Figure 1). The composition of aquatic insects in running water is quite different from that in lakes and ponds, where Odonata, Hemiptera and Coleoptera are more abundant. From mountain streams to midstream, Ephemeroptera nymphs are abundant in number and Trichoptera larvae are abundant in biomass and species richness. Plecoptera nymphs are less abundant and less diverse than Ephemeroptera or Trichoptera. Chironomidae larvae are abundant and rich in species number from headwaters to downstream reaches.

Some crustacean species, freshwater crabs and shrimps, are important members of the benthic community and some species have economic and nutritional importance; i.e. Palaemonidae, Astacidae, Cambaridae and Grapsidae. Crustacean species become distinctive faunal elements in tropical running waters. Freshwater Crustacea originated in the marine environment and expanded into freshwaters. Some estuarine species often invade further into freshwater habitats; this is more commonly observed in tropical and subtropical rivers and streams. Some crustacean species have anadromous life cycles, growing in rivers and streams and migrating downward to estuaries or coastal area to reproduce. Some Potamoidea crabs spend their entire lives in streams and rivers and never return to the ancestral marine habitat. Gammarid species are abundant in spring flows and upstream reaches, especially in temperate streams; these also originated in the marine environment but spend their entire lives in freshwater. In streams on oceanic islands, where aquatic insects are scarce for geo-historical reasons, anadromous crustacean and mollusk species become the dominant zoobenthos.

As for other invertebrates, freshwater sponges (Porifera), coelentrerates (Cnidaria), moss animals (Polyzoa or Ectoptera), flatworms (Platyhelminthes; Turbellaria), ribbon worms (Nemertea), horsehair worms (Nematoptera), snails and mussels (Mollusca), Prosobranchia, Pulmonata, and true worms and leeches (Annelida) are the principal members of the lotic invertebrate fauna other than insects and crustaceans. Considering ecological roles and abundances, freshwater sponges, true worms, leeches, snails and mussels are the next most important in running waters besides insects and crustaceans.

Most species of freshwater sponge occur in lentic waters and only restricted genera, such as Spongilla, occur in running waters. Spongilla fly larvae (Neuroptera; Sisyridae) and some species of leptocerid caddis larvae (genus Ceraclea) feed on freshwater sponges. Caddis larvae (Trichoptera) construct their cases using sponge shells.

In Annelida, Polychaeta species are abundant in marine or brackish waters, but it is Oligochaeta species that are fairly common in running waters, from upstream to downstream reaches. Tubificidae and Naididae are common worms and rich in species number. They become important members of the meiofauna and play similar roles to terrestrial oligochaetes. Snails, limpets and bivalves are common and rich in species number, but they are poorer in abundance and diversity in lotic waters than lentic waters. Only a few families are found in running waters. Snails, mussels and limpets, however, are important components of river zoobenthos from both commercial and nutritional viewpoints. Limpets belong to Gastropoda and the family Ancylidae species are common in running waters, especially in the tropics and sub-tropics. Most limpets are scrapers, and most snails are shredders or scrapers, often becoming scavengers. Most mussel species are filterers or suspension feeders, and they are more sedentary than snails.

6. Adaptation and characteristics of aquatic insects

Life history patterns of aquatic insects are different from terrestrial insects. Most mayfly species have comparatively short imaginal (adult) periods, from a few hours to a couple of days, including the subimaginal stage. Some species can reproduce as subimagines just after emergence from nymphs, e.g. *Ephoron* species (Polymitarcyidae). Stoneflies and caddisflies also have short adult periods of several days to a couple of weeks, but a few species spend two to three months in the adult phase. Some limnephilid species emerge in spring, aestivate during summer, and reproduce in autumn. Winter stonefly species of Capniidae have peculiar life history patterns: they emerge in autumn, mature in winter (appearing sometimes on snow), and reproduce in early spring. The newly hatched larvae diapause in the river bottom until autumn. Odonata (dragonflies and damselflies) have longer adult periods than other aquatic insect orders.

Larval drift is well known and extensively studied in stream insects. Drift nets have been widely used to monitor diurnal and seasonal patterns of drift, and there have also been many other studies of colonization of substrata on river bottoms. Early studies on drift of stream insects revealed the nocturnal periodicity of drifting organisms. Floods, drought, temperature stresses, anchor ice (when the water column freezes to the bottom), and human disturbance can have catastrophic effects on drifting invertebrates. There are two types of drift, passive and active. Passive drift refers to the drift caused by some kinds of disturbances, turbulent flows, predators, etc, and active drift refers to the voluntary movements by larvae. Active drift enhances colonization of downstream reaches. "Downstream tail" refers to the pattern of longitudinal (downstream) distribution that extends more to downward reaches; this is mostly caused by larval drift.

Upstream flights of adults are widely recognized in a variety of insect groups, e.g. Trichoptera, Plecoptera and Ephemeroptera; these compensate for larval drift, and are part of a "colonization cycle". The colonization cycle play an important role in maintaining populations in running waters, but there are several claims on the function of colonization cycles. Macroinvertebrates without any flight capability, such as gammarid species, also drift abundantly but move upward only sparsely. However, the populations in upstream reaches are maintained. Excess populations in upstream reaches also sustain riverine invertebrates. Although there is a claim that upstream flights are not universal, flights by egg-carrying females are commonly observed in streams and rivers all over the world. Catastrophic drifts caused by floods also occur frequently in some predictable manner. Upstream migration flights of adults seem fairly adaptive in riverine environments with frequent disturbances.

Adaptations to currents are well known among lotic fauna, especially in aquatic insects. Baetid nymphs (Baetidae; Ephemeroptera) adopt streamlined body shapes. Dorso-ventral compressed body shapes were evolved in heptagenid mayfly nymphs (Heptaganiidae; Ephemeroptera), psephenid larvae (penny worms, Psephenidae; Coleoptera) and the larvae of net-winged midges (Blepharoceridae; Diptera). But both types of body shapes are also adaptive for interstitial lives between boulders and cobbles. Sucker-like structures are developed in the mayfly nymphs of Heptageniidae and blepharocerid larvae. The nymphs of some species of *Epeorus*, *Iron* and

Rhithrogena have enlarged first gills and use these gills and other abdominal gills, as sucking apparatus. Nymphs with such gills live in the faster current area in streams. Blepharocerid larvae have pseudopods on venters of abdominal segments as sucking organs; these are strong enough to keep their positions in fast flowing streams and on smooth rock faces. The lateral extensions of tergites of psephenid larvae also act as a sucking apparatus.

Many sedentary animals use silk-like excretion or other material to fasten their bodies or nests to the substratum. Simulid larvae (Simuliidae; Diptera) excrete silk to make mats (see Figure 1). Net-spinning caddis larvae excrete silk to make retreats (nests) and capture nets, and their retreats are firmly attached to the substratum even in fast and turbulent flows.

Some caddisfly larvae construct their portable cases with mineral particles using silk-like strands, and some add larger sand grains as lateral wings or fringes. Their cases undoubtedly give more weight and this was considered to be an adaptation to current. However, most cased caddis larvae with wings or fringes are found in slow flowing area of streams or lentic habitat. Thus, it is considered that the adaptation is to avoid predators by camouflage.

Caddis larvae use silk to anchor their bodies and cases. Some caddis larvae with portable cases move from the substratum into the stream flow when predators attack them. They fasten one end of silk to the substratum and extend silk lines into the water, this enables them to come back to the original places. Some caddis larvae excrete silk lines onto rock faces and use them as holding lines.

Macroinvertebrates, especially aquatic insects, are widely used for monitoring the water quality of running waters. There are a large number of methods to sample, identify, calculate and make indices. The biological monitoring systems have several advantages compared with chemical analyses or monitoring.

The ubiquitous nature of macroinvertebrates covers wide habitat and area, the large number of species covers a wide spectrum of pollution and pollutants, the sedentary lives of macroinvertebrates allows spatial analysis of pollution, and relatively long life spans allow us to elucidate temporal changes (continuous monitoring). Biomonitoring using macroinvertebrates needs less expensive equipment than chemical analysis and is sometimes more sensitive to pollutants. The monitoring is appropriate for citizens and students. The ecological soundness of riverine environments, e.g. ecological integrity, can also be professionally monitored using macroinvertebrates.

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Biographical Sketch

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