Chapter I —The Zoobenthos of Freshwaters- An Introduction

"The freshwater world has more than 500,000 different species of insects. They occur in habitats that range from hot springs, discarded tin cans, temporary ponds, spring seeps, wetlands, rivers, lakes, to arctic and mountain pools. In fact, if water will stand for a few days, one or another of the ubiquitous chironomids will probably be the first to inhabit that water............ Take a walk down to the lake. It doesn't matter what time it is - there will be insect activity somewhere!"
.... Richard Narf (1997)

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Introduction

The benthic animals inhabiting lakes constitute an extremely diverse assemblage, both taxonomically and ecologically. There is usually a great proportion of insects present in striking contrast to what is met with in the sea. Except in the freshwater sponges and coelenterates with photosynthetic symbionts and in the groups of larger nektobenthic animals, mostly arthropods and fishes that find their food by sight, the occurrence of zoobenthos seems less affected by the light gradient than would be expected, as most groups of benthic animals have representatives that extend far into the dysphotic zone.

The number of species may be very large, particularly in the chironomids which are often the most numerous species present. The ecological specialization in the larvae is very great and of enormous importance in lake classification on account of the variation in tolerance of oxygen and other environmental conditions, so that in stratified lakes the hypolimnetic zones having different oxygen concentrations and different physical types of sediment have different chironomid inhabitants. *Since the different species are in most cases at least generally and in some cases specifically determinable from their fossilized head capsules, study of these larvae can give a great deal of paleolimnological data. Fortunately they have been intensively studied, most in connection with lake classification, notably by Thienemann*.

In the evolution of the freshwater biota, it is reasonable to suspect the sponges, Coelenterata, annelids, bivalves and lower gastropod molluscs, most crustacean groups, the Cyclostomata, and ultimately the fishes, as having moved from the sea to fresh water directly, while the insects entered fresh water from the land. Though the history of more phyla involves a direct aquatic path than an indirect path over land, the insects are much more prominent than the other groups in all except the largest lakes.

Categories of animal benthos

The benthic animals of lakes constitute an extremely diverse assemblage, containing representatives of almost every major group of animals living in fresh water. Most insects, supposedly on the order of 500,000 species, in both immature and adult stages live in some sort of terrestrial habitat. The total number of aquatic insect species is estimated at over 40,000. Two patterns of life history are; those in which all stages are passed in water (e.g. Hemiptera, Coleoptera) number about 9000, while those in which the adult emerges as a terrestrial or aerial being number over 30,000 species, mostly in the Diptera. The fourth possible logical set, namely more or less terrestrial but usually hygrophil larvae with aquatic adults, is limited as far as is known to the beetles of the families Hydraenidae and Dryopidae (ca. 100 species of Coleoptera).

- **In striking contrast to the marine benthos, insects are extremely important and are proportionately more abundant in dilute oligotrophic lakes than in less dilute eutrophic waters.** It is possible that this is related to the insects being of terrestrial origin and so less able to take up calcium and other essential substances from fresh water than are soft-bodied and other invertebrates of marine affinities; on this hypothesis, which is clearly not universally valid, insects usually obtain most of what they need by mouth but compete less well with animals having other means of absorption when the needed ions are abundant.
- It has been suggested that in the less eutrophic regions, the noninsectan community, ultimately derived directly from the sea, would consist of animals that at some stages depended on dissolved inorganic ions as a source of nutrients, and that such substances would be enriched where such animals lived. The insectan communities being derived from the land would have lost this capacity and, insofar as they have become important members of the fauna of electrolyte-poor water, probably receive their inorganic nutrients from solid food blown or washed into the lake. It was further suggested that the absence of these insects in the noninsectan community is due to the high level of various invertebrates dependent on dissolved nutrients being able to produce large enough populations of predators to limit severely the survival of insect eggs.

⇒ "Though this hypothesis to me is very reasonable, it is characteristic of much of benthic ecology, in which the simplest situation depends on a complicated, often hidden, set of interspecific interactions. .... Yet in the simplest form the hypothesis seems unlikely to be true. There is evidence that runs counter to it. All the lower insects- Odonata, Ephemeroptera, and Plecoptera- have salt-absorbing organs on the gills, and there are dragonfly nymphs that do need more electrolytes in solution than might be expected. The dragonfly Libellula as a nymph requires more salt than most other freshwater animals". .... G. Evelyn Hutchinson a.k.a. Father of modern Limnology and the modern Darwin (1993).

A size categorization roughly into the macrobenthos (≥1000 μm), mesobenthos (500-1000 μm), and microbenthos (≤500 μm) is used. The same sorts of distinction that have been made in the case of benthic algae apply also to animal benthos.

The following qualitative categories are convenient if not particularly tidy:

I. Truly haptobenthic or periphytic animals living attached to a solid substratum, whether permanently, as adults only (sessile haptobenthos), or during most of their lives with intermittent periods of wandering (subsessile haptobenthos). The sessile members are flagellate and ciliate Protista, sponges, Cordylophora among the Coelenterata, sessile Rotifera, Urnatella among the Endoprocta, all Ectoprocta save Cristatella (which is subsessile), and a few bivalve molluscs. The subsessile members include some ciliates, the Hydridae among the Coelenterata, Cristatella in the Ectoprocta, a few molluscs, and, less typically, various insect larvae.
II. Animals living free in the haptobenthos and capable of movement among the attached organisms. These constitute the lasion. It consists of a great number of species of Protista, Turbellaria, Nemertea, Nematoda, Rotifera, Gastrotricha, Oligochaeta, Tardigrada, and most fresh water groups of small arthropods. The whole category in some ways provides a small-scale aquatic analogue to the insects and small mammals in an herbaceous plant community. The members of the analogous terrestrial community must presumably be larger to prevent destruction by evaporation.
III. Motile animals, larger than those of category II, either poor swimmers or unable to swim at all and habitually not leaving the substratum. Such animals have linear dimensions greater than the thickness of a typical growth of haptobenthic algae and its accompanying sessile animals. They move through or over this growth on which they may feed. Nearly all gastropod molluscs, some insects, and a few Crustacea such as Asellus belong here. Among the molluscs, some may move on to the surface film. As formally the most typical benthic animal community, they may be termed eubenthos.
IV. Motile swimming animals, again larger than the thickness of the haptobenthos; these animals are essentially nektobenthos, feeding on bottom-living organisms but moving from place to place in search of food in the free water. They are in some ways analogous to birds living on herbs, bushes, or trees, but likewise moving from place to place to forage. The category includes a few soft-bodied invertebrates, notably leeches, the most benthic malacostracan Crustacea, a vast number of insects, and quite reasonably some fishes. The nektobenthos is presumably the most numerous taxonomic group in the lacustrine fauna and forms a transition to the nekton.
V. Animals living on or in mud and moving through it, constituting the animal herpobenthos. These organisms live mainly in fairly deep water below the higher vegetation. The category consists of organisms of a great range of sizes. The group is very numerous in spite of the uniformity in their part of the benthic habitat. It consists largely of insect larvae notably of Chironomidae, but it also includes Protista that are relatively little known, some flatworms, a large number of nematodes, some oligochaetes, many small and a few larger Crustacea, and many bivalve molluscs. In general, the typical herpobenthos is found on the deeper parts of the lake bottom. Some members of categories III and IV may extend into deep water and here live moving over, rather than through, the mud.
VI. A final category of the benthos involves the psammon, or sand fauna. This may be regarded in a way as a shallow-water alternative to the herpobenthos from which the finest particles have been washed out. It has mainly been studied in the psammolittoral, where there is often a triphasic arrangement of liquid, solid, and gas in which a very interesting fauna develops.

Substrate influence

(Allan, 1995)

Substrate is a complex aspect of the physical environment. What comes to mind first are the cobbles and boulders in the bed of a mountain stream, and silts and sands that are more typical of lowland rivers. Organic detritus is found in conjunction with mineral material, and can strongly influence the organism's response to substrate. Determination of the role of substrate is further complicated by its tendency to interact with other environmental factors. Fro example, slower currents, finer substrate particle size and (possibly) lower oxygen are often correlated. In addition, the size and amount of organic matter, which affect algal and microbial growth, vary with substrate. This natural covariation of environmental factors makes it very difficult to ascribe causality from field surveys.

Inorganic Substrates

Table I-1: The classification of mineral substrates by particle size, according to the Wentworth Scale

Size Category	Particle Diameter (range in mm)
Boulder	>256
Cobble	
Large	128-256
Small	64-128
Pebble	
Large	32-64
Small	16-32
Gravel	
Coarse	8-16
Medium	4-8
Fine	2-4
Sand	
Very coarse	1-2
Coarse	0.5-1
Medium	0.25-0.5
Fine	0.125-0.25
Very fine	0.063-0.125
Silt	<0.063

Substrate ofcourse depends on the parent material available, but there is a general tendency for particle size to decrease as one proceeds downstream.

Organic substrates

Very small organic particles (less than 1 mm) usually serve as food rather than as substrate, except perhaps for the smallest invertebrates and micro-organisms. Larger organic material, from plant stems to submerged logs, generally functions as substrate rather than food. However, autumn-shed leaves on the streambed are a substrate to insects that graze algae from their surfaces, and food to insects that eat the leaves themselves. Aggregations of leaves on the stream bottom usually support the greatest diversity and abundance of invertebrates, and the addition of leaves to mineral substrates results in higher densities of animals. Even logs meet the nutritional needs of some invertebrates. More commonly, however, large organic substrates serve as perches from which to capture food items transported in the water column, as sites where fine detrital material accumulates, and as surfaces for algal growth.

Fine-scale heterogeneity in current and mineral substrate affects the distribution of organic detrital particles, and the availability of detritus influences the distribution of organisms within the substrate.

Characteristic fauna of major substrate categories

The great majority of stream-dwelling macroinvertebrates live in close association with the substrate, and so they have been the main focus of organism-substrate studies. When one compares broad categories such as sand, stones, and moss, many taxa show some degree of substrate specialization. When one examines preferences among stones of various sizes, substrate specialization is less apparent, and preference is often exhibited as statistical patterns of abundance across the particle size spectrum. However, some stream-dwelling organisms are quite restricted in the conditions they occupy.

Lithophilous taxa are those found in association with stony substrates. Streambeds of gravel, cobble and boulders occur in a great many areas around the world, harbouring a diverse fauna that Hynes (1970) remarks is broadly similar almost everywhere. Many species are equally common on stones of all sizes, some are demonstrably more likely to be found associated with a particular size class, and a few are highly restricted in their occurrence.

- Larvae of the water penny (Psephenidae) occur mainly on the undersides of rocks, and often under boulders in torrential flow. Pyralid moth larvae live underneath silken shelters constructed within depressions on rock surfaces.
- Attached and encrusting growth forms require a substrate that is not easily overturned by current, and large stones are ofcourse more stable. The longer the life-span, the more critical this is.
- Because they grow more slowly, mosses, bryozoans and sponges are found mainly on larger stones or in locations where scouring is infrequent.

Sand is generally considered to be a poor substrate, especially for macroinvertebrates, due to its instability, and because tight packing of sand grains reduces the trapping of detritus and can limit the availability of oxygen. Nevertheless, a variety of taxa, termed **psammophilous**, are specialists of this habitat. The meiofauna, defined as invertebrates passing through a 0.5 mm sieve, can be very abundant, dwelling interstitially to considerable depth. The psammophilous fauna includes some macroinvertebrates as well, and they can exhibit distinctive adaptations, often associated with respiration.

- In a sandy bottom stream in Virginia, meiofaunal densities (rotifers, oligochaetes, early instar chironomids, nematodes and copepods) averaged over 2,000 per 10 sq.cm. and at times reached nearly 6,000 per 10 sq.cm.
- Densities of very small midge larvae (Chironomidae) as high as 85,000/sq.m. were recorded from shifting-sand regions within a large river of Northern Alberta.
- The dragonfly nymph *Lestinogomphus africanus*, found burrowing deep in sandy-bottom pools in India, has elongated respiratory siphons that reach above the sand surface.
- Several mayflies, including *Dolania* in the southeastern USA, have dense hairs that apparently serve to keep their bodies free of sand.
- The larva of a South American species of *Macronema*, a caddisfly in the family Hydrophychidae, builds a chimney-like intake structure into its feeding chamber in order to exclude sand grains from its food-capturing net.

Burrowing taxa can be quite specific in the particle size of substrate they inhabit. The mayflies *Ephemera danica* and *E. simulans* burrow effectively in gravel. *Hexagenia limbata* cannot, but does well in fine sediments. Substrates composed of finer sediments generally are low in oxygen, and *H. limbata* meets this challenge by beating its gills to create a current through their U-shaped burrows.

Xylophilous or wood-dwelling taxa illustrate that woody debris constitutes yet another substrate category of lotic environments. Wood appears to be substrate more often than it is food, although some taxa, such as the beetle *Lara avara*, feed mainly on wood and many taxa obtain some nourishment from a mix of algae, microbes and decomposing wood fibre found on wood surfaces. Woody material is an important substrate in the headwater streams of forested areas, where 25-50% of the streambed is wood and wood-created habitat. It is also very important in lowland rivers where 70% or more of the bed is composed of sand, and wood provides the only stable substrate. In lowland streams that flood nearby forests, wood is a significant component of habitat available seasonally.

Phytophilous are the invertebrate taxa that live in association with aquatic plants. Many species utilize moss, and a few are found primarily in moss.

- Examples include the free-living caddis larva *Rhyacophila verrula*, and a number of mayflies with backward-directed dorsal spines, evidently to prevent entanglement.
- A substantial number of invertebrates are also found on the surface of submersed macrophytes.

The influence of substrate on organism abundance and diversity

In general, diversity and abundance increase with substrate stability and the presence of organic detritus. Other factors which appear to play a role include the mean particle size of mineral substrates, the variety of sizes, and surface texture, although it is difficult to generalise about their effects.

Table I-2: Abundance and species diversity of aquatic insects found in five habitats (characterised mainly by their substrates) in a Quebec stream. Values are annual averages.

Habitat	Abundance (no./sq.m.)	No. of species	Diversity =(S-1)/$\log_e$N
Sand	920	61	1.96
Gravel	1,300	82	2.31
Cobbles and pebbles	2,130	76	2.02
Leaves	3,480	92	2.40
Detritus (finely divided leaf material in pools and along stream margins)	5,680	66	1.73

In general, diversity and abundance of benthic invertebrates increase with median particle size (MPS), and some evidence suggests that diversity declines with stones at or above the size of cobbles. The amount of detritus trapped within the crevices is also likely to be important, and substrates of intermediate size are superior in this regard. A variable mix of substrates ought to accommodate more taxa and individuals, and particle size variance usually increases with MPS. Evidently the amount and type of detritus contained within the sediments is sufficiently dependent on the size and mix of the mineral substrates that it is unwise to measure substrate preference without concurrent study of trapped organic matter.

Silt, in small amounts, benefits at least some taxa. When silt was added to larger mineral substrates in laboratory preference tests, silt enhanced the preference for coarse substrates in the mayfly *Caenis latipennis* and the stonefly *Perlesta placida*. In large amounts, silt generally is detrimental to macroinvertebrates. It causes scour during high flow, fills interstices thus reducing habitat space and the exchange of gases and water, and reduces the algal and microbial food supply.

Substrate texture refers to surface properties such as hardness, roughness, and perhaps ease of burrowing, along with other aspects. Researchers have found that more invertebrates colonized granite and sandstone, which have comparatively rough surfaces, than the smoother quartzite. Other experiments also found diversity and abundance to be greater on irregular than on smooth substrates of the same overall size.

International Code of Zoological Nomenclature (some of the following endings are customary but not cited in the code):

Kingdom
Phylum
Class
Cohort
Order
Suborder
Superfamily (-oidea)
Family (-idae)
Subfamily (-inae)
Tribe (-ini)
Subtribe (-ina)
Genus
Species

Insects of Inland Waters: Intro

Insects constitute a very important element of the metazoan life in lakes and other inland aquatic habitats. Most are benthic or nektobenthic; a very few are planktonic. Most are rheophili but a few among the minority of lacustrine species may occur in immense numbers.

Most insects, supposedly on the order of 500,000 species, in both immature and adult stages live in some sort of terrestrial habitat. The total number of aquatic insect species is estimated at over 40,000. Two patterns of life history are; those in which all stages are passed in water (e.g. Hemiptera, Coleoptera) number about 9000, while those in which the adult emerges as a terrestrial or aerial being number over 30,000 species, mostly in the Diptera. The fourth possible logical set, namely more or less terrestrial but usually hygrophil larvae with aquatic adults, is limited as far as is known to the beetles of the families Hydraenidae and Dryopidae (ca. 100 species of Coleoptera).

Classification

Within the class Insecta, 10 orders of the subclass Pterygota contain species with one or more aquatic life history stages (Table-1), including some of the most primitive insects (infraclass Paleoptera, meaning “old wings” because they cannot be folded over the dorsum), and some more advanced (infraclass Neoptera, meaning “new wings” because they fold over the dorsum). Of the Neoptera, both Exopterygota (wings develop outside the body) and Endopterygota (wings develop inside the body) have aquatic representatives. The class Collembola, which contains semi-aquatic species, was formerly included in the Apterygota, a primitive subclass of Insecta. Collembolans are wingless.

Table I-3: Orders of the Class Insecta that contain aquatic or semiaquatic species, in sequence of ascending evolutionary development (Peckarsky *et al*, 1995)

Order	Life stage(s)	Infraclass	Division	Common name
Ephemeroptera[a]	Larvae	Paleoptera		Mayflies
Odonata[a]	Larvae			Dragonflies and damselflies
Plecoptera[a]	Larvae	Neoptera	Exopterygota	Stoneflies
Hemiptera[b,c]	All			True bugs
Trichoptera[a]	Larvae, pupae		Endopterygota	Caddisflies
Lepidoptera[c]	Larvae, pupae			Moths
Coleoptera[c]	Larvae[c], adults[c]			Beetles
Megaloptera[a]	Larvae			Dobsonflies, fishflies, alderflies
Neuroptera[c]	Larvae			Spongillaflies
Diptera[c]	Larvae, pupae[c]			True flies

[a] All members of the order are aquatic in the life stage given
[b] Contains semiaquatic species
[c] Some members of the order are aquatic in the life stage given

Abundance

Table I-4: Orders of aquatic insects and their abundances today (Hutchinson, 1993)

Order	Australia	North America	Europe	World
Palaeoptera				
Ephemeroptera (mayflies)	84	614	224	2,250
Odonata (dragonflies and damselflies)	302	415	127	4,875
Neoptera				
Orthopteroid orders				
Plecoptera (stoneflies)	196	578	387	2,140
Orthoptera (grasshoppers, crickets, katydids)	---	c. 20	---	c. 20
Blattodea	---	0	---	c. 10
Hemipteroid orders				
Hemiptera (bugs)	236	404	129	3,200
Endopterygote orders				
Megaloptera (hellgrammites, dobsonflies, fishflies)	26	43	6	300
Neuroptera (orlflies, lacewings)	58	6	9	c. 100
Coleoptera (beetles)	730	1655	1072	5,000
Hymenoptera (bees and wasps)	---	55	74	c. 100
Diptera (true or two-winged flies	1300	5547	4050	>20,0
[flies, mosquitoes, true midges])	478	1340	895	00
Trichoptera (caddisflies)	---	---	5	7,000
Lepidoptera (butterflies and moths)				c. 100

Table I-5: Approximate number of known species of major North American groups of freshwater benthic invertebrates (Rosenberg et al, 1997 [after Thorp and Covich, 1991])

Taxon	Common Name	No. of Known Species
Turbellaria	Flatworms	>200
Gastropoda	Snails	ca. 350
Bivalvia	Molluscs (mussels and clams)	>250
Oligochaeta	Worms	ca. 150
Hirudinea	Leeches	ca.80
Acari	Water mites	>1,500
Insecta		
Ephemeroptera	Mayflies	ca. 575
Odonata	Dragonflies and damselflies	ca. 415
Plecoptera	Stoneflies	ca. 550
Trichoptera	Caddisflies	>1,340
Heteroptera/Hemiptera	True bugs	324
Coleoptera	Beetles	>1,100
Diptera		
Chironomidae	Midge flies	>2,000
	Total	ca. 8,834

Table I-6: Approximate number of known species of water mites and aquatic insects in Canada (Rosenberg et al., 1997 [after Danks and Rosenberg, 1987])

Taxon	Common Name	No. of Known Species
Acari	Water mites	500
Ephemeroptera	Mayflies	301
Odonata	Dragonflies and damselflies	195
Plecoptera	Stoneflies	250
Hemiptera	True bugs	138
Coleoptera	Beetles	579
Diptera	True flies	
Culicidae	Mosquitoes	74
Tabanidae	Horse and deer flies	132
Ceratopogonidae	No-see-ums	180
Chironomidae	Midge flies	480
Other families		1,170
Trichoptera	Caddisflies	546
Others		90
	Total	4,635

Life history

Four general life history patterns are exhibited by the 10 insect orders and the Collembola that have aquatic or semiaquatic representatives. Collembola are *ametabolous*, meaning they do not metamorphose. Ephemeroptera, Odonata, and Plecoptera are *hemimetabolous*; they undergo incomplete metamorphosis from egg to larva (or nymph) to adult with no pupal phase. Hemiptera are *paurometabolous*; their pattern of development is similar to that of hemimetabolous insects except that the nymph and adult of the hemimetabola are very different from each other, whereas the paurometabola undergo very gradual metamorphosis, which results in strong similarity--morphologically, behaviourally, and ecologically-- between the nymphs and adults. The only differences are that wings and genitalia are developed in the adults. All the other orders are *holometabolous*, that is, they undergo complete metamorphosis from egg to larva to pupa to adult.

Respiration

Respiration is by means of tracheal gills, plastron, or siphon. Some plastron breathers (e.g., gyrinids) may also be active on the water surface.

Feeding

Four main feeding types are distinguished: (1) Those which feed on phytoplankton; (2) benthic vegetation feeders; (3) feeders on terrestrial plant products that enter the water; and (4) those which feed on arthropod fallout (i.e., airborne arthropods that reach and are trapped at the water surface). Several modes of handling food material are distinguished. There are shredders, collectors, piercers, and engulfers. Detritus feeders are very important, especially inshallow fresh water.

Table I-7: Types of nonparasitic insect nutrition

	Food Material	Comments on Feeding	
Shredders	Living plants Coarse particulate organic matter	Browsers Borers and gougers of wood may be distinguished	Herbivores Detritivores
Collectors	Fine suspended particulate organic matter and included microbiota Fine sedimented organic and included biota	Filter or suspension feeder Gatherers of sedimented matter	Detritivores Detritivores
Scrapers	Attached organisms, notably algae and detritus on surface	On plant surfaces On animal surfaces	Herbivores and Detritivores
Piercers	Some algae, for cell sap Animals, for body fluids		Herbivores Carnivores
Engulfers	Animals	Animals seized whole or masticated	Carnivores

The nutritional quality of food may be variously affected by leaching and microbial activity. The reproductive patterns of aquatic insects are comparable in complexity with those of fish.

Recognition characteristics

Table I-8: Recognition characteristics of commoner forms of aquatic insect larvae (Needham and Needham, 1962) *(single distinctive characters are printed in italics)*

Forms in which the immature stages (commonly known as nymphs) are not remarkably different from the adults. The wings develop externally and are plainly visible upon the back

Order and Common Name	Form	Tails	Gills	Other peculiarities	Habitat	Food habits
Plecoptera (Stoneflies)	depressed	2, long	many, minute, around bases of the legs		rapids	mainly carnivorous
Ephemeroptera (Mayflies)	elongate, variable	3, long: (rarely 2)	7 pairs dorsa on abdomen		all waters	mainly herbivorous
Odonata (Damselflies)	slender, tapering rearward	see gills	3 leaf-like caudal gill-plates	immense grasping lower lip	slow and stagnant	carnivorous
Odonata (Dragonflies)	stout, variable	very short, spine-like	internal gill chamber at end of body	immense grasping lower lip	slow and stagnant	carnivorous
Hemiptera (Water bugs)	short, stout, very like adults	variable	wanting	pointed beak for puncturing and sucking	all waters	carnivorous

Forms in which the immature stages differ very greatly from the adults of the same species, being more or less worm-like, having wings developed internally and not visible from the outside, and having the legs shorter, rudimentary, or even wanting (larvae proper)

Order and Common Name	Legs	Gills	Rear end of body	Other peculiarities	Habitat	Food habits
Lepidoptera (Water moths)	3 pairs of minute jointed legs followed by a number of pairs of fleshy prolegs	of numerous soft white filaments, or entirely wanting	1 pair of fleshy prolegs with numerous claws on them	claws (crotchets) on all prolegs	all waters	herbivorous
Trichoptera (Caddisfly larvae)	3 pairs rather long	variable or wanting	same as above, with paired larger hooks at tips	mostly living in portable cases	all waters	mostly herbivorous
Neuroptera (Orlflies or Lacewings)	3 pairs shorter	7 pairs of long, lateral filaments	a long tapering tail		gravelly beds	carnivorous
Megaloptera (Hellgrammites, Dobsonflies, Fishflies)	3 pairs	tufted at base of lateral filaments, or wanting	paired hooked claws		all waters	carnivorous
Coleoptera (Water beetles)	3 pairs	usually wanting	variable		slow or stagnant	carnivorous
Diptera (True flies)	wanting	usually only a bunch of retractile anal gills	see table below	head small often apparently wanting	all waters	see table below

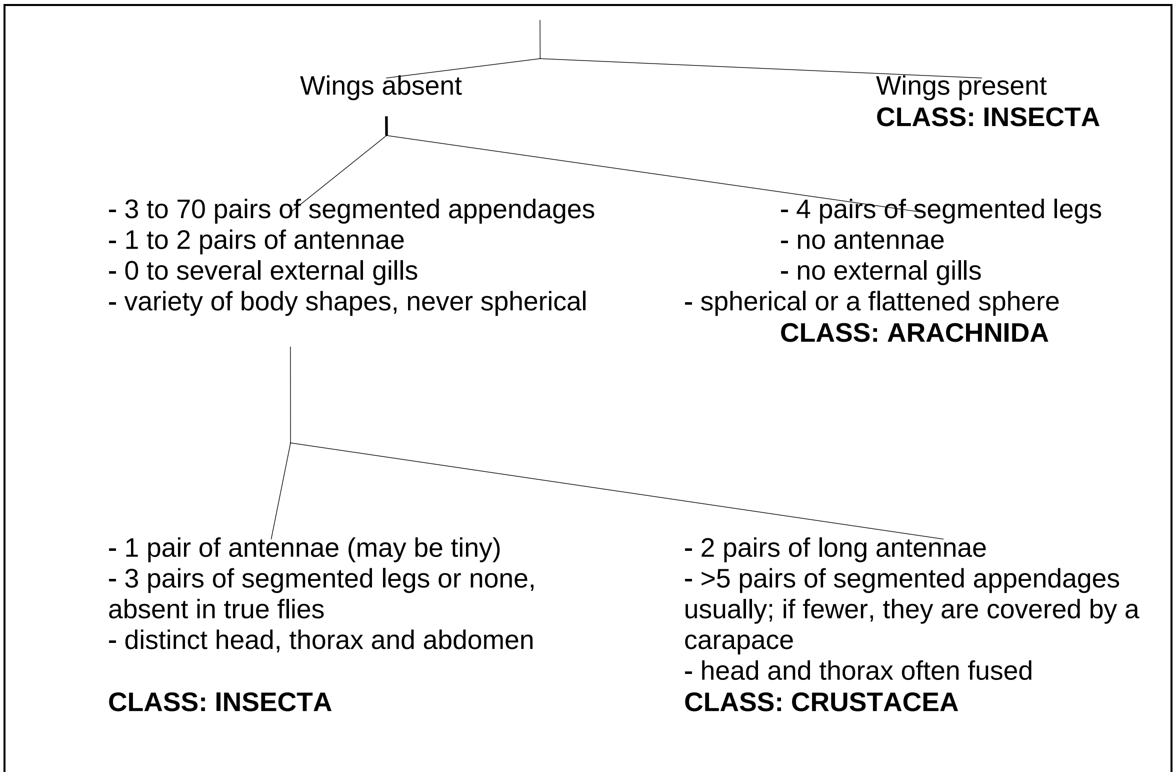
Further characters of some common dipterous larvae: these are distinguished from aquatic larvae of other groups by the absence of true legs

Family and Common name	Head	Tail	Fleshy legs, or prolegs	Other peculiarities	Habitat	Food habits
Tipulidae (Craneflies)	retracted and invisible	a respiratory disc bordered with fleshy appendages	variable		shoals	mostly herbivorous
Blepharoceridae (Net veined midges)	tapering into body	wanting	wanting	flat lobed body with row of ventral suckers	rocks in falls	diatoms, etc.
Culicidae (Mosquitoes)	free	with swimming fin of fringed hairs	wanting	swollen thoracic segments	pools at surface	herbivorous
Simuliidae (Blackflies)	free	with caudal ventral attachment disk	one beneath the mouth	"fans" on head for food gathering	rocks in rapids	herbivorous
Chironomidae (True midges)	free	tufts of hairs	1 in front 2 at rear end of body	live mostly in soft tubes	all waters	herbivorous
Stratiomyiidae (Soldier flies)	small, free	floating hairs	wanting	depressed form	still water at surface	herbivorous
Tabanidae (Horse flies)	acutely tapering	tapering body	wanting	tubercle covered spindle shaped body	beds in pools	carnivorous
Leptidae (Snipe flies)	tapering retractile	with two short tapering tails	stout paired beneath		rapids under stones	carnivorous
Syrphidae (Syrphus flies)	minute	extensile process as long as the body	wanting		shallow pools	
Muscoidae (Muscid flies)	rudimentary	truncated	usually wanting			

Select definitions

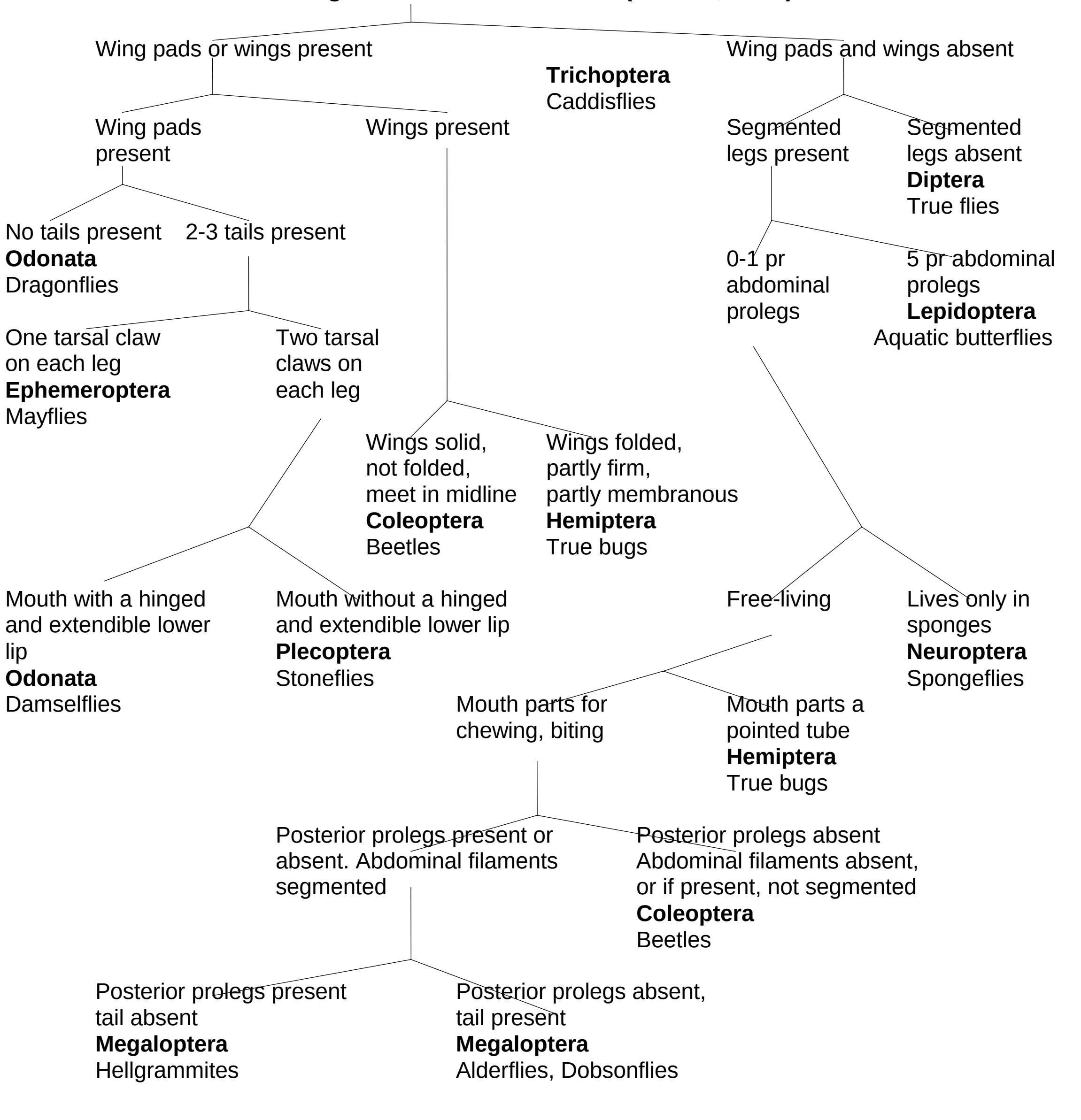
Plankton (Greek: planktos= drifting) drift passively or swim so weakly that even modest currents push them around. They are often defined as small animals and plants less than 5 mm long (0.197 in) although a few ocean forms can be bigger than humans. An object 1 mm (1,000 μm) long is about as small as the unaided human eye can comfortably see. Plankton size is usually measured in microns. 1,000 microns (μm) equals 1 mm or 0.03937 inch.
Copepods - (Latin: cope= 1 shell) a subclass of crustaceans.
Crustacea - (Latin: Crusta= crust, shell) arthropods with a chitinous exoskeleton. These are the most abundant zooplankton which eat diatoms, copepods, fish eggs, larva, and other small organisms. Large freshwater daphnia (water fleas) may be from 153-5,000 μm. A 20 or 30 power magnifier will often allow easy viewing of their insides.
Microcrustacea - Those crustaceans between 153 μm and 363 μm in length.
Zooplankton - (Greek: zoi= animal life). Includes the eggs, young, and even small adult animals of all animal species. Zooplankton are generally longer than 153 μm, up to about 5,000 μm (5 mm) or about 0.2 inches.
Macroplankton or Macroinvertebrates - (Greek: makro-= big) usually means zooplankton. Several lower size definitions exist; the Canadian E-MAN protocol indicates that these organisms are retained by mesh sizes of approx. 200-500 μm; the USEPA likes 500 μm, some US states prefer 425 μm, and much historical research used 363 μm.

Figure I-1: Phylum Arthropoda- The Arthropods (Mackie, 1998)



(Diagnostic features of 3 classes of arthropods)

Figure I-2: Class INSECTA (Mackie, 1998)



(Diagnostic features of aquatic orders of insects)

The aquatic insects may be roughly divided into those that are aquatic only before the adult emerges and those in which the adult is adapted to aquatic life.

Insects of Inland Waters: Lower Insects Aquatic Only in Their Juvenile Stages

In this category are the members of all the orders that are aquatic only in their immature stages and often have tracheal gills. They are almost always denizens of quite shallow water except for the Diptera.

Superphylum Arthropoda, Phylum Entoma, Subphylum Uniramia, Superclass Hexapoda, Class Insecta, Subclass Ptilota, Infraclass Palaeopterygota (Williams & Feltmate, 1992)

Order Ephemeroptera (Mayflies) (Chapter III)

Order Odonata (Dragonflies and Damselflies) (Chapter IV)

Superphylum Arthropoda, Phylum Entoma, Subphylum Uniramia, Superclass Hexapoda, Class Insecta, Subclass Ptilota, Infraclass Neopterygota (Williams & Feltmate, 1992)

Order Plecoptera (Stoneflies) (Chapter V)

Order Trichoptera (Caddisflies) (Chapter VII)

Order Lepidoptera (Butterflies and moths) (Chapter VIII)

Order Megaloptera (Alderflies, Dobsonflies, Fishflies) (Chapter X)

Order Neuroptera (Spongillaflies) (Chapter XI)

Order Diptera (Two-winged or “true flies”) (Flies, Mosquitoes, Midges) (Chapter XII)

Families Chironomidae (true midges)- (Chapter XIII), Culicidae (mosquitoes)- (Chapter XIV), Tipulidae (crane flies)- (Chapter XV), Simuliidae (black flies)- (Chapter XVI), and Chaoboridae (phantom midges)- (Chapter XVII)

Order Orthoptera and Grylloptera (Grasshoppers, Crickets) (Chapter XIX)

Superphylum Arthropoda, Phylum Entoma, Subphylum Uniramia, Superclass Hexapoda (Williams & Feltmate, 1992)

Class Collembola (Springtails) (ChapterXVIII)

Insects of Inland Waters: Orders Having Aquatic Adults

This group contains the Coleoptera, the fully aquatic Hemiptera, and a very few members of the orthopteroid ordes- that are aquatic as adults but very rarely descend below a few meters; no gills are ever present in the adults. A limited number of Orthoptera and Blattaria can swim, usually as a method either of avoiding predators or sometimes of crossing rivers or even arms of the sea in migration. A few Hymenoptera, mostly egg parasites, have become aquatic and may swim as adults using their wings.

Superphylum Arthropoda, Phylum Entoma, Subphylum Uniramia, Superclass Hexapoda, Class Insecta, Subclass Ptilota, Infraclass Neopterygota (Williams & Feltmate, 1992)

Order Hemiptera (Water bugs) (Chapter VI)

- **Heteroptera** and the **Homoptera** (the “true” bugs)

Order Coleoptera (Beetles) (Chapter IX)

- **Elmidae** (Riffle Beetle), **Psephenidae** (Water Penny), and **Gyrinidae** (Whirligig Beetle)

Order Hymenoptera (Aquatic wasps, etc.) (Chapter XX)

Other Benthic Macroinvertebrates

Superphylum Arthropoda, Phylum Entoma, Subphylum Chelicerata, Class Arachnida, Subclass Acari, Order Acariformes Suborder Prostigmata (= suborder Trombidiformes, = suborder Actinedida), Cohort Parasitengona (Williams & Feltmate, 1992; Peckarsky et al., 1990)

Subcohort Hydrachnidia (True water mites) (Chapter XXI)

Superphylum Arthropoda, Phylum Entoma (Williams & Feltmate, 1992; Thorp & Covich, 1991), Subphylum Crustacea (Chapter XXII)

Class Malacostraca, Subclass Eumalacostraca

Superorder Peracarida, Order Amphipoda (Scuds) and Order Isopoda (Sowbugs) (Chapter XXII)

Superorder Eucarida, Order Decapoda (Shrimps, Crabs, etc.), Order Mysidacea (Opossum Shrimps)

Class Ostracoda

- **Order Podocopa (Seed Shrimp)**

Class Branchiopoda

- **Order Anostraca (Fairy Shrimp)**
- **Order Conchostraca (Clam Shrimp)**
- **Order Cladocera (Water Fleas) (Chapter XXII)**

Class Maxillopoda, Subclass Copepoda (Copepods) (Chapter XXII)

- **Order Calanoida**
- **Order Cyclopoida**
- **Order Harpacticoida**
- **Order Caligoida**
- **Order Lernaeopodoida**

Class, Maxillopoda, Subclass Branchiura, Order Arguloida (Fish lice) (Chapter XXII)

Phylum Mollusca

Freshwater mollusks have a soft body and the adults have a hard shell composed of calcium carbonate. Both clams (including mussels) and snails (including limpets) are included in this group. The molluscan fauna of the northeastern United States contains about 135 species distributed among 13 families. The fauna can be divided into five groups: the prosobranch and pulmonate snails and the corbiculid, sphaeriid, and unionacean clams.

Class Gastropoda (Snails and Limpets) (Chapter XXIII)

Class Bivalvia (Clams and Mussels) (Chapter XXIV)

Phylum Annelida (True Worms)

Class Oligochaeta (Aquatic Earthworms) (Chapter XXV)

Class Hirudinea (Leeches and Bloodsuckers) (Chapter XXVI)

Class Polychaeta (Freshwater Tube Worms)

Phylum Platyhelminthes (The Flatworms), Class Turbellaria (Flatworms or Planarians/Dugesia) (Chapter XXVII)

Phylum Nematoda (The Roundworms)

Phylum Nematomorpha (The Horsehair Worms or Gordian Worms)

Phylum Bryozoa (The Moss Animals)

Phylum Cnidaria (The Freshwater Jellyfish and Hydras), Class Hydrozoa (Hydroids and Jellyfish)

Phylum Porifera (The freshwater sponges)

Phylum Protozoa

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