Essentials in Urban Lake Monitoring and Management

CiSTUP Technical Report: 1

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Backgroundmaterial for the workshop on Urban Lake Monitoring and Management
Date: 23-25 September 2009

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PREFACE

A three day workshop on "Urban Lake monitoring and Management" for capacity building of young researchers is being organized at C*i*STUP Conference Hall at IISc campus from 23rd to 25th September 2009. The aim of the workshop was to provide hands on training in aquatic ecological field techniques to researchers and other lake stakeholders. The workshop included training in field sampling for i) characterization of lentic waterbodies (physical, chemical and biological), ii) birds, iii) amphibians. In addition to these, a brief overview of GIS and usage of Geographical Position systems will be demonstrated. This publication includes the protocol with data format for sampling birds, amphibians, diatoms (Unicellular algae) and fishes and also water quality analysis.

We acknowledge the financial and infrastructure support from the Centre for *Infrastructure*, Sustainable Transportation and Urban Planning (C*i*STUP), IISc. We are grateful to Prof. T.G. Sitharam, Chairman and colleagues at C*i*STUP for useful suggestions during the discussions. We thank Mr.Ambareesha for the assistance in photocopying and other help in conducting the workshop.

17th September 2009

AQUATIC ECOSYSTEM - INTRODUCTION

Aquatic ecosystem is the most diverse ecosystem in the world. The first life originated in the water and first organisms were also aquatic where water was the principal external as well as internal medium for organisms. Thus water is the most vital factor for the existence of all living organisms. Water covers about 71% of the earth of which more than 95% exists in gigantic oceans. A very less amount of water is contained in the rivers (0.00015%) and lakes (0.01%), which comprise the most valuable fresh water resources. Global aquatic ecosystems fall under two broad classes defined by salinity – freshwater ecosystem and the saltwater ecosystem. Freshwater ecosystems are inland waters that have low concentrations of salts (< 500 mg/L). The salt-water ecosystem has high concentration of salt content (averaging about 3.5%).

An aquatic ecosystem (habitats and organisms) includes rivers and streams, ponds and lakes, oceans and bays, and swamps and marshes, and their associated animals. These species have evolved and adapted to watery habitats over millions of years. Aquatic habitats provide the food, water, shelter, and space essential for the survival of aquatic animals and plants. Aquatic biodiversity is the rich and harbors variety of plants and animals, from primary producer algae to tertiary consumers large fishes, intermittently occupied by zooplankton, small fishes, aquatic insects and amphibians. Many of these animals and plants species live in water; some like fish spend all their lives underwater, whereas others, like toads and frogs, may use surface waters only during the breeding season or as juveniles.

The study of freshwater habitats is known as limnology. Freshwater habitats can be further divided into two groups as lentic and lotic ecosystems based on the difference in the water residence time and the flow velocity. The water residence time in a lentic ecosystem on an average is 10 years and that of lotic ecosystem is 2 weeks. In lotic ecosystem, the average flow velocity ranges from 0.1 to 1 m/s whereas lentic ecosystems are characterized by an average flow velocity of 0.001 to 0.01 m/s (Wetzel, 2001;). The lentic habitats further differentiate from lotic habitats by having a thermal stratification with is created in a lake due to differences in densities. Water reaches a maximum density at 4^0C, a warm, lighter water floats on top of the heavier cooler water thus creating thermally stratified zones which corresponds to epilimnion, the warm layer, the hypolimnion, the colder layer separated by a barrier called thermocline. The lotic ecosystem is characterized by stream orders depending on the origin and flow and various types of stream pattern namely Dendritic, Radial, Rectangular, Centripetal, Pinnate, Trellis, Parallel, Distributory and Annular, which determines the flooding and soil erosion hazards of the region. However, the basic unity among these ecosystems is that any alteration in the catchment area of these ecosystems will affect the water quality of both lotic and lentic ecosystem. The catchment area is all land and water area, which contributes runoff to a common point, which may be a lake or a stream. The term catchment is equivalent to drainage basin and watershed (Davie, 2002; Tideman, 2000). Physical, Chemical and biological characteristics of lentic and lotic ecosystems are listed in Table 1.

The term lotic (from lavo, meaning 'to wash') represents running water, where the entire body of water moves in a definite direction. It includes spring, stream, or river viewed as an ecological unit of the biotic community and the physiochemical environment. Lotic ecosystems are characterized by the interaction between flowing water with a longitudinal gradation in temperature, organic and inorganic materials, energy, and the organisms within a stream corridor. These interactions occur over space and time.

Table 1: Physical, Chemical and Biological Characteristics of Lentic and Lotic Ecosystems

FRESHWATER HABITATS	
LENTIC ECOSYSTEM	LOTIC ECOSYSTEM
The term lentic (meaning 'to make calm') is used for still waters of lakes and ponds, which offer environmental conditions, which differ sharply with that of the streams. Light penetrates only to a certain depth depending upon turbidity. Temperature varies seasonally and with depth. Because only a small portion is in direct contact with the atmosphere and because decomposition takes place actively at the bottom, the oxygen content of lentic ecosystem is relatively low when compared to the lotic.	The term lotic (from lavo, meaning 'to wash') represents running water, where the entire body of water moves in a definite direction. These may comprise brooks, streams, rivers and springs. Brook is a term used for the small body of water while river is a term used for a relatively large natural body of water. The stream is generally designated as smaller than a river but bigger than a brook. Spring is an issue of water from the earth, which takes the form of a stream on the surface (Wetzel, 2001).

Physical characteristics

Stratification and Water movement: The presence of stratification is created by the difference in density resulting from differential heating of lake waters. In the presence of strong winds, the lake water is well mixed if the temperature is uniform at more than 4^0C. If the temperature is not uniform, due to density difference, the lake is stratified into epilimnion, hypolimnion and thermocline. According to the circulation patterns, lakes are thus classified into amictic, meromictic, holomictic, oligomictic, monomictic, dimictic and polymictic lakes. Thus the water movement is strongly influenced by wind pattern and temperature. Often, the movement of water in lake is multidirectional.	Currents and stream pattern: The velocity of current in running waters depends on the nature of their gradient and substrates. In contrast to lentic waters, wind has little influence on currents in running waters. The continual downstream movement of water, dissolved substances and suspended particles is depended primarily on the drainage basin characteristics. There are many stream patterns according to this gradient and they include dendritic, rectangular, radial, trellised, parallel, annular, deranged and pinnate. The stream pattern determines the soil erosion hazards.
Suspended solids: Materials in suspension can be divided into two types depending on origin. Autochthonous matter, which is generated from lake itself, and allochthonous matter originating from outside the lake and brought into it. The autochthonous matter is mainly derived from growth of algae and macrophytes. The allochthonous organic matter is derived from peat, fallen leaves and other decaying types of vegetation.	Suspended solids: The erosion, transportation and deposition of solid materials within a running water is closely linked to current velocity. The organic matter in suspended form is mainly from litter that is brought into the river. The other suspended matter includes inorganic matter such as silt, detritus and materials removed from the sediments, which cause turbidity to the water.
Light: The depth to which rooted macrophytes and attached algae can grow on suitable substrates is largely controlled by the spectral composition and intensity of light there. According to penetration of light, a lake can be divided into tropogenic zone and tropolytic zone. Light determines the primary productivity of lake and phytoplankton	Light, temperature and runoff: The penetration of light in running waters is strongly influenced by the turbidity. In addition to scattering by particles, there is also a loss due to absorption by water. If water is clear or hollow adequate light can reach the substrate and photosynthesis can take place. The stratification due to temperature is absent and due to more

inturn determine the depth of light penetration.	contact with air, the temperature of a stream follows that of air temperature. The temperature of lotic water is influenced by many factors and they include: Origin, depth, substrate, tributaries, exposure and time of the day. The contribution of surface and ground waters to the flow of stream varies according to a number of factors especially local geology and climate. Running water fed mainly by surface runoff have variable flow and may spate with each heavy rainfall and those fed largely by ground water are usually regular in flow.

Chemical characteristics:

Dissolved gases:	Dissolved gases:
The quantities of oxygen in a lake depend on the extent of contact between water and air, on the circulation of water and on the amounts produced and consumed within each lake. The thermal stratification produces a marked difference in oxygen levels. The oxygen in the hypolimnion is always low and the surface layer has adequate oxygen. The lake productivity also plays an important role and the balance between primary production and respiration influences the oxygen level. In the bottom sediments it may be completely anoxic and gases such H_2S and CH_4 are produced. The free carbondioxide plays an important role in the regulation of pH. In well-mixed waters, the pH and CO_2 concentrations are uniform from surface to bottom. In stratified lakes, the algae and macrophytes reduce the amount of CO_2, thus increasing the pH, whereas in deeper water, there is a tendency for increase in the carbondioxide and	Of the dissolved gases present in running waters, oxygen is the most abundant and important. The concentration of oxygen is high due to turbulence and mixing. Low concentration usually indicates organic pollution. However, there is a difference in the oxygen concentration in diurinal basis. The amount of oxygen present is related to current, the water temperature and the presence of respiring plants and animals. The carbondioxide content of the running waters tend to be scarce due to constant turbulence of water and its frequent contact with air.

calcium carbonate and reduction in pH.	
Dissolved solids: The quantity of dissolved solids is dependent on the stratification of the lake. It is also dependant on the water inlet that comes to the lake. Thus the dissolved solids content of standing water is dependent on the catchment area. The dissolved solids are also fixed by phytoplankton. Major nutrients like nitrogen, phosphorus, iron, silicon and others may be depleted and so limit production or alter the composition of algal community.	Dissolved solids: The dissolved solids present in a river may vary greatly from source to mouth, usually increasing in downstream direction. The effect of rainfall also plays an important role. The quality and quantity of solids dissolved from the ground depend on the character of soil and rocks in the substratum (Maitland, 1990).

Biological characteristics:

The biological characteristics of still water bodies may be broadly classified into – pelagic and benthic systems. Benthic system is subdivided into littoral and profundal types. The species composition of communities of all those types is greatly influenced by the nutrient status of the water concerned. The pelagic habitat is that of the open water away from the influence of shore or bottom substrate, while benthic habitat is associated with the substrate of the lake. The littoral habitat is extending from the shoreline out to the deeper water. The plankton community, phytoplankton and zooplankton, occupy the regions of high light intensities namely on the surface layer of pelagic zone and the littoral zone. Some of the zooplankton members also inhabit the benthic zone feeding on detritus and sinking phytoplankton. Fishes occupy the littoral, pelagic and occasionally profundal zones, when the dissolved oxygen content in the lake is high. Macroinvertebrates are confined to	In the lotic habitats, the water moves continually in one direction. The current is more pronounced at the surface than in the bottom substrate. Hence, the bottom substrate conditions are similar to lentic habitats. Often the plankton community is at the mercy of currents. In riffles and pools, the plankton exhibit the characteristics similar to lentic ecosystem. The fishes are highly adopted to resist water currents. Since the dissolved oxygen levels are high throughout the water column due to water turbulence, the fishes are distributed from surface to bottom substrate and often among the rocks (Moss, 1998).

the benthic zone.	

As in the terrestrial ecosystem, the main source of energy in aquatic ecosystem is the solar energy. The transfer of solar energy from one community to another takes a specific path. The solar energy is trapped by the phytoplankton, the producers which inturn are consumed by the zooplankton, which are primary consumers and secondary consumers are the macroinvertebrates and planktivorous fish, which are consumed by large fishes. At each step of energy transfer, a proportion of energy is lost as heat. Thus the transfer of food energy from the source (phytoplankton) through a series of organisms that consume and are consumed is called as food chain. Food chains are of two basic types, the grazing food chain, which starts from the phytoplankton to the herbivores and carnivores and the detritus food chain that goes from non-living organic matter into microorganisms and then to detritus feeding organisms and their predators. These food chains are interconnected and often this interlinking pattern is called the food web (Figure 1).

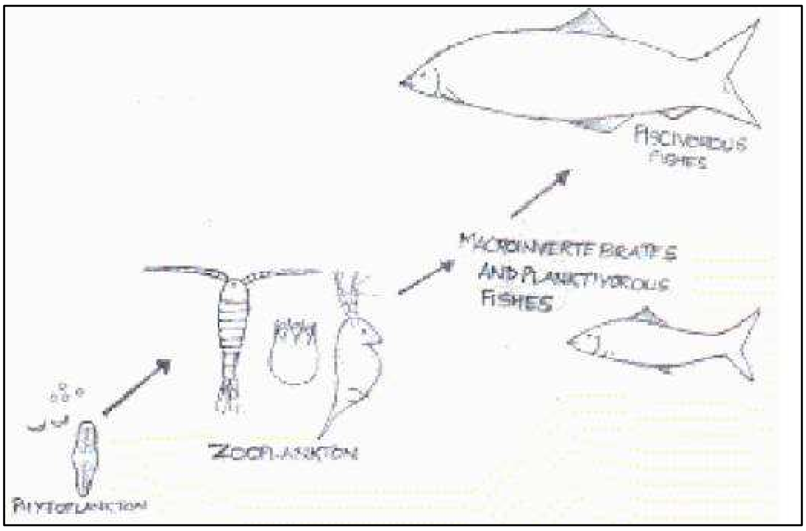


Figure 1: Food web in an aquatic ecosystem

PLANKTON IN AQUATIC FOOD CHAIN

The term "Plankton" refers to those minute aquatic forms which are non motile or insufficiently motile to overcome the transport by currents and living suspended in the open or pelagic water. The planktonic plants are called phytoplankton and planktonic animals are called zooplankton (APHA, 1985). Phytoplankton are the base of aquatic food webs and energy production is linked to phytoplankton primary production. Excessive nutrient and organic inputs from human activities in lakes and their watersheds lead to eutrophication, characterized by increases in phytoplankton biomass, nuisance algal blooms, loss of water clarity from increased primary production and loss of oxygen in bottom waters. The freshwater phytoplankton of the Indian region belongs to the following classes:

- **Cyanophyceae:** Cyanophyceae comprises of prokaryotic organisms popularly known as blue-green algae. They are like gram-negative bacteria and due to the nature of the cell wall, cell structure and capacity to fix atmospheric nitrogen these are considered as bacteria and named cyanobacteria. However, they possess the oxygen evolving photosynthetic system, chlorophyll a accessory pigments and thallus organizations resembling other algae. They occur abundantly in freshwater habitats along with other groups of algae. Cyanophyceae members are broadly classified into coccoid and filamentous forms. The coccoid forms range from single individual cell to aggregates of unicells into groups or in regular or irregular colonies and pseudoparenchymatous conditions. The filament forms range from simple uniseriate filaments to heterotrichous filaments, which may be differentiated into heterocysts and akinetes (spores). These are truly cosmopolitan organisms occurring in habitats of extreme conditions of light, pH and nutritional resources. They abound various types of natural and artificial aquatic ecosystems.
- **Chlorophyceae:** Chlorophyceae (green algae) constitutes one of the major groups of algae occurring in freshwater habitats. The cells are typically green in colour due to the presence of chlorophyll *a* and *b.* The cells contain chloroplast of various shapes, which are dispersed differently in each group of organisms. The chloroplast also contains pyrenoids. In majority of the organisms there is a single nucleus but some genera are multinucleate. Flagellated cells are common either in the vegetative phase or reproductive units. Chlorophyceae is generally divided into several orders based on the diversity of the thallus.
- **Euglenophyceae:** The members are single cells, motile found swimming with the help of usually one prominent flagellum and in some cases with two flagella. In the anterior portion a gullet is visible and there are many chloroplasts in the autotrophic forms and the chloroplasts vary in shape. Euglenoid cells are covered by a proteinaceous pellicle and at times help the organisms attain various shapes. These are widely distributed in all types of water bodies specifically in organically rich aquatic ecosystems.

- **Bacillariophyceae:** The members belonging to this class are popularly known as diatoms. All are basically unicellular, in some cases become pseudofilamentous or aggregated into colonies. The cell wall of diatoms is impregnated with silica and several diatoms have been well preserved as microfossils. The diatom cell is also called as frustule and the classification of diatoms is based on the pattern of ornamentation on the wall of the frustule. The cells have either bilateral or radial symmetry. The frustules are composed of two halves, epitheca and hypotheca and connecting girdle bands. The valve surfaces have several types of markings. Radial symmetry forms are grouped as Centrales and bilaterally symmetric ones are Pennales.
- **Dinophyceae:** The members are unicellular motile cells with two flagella one located in the transversely aligned groove or furrow and other in a longitudinally arranged furrow. One is considered to propel the cell and the other is called the trailing flagellum. The cells while moving forward also get rotated by the flagellar action. The motile cells have a thick pellicle instead of a cell wall, which sometimes becomes very thick, and called theca. Certain genera have thecal plates on their outer covering and called as unarmoured dinoflagellates, while others have horny projections and called armoured dinoflagellates (Anand, 1998).

Zooplankton are the central trophic link between primary producers and higher trophic levels. The freshwater zooplankton comprise of Protozoa, Rotifers, Cladocerans, Copepods and Ostracods. Most of them depend to a large extent, on various bacterioplankton and phytoplankton for food. Many of the larger forms feed on smaller zooplankton, forming secondary consumers. Some of them are detritivore feeders, browsing and feeding on the substrate attached organic matter, phytoplankton or concentrating on the freely suspended organic matter particles or those lying on the bottom sediment. Many of these organisms are also fish food organisms and are consumed by the other aquatic macrofauna. The freshwater zooplankton is mainly constituted of five groups:

- **Protozoans (first animals):** A very diverse group of unicellular organisms are found in this major zooplanktonic community. Most of the protozoans are usually not sampled due to their minute size. Planktonic protozoans are limited to ciliates and flagellates. Among the unicellular protozoa, the heterotrophic nanoflagellates are the major consumers of free-living bacteria and other smaller heterotrophic nanoflagellates. The abundant heterotrophic nanoflagellates (10^5 to 10^8/L in highly eutrophic lentic ecosystems) range in size from about 1.0 to about 20µm. They include non-pigmented species that structurally have very closely related pigmented species in the phytoplankton. The ciliates are larger in size (8µm to 300µm) but are less abundant (10^2 to 10^4/L). While the smallest planktonic ciliates feed on the picoplankton, the larger ciliates feed on the heterotrophic nanoflagellates and small nanophytoplankton. Among the ciliates, those containing captured chloroplasts from the ingested algae or those containing more permanent symbiotic green algae (zoochlorellae) are common. Among the protozoans are two orders of amoebae that are primarily associated with the sediments and littoral aquatic vegetation and large numbers of meroplanktonic species (Edmondson, 1959; Battish, 1992).

- **Rotifers (wheel bearers):** Rotifers, typically an order of magnitude less abundant the protozoans, are the most important soft-bodied metazoans (invertebrates) among the plankton. Their name comes from the apparently rotating wheels of cilia, known as corona, used for locomotion and sweeping food particles towards the mouth. The mouth is generally anterior and the digestive tract contains a set of jaws (trophi) to grasp the food particles and crush them. Relatively few (about 100) ubiquitous rotifer species are planktonic and a much larger number (about 300) are sessile and are associated with sediments and the vegetation of the littoral zones. Planktonic rotifers have a very short life cycle under favourable conditions of temperature, food and photoperiod. Since the rotifers have short reproductive stages they increase in abundance rapidly under favourable environmental conditions (Dhanapathi, 2000).

- **Crustaceans:** This group comprises of members all belonging to the well-known Phylum Arthropoda. This is the largest phylum in terms of number of species and among zooplankton holds the highest position both in terms of systematics and as secondary consumers in the food chain. In healthy habitats wherein external influences of pollution are absent or at least low, members of this group constitute a sizeable population.

- **Cladocerans (Branched horns):** Cladocerans are a crucial group among zooplankton and form the most useful and nutritive group of crustaceans for higher members of fishes in the food chain. Cladocerans are normally covered by the chitinous covering termed as the carapace. The two large second antennae are responsible for giving the cladocerans their common name, water fleas and are used for rowing through the water. Cladocerans are filter feeders as they filter the water to trap the organisms in it. Cladocerans are highly sensitive against even low concentrations of pollutants. The food source of this group is smaller zooplankton, bacterioplankton and algae (Murugan et al, 1998).

- **Copepods (Oar foot):** The copepods comprise of calanoids, cyclopoids and harpacticoids. The copepods also form important organisms for fish and are influenced by negative environmental factors as caused by excessive human interference in water bodies but to a lesser extent than the cladocerans. Copepods are much more hardier and strongly motile than all other zooplankton with their tougher exoskeleton and longer and stronger appendages. They have long developmental time and a complex life history with early larval stages difficult to distinguish. They are almost wholly carnivorous on the smaller zooplankton for their food needs. Among the three orders of copepods, cyclopoid copepods are generally predatory on (carnivorous) on other zooplankton, and fish larvae. The cyclopoid copepods also feed on algae, bacteria and detritus. The second groups of copepods, calanoid copepods change their diet with age, sex, season, and food availability. The calanoid copepods are omnivorous feeding on ciliates, rotifers, algae, bacteria and detritus. The third group harpacticoid copepods are primarily benthic. Copepods, in general can withstand harsher environmental conditions as compared to cladocera.

- **Ostracods (Shell like):** The Ostracods are bivalved organisms and belong to phylum Arthropoda. They mainly inhabit the lake bottom and among macrophytes and feed on detritus and dead plankton. Ostracods are in turn consumed by fishes and benthic macroinvertebrates (Chakrapani, 1996).

Basic differences among Rotifera, Cladocera, Copepoda and Ostracoda are given in Table 2. Protozoa is not included since there is a vast difference between protozoa and other groups.

Table 2: Basic taxonomic differences among the freshwater Zooplankton community

ROTIFERA	CLADOCERA	COPEPODA	OSTRACODA
• Body divided into head, trunk and abdomen. • Locomotion by the means of coronal cilia, which gives them the name wheel bearers. • With protonephridia for osmoregulation. • Reproduction by parthenogenesis • No special organs for circulatory or gas exchange system.	• A pair of biramous antennae used for swimming gives them the name cladocera. • Carapace large bivalved enclosing the trunk but not the head. • Eyes sessile, ocellus present. • Trunk limbs 4 to 6 pairs.	• No carapace • Antennules uniramous. • The body has nine appendages usually. • Six pairs of biramous limbs. • Presence of caudal rami.	• Carapace forms a bivalved shell. • Antennules uniramous. • Not more than five pairs of limbs behind mandible. • One to three pairs of limbs before mandibles.

TROPHIC INTERACTIONS IN AQUATIC FOOD CHAIN

In most aquatic food chains, the community interactions are often controlled by abiotic factors or predation at higher levels of food chain. The control of primary production by abiotic factors such as nutrients is called “bottom-up control”. The control of primary production by the upper levels of food chain is referred to as “top-down control”. The idea that predation at upper levels of food chain can have cascading effect down through the food chain is called the “trophic cascade” (Dodds, 2002). The bottom-up hypothesis requires that the biomass of all trophic levels is positively correlated and depend on fertility (limiting resources) of the habitat. The schematic representation of bottom-up control is given in figure 2.

More available nutrients ⟶ more algae ⟶ more zooplankton ⟶ more planktivorous fish ⟶ more piscivorous fish.

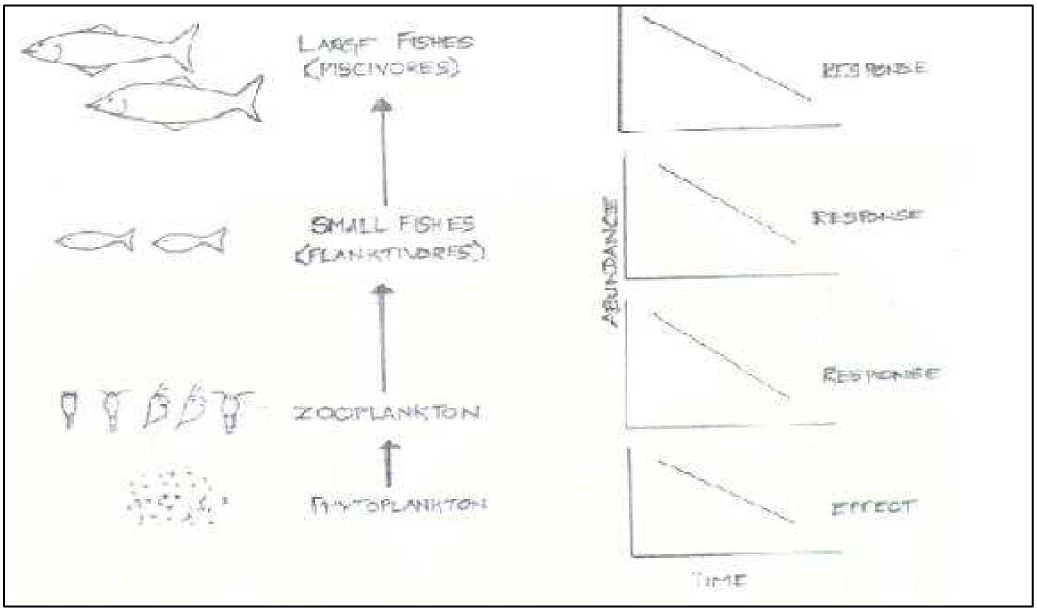


Figure 2: Bottom up control in the aquatic ecosystem

The top-down hypothesis predicts, however, that the adjacent trophic levels will be negatively correlated. The schematic representation of top-down control is given figure 3.

More piscivorous fish ⟶ fewer planktivorous fish ⟶ more zooplankton ⟶ fewer phytoplankton ⟶ more available nutrients

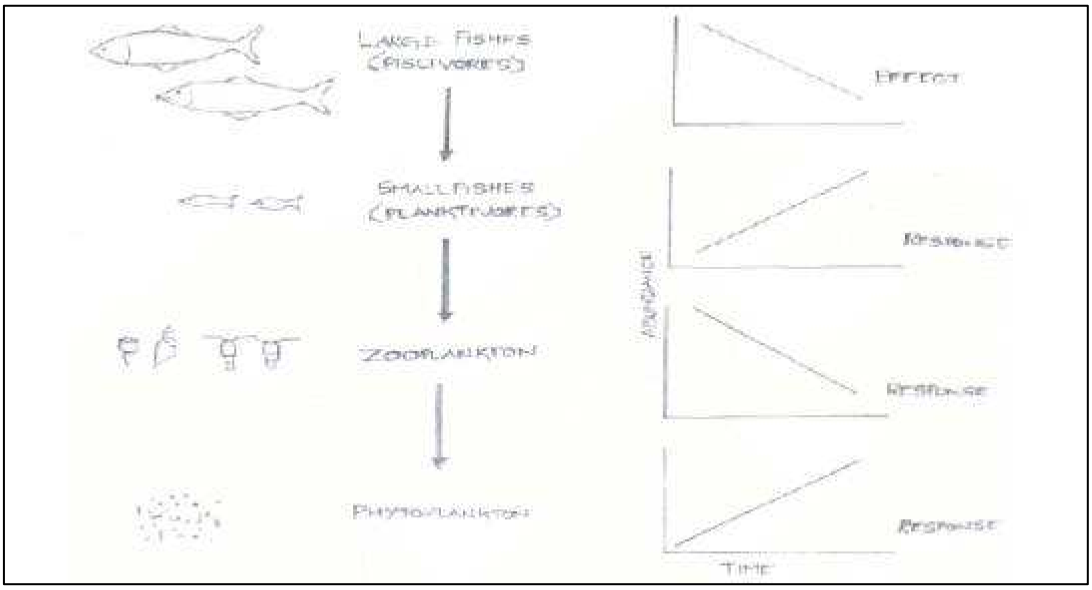


Figure 3: Top down control in the aquatic ecosystem

Any disturbance to the water body due to over-exploitation of fish resources or due to various anthropogenic activities leads to deterioration of the water quality and hence will have an impact on the communities in the aquatic ecosystem (Lampert and Sommer, 1997). Bio-monitoring the water bodies at regular intervals does help to understand the implications of water quality on trophic structure and vice versa.

MONITORING OF WATER BODIES

With the advent of industrialization and increasing populations, the range of requirements for water has increased together with greater demands for higher water quality. Industrialization coupled with intensive agriculture in early 1980's to meet the growing demand of ever increasing populations, the range of requirements for water has increased manifolds. In addition to many intentional water uses, there are several human activities, which have indirect and undesirable, if not devastating, effects on the aquatic environment, which include uncontrolled and unplanned land use for urbanization or deforestation, accidental (unauthorized) release of chemical substances, discharge of untreated waste or leaching of noxious liquids form solid waste deposits. Similarly, uncontrolled and excessive use of fertilizers and pesticides for agricultural purposes has long-term effects on the ground and surface water resources.

In order to protect the water resources from continuing deterioration, and to supply higher quality water for human consumption, there is a need to assess the quality of water. The main reason for assessment of quality of aquatic environment has been to verify whether the observed water quality is suitable for intended use. The overall process of evaluation of physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly the uses which may affect human health and health of the aquatic ecosystem itself is termed as water quality assessment.

Water quality assessment includes the use of monitoring to define the condition of water, to provide the basis of detecting trends and to provide the information enabling the establishment of cause-effect relationship. Thus the water quality assessment program aims,

- To provide water quality details to decision makers and public on the quality of freshwater relative to human and aquatic ecosystem health and specifically,
- To define the status of water quality
- To identify and quantify trends in water quality
- To define the cause of observed conditions and trends
- To identify the types of water quality problems that occurs in specific geographic areas.
- To provide the accumulated information and assessment in a form that resource management and regulatory agencies can use to evaluate alternatives and make necessary decisions.

To begin the monitoring of freshwater resources, there is always a need for preliminary survey. A survey of a water body is done with specific objectives. A finite duration, intensive program to measure and observe the quality of the aquatic environment for a specific purpose is termed as a survey. A physicochemical approach to monitor water pollution gives the causes and levels of pollutants in the water body. Biological approach highlights the impact of pollution on the aquatic biota and on the overall status of the water body. However, a combined approach depicts a comprehensive picture of the water quality and aquatic biota enabling effective interpretation and proper decision-making.

The root of the word monitoring means, "to warn" and one essential purpose of monitoring is to raise a warning flag that the current course of action is not working. The essential purpose of monitoring is to raise a warning flag that the current course of action is not working. Thus, monitoring is defined as the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a specific objective (Elzinga *et al*., 2001). Biomonitoring involves the use of biotic components of an ecosystem to assess periodic changes in the environmental quality of the ecosystem. A variety of effects can be produced on aquatic organisms by the presence of harmful substances, the changes in the aquatic environment that result from them, or by the physical alteration of the habitat. Some of the common effects on the aquatic organisms are:

- Changes in the species composition of the aquatic communities,
- Changes in the dominant groups of organisms in a habitat,

- Impoverishment of species,
- High mortality of sensitive life stages (larvae and eggs),
- Mortality in the whole population,
- Changes in the behaviour of the organisms,
- Changes in the physiological metabolism, and
- Histological changes and morphological deformities.

As all of these effects are produced by a change in the quality of aquatic environment, they can be incorporated into biological methods of monitoring and assessment to provide information on a diverse range of water quality issues and problems, such as:

- The general effects of anthropogenic activities on ecosystems,
- The presence and effects of common pollution issues (eutrophication, toxic organic chemicals, toxic metals, industrial inputs),
- Common features of deleterious changes in the aquatic communities,
- Pollutant transformation in water and in the organisms,
- Long-term effect of substances in the water bodies (biomagnification and bioaccumulation),
- Condition resulting from waste disposal and of the character and dispersion of wastewaters,
- The dispersion of atmospheric pollution (acidification arising from wet and dry deposition of acid-forming compounds),
- The effects of hydrological control regimes (impoundments),
- The effectiveness of environmental protection measures, and
- The toxicity of substances under controlled, defined laboratory conditions, (i.e. acute or chronic toxicity, genotoxicity or mutagenicity.

Biological methods can also be useful for:

- Providing systematic information on water quality (as indicated by aquatic communities),
- Managing fishery resources,
- Defining clean waters by means of biological standards or standardized methods,
- Providing an earlier warning mechanism,
- Assessing water quality with respect to ecological, economic and political implications.

METHODS IN BIOLOGICAL MONITORING

Biological monitoring (or bio monitoring) of water and water bodies is based on five main approaches.

i. Ecological methods:
   - Analysis of biological communities of the water body;
   - Analysis of biological communities on artificial substrates placed in a water body; and
   - Presence or absence of specific species.

ii. Physiological and biochemical methods:
   - Oxygen production and consumption, stimulation or inhibition,
   - Respiration and growth of organisms suspended in water, and
   - Studies of the effects on enzymes.

iii. The use of organisms in controlled environments:
   - Assessment of toxic effects of samples on organisms under defined laboratory conditions (toxicity tests or bioassays), and
   - Assessing the effects on defined organisms of waters in situ or on site, under controlled situations.

iv. Biological accumulation:
   - Studies of the bioaccumulation of substances by organisms living in the environment, and
   - Studies of the bioaccumulation of substances by organisms deliberately exposed in the environment.

v. Histological and morphological methods:
   - Observation of histological; and morphological changes, and
   - Embryological development or early life stage tests.

ECOLOGICAL METHODS IN BIOMONITORING OF AQUATIC ECOSYSTEM

All environmental components and processes within the hydrological cycle depend on and are regulated by the structural, functional and compositional aspects of biodiversity. Environmental components and processes also respond to an impact on society's decisions and actions. Historically, research has been narrowly focused on separate environmental components within the hydrological cycle rather than the processes and relationships between them. This thrust focuses on understanding these relationship leads to monitoring aquatic ecosystems by ecological methods. The use of ecological methods in biomonitoring of aquatic ecosystem is becoming increasingly important due to the deterioration of water bodies through anthropogenic activities. The quality of water affects the species composition, abundance, productivity and physiological conditions of the aquatic community. The structure and composition of these aquatic communities is an indicator of water quality. Some of the advantages of using ecological methods are as follows:

- Biological communities reflect overall ecological integrity (i.e., physical, chemical and biological integrity). The monitoring of a single representative community for e.g., Zooplankton, among various communities in aquatic ecosystem gives a fair idea of the status of all the communities because of the interrelationship they share in food webs. Therefore, biomonitoring results in directly assessing the status of the entire water body.
- Biological communities integrate the effect of different pollutant stressors and thus provide a holistic measure of their impact.
- Routine monitoring of the biological communities can be relatively inexpensive particularly when compared to the cost of assessing toxic pollutants either chemically or with toxicity studies.
- Where criteria for specific ambient impact do not exist (e.g., non-point source impacts that degrade habitats), biological communities may be the only practical means of evaluation (Ramachandra, T.V. *et al*., 2002).

The ecological methods useful in biomonitoring include the collection, identification and counting of bioindicator organisms, biomass measurements, measurements of metabolic activity rates, and investigation on the bioaccumulation of pollutants. The communities that are useful in biomonitoring are plankton, periphyton, macrophytes, fishes, macroinvertebrates, amphibians, aquatic reptiles, birds and mammals. These organisms reflect a certain range of physical and chemical conditions. Some organisms can survive a wide range of conditions and are tolerant to pollution. Others are very sensitive to changes in conditions and are intolerant to pollution. These organisms are called bioindicators.

STEPS IN BIOMONITORING USING ECOLOGICAL METHODS

The first step in a biomonitoring programme is setting one's objectives because the methods of monitoring vary according to the objectives. In order to biomonitor a water body the following steps have to be considered.

- Selection of a biological community, which gives an immediate and holistic picture of slightest of impacts caused by different pollution stressors.
- To know about the species and ecology of the biological community selected.
- To select an appropriate sampling method to represent whole of the population (Sutherland, 1997)

PHYTOPLANKTON FOR BIOMONITORING OF WATER BODIES

Phytoplankton forms the very basis of aquatic food chain. The water quality especially the nutrients influence its population. Phytoplankton survey thus indicates the trophic status and the presence of organic population in the ecosystem. Nutrients enrichment in water bodies is known as eutrophication, which is a common phenomenon with algal blooms.

PHYTOPLANKTON ANALYSIS

Phytoplankton collection: Water was collected from the surface with minimal disturbance and filtered in a No. 25 bolting silk cloth net of mesh size 63 µm and 30 cm diameter. The final volume of the filtered sample was 125ml. The sample was transferred to another 125ml plastic bottle and labeled mentioning the time, date and place of sampling.

Preservation: The samples collected in 125ml plastic bottles were preserved by adding 5ml of 4% formalin.

Concentration: The preserved samples were kept for 24 hours undisturbed to allow the sedimentation of plankton suspended in the water. After 24 hours, the supernatant was discarded carefully without disturbing the sediments and the final volume of concentrated sample was 50ml.

Qualitative and quantitative analysis of phytoplankton: The qualitative and quantitative analysis of phytoplankton was done by Lackey's drop method. In Lackey's drop method, the coverslip was placed over a drop of water in the slide and whole of the coverslip was examined by parallel overlapping strips to count all the organisms in the drop. About 20 strips were examined in each drop. Number of subsamples to be taken was dependent on the examining 2 to 3 successive subsamples without any addition of unencountered species when compared to the already examined subsamples in the same sample (APHA, 1985).

The species belonging to each group were noted down and number of individuals in each species was counted. The number of organisms was expressed in Total organisms per liter using the formula,

CALCULATION:

<u>For Lackey's drop method:</u>

$$\text{Organisms per liter (N)} = \frac{R * A_t * 10^3}{A_s * S * V}$$

Where R = Number of organisms counted per subsample

A_t = Area of coverslip, mm^2

A_S = Area of one strip, mm^2

S = Number of strips counted, and

V = Volume of sample under the coverslip, ml

Therefore, Total organisms per liter = N * 1/C

$$\text{Where concentration factor, } C = \frac{\text{Volume of original sample (ml)}}{\text{Volume of concentrated sample (ml)}}$$

DIATOMS

Diatoms constitute a fundamental link between primary (autotrophic) and secondary (heterotrophic) production and form a vital component of aquatic ecosystems. Features such as siliceous cell wall (frustules), possession of unique photosynthetic pigments and specific storage products make them unique amongst the algae. The use of diatom tolerance values in water quality monitoring traces its history to Europe, where it has been used for a century and considered important for biomonitoring across the globe. Diatoms are frequently used as bio-indicators, and if they are not investigated live, they may be perceived simply as "glass boxes" used to give information about water quality. Diatoms have been shown to be reliable indicators of specific water quality problems such as organic pollution, eutrophication, acidification and metal pollution.

COLLECTION METHODS:

EPILITHIC DIATOMS: At least five cobbles (> 64, 256 mm) or small boulders (> 256 mm) should be collected without bias to one side of the river or the other from areas which have an obvious diatom film (detected by either its brown colour or slimy texture). Stones should be selected, as far as possible, from unshaded areas within the main flow and free from obvious filamentous algae or siltation. Any loosely attached surface contamination on the biofilm should be removed by gentle agitation in the stream water. The stones should be placed in a tray, along with approximately 50 ml of river water. Wash a stiff toothbrush in clean river water and rub it on waders or a similar surface in order to remove any diatom contamination from previous samples. Brush the upper surface of the stone vigorously to remove the diatom film, rinsing the toothbrush periodically in the water in order to transfer the diatoms. Replace the stone in the stream, and repeat the process for the other replicate stones. Transfer the water (which should now be brown and turbid due to the presence of diatoms) from the tray into the sample bottle. All sample containers must be labeled. Preserve the sample with Ethanol.

EPIPHYTIC DIATOMS: Replicate samples from five different plants of the same species should be taken. Samples of plants growing in the main flow of the river should be placed into a plastic bag along with about 50 ml of stream water. Each replicate should consist of a single stem plus associated branches of the plant from the lowest healthy leaves to the tip. Diatom epiphytes should be present as a brown floc or film associated with the macrophytes. The plants should be shaken vigorously in the plastic bag in order to dislodge attached diatoms. The result should be a brown suspension that can then be poured into a bottle. All sample containers must be labeled. Preserve the sample with Ethanol.

DATA SHEET FOR DIATOM SAMPLING

SITE DETAILS

River: ___________Site: ______________Date & Time: ______________________

Lab Code: __________Habitat: ____________Sample collected by: __________

Co-ordinates______________________ Elevation: _________________________

PHYSICAL RECORDS

Width________________Depth:____________________velocity:______________

SUBSTRATE & COVER (record estimated percentage)

Bedrock________ Boulders/cobbles_________ Pebbles/gravel_______ Sand silt/clay________

Peat ____________

Filamentous Algae: ____

Macrophytes____

SHADING (record estimated percentage)

Notes on Shading at the place of sample: _______________________________

____

WATER QUALITY:

pH: ____

Electrical Conductivity: ____

Water Temperature: ____

Dissolved Oxygen: (Burette Reading) ____________________________________

Turbidity: ____

Chlorides: (Burette Reading) ____

Alkalinity: (Burette Reading) ____

NB It is important to include an immovable structure in a photograph as a reference for future comparison e.g. a bridge

ZOOPLANKTON FOR BIOMONITORING OF WATER BODIES

Plankton has been used recently as an indicator to observe and understand changes in the ecosystem because it seems to be strongly influenced by climatic features (Beaugrand et al., 2000). The variability observed in the distribution of zooplankton is due to abiotic parameters (e.g. climatic or hydrological parameters: temperature, salinity, stratification, advection), to biotic parameters (e.g. food limitation, predation, competition) or to a combination of both (Beyst et al., 2001). Although zooplankton exists under a wide range of environmental conditions, yet many species are limited by temperature, dissolved oxygen, salinity and other physicochemical factors. The use of zooplankton for environmental characterization of lakes is potentially advantageous. Zooplankton species tend to have wide geographic distributions (Shurin et al., 2000), so local differences in community occurrence do not generally result from dispersal limitation. Trophic roles (predators, herbivores, and omnivores) are well represented in the zooplankton, and individual generation times are short enough that they quickly respond to acute stress but long enough for them to integrate the effects of chronic problems, making them favorable candidates for a community indicator of ecosystem health (Cairns et al., 1993). Finally, zooplankton are relatively easy to identify, so they are particularly useful when community sensitivity can be detected based on zooplankton body sizes or gross taxonomic classifications.

ZOOPLANKTON ANALYSIS

Zooplankton collection: Sample collected from the surface of the lake with minimal disturbance and filtered in a No. 25 bolting silk cloth net of mesh size 63 μm and 30 cm diameter. The final volume of the filtered sample was 125ml, which was transferred to another 125ml plastic bottle and labeled mentioning the time, date and place of sampling.

Preservation: The samples collected in 125ml plastic bottles were preserved by adding 2ml of 4% formalin.

Concentration: The preserved samples were kept for 24 hours undisturbed to allow the sedimentation of plankton suspended in the water. After 24 hours, the supernatant was discarded carefully without disturbing the sediments and the final volume of concentrated sample was 50ml.

Qualitative and quantitative analysis of zooplankton: The qualitative and quantitative analysis of zooplankton was done by using Sedgwick-Rafter cell or by Lackey's drop method. Six strips were counted in Sedgwick-Rafter cell with dimensions of 50mm * 20mm * 1mm. In Lackey's drop method, the coverslip was placed over a drop of water in the slide and whole of the coverslip was examined by parallel overlapping strips to count all the organisms in the drop. About 20 strips were examined in each drop. Number of subsamples to be taken was dependent on the examining 2 to 3 successive subsamples without any addition of unencountered species when compared to the already examined subsamples in the same sample. The zooplankton were identified upto a taxonomic precision of species level in Rotifera, genus level in both Cladocera and Copepoda using self made keys given in Appendix and standard identification keys (Murugan *et al.,* 1998; Dhanapathi, 2000).

The species belonging to each group were noted down and number of individuals in each species was counted. The number of organisms was expressed in Total organisms per liter using the formula,

CALCULATION:

For Sedgwick – Rafter cell:

$$\text{Organisms per liter (N)} = \frac{R * 1000mm^3 * 10^3}{L * D * W * S}$$

Where R = number of organisms counted per subsample

L = length of each strip, mm

D = depth of a strip, mm

W = width of a strip, mm

S = number of strips counted.

Therefore, Total organisms per liter = N * 1/C

$$\text{Where concentration factor, } C = \frac{\text{Volume of original sample (ml)}}{\text{Volume of concentrated sample (ml)}}$$

For Lackey's drop method:

$$\text{Organisms per liter (N)} = \frac{R * A_t * 10^3}{A_s * S * V}$$

Where R = Number of organisms counted per subsample

A_t = Area of coverslip, mm^2

A_s = Area of one strip, mm^2

S = Number of strips counted, and

V = Volume of sample under the coverslip, ml

Therefore, Total organisms per liter = N * 1/C

$$\text{Where concentration factor, } C = \frac{\text{Volume of original sample (ml)}}{\text{Volume of concentrated sample (ml)}}$$

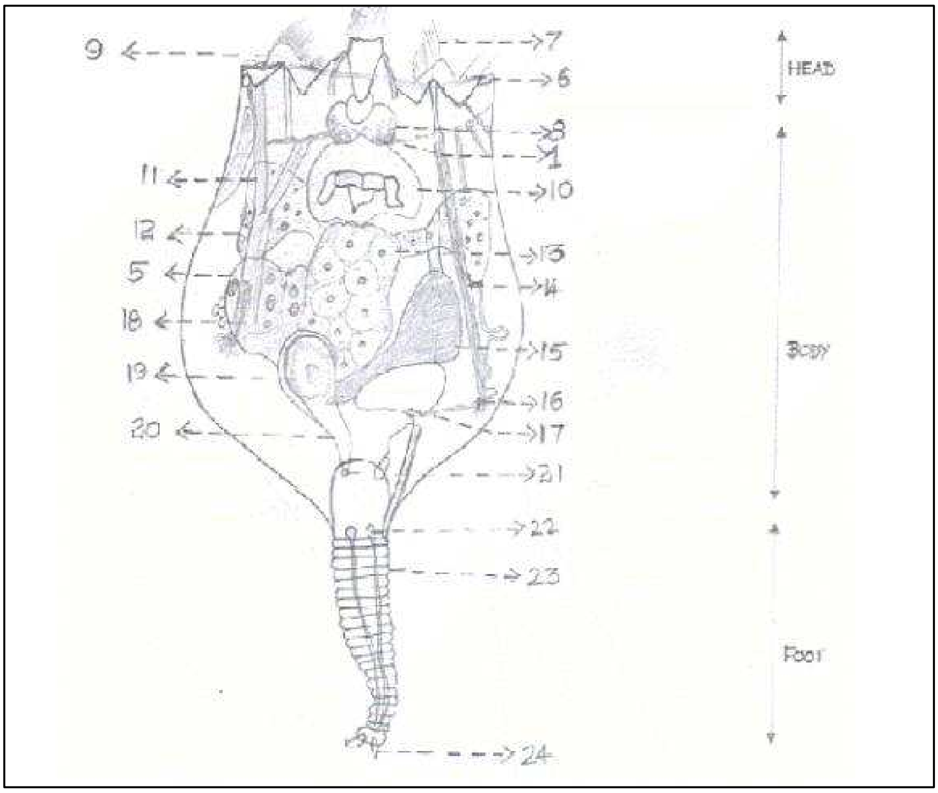


Figure 4: Schematic representation of Rotifera

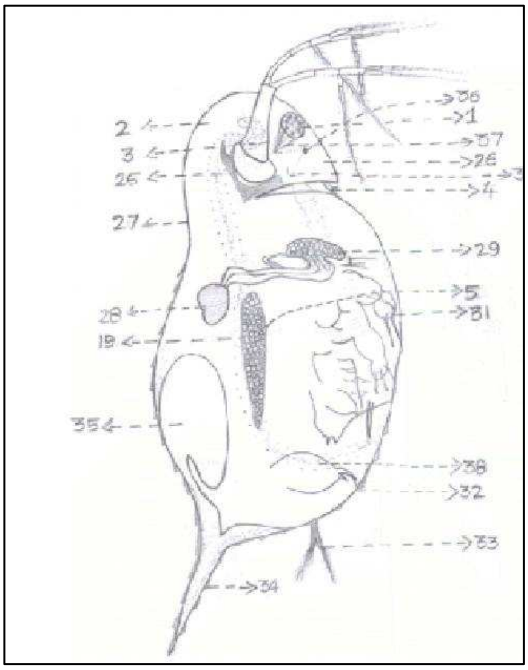


Figure 5: Schematic representation of Cladocera

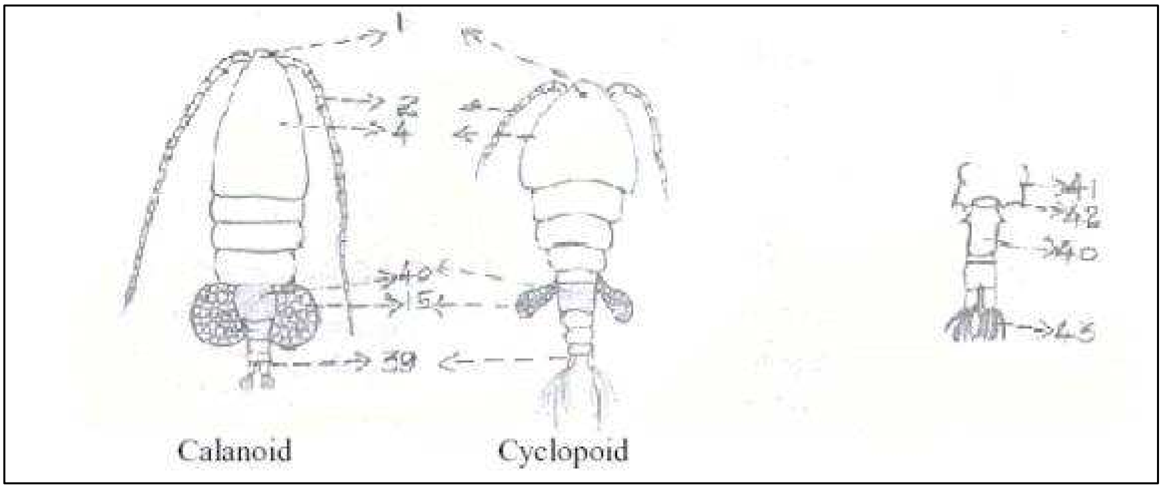


Figure 6: Dorsal view of copepoda – calanoid and cyclopoid.

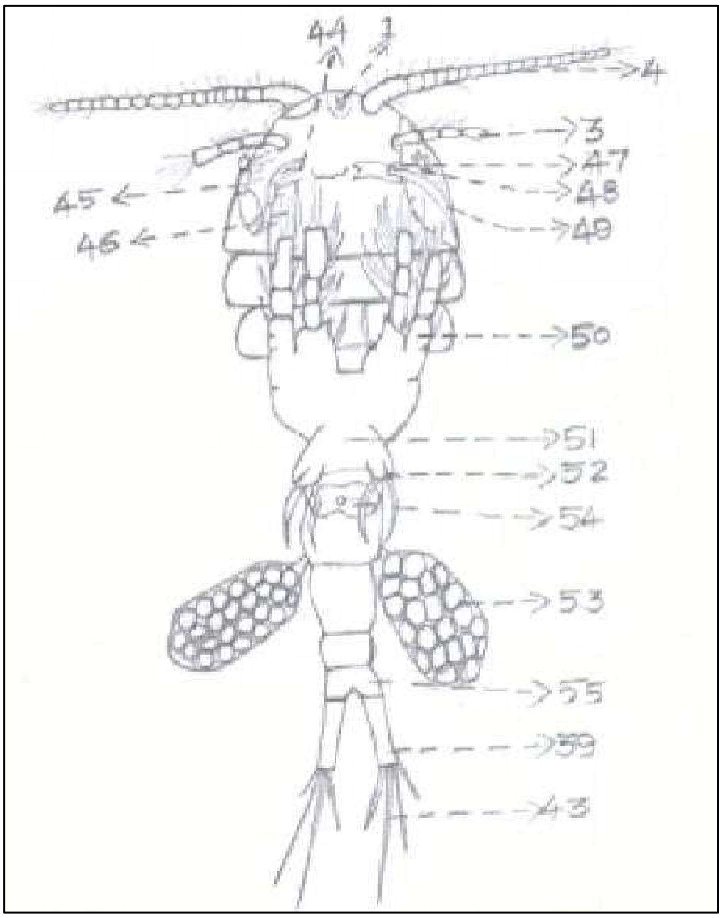


Figure 7: Ventral view of cyclopoid

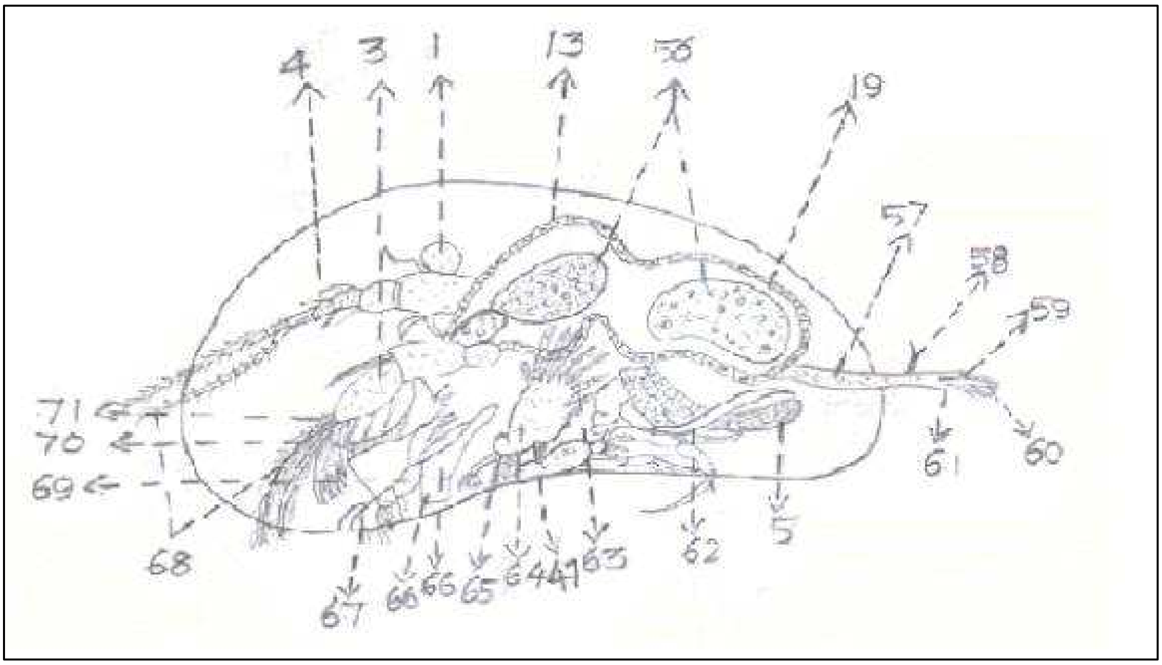


Figure 8: Schematic representation of Ostracoda

Table 3 Legend for the **Figures 4 to 8**.

1.	Eye	20.	Rectum
2.	Head/Cephalic segment	21.	Cloaca
3.	Antennae	22.	Foot glands
4.	Antennules	23.	Foot
5.	Ovary	24.	Toe
6.	Ciliary wrath	25.	Fornix
7.	Tactile style	26.	Rostrum
8.	Gangilion	27.	Cervical depression
9.	Styligerous prominence	28.	Heart
10.	Mastax	29.	Shell gland
11.	Trophi	30.	Cerebral gangilion
12.	Gastric glands	31.	Legs
13.	Stomach	32.	Claw
14.	Longitudinal muscle	33.	Post abdominal setae/process
15.	Oviduc	34.	Posterior spine
16.	Lateral canal	35.	Brood chamber
17.	Contractile vessel	36.	Ocellus
18.	Sperms	37.	Optical gangilion
19.	Intestine	38.	Post abdomen

39.	Caudal/Furcal rami	57.	Food
40.	Genital segment	58.	Furca
41.	Metasomal wing	59.	Dorsal skin
42.	Metasomal spine	60.	Subterminal claw
43.	Caudal setae	61.	Terminal claw
44.	Maxillule	62.	Terminal setae
45.	Maxilla	63.	Thoracic leg
46.	Maxilliped	64.	Branchial setae of maxillae
47.	Mandible	65.	Branchial plate of mandible
48.	Maxillary gland	66.	Mandibular projection
49.	Maxillary gland	67.	Mandibular pulp
50.	Mandibular setae antennule	68.	Natatory setae of antennae and
51.	4^{th} leg	69.	Labrum
52.	6^{th} leg	70.	Mouth
53.	5^{th} leg	71.	Labium
54.	Ovisac		
55.	Spermatheca		
56.	Telson		

Keys for identification of some of the commonly occurring freshwater zooplankton

Rotifera

Class: Monogononta

Order: Ploimida, Flosulariceae and Collothecaceae

I. Order: Ploimida

1. **Family: Epiphanidae**

Lorica absent, body transparent, sometimes sacciform with true tufts of cilia. Trophi mallaete type.

Genus: *Epiphanes*

a. *Epiphanes clavulata*

The body expands dorsally towards posterior, ventrally straight. Corona has five styligerous prominences each with fur like arrangement of slender styles. Antennae dorsal, gonod ribbon like and bent as a horseshoe. Foot short with small toe.

b. Epiphanes macrourus

Body saccate with three tufts of cilia. Dorsal antennae present. Foot long and segmented with short toes.

Genus: *Mikrocodides*

a. Microcodies chlaena

Body cylindrical, gradually narrowing posteriorly. Foot broad, segmented with a prominent spur on the dorsal side near the toe. Toe single, broad and tapering into a point. The organism looks like a shell.

Genus: *Liliferotrocha*

a. Liliferotrocha subtilis

Body elongate and cylindrical. Dorsal antennae prominent. Toes slender, short, triangular and pointed. The body as such cannot be divided into head trunk and foot. Foot is not prominent and body irregular in shape.

2. **Family: Brachionidae**

Mostly stout rotifers, planktonic, lorica heavy and dorso-ventrally flattened, often carrying visible spines or projections or ringed foot. Trophi malleate type. The oral opening is funnel like in the buccal field with a simple circumapical band of cilia. Corona lacks hood or lamellae. The body is somewhat rounded in shape with most of the members of the family.

Genus: *Anuraeopsis*

a. Anuraeopsis fissa

Lorica with two plates, dorsal and ventral with lateral sulci. Dorsal plate arched and ventral plate flat. The foot part is lobe shaped with no prominent toe. Prominent dorsal antennae.

Genus: *Brachionus*

a. Brachionus angularis

Lorica stippled, with two very small projections in the occipital margin. Posterior spines absent. No foot part and toes.

b. *Bracionus aculeatus flateralis*

Lorica stippled with four occipital spines of equal length. Posterior lateral spine apart with tooth like projections on the inner side.

c. *Brachionus budapestinensis var punctatus*

Lorica stiff and stipples with four occipital spines of which median are longer than lateral.

d. *Brachionus caudatus*

Lorica with four occipital spines, the lateral slightly longer than the median. Posterior spines are long. The body is slightly oval in shape. The occipital spines are small.

e. *Brachionus diversicornis*

Lorica is elongated (different from other Brachionus species) with four occipital spines with lateral spines much longer than the median. Right posterior spine is longer than left. Foot long and toes with characteristic claws.

f. *Brachionus forficula f typicus – urawensis*

Lorica with four occipital spines. Posterior spines stippled and bowed inwards with characteristic knee like swellings at the inner side. This species is similar to *B. aculeatus* in the occipital spine region but differs in shape of body and posterior spines.

g. *Brachionus calyciflorua*

Lorica flexible, smooth. Anterior margin with stout spines, broad at the base and with rounded tips. Median spines slightly longer than the laterals. Posterior spines absent. This species has many polymorphic forms, which have posterior spines.

h. *Brachionus falcatus*

Anterior dorsal margin with six equal spines, the medians log and curved out ward at the end. Posterior spines very long, bent inwards and in some forms almost touch each other at their tips.

Genus: *Plationus*

a. *Plationus patulas*

Occipital margin with six species of which medians slightly longer than the outer ventral margin with four spines. Posterior lateral spines are longer than the median.

Genus: *Keratella*

a. *Keratella cochlearis*

Lorica with strong median spine. Dosrum with characteristic median longitudinal line, with symmetrically arranged plaques on either side. Foot is present with toes.

b. *Keratella procurva*

Three median plaques on the dorsum, the posterior one is pentagonal and terminates in a short median line. Posterior margin of lorica is narrower than the anterior. Posterior spines are short and sub equal and sometimes absent. The median spines on the occipital part are longer than lateral spines.

c. *Keratella quadrata*

Three median plaques on the dorsal side of the lorica, the posterior one has a common border with posterior margin of the lorica. The posterior spines are sub equal. The body is segmented into polygonal shapes.

Genus: *Notholca*

a. *Notholca lebis*

Lorica oval, dorsoventrally flat with six spines at occipital margin, the medians and laterals of same length. Posterior end of lorica with broad blunt process. Posterior margin truncated.

Genus: *Platyas*

a. *Platyas quadricornis*

Lorica firm, stippled, dorsoventrally compressed with regular patterns of facets. Occipital margin with two stout spines having truncated ends. Posterior spines equal in length. At the posterior end there is an antennae like structure. Body is rounded in shape.

3.**Family: Euchlanidae**

Body dorso-ventrally flattened with thin lorica, usually lacking any projections. Two prominent toes are present.

Genus: *Euchlanis*

a. *Euchlanis dialatata*

Lorica with dorsal and ventral plates with longitudinal sulci. Dorsal plate with 'U' shaped notvh posteriorly. Mastax with four club shaped teeth on each uncus. Foot slender and two jointed. Toes blade-like and fusiform.

b. *Euchlanis brahmae*

Body truncated anteriorly and rounded behind, triradiate in cross-section. Dorsal plate laterally produced into flanges and with a dorsal median keel extending its entire length. Posterior notch absent. Ventral plate absent, but a thin membrane joins dorso-laterally. Mastax with four clubbed shaped teeth on each uncus. Foot two-jointed. Toes slender parallel sided tapering into points and one-third of the length of the dorsal plate.

Genus: *Dipleuchlanis*

a. Dipleuchlanis propatula

Lorica oval, dorsal plate is concave and smaller than the ventral. Both the plates have shallow sinuses at the anterior margin. Toes long, parallel sided and ending in points.

Genus: *Tripleuchlanis*

a. Tripleuchlanis plicata

Dorsal plate of lorica with emargination posteriorly. Ventral plate is of same size as the dorsal. Lateral sulci separated by cuticular flange giving bellow like folds laterally. Trophi malleate type with six opposing teeth on each incus, Foot glands long including a pair of accessories. Foot three jointed, first joint covered by cuticular plate. Toes short. Lorica has an ornamented pattern with core shaped foot.

Genus: *Pseudoeuchlanis*

a. Pseudoeuchlanis longipedis

Dorsal plate of lorica with anterior margin raised in the middle into small non-retractile semicircular plate and without a notch in posterior end. Ventral side is membranous, lateral sulci absent. Foot slender. Long ending in points and three-fourth length of dorsal plate. Trophi malleate, six slender club-shaped teeth on each uncus. Stomach gastric gland and foot glands present.

4. **Family: Mytilinidae**

Body stout and laterally compressed. In some species, often ringed lorica, cylindrical. Foot with indistinct segments.

Genus: *Mytilina*

a. Mytilina ventralis

Body cylindrical, lorica firm with dorsal ridges. Anterior end of the lorica stippled and with curved short spines at the margin, posteriorly with single dorsal and two ventral spines of equal length in the typical form. Foot indistinctly segmented and toes ending in blunt points

5. **Family: Trichotridae**

Body stout, lorica stiff and stippled, foot with triangular spines in some species. Toes slender and long.

Genus: *Trichotria*

a. Trichotria tetractis

Antero lateral margins pointed with the spiny projections. Dorsum stiff, stippled and with usual plates and ridges. Foot joints also stippled. Penultimate foot segment with air of triangular spines. Toes slender, long and ending in points.

6. **Family: Collurellidae**

Head of these animals in some cases has a semicircular, nonretractable, transparent hood like extension. Lateral eyespot present. In some species, one or two very long spines in the midline of the back are present. One or two very long spines in the midline of the back are present.

Genus: *Colurella*

a. Colurella bicuspidate

Lorica with two lateral plates, like mussel shell, smooth and laterally compressed. Lorical plates join an abdominal area leaving long openings near anterior and posterior ends. Foot jointed and toes small and pointed.

Genus: Lepadella

b. Lepadella acuminata

Lorica oval in shape with a pointed projection at the posterior end. Toes small, narrow and pointed.

7. Family: Lecanidae

Dorso-ventrally flattened, more or less rigid lorica, and divided into dissimilar dorsal and ventral plates connected by a soft sulcus. Mouth opening is not funnel shaped in the buccal field. Foot protrudes through an opening in the ventral plate carrying one or two long toes, in some partially fused toes.

Genus: *Lecane*

a. Lecane papuana

Lorica sub-circular, anterior dorsal margin straight and ventral with 'V' shaped sinus. Ventral plate slightly narrower than the dorsal. Second foot joint robust. Toes two, slender, parallel sided ending in claws with basal spicule.

8. **Family: Notammatidae**

Littoral. Trophi virgate and sometimes asymmetric. Body slender, elongated and soft. Corona is characterized by ventrally tilted buccal field. A small apical field and thin, usually large retractable ciliated ears. Foot short and stout, toes stubby.

Genus: *Cephadella*

a. Cephalodella catellina

Body transparent and gibbous. Lateral clefts of lorica parallel sided. Foot small and posterior to the projecting abdomen. Toes short, nearly straight, tapering into acute points.

b. Notommata copeus

Body elongate and transparent. Head, neck and abdomen marked by transverse folds. Corona projects as bluntly pointed chin. Tail is characteristic with conical projection ending with blunt point. Toes slender and conical, foot glands long and club shaped. Dorsal antennae stout and long. Trophi asymmetrical, the left prevails over the right. Manubrium long and curved inwards. Stomach is seen distinctly.

9. **Family: Asplanchnidae**

Cuticle thin and delicate, body sac like or pear or conical shaped. Sometimes wing like side appendages present, trophi incudate, corona reduced to a circumapical band.

Genus: *Asplanchna*

a. Asplanchna brightwelli

Body large, saccate and transparent. Intestine, foot and toes are absent. Trophi incudate with rami having horn like projections at outer margins of the base and inner spine at the middle.

10. **Family: Synchaetidae**

Trophi modified virgate or virgate, complex pair of hypopharyngeal muscles sometimes present. Saclike or conical or bell shaped, transparent and soft body.

Genus: *Polyarthra*

a. Polyarthra indica

Body illoricate and little squarish. Four groups of lateral paddles inserted dorsally and ventrally in the neck region. Each group with three paddles of equal length extending beyond the posterior and of the body. Accessory pair of ventral paddles present between ventral bundles.

II. Order: Flosulariceae

1. **Family: Hexaarthridae**

Body transparent and conical, carries six heavily muscled arm like appendages tipped with feathery setae.

Genus: *Hexarthra*

a. Hexarthra intermedia

Body large, ventral arm with one pair of hooks and eight filaments. Unicellular five teeth, lower lip and foot are absent. Indistinct antennae on the dorsal side below the corona. Corona is rounded structure surrounded by cilia. The right arm is longer than the left.

2. **Family: Filinilidae**

Pelagic, body delicate, saclike, three or four appendages present, which can be long spines or stout thorns.

Genus: *Filinia*

a. Filinia longiseta

Body oval and transparent with long anterior skipping and a posterior spine on the ventral side. Spine not bulged, foot absent. The body is segmented into head and trunk.

3. **Family: Testudinellidae**

Lorica thin, dorso-ventrally flattened, round or shield like armour, body transparent. In some species foot is absent.

Genus: *Testudinella*

a. Testudinella mucronata

Lorica nearly circular, slightly stippled and anterior dorsal margin with a blunt tooth like projection. Foot opening ventral and at one-third distance from the posterior end. Foot is distinctly segmented with toes.

III. Order: Collothecaceae

1. **Family: Collothecidae**

Almost entirely sessile, these rotifers have an expanded funnel shaped anterior end and live mostly in a gelatinous case, attached to the substratum by a long foot and disc.

The funnel may cause a variable number of scalloped lobes that are studded with bristles, setae or cilia.
Genus: *Collotheca* *a. Collotheca ornate* Corona with five short blunt lobes arranged pentagonally with long cilia. Posterior part covered by transparent long gelatinous case. Hold fast short. The body narrows down posteriorly into a long tail portion.

<u>Cladocera:</u> 1. **Family: Sididae**
Genus: *Diaphanosoma* Head is large, without rostrum and ocellus. Antennules are small and truncated. Dorsal ramus of antennae is two segmented. Post abdomen is without anal spine and claw with three basal spines.
2. **Family: Daphnidae** Antennules are small, immobile or rudimentary. Antennae are long and cylindrical. Dorsal ramus consists of 4 segments and 3 ventral segments. Post abdomen distinctly set off from the body, usually more or less compressed and always with anal spines. Claws are mostly denticulate or pectinate. This family consists of five pairs of legs and first two pairs are prehensile and without branchial lamellae.
Genus: *Ceriodaphnia* Body forms are rounded or oval in shape. Valves oval or round to sub-quadrate and usually ending posteriorly, sharp spine present. Head small and depressed. Antennules are small and not freely movable.
3. **Family: Moinidae** Moinids are characterized by their head with a pair of long and thin cigarette shaped antennules. These arise from ventral surface of the head. Most species have hairs on head region or on shell surface. Ocellus is usually absent. Post abdomen has single row of teeth with no marginal spine.
Genus: *Moina* Body is thick and heavy. Valves are thin, reticulated or striated. Antennules are large and movable: they originate from the flat surface of the head. Eye is located in the center of the head. Ocellus is rarely present. Post abdomen with bident tooth and 3-16 featured teeth is present.
4. **Family: Bosminidae** Body is short and usually oval or rounded in outline. Antennules are large and immovably fixed to head. They have no ocellus, abdominal process consists of six pairs of legs.
Genus: *Bosmina* Body is usually transparent. Antennules are almost parallel to each other. Antennae with 3 or 4 segmented rami. Post abdomen almost quadrate.
5. **Family: Chydoridae**

Body is generally oval in shape. Head is completely enclosed with in carapace. Antennules are one segmented and generally not extending beyond the tip of the rostrum. Antennae are short and consist of 3 segmented rami. Post abdomen consists of anal spines and lateral setae.
Subfamily: Chydorinae Width of the body generally greater than the length. Head pores are separated and situated in the median line of head shield. Anus situated in proximal part of post abdomen.
Genus: *Pleuroxus* Rostrum is long and pointed. Ocellus is smaller than eye. Post abdominal claws consists of two basal spines.
Subfamily: Aloninae Head has two or three head pores situated in median line of head with two small pores located at either side. Claws consist of single basal spine or sometimes without basal spines.
Genus: Alona Body subquadrate in outline. Values are rectangular and marked with lines. Three main connected head pores are situated at the median line of the head shield. Rostrum is short and blunt. Anus is situated in proximal part of post abdomen.

Copepoda I. Order: Calanoida
1. **Family: Diaptomidae** Endopodite of P1 two segmented, endopodite of P2-P4 three segmented and P5 with endopodite in both sexes.

II. Order: Cyclopoida
2. **Family: Cyclopoidae** Mandibular palp not well developed, reduced to one segment with three setae.

Table 4 Taxonomic classification of Freshwater zooplankton

TAXA	ROTIFERA	CLADOCERA	COPEPODA	OSTRACODA
Kingdom	Animalia	Animalia	Animalia	Animalia
Phylum	Rotifera Triploblastic, bilateral, unsegmented blastocoelomates. Body divided into	Arthropoda Bilateral, triploblastic coelomates. Body segmented into head,	Arthropoda Bilateral, triploblastic coelomates. Body segmented	Arthropoda Bilateral, triploblastic coelomates. Body segmented

	head, trunk and foot. Locomotion by the means of coronary cilia. With protonephridia for osmoregulation. No special organs for circulatory or gas exchange system.	abdomen and post abdomen. Locomotion by the means of antennae. Circulatory system is open, dorsal heart present. Gas exchange through body or gill like structure. Males present, both sexual and asexual reproduction.	into head, abdomen and post abdomen. Locomotion by the means of antennae. Circulatory system is open, dorsal heart present. Gas exchange through body or gill like structure. Males present, both sexual and asexual reproduction.	into head, abdomen and post abdomen. Locomotion by the means of antennae. Circulatory system is open, dorsal heart present. Gas exchange through body or gill like structure. Males present, both sexual and asexual reproduction.
Subphylum	-	**Crustacea** Body divided into head and trunk, which may be divided into thorax and abdomen. Head has eye, antennules, antennae, mandibles and maxillae. Antennae uniramous or biramous. Head is surrounded by carapace except	**Crustacea** Body divided into head and trunk, which may be divided into thorax and abdomen. Head has eye, antennules, antennae, mandibles and maxillae. Antennae uniramous or biramous. Head is surrounded by	**Crustacea** Body divided into head and trunk which may be divided into thorax and abdomen. Head has eye, antennules, antennae, mandibles and maxillae. Antennae uniramous or biramous.

		for copepods. Both ocelli and compound eye occur in all taxa. Excretion by maxillary glands and antennal glands	carapace except for copepods. Both ocelli and compound eye occur in all taxa. Excretion by maxillary glands and antennal glands	Head is surrounded by carapace except for copepods. Both ocelli and compound eye occur in all taxa. Excretion by maxillary glands and antennal glands
Class	**Digononta** Has paired ovaries No lorica or tubes Monogononta Lorica may be present or absent. Benthic, free swimming and sessile forms. Females with single ovary and a vitelarium.	**Branchiopoda** Limbs usually phyllopodous. Antennules simple and reduced. Mandible without palp. Maxillae reduced or absent.	**Copepoda** No carapace. Antennules uniramous. The body has nine appendages usually. Six pairs of biramous limbs. Presence of caudal rami. Twenty genera have been reported in India.	**Ostracoda** Carapace forms a bivalved shell. Antennules uniramous. Not more than five pairs of limbs behind mandibles. One to three pais of limbs before mandible.
Order	The class Digononta has 2 orders, namely **Bdelloidea and Seisonidea**, but both the orders are primarily benthic and epizoic forms. The class	**Cladocera** Carapace large bivalved enclosing trunk but not head. Antennae large biramous used for swimming. Eyes sessile,	The copepoda has three orders namely **Calanoida, Cyclopoida and Harpacticoida.**	The Class **Ostracoda** has a order **Podocopa** The order Podocopa consists of five families namely

	Monogononta has 3 orders namely **Ploimida, Gnesiotrocha and Collothecaceae**.	ocellus present. Trunk limbs 4 to 6 pairs.		Cyprididae, Cyclocypridae, Notodromadidae, Eucandonidae and Iiyocyprididae. In India, 61 species of Ostracods have been reported.
Family	There are 26 families reported in India. **Epihanidae** This family has 3 genus namely *Epiphanes, Mikrocodides, Liliferotrocha* **Brachionidae** This family has 5 genus namely *Brchionus, Keratella, Plationus, Anuraeopsis Platyas,Notholca.* **Euchlanidae** The family has 6 genus namely *Euchlanis, Pseudoeuchlanis, Dipleuchlanis, Tripleuchlanis, Beauchampiella, Diplois* **Mytilinidae** This family has 1 genus *Mytilina*	About 8 families are reported in India **Sididae** Trunk and thoracic limbs covered by valves. Body length much greater than the height. Head clearly delimited. Antennae not branched. **Bosminidae** 5 to 6 pairs of thoracic limbs, dissimilar. Antennae fused with rostrum. **Chydoridae** Antennae not fused with rostrum. Dorsal and ventral rami of antennae three segmented.	The order **calanoida** has a single family **Diaptomidae** Endopodite of P1 two segmented, endopodite of P2-P4 three segmented and P5 with endopodite in both sexes. Some of the genera reported in India include, *Phyllodiaptomus, Heliodiaptomus, Paradiaptomus* …… The order **cyclopoida** has a single family **Cyclopidae** Mandibular	The order **Podocopa** has five families – **Cyprididae, Cyclocyprididae, Notodromadidae, Eucandonidae, Iilyocyprididae** The family **Cyprididae** has 4 subfamilies namely **Cypridinae, Cyprettinae, Stenocyprinae, Cypridosinae.** The family **Cyclocyprididae** Has 1 species namely

	which has 5 species *Mytilina ventralis* *Mytilina ventralis brevispina* *Mytilina ventralis macracantha* *Mytilina mucronata* *Mytilina bisulcata* **Trichotridae** The family supports 2 genus namely *Trichotria, Macrochaetus* **Colurellidae** The family has 3 genus – *Colurella, Lepadella, Squatinella* **Lecanidae** This family has the single largest genus *Lecane* among rotifera with 70 species. **Proalidae** This family has single genus with two species namely *Proales decipiens* *Proales indirae* **Notommatidae** The family is represented by five genus namely *Cephalodella, Esophora, Notommata, Itura,Taphrocamp*	**Daphnidae** Dorsal ramus of antanne 3 and ventral ramus 4 segmented. Antennules immovable and short. **Moinidae** Antennae movable and mostly long. Antennules situated in the posterior side of the head. **Macrothricidae** Antennule in the anterior side of the head. **Leptodoridae** Trunk and thoracic limbs not covered by valves. Head elongated. **Podonidae** Trunk and thoracic limbs not covered by valves. Head short. Caudal appendage very short.	palp not well developed, reduced to one segment with three setae. Some of the genera reported from India include, *Macrocyclops, Paracyclops, Microcyclops…* …. The order **Harpacticoida** has a single family **Cletodidae** Harpacticoid are usually benthic but rarely planktonic. Tapering body with each segment distinct. Female genital segment with a suture dorsally. Maxilliped prehensile. Freshwater planktonic species reported from India include *Cletocampus albuquerquens*	*Physocypria fufuracea* The family **Notodromadidae** has 2 genera – *Centropypris, Indiacypris* The family **Eucandonidae** has a single species *Canadonopsis putealis* The family **Iilyocyprididae** has single species – *Ilyocypris nagamalaiensis*

	a **Scarididae** The family has a single species namely *Scaridium longicaudatum* **Linidae** The family has a single genus *Lindia* **Trichocercidae** The family has a single genus with 21 species. **Asplanchnidae** The family has 4 genus *Asplanchna, Asplanchnopus.* The genus *Asplanchna* are predatory rotifers. **Synchaetidae** The family has 2 genus namely *Polyarthra, Synchaeta* with 6 and 5 species respectively. **Gastropodidae** The family has 2 genus *Ascotrocha, Gastropus* **Dicranophoridae** The family has single genus with		*is……*	

	5 species namely *Dicranophorus dolerus* *Dicranophorus tegillus* *Dicranophorus epicharis* *Dicranophorus forcipatus* *Dicranophorus lutkeni* **Order Gnesiotrocha** The order has 6 families. **Flosculariidae** The family has 5 genus – *Limnias, Floscularia, Beauchampia, Lacinularia, Sinantherina* **Conochilidae** The family has single genus with six species – *Conochilus arboreus* *Conochilus dossuarius* *Conochilus hippocripis* *Conochilus madurai* *Conochilus natans* **Hexarthridae** The family has 1 genus with four			

	species – *Hexarthra intermedia* *Hexarthra mira* *Hexarthra bulgaria* *Hexarthra fennica* **Filinidae** The family has 1 genus with 5 species *Filinia longiseta* *Filinia opoloensis* *Filinia pejleri* *Filinia cornuta* *Filinia terminalis* **Testudinellidae** The family has 1 genus *Testudinella* with 6 species **Trichosphaeridae** The family has 1 species namely *Horaella brehmi* **OrderCollot hecaceae** The order has 1 family **Collothecida e** The family has 2 genus with 4 species – *Cupelopagis vorax* *Collotheca ornate* *Collotheca trilobata* *Collotheca mutabilis* **Order Bdelloida** The order has 1			

	family with 18 species **Philodinidae** The family has 4 genus – *Rotaria, Pseudoembata,* **Philodina** *Macrotrachela*			
Genus		**Sididae** The family consists of 4 genus – *Sida, Pseudosida, Latonopsis, Diaphanosoma,* **Daphnidae** The family has 5 genus – *Ceriodaphnia, Daphnia, Daphniopsis, Scapholeberis Simocephalus* **Moinidae** The family has 2 genus – *Moina, Moinodaphnia* **Bosminidae** The family has 2 genera – *Bosmina, Bosminopsis* **Macrothricidae** The family has 4 genus – *Macrothrix, Echinisca,*		

		Streblocerus, Ilyocrptus. **Chydoridae** This family has two subfamily **Eurycercinae, Aloninae** **Eurycercinae** The subfamily has 4 genus – *Eurycercus, Pleuroxus Alonella, Chydorus.* **Aloninae** The subfamily has 10 genus – *Alona, Acroperus, Camptocerus, Graptoleberis, Leydigia, Biapertura, Oxyurella, Kurzia, Euryalona, Indialona.* **Leptodoridae** This family has a single genus *Leptodora*		

AMPHIBIANS

Amphibians are tetrapod vertebrates first appeared on the earth nearly 360 million years ago. Amphibians are one of the best bioindicators as they respond to the minute disturbances in their habitat or in the environment. Their relatively wide distribution, bimodal life style (aquatic tadpole and terrestrial adults), ectothermic conditions with stable environmental temperature of 20-30°C and moist permeable skin have made them highly sensitive and susceptible to the external changes. Amphibians are pivotal organisms both as prey and predator in many food chains and constitute a vital component of the ecosystem. In ecosystem management, they are the best biological pest controllers.

Amphibians are present in many habitats and microhabitats. They can be found inside the lake/pond water, muddy and rock crevices, burrowing deep in the soil, or bushes, high canopy trees etc. Amphibians are a plenty during rainy season, as they require water to breed and to lay eggs. Majority of the amphibians are active during night (nocturnal). Amphibians are well known for their croaking noises (vocal calls), which they generally do to attract the partner. One can easily locate and identify the amphibian species based on their calls.
(http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue6/index.htm)

General outlook

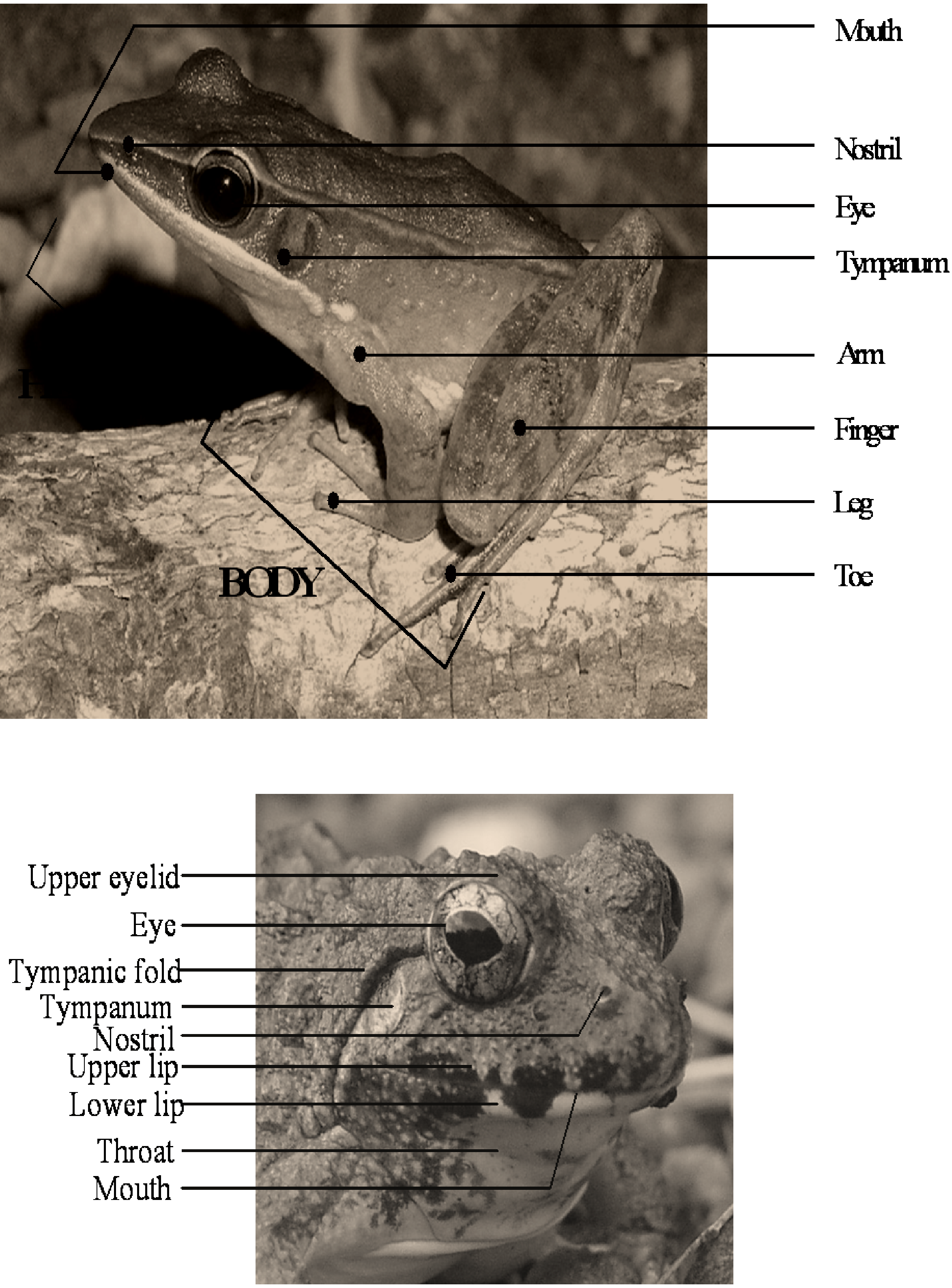
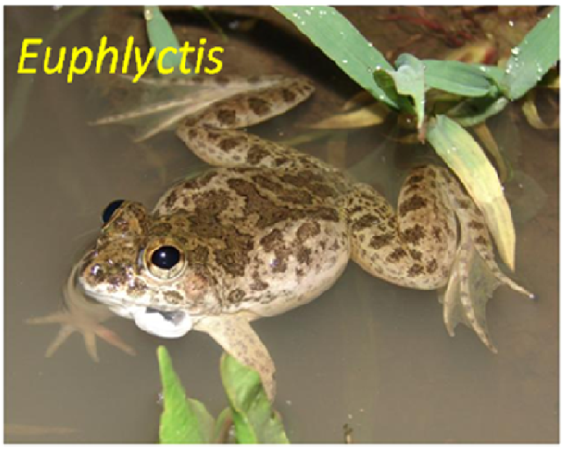
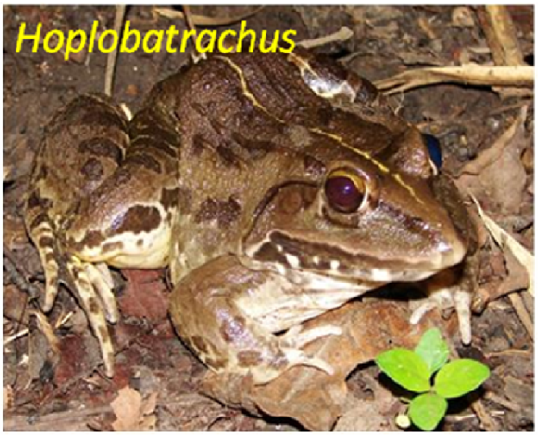


Fig. 9 Body parts of a Frog

Some common Genera (photos: Gururaja KV)


Fejervarya

Euphlyctis

Hoplobatrachus

Nyctibatrachus

Clinotarsus

Hydrophylax

Polypedatus

Philatus

Method

Time constrained sampling: # of man hour search in all-most-all micro habitats. The sampling is done in torch light preferably in late evenings. Usually a search for half an hour by two individuals that is a total of one man hour is sufficient for sampling.

Data Sheet for Amphibian survey

Date:

Time (start):

Time (End):

Latitude: Longitude: Altitude:

Land-use (major): Agriculture/ Pond/ stream/ Evergreen/ Deciduous/ Grassland/

Air temperature: Water temperature:

Relative humidity Canopy cover:

Asphalted road nearby

Table 5: Data table for Amphibian Sampling.

Species encountered	Microhabitat/ activity	# individuals

FISH

Parameters to be considered:

- Lake or Stream Type
- Nature of Catchment area -
- Terrain of the surrounding region – plain, hilly, coastal, etc.,
- Micro-habitat conditions – Riparian forest, canopy cover, substrate type, dimensions of the water body, flow,
- Perennial, intermittent streams
- Effluent discharge

Seasonal Sampling: Seasonal variation in species occurrence and composition can be seen. Hence, sampling across the seasons is necessary to get the complete picture. Moreover, in each sampling event repeated daily sampling will yield the best results.

Sampling Time: Early morning or late evening is the ideal time for fish sampling

Sampling Types:

a). Gill net sampling: This is the appropriate sampling method for moderately deep pools. Fishes are trapped through their gills in the net. One has to use sufficient reasoning to choose the mesh size of the net to trap appropriate fishes. This reasoning has to come from size of the water body. On the other hand, gill nets with varying mesh sizes can also be effective.

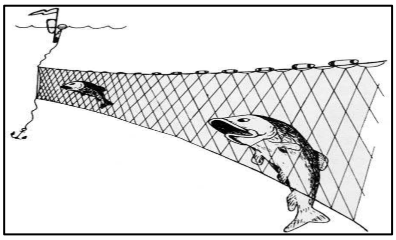


Fig 10 Gill Net Sampling

Fig 11 Cast Net Sampling

b). Cast net sampling: This is the appropriate sampling method for shallow water bodies. However, art of using cast net is essential to use the net effectively.

c). Drag net sampling: One of the most effective sampling techniques in shallow and small pools, wherein, the net is dragged to sweep out the fishes of the water body. Although this technique is effective, this results in massive destruction of the fish communities and hence should be carefully used.

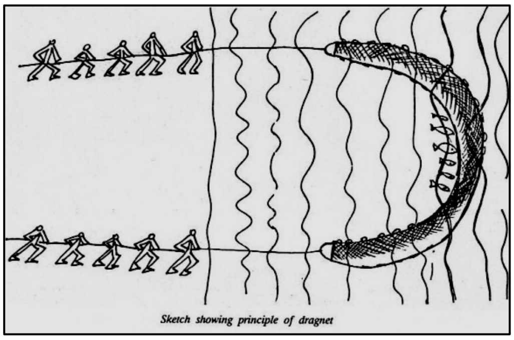


Fig 12 Drag net sampling

Fig 13 Hooks

d). Hooks and lines:
For large carnivorous fishes, hooks and lines should be used for sampling. Especially in deep and rocky pools this method is effective to capture such fishes.

e). Opportunistic sampling in streams and rivers using unconventional methods: Several methods are available for opportunistic sampling that ranges from observation using naked eye till using cloths for sweeping the water bodies. However, one should avoid using destructive fishing methods such as poisoning, use of explosives, etc.

Some tips to locate the fishes in water:

- Swampy pools are known for air-breathing fishes
- Deep pools with clear water and rocky substrate are known for Mahaseers/huge carnivorous fishes, etc.
- You can also get the knowledge of fishes from the local fisherman.

MOLLUSCS

INTRODUCTION

The name Mollusc (=Mollusk) was derived from Latin mollus meaning soft. They belong to the Phylum Mollusca. The first Mollusc appeared as far back as the Cambrian period, approximately 500 million years ago. They are the second largest phylum among the invertebrates comprising more than 100,000 species. In India, till today, 5070 species of Mollusca have been recorded of which, 3370 species are from marine environment, while rest from the freshwater and terrestrial environment. Freshwater molluscs broadly occurs in two environments lentic and lotic. In general gastropods occur in the littoral region attached to vegetation or under stones. Bivalves are benthic forms, lived partly buried in the soft mud. Those engaged in freshwater molluscs collection have to consider two factors:

i) forehand knowledge of habitats of molluscs;
ii) a sensible and suitable choice of collecting equipments.

GENERAL FEATURES

It is a specialised group of the animal kingdom having mantle and radula not found elsewhere. A typical mollusca possesses a head (wanting in bivalves) bears a terminal mouth, eyes, tentacles and often sensory organs; a muscular foot for locomotion; posterior dorsal visceral mass containing most of the viscera; a fold of body wall (mantle) that leaves between itself and the main body mass a cavity (mantle cavity); into which opens the termination of digestive, nephridial and reproductive system; gills; and a external shell secreted by the mantle that partly or wholly encloses the soft body.

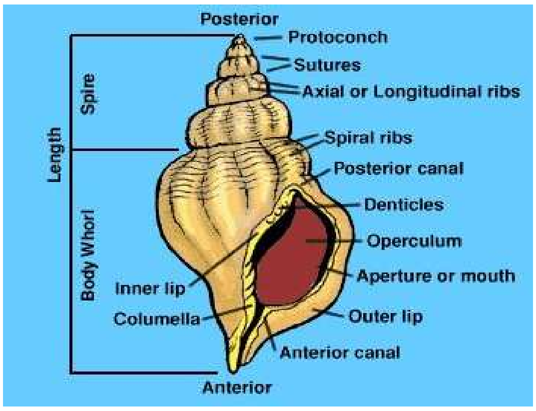


Fig 14 General features of Gastropoda

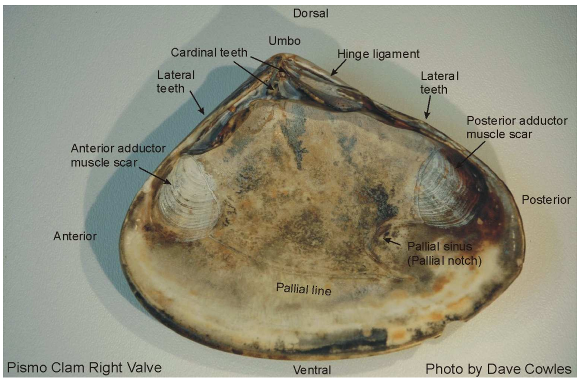


Fig 15 General features of Bivalvia

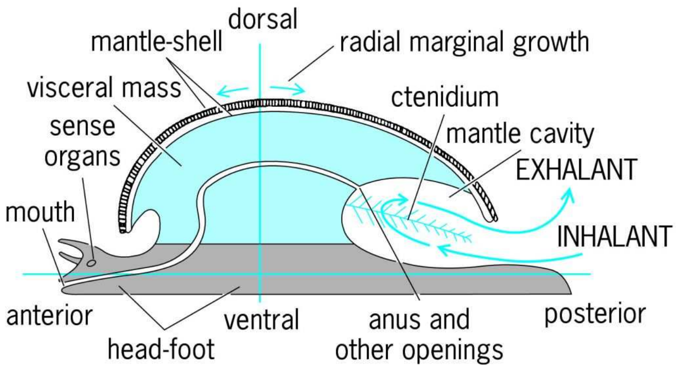


Fig 16 Anatomy of a gastropod.

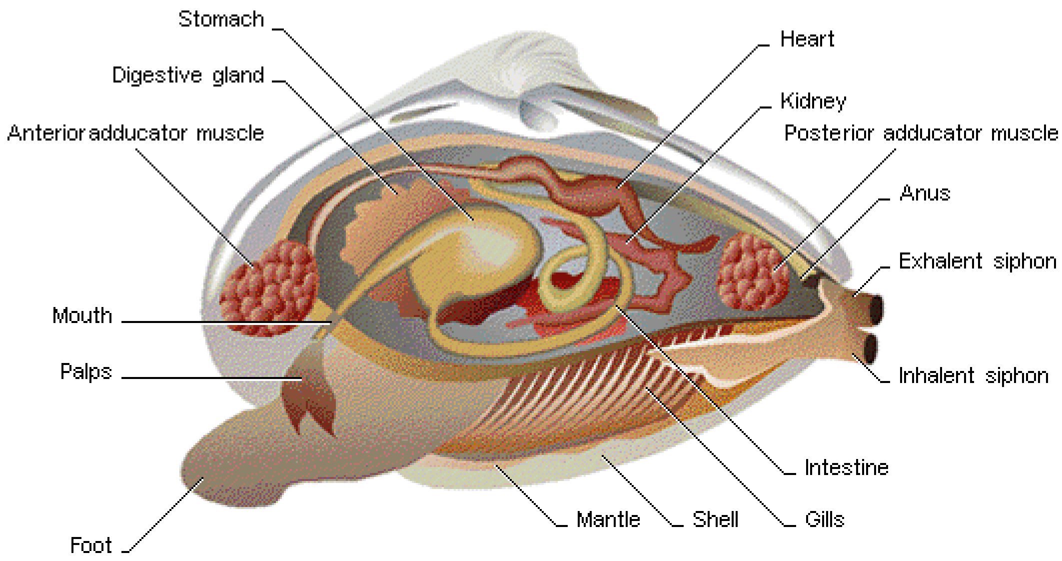


Fig 17 Anatomy of a bivalve.

MOLLUSCS AS BIOINDICATORS

The use of mollusks as biological indicators and controls in monitoring climate and environmental change are currently being used in most Bioassessment programs. With increasing needs for research on contaminant effects in freshwater ecosystems, this kind of biomonitoring is likely to develop further in the future. Molluscan communities are good indicators of localized conditions. They have limited migration patterns and are particularly well suited for assessing site-specific impacts. For example, genera like *Thiara* and *Indoplanorbis* (Fig 18) thrive in slightly polluted environments whereas species like *Pseudomulleria dalyi* reside in highly specialized environments and are sensitive to pollution. The members of the freshwater genus *Lymnaea* (Fig 19) are opportunistic and thrive in polluted environments.

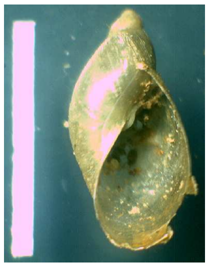


Fig 18. *Indoplanorbis* (scale: 2 mm) Fig 19. *Lymnaea* (scale: 5 mm)

FIELD EQUIPMENTS NEEDED

1. Hip boots or chest waders will be required for the mountains.
2. Shorts and canvas wading shoes are suitable for the swamps.
3. Bucket.
4. Sieve (mesh 0.5 mm).
5. Enamel tray.
6. Unbreakable containers for specimens.
7. Polythene bags and small vials for species like *Gyraulus* (Fig 3a) and *Segmentina* (Fig 3b).
8. Forceps.
9. Small painting brush.
10. Knife or scalpel.
11. Gloves.
12. Global Positioning System (GPS)
13. Field note book and data sheets.
14. Labels.
15. Long-handed net or dipper, "kick net" with a rectangular or triangular opening (mesh 0.5 mm).
16. D-frame nets combine the benefits of both types.

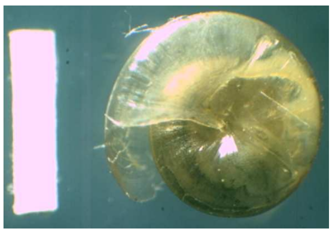


Fig 20 *Gyraulus* (scale: 2 mm) Fig 21 *Segmentina* (scale: 2 mm)

INSTRUCTIONS FOR FRESHWATER MOLLUSCS COLLECTORS

1. Inventory of all available habitat types.
2. Rivers should be surveyed in both riffle and pool.
3. Lakes should be surveyed both in quiet, protected bays and on exposed shores.

4. Inspect plastic bags and floating garbage.
5. The entire range of substrate types should be sampled, including mud, sand, and rock, as should the entire macrophyte flora, both floating and attached. Consider collecting from a boat.
6. Enter the water only after sampling snails from all visible surfaces.
7. Take good notes for each collection. Record the locality as specifically as possible, ideally on site. Habitat notes and environmental observations are often useful.
8. Label should contain the following fields.
   a) Date (dd/mm/yyyy)
   b) Place name and/or water body name
   c) Habitat (lentic or lotic)
   d) Collection method
   e) Latitude and longitude
   f) Collector's name(s)

COLLECTION METHODS

Quantitative studies

It is evident that no single technique is suitable for this purpose. The choice of method being dependent on the objectives of study, the nature of the habitat and the facilities and personnel available.

Quadrat method
A metal ring or square is dropped in the area of the study, and all the snails collected within that ring or square are collected and counted.

Standard Scoop or Dredge method
A scoop or dredge of standard size is passed over the required area over the aquatic vegetation, and contents are poured out on a spread out cloth piece. The leaves and branches of the plant carefully searched out and snails are picked up with hand or forceps.

Bivalves can be collected by dredge. By hand picking in case of bigger specimens from the bottom of the pond or streams. The collections may be made by scooping the bottom mud and then put into the sieve and washed with water. After washing bivalves can be easily picked up from the sieve.

Counts per Unit Time
It involves counting the number of snails, collected systematically with sieves by on or more trained collectors in a measured or marked area for a given length of time.

PRESERVATION

Preserve the collected specimens immediately with alcohol, together with a field label. A few dry shells may be preserved. The molluscs are kept in boiling water for a few minutes and then the animal extracted from the shell with a bent tipped forceps. The empty shells are further cleaned and dried in air. In case of operculates the operculum should be retained by pushing it to a cotton plug inserted into its aperture.

For further readings

1. Ramakrishna and Dey, A., 2007. Handbook on Indian Freshwater Molluscs . Zoological Survey of India, Kolkata. 1-399.
2. Subba Rao. N.V., 1989. Handbook Freshwater Molluscs of India. Zoological Survey of India, Kolkata. 1-289.
3. Sturm, C. F., Pearce, T. and Valdés. A., (Eds.) 2005. The Mollusks: A Guide to Their Study, Collection, and Preservation. American Malacological Society.

Data sheet for freshwater molluscs sampling

Sample no.:__________________ Date (dd/mm/yyyy):__________________

Place name and/or water body name: ____

Coordinates: ____

Habitat (lentic / lotic):____

Sampling method: ____

Sampling Time: Start Time: __________________________ End Time: __________________________

Substrate type: ____

Collector's name(s):____

pH:_______________ Water Temperature:_______________ Salinity:_______________

Dissolved Oxygen:_______________ Calcium:_______________ Hardness:_______________

Others:

____

____

____

____

____

WATER QUALITY

Water is the most vital resource for all kinds of life on this planet and is affected both qualitatively and quantitatively by varieties of activities on land, water & air. Water quality has a vital role in assessing the impacts in an around the streams & lakes. Basic physico-chemical studies reveal the status of water and the nature of the catchment responsible for the flow. Polluted state of water resources can lead to a steady decline in wildlife & fishes and often has miscellaneous effects on the environment. Some of the basic Physico-chemical parameters are:

pH: This indicates the extent and nature of the water, how acidic or basic the water is? Natural water usually has pH values between 5.0 and 8.5. These values are typical with slight seasonal variations; a sudden change would indicate industrial pollution. Many chemical reactions are controlled by pH and biological activity is usually restricted to a fairly narrow pH range of 6.0 to 8.0. Highly acidic or highly alkaline waters are undesirable because of corrosion hazards and possible difficulties in treatment.

Temperature: It is expressed in ^{0}C or ^{0}F. Many of the industries use the natural water for cooling the boilers and release the water in the streams again but at an elevated temperature. The abnormal increase in temperature can cause decline in the dissolved oxygen concentration and in turn affect the survival of aquatic organisms

Salinity: Expressed in mg/l or ppm it represents the total concentration of salt present in the water body.

Electrical Conductivity: Conductivity of solution depends upon the quantity of dissolved salts present. It is related to TDS content. Its value becomes greater with the increase of the degree of pollution.

Turbidity: The presence of colloidal solid gives liquid a cloudy appearance, which is aesthetically unattractive and may be harmful. Turbidity in water may occur due to clay and silt particles, discharge of sewage or industrial waste or to the presence of large number of microorganisms.

Total Dissolved Solids (TDS): The total dissolved solids in the water are measured in mg/liter or ppm. The value of TDS is higher in rainy season because of the mud dissolved in the water. Run off generally increases the TDS in streams.

Total Hardness as $CaCO_3$ This is the property of water, which prevents lather formation with soap and produces scales in boilers. It is mainly due to the dissolved calcium and magnesium salts. There is no health hazard but economic disadvantages of hard water include increased soap consumption and higher fuel costs.

Chloride: It enters into the surface water due to the weathering of some sedimentary rocks, from sewerage, industrial or agricultural runoff. It is responsible for the brackish taste in water and is an indicator of sewage pollution because of the chloride content in urine.

Nitrogen - Nitrate (NO_3 - N): Nitrogen - Nitrate is the final oxidation product of nitrogen. Natural sources of nitrate to surface waters include igneous rocks, land drainage and plant and animal debris. Natural levels, which seldom exceed 0.1mg/L NO_3

- N, may be enhanced by municipal and industrial wastewater, including lechates from waste disposal sites and sanitary landfills. In rural and suburban areas the use of inorganic nitrate fertilizers can be a significant source.

Phosphate: Phosphate is essential for the growth of organisms and can be nutrient that limits the primary productivity of a body of water. In instances where phosphate is a growth - limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of photosynthetic aquatic micro- and macro- organisms in nuisance quantities.

Biochemical Oxygen Demand (BOD): BOD is a measurement of the Oxygen required for microorganisms whilst breaking down organic matter to stable inorganic forms such as CO_2, NO_3, and H_2O. So the water with high BOD indicates the organic pollution.

Chemical Oxygen Demand (COD): COD is used as a measurement of the Oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. Usually the concentrations of COD in surface water ranges from 20mg/L or less in unpolluted water to greater than 20 mg/L in water receiving effluents.

Prerequisites & Precautions while sampling & analysis of Water samples

1. The sampling bottles or containers should be washed with non-phosphate detergent, rinsed thoroughly with running water, and finally rinsed with demonized water. (Traces of chemicals or detergent can interfere with the analysis.)
2. The inner portion of the sample bottle & caps should not be touched with bare hands.
3. Sample should be never permitted to stand in the sun; they should be stored in cool place.
4. The glasswares should be properly washed & rinsed with distilled water.

Water Sampling Protocol:

1. Shore samples are to be collected from the surface of water, by gently putting the thoroughly washed container into the water which is free flowing (for the river samples) or from a clear place (in lake samples) taking into account that no other substances enter the container.

2. The on-site parameters which should be measured at the sampling point are the water temperature which can be either done by the help of a thermometer or with the help of a probe.

3. pH can be determined either through pH paper or by pH probes (for better accuracy).

4. Total dissolved solids can be measured with the help of probes which will give the idea of the total dissolved ions in the water sample.

Data Sheet for Water Quality

Place of Collection: ____

Date: __________________ Time: ________________________________

Latitude__________________Longitude_______________Altitude:______

Site Details:

____

____

pH:____

Water Temperature: ____

Air Temperature: ____

Electrical Conductivity: ____

Total Dissolved Solids: ____

Turbidity: ____

Dissolved Oxygen: ____

Chlorides: ____

Alkalinity: ____

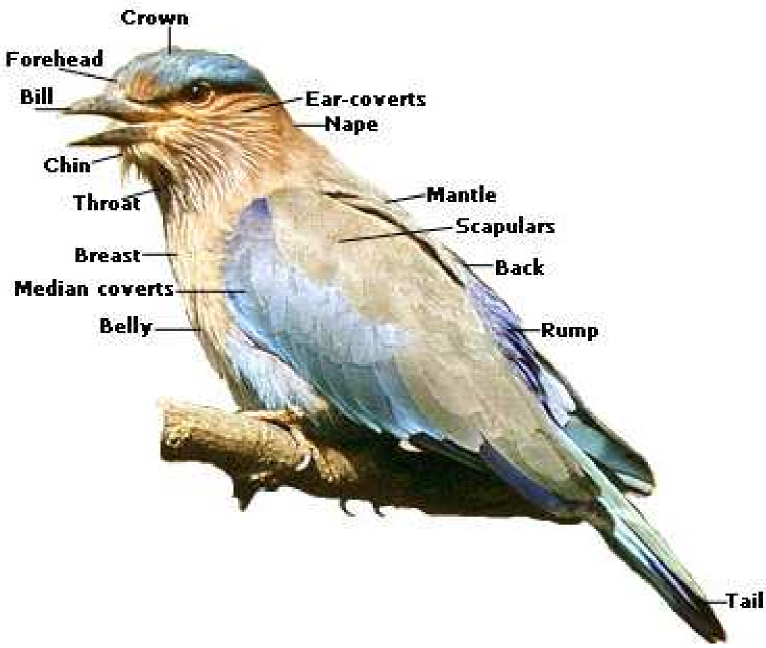
Table 6: Methods for physicochemical and biological analysis

PARAMETERS	METHOD USED	TOLERANCE LIMIT*	
		Drinking	Inland waters
Physical:			
Turbidity, NTU	Turbidity tube method	10	-
Water temperature, ^{0}C	Temperature sensitive probe	-	40
Air temperature, ^{0}C	Mercury thermometer	-	-
EC, µS/cm	Electrometric method	-	-
TDS, mg/L	Electrometric method	500	200
Chemical:			
pH	Electrometric method	6.5 to 8.5	5.5 to 9.0
Free CO_2, mg/L	Titrimetric method	-	-
DO, mg/L	Winkler's iodometric method	6.0	3.0
Chlorides, mg/L	Titrimetric method	250	1000
Total alkalinity, mg/L	Titrimetric method	200	-
Total hardness, mg/L	Titrimetric method	300	-
Calcium hardness, mg/L	Titrimetric method	75	-
Magnesium hardness, mg/L	Titrimetric method	30	-
Sulphates, mg/L	Spectrophotometric method	150	1000
Nitrates, mg/L	Spectrophotometric method	45	100
Phosphates, mg/L	Spectrophotometric method	-	5
Sodium, mg/L	Flame photometric method	-	-
Potassium, mg/L	Flame photometric method	-	-
Mercury, mg/L	Spectrophotometric method	0.001	0.01
Chromium, mg/L	Spectrophotometric method	0.05	0.1
Iron, mg/L	Spectrophotometric method	0.3	-
Biological:			
Coliforms	Hydrogen sulphide strip test	-	-

*** -** The tolerance limit is as prescribed by the Indian Standards Institution (IS 10500-1989).

BIRDS

Birds are one of the most widely studied and the best biological indicators because they are easy to identify, compared to many of the other class of organisms and virtually inhabit all the kinds of habitat. Because of their omnipresence, the attractive colour and the characteristic vocal calls, they have attracted many of the scientist and amateurs in field of ornithology and today the best of the field guides are available for identifying birds.



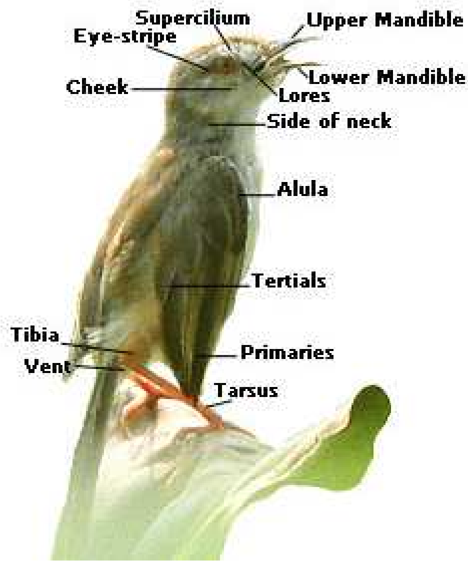


Fig.22: Body parts of Birds
Image Source: http://www.kolkatabirds.com/topography.htm

Table 7: Data sheet for bird survey

Data Sheet No:

Name of the Observers:

Date
Start time: End time:
Count Type:

Start	Lat.	Long.	Alt.
End	Lat.	Long.	Alt.

Habitat: Deciduous forest/Plantation/ Farm land/ Grass land/ Barren land/ Water body
Notes about Habitat:

Sr. no.	Name of the bird	Frequency	Special remarks (if any)

ECOLOGICAL MEASUREMENTS

A number of basic measurements are used in describing population and communities. Among these are density, frequency, coverage and biomass. Other important ecological measurements such as population distribution, species diversity and productivity are made from these.

Diversity is an indicator of status of an ecosystem. It consists of two components, the variety and the relative abundance of species. The higher value indicates higher diversity. Diversity is estimated using the Shannon-Weiner and Simpson methods. Various indices that are used in the biodiversity studies, which include both flora and fauna, are listed in Table 4.

Table 8. Diversity parameters and indices commonly used in Ecological studies.

Index	Equation	Remarks	References
Density	$\frac{\text{Number of species A}}{\text{Area sampled (m}^2\text{)}}$	Compactness with which a species exists in an area.	Elzinga et al, (2001)
Relative Density	$\frac{\text{Density of species A x 100}}{\text{Total density of all species}}$		
Dominance	$\frac{\text{Basal area of species A}}{\text{Area sampled (m}^2\text{)}}$	The occupancy of a species over an area	
Relative dominance	$\frac{\text{Dominance of species A x 100}}{\text{Total dominance of all species}}$		
Frequency	$\frac{\text{Number of quadrats with species A}}{\text{Total number of quadrats sampled}}$	The repeated occurrence of a species	Elzinga et al, (2001)
Relative Frequency	$\frac{\text{Frequency of species A x 100}}{\text{Total frequency of all species}}$		
Important Value Index	R. density + R. frequency + R. basal area		
Abundance	$\frac{\text{Number of individuals of a species x 100}}{\text{Number of sampling units}}$		
Numerical Species richness	$(S-1)/(\log N)$	It is the numerical estimation of species richness dependent on	Margalef (1958), Ludwig and

		sample size. But it completely ignores the composition and misses information of rare and commonness of a species.	Reynolds (1988)
Shannon Weiner's	$H' = -\sum_{i=1}^{s} p_i \ln p_i$	The value ranges between 1.5 and 3.5 and rarely surpasses 4.5.	Ludwig and Reynolds (1988); Legendre and Legendre 1998
Simpson's	$D = \frac{\sum n_i(n_i - 1)}{N(N-1)}$ or $D = 1 - \sum_{i=1}^{s} p_i^2$ Or $D = 1 \Big/ \sum_{i=1}^{s} p_i^2$	The value varies from 0 to 1. A value of 0 indicates the presence of only one species, while 1 means that all species are equally represented.	Ludwig and Reynolds (1988)

Ref: Ramachandra T.V., Subash Chandran M D., Gururaja K V and Sreekantha, 2007. Cumulative Environmental Impact .Assessment, Nova Science Publishers, New York

RESTORATION OF AQUATIC ECOSYSTEM

Restoration is the "return of an ecosystem to a close approximation of its condition prior to disturbance" or the reestablishment of predisturbance aquatic functions and related physical, chemical and biological characteristics. It is holistic process not achieved through the isolated manipulation of individual elements. The objective is to emulate a natural, self-regulating system that is integrated ecologically with the landscape that occurs. Often, restoration requires one or more of the following processes: reconstruction of antecedent physical conditions, chemical adjustment of the soil and water; and biological manipulation, including the reintroduction of absent native flora and fauna.

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values is to be considered. Coordination with the local people and organizations that may be affected by the project can help built the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with all stakeholders can also add useful resources, ranging from finance and technical expertise to volunteer help with implementation and monitoring (Ramachandra T.V., 2001). Restoration principles are

- **Preserve and protect aquatic resources:** Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems.
- **Restore ecological integrity:** Ecological integrity refers to the condition of an ecosystem – particularly the structure, composition and natural processes of biotic communities and physical environment.
- **Restore natural structure:** Many aquatic resources in need of restoration have problems originated with harmful alteration physical characteristics, which in turn may have led to problems such as habitat degradation and siltation.
- **Restore natural function:** Structure and function are closely linked in river, wetlands and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions.
- **Work within the catchment area:** Restoration requires a design based not only on the lake but also on it's catchment area. Activities throughout the catchment area of a lake play have an adverse effect on the water body since the catchment determines the quality and quantity of runoff to the lake.
- **Address on going causes of degradation:** Identify the causes of degradation and eliminate or remediate ongoing stresses whenever possible.
- **Develop clear, achievable and measurable goals:** Goals direct implementation and provide the standards for measuring success. The chosen goals should be achievable ecologically, given the natural potential of the area,

and socio-economically, given the available resources and the extent of community support for the project.

- **Focus on feasibility** taking into account scientific, financial, social, and other considerations.
- **Anticipate future changes:** As the environment and our communities are both dynamic, many foreseeable ecological and societal changes should be factored into restoration design.
- **Involve the skills and insights of a multi-disciplinary team:** Universities, government agencies, and private organizations may be able to provide useful information and expertise to help ensure that restoration projects are based on well-balanced and thorough plans.
- **Design for self-sustainability:** Ensure the long-term viability of a restored area by minimizing the need for continuous maintenance of the site. In addition to limiting the need for maintenance, designing for self-sustainability also involves favouring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.
- **Use passive restoration, when appropriate:** Simply reducing or eliminating the sources of degradation and allowing recovery time to allow the site to naturally regenerate. Passive restoration relies mainly on natural processes and it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.
- **Restore native species and avoid non-native species:** Many invasive species out compete natives because they are expert colonizers of disturbed areas and lack natural controls. Invasive species cause undesirable structural changes to the ecosystem.
- **Use natural fixes and bioengineering techniques, where possible:** Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce, functioning systems to prevent erosion, control sediment and other pollutants, and provide habitat. These techniques would be successful for erosion control and shoreline stabilization, flood mitigation and even water treatment.
- **Monitor and adapt where changes are necessary:** Monitoring program is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the projects should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

THE TWENTY COMMONEST CENSUS SINS IN ECOLOGY

(Source: William J Sutherland – School of biological sciences, University of East Anglia, Norwich NR4 7TJ, UK).

1. Not Sampling Randomly: It is very satisfying to sample rarities or rich patches but it ruins the exercise. One common error is just to visit the best sites and use the data to estimate the population size.
2. Collecting far more samples than can possibly be analysed.
3. Changing the methodology in monitoring unless there is a careful comparison of the different methods, changing the methodology prevents comparison between the years.
4. Counting the same individuals in two locations and counting it as two individuals.
5. Not knowing your species: knowing your species is essential for considering biases and understanding the data.
6. Not having controls in management experiments. This is the greatest problem in interpreting the consequences in management.
7. Not storing information from where it can be retrieved in the future.
8. Not giving precise information as to where sampling occurred:- Give date and precise location. Site 'A', behind the tree' of 'near to the road' may be sufficient now but mean nothing later.
9. Counting in one or more or a few large areas rather than a large number of small ones:- A single count gives no measure of the natural variation and it is then hard to see how significant any changes are. This also applies to quadrats.
10. Not being honest about the methods used:- If you only survey butterflies on warm still days or place small mammal traps in the location most like to be successful then this is fine but say so. Someone else surveying on all days or randomly locating traps, may otherwise conclude that the species has declined.
11. Believing the results: - Practically every census has biases and inaccuracies. The secrete is to evaluate how much these matter.
12. Believing that the density of trapped individuals is the same as the absolute density.
13. Not thinking about how your will analyse your data before collecting it.
14. Assuming you know where you are: - This can be one problem when marking individuals on maps or even when censusing areas, e.g. a one-kilometer square kilometer marked on a map. Population overestimates can result from incorrectly marking the same individuals as occupying very different locations or by surveying a larger block than intended.
15. Assuming sample efficiency is similar in different habitats:- Difference in physical structure or vegetation structure will influence almost every censusing technique and thus confound comparisons.
16. Thinking that someone else will identify all your samples for you.

17. Not knowing why you are censusing: - Think exactly what the question is and that what data you need to answer it. It is nice to collect additional data but will this slow down the project so that the objectives are not accomplished?
18. Deviating from transect routes:- On one reserve the numbers of green Hairstreaks Callophyrus rubi seen on the butterfly-monitoring transect increased markedly one year. It turned out that this was because the temporary warden that year climbed through the hedge to visit the colony on the far side.
19. Not having a large enough area for the numbers to be meaningful; If it is impossible to have a large enough area then question whether the effort might not be better spent on another project.
20. Assuming others will collect data exactly in the same manner and with the same enthusiasm. The international Biological Programme gave very specific instructions, yet it was hard to make such sense of data because the slight differences in interpretation led to a very different results.

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ANNEXURE

National Water Policy

Ministry of Water Resources April 1, 2002

Government of India
Ministry of Water Resources
NATIONAL WATER POLICY
New Delhi
April, 2002

Ministry of Water Resources 1 April 1, 2002

Need for a National Water Policy

1.1. Water is a prime natural resource, a basic human need and a precious national asset. Planning, development and management of water resources need to be governed by national perspectives.

1.2. As per the latest assessment (1993), out of the total precipitation, including snowfall, of around 4000 billion cubic metre in the country, the availability from surface water and replenishable ground water is put at 1869 billion cubic metre. Because of topographical and other constraints, about 60% of this i.e. 690 billion cubic metre from surface water and 432 billion cubic metre from ground water, can be put to beneficial use. Availability of water is highly uneven in both space and time. Precipitation is confined to only about three or four months in a year and varies from 100 mm in the western parts of Rajasthan to over. 10000 mm at Cherrapunji in Meghalaya. Rivers and under ground aquifers often cut across state boundaries. Water, as a resource is one and indivisible: rainfall, river waters, surface ponds and lakes and ground water are all part of one system.

1.3. Water is part of a larger ecological system. Realising the importance and scarcity attached to the fresh water, it has to be treated as an essential environment for sustaining all life forms.

1.4. Water is a scarce and precious national resource to be planned, developed, conserved and managed as such, and on an integrated and environmentally sound basis, keeping in view the socio-economic aspects and needs of the States. It is one of the most crucial elements in developmental planning. As the country has entered the 21st century, efforts to develop, conserve, utilise and manage this important resource in a sustainable manner, have to be guided by the national perspective.

1.5. Floods and droughts affect vast areas of the country, transcending state boundaries. One-sixth area of the country is drought-prone. Out of 40 million hectare of the flood prone area in the country, on an average, floods affect an area of around 7.5 million hectare per year. Approach to management of droughts and floods has to be co-ordinated and guided at the national level.

1.6. Planning and implementation of water resources projects involve a number of socio-economic aspects and issues such as environmental sustainability, appropriate resettlement and rehabilitation of project-affected people and livestock, public health concerns of water impoundment, dam safety etc. Common approaches and guidelines are necessary on these matters. Moreover, certain problems and weaknesses have affected a large number of water resources projects all over the country. There have been substantial time and cost overruns on projects. Problems of water logging and soil salinity have emerged in some irrigation commands, leading to the degradation of agricultural land. Complex issues of equity and social justice in regard to water distribution are required to be addressed. The development, and over-exploitation of groundwater resources in certain parts of the country have raised the concern and need for judicious and scientific resource management and conservation. All these concerns need to be addressed on the basis of common policies and strategies.

1.7. Growth process and the expansion of economic activities inevitably lead to increasing demands for water for diverse purposes: domestic, industrial, agricultural, hydro-power, thermal-power, navigation, recreation, etc. So far, the major consumptive use of water has been for irrigation. While the gross irrigation potential is estimated to have increased from 19.5 million hectare at the time of independence to about 95 million hectare by the end of the Year 1999-2000, further development of a substantial order is necessary if the food and fiber needs of our growing population are to be met with. The country's population which is over 1027 million (2001 AD) at present is expected to reach a level of around 1390 million by 2025 AD.

1.8. Production of food grains has increased from around 50 million tonnes in the fifties to about 208 million tonnes in the Year 1999-2000. This will have to be raised to around 350 million tonnes by the year 2025 AD. The drinking water needs of people and livestock have also to be met. Domestic and industrial water needs have largely been concentrated in or near major cities. However, the demand in rural areas is expected to increase sharply as the development programmes improve economic conditions of the rural masses. Demand for water for hydro and thermal power generation and for other industrial uses is also increasing substantially. As a result, water, which is already a scarce resource, will become even scarcer in future. This underscores the need for the utmost efficiency in water utilisation and a public awareness of the importance of its conservation.

1.9. Another important aspect is water quality. Improvements in existing strategies, innovation of new techniques resting on a strong science and technology base are needed to eliminate the pollution of surface and ground water resources, to improve water quality. Science and technology and training have to play important roles in water resources development and management in general.

1.10. National Water Policy was adopted in September, 1987. Since then, a number of issues and challenges have emerged in the development and management of the water resources. Therefore, the National Water Policy (1987) has been reviewed and updated.

Information System

2.1 A well developed information system, for water related data in its entirety, at the national / state level, is a prime requisite for resource planning. A standardised national information system should be established with a network of data banks and data bases, integrating and strengthening the existing Central and State level agencies and improving the quality of data and the processing capabilities.

2.2 Standards for coding, classification, processing of data and methods / procedures for its collection should be adopted. Advances in information technology must be introduced to create a modern information system promoting free exchange of data among various agencies. Special efforts should be made to develop and continuously upgrade technological capability to collect, process and disseminate reliable data in the desired time frame.

2.3 Apart from the data regarding water availability and actual water use, the system should also include comprehensive and reliable projections of future demands of water for diverse purposes.

Water Resources Planning

3.1 Water resources available to the country should be brought within the category of utilisable resources to the maximum possible extent.

3.2 Non-conventional methods for utilisation of water such as through inter-basin transfers, artificial recharge of ground water and desalination of brackish or sea water as well as traditional water conservation practices like rainwater harvesting, including roof-top rainwater harvesting, need to be practiced to further increase the utilisable water resources. Promotion of frontier research and development, in a focused manner, for these techniques is necessary.

3.3 Water resources development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin, multi-sectorally, taking into account surface and ground water for sustainable use incorporating quantity and quality aspects as well as environmental considerations. All individual developmental projects and proposals should be formulated and considered within the framework of such an overall plan keeping in view the existing agreements / awards for a basin or a sub-basin so that the best possible combination of options can be selected and sustained.

3.4 Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted. Efforts shall be to conserve the water in the catchment.

3.5 Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another, based on a national perspective, after taking into account the requirements of the areas / basins.

Institutional Mechanism

4.1 With a view to give effect to the planning, development and management of the water resources on a hydrological unit basis, along with a multi-sectoral, multi-disciplinary and participatory approach as well as integrating quality, quantity and the environmental aspects, the existing institutions at various levels under the water resources sector will have to be appropriately reoriented / reorganised and even created, wherever necessary. As maintenance of water resource schemes is under non-plan budget, it is generally being neglected. The institutional arrangements should be such that this vital aspect is given importance equal or
even more than that of new constructions.

4.2 Appropriate river basin organisations should be established for the planned development and management of a river basin as a whole or sub-basins, wherever necessary. Special multi-disciplinary units should be set up to prepare comprehensive plans taking into account not only the needs of irrigation but also harmonising various other water uses, so that the available water resources are determined and put to optimum use having regard to existing agreements or awards of Tribunals under the relevant laws. The scope and powers of the river basin organisations shall be decided by the basin states themselves.

Water Allocation Priorities

5. In the planning and operation of systems, water allocation priorities should be broadly as follows:

· Drinking water
· Irrigation
· Hydro-power
· Ecology
· Agro-industries and non-agricultural industries
· Navigation and other uses.

However, the priorities could be modified or added if warranted by the area / region specific
considerations.

Project Planning

6.1 Water resource development projects should as far as possible be planned and developed as multipurpose projects. Provision for drinking water should be a primary consideration.
6.2 The study of the likely impact of a project during construction and later on human lives, settlements, occupations, socio-economic, environment and other aspects shall form an essential component of project planning.
6.3 In the planning, implementation and operation of a project, the preservation of the quality of environment and the ecological balance should be a primary consideration. The adverse impact on the environment, if any, should be minimised and should be offset by adequate compensatory measures. The project should, nevertheless, be sustainable.
6.4 There should be an integrated and multi-disciplinary approach to the planning, formulation, clearance and implementation of projects, including catchment area treatment and management, environmental and ecological aspects, the rehabilitation of affected people and command area development. The planning of projects in hilly areas should take into account the need to provide assured drinking water, possibilities of hydro-power development and the proper approach to irrigation in such areas, in the context of physical features and constraints of the basin such as steep slopes, rapid run-off and the incidence of soil erosion. The economic evaluation of projects in such areas should also take these factors into account.
6.5 Special efforts should be made to investigate and formulate projects either in, or for the benefit of, areas inhabited by tribal or other specially disadvantaged groups such as socially weak, scheduled castes and scheduled tribes. In other areas also, project planning should pay special attention to the needs of scheduled castes and scheduled tribes and other weaker sections of the society. The economic evaluation of projects benefiting such disadvantaged sections should also take these factors into account.
6.6 The drainage system should form an integral part of any irrigation project right from the planning
stage.
6.7 Time and cost overruns and deficient realisation of benefits characterising most water related projects should be overcome by upgrading the quality of project preparation and management. The inadequate funding of projects should be obviated by

an optimal allocation of resources on the basis of prioritisation, having regard to the early completion of on-going projects as well as the need to reduce regional imbalances.
6.8 The involvement and participation of beneficiaries and other stakeholders should be encouraged right from the project planning stage itself.

Ground Water Development
7.1 There should be a periodical reassessment of the ground water potential on a scientific basis, taking into consideration the quality of the water available and economic viability of its extraction.
7.2 Exploitation of ground water resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity. The detrimental environmental consequences of over-exploitation of ground water need to be effectively prevented by the Central and State Governments. Ground water recharge projects should be developed and implemented for improving both the quality and availability of ground water resource.
7.3 Integrated and coordinated development of surface water and ground water resources and their conjunctive use, should be envisaged right from the project planning stage and should form an integral part of the project implementation.
7.4 Over exploitation of ground water should be avoided especially near the coast to prevent ingress of seawater into sweet water aquifers.

Drinking Water
8. Adequate safe drinking water facilities should be provided to the entire population both in urban and in rural areas. Irrigation and multipurpose projects should invariably include a drinking water component, wherever there is no alternative source of drinking water. Drinking water needs of human beings and animals should be the first charge on any available water.

Irrigation
9.1 Irrigation planning either in an individual project or in a basin as a whole should take into account the irrigability of land, cost-effective irrigation options possible from all available sources of water and appropriate irrigation techniques for optimising water use efficiency. Irrigation intensity should be such as to extend the benefits of irrigation to as large a number of farm families as possible, keeping in view the need to maximise production.
9.2 There should be a close integration of water-use and land-use policies.
9.3 Water allocation in an irrigation system should be done with due regard to equity and social justice. Disparities in the availability of water between head-reach and tail-end farms and between large and small farms should be obviated by adoption of a rotational water distribution system and supply of water on a volumetric basis subject to certain ceilings and rational pricing.
9.4 Concerted efforts should be made to ensure that the irrigation potential created is fully utilised. For this purpose, the command area development approach should be adopted in all irrigation projects.
9.5 Irrigation being the largest consumer of fresh water, the aim should be to get optimal productivity per unit of water. Scientific water management, farm practices and sprinkler and drip system of irrigation should be adopted wherever feasible.
9.6 Reclamation of water logged / saline affected land by scientific and cost-effective methods should form a part of command area development programme.

Resettlement and Rehabilitation

10. Optimal use of water resources necessitates construction of storages and the consequent resettlement and rehabilitation of population. A skeletal national policy in this regard needs to be formulated so that the project affected persons share the benefits through proper rehabilitation. States should accordingly evolve their own detailed resettlement and rehabilitation policies for the sector, taking into account the local conditions. Careful planning is necessary to ensure that the construction and rehabilitation activities proceed simultaneously and smoothly.

Financial and Physical Sustainability

11. Besides creating additional water resources facilities for various uses, adequate emphasis needs to be given to the physical and financial sustainability of existing facilities. There is, therefore, a need to ensure that the water charges for various uses should be fixed in such a way that they cover at least the operation and maintenance charges of providing the service initially and a part of the capital costs subsequently. These rates should be linked directly to the quality of service provided. The subsidy on water rates to the disadvantaged and poorer sections of the society should be well targeted and transparent.

Participatory Approach to Water Resources Management

12. Management of the water resources for diverse uses should incorporate a participatory approach; by involving not only the various governmental agencies but also the users and other stakeholders, in an effective and decisive manner, in various aspects of planning, design, development and management of the water resources schemes. Necessary legal and institutional changes should be made at various levels for the purpose, duly ensuring appropriate role for women. Water Users' Associations and the local bodies such as municipalities and gram panchayats should particularly be involved in the operation, maintenance and management of water infrastructures / facilities at appropriate levels progressively, with a view to eventually transfer the management of such facilities to the user groups / local bodies.

Private Sector Participation

13. Private sector participation should be encouraged in planning, development and management of water resources projects for diverse uses, wherever feasible. Private sector participation may help in introducing innovative ideas, generating financial resources and introducing corporate management and improving service efficiency and accountability to users. Depending upon the specific situations, various combinations of private sector participation, in building, owning, operating, leasing and transferring of water resources facilities, may be considered.

Water Quality

14.1 Both surface water and ground water should be regularly monitored for quality. A phased programme should be undertaken for improvements in water quality.

14.2 Effluents should be treated to acceptable levels and standards before discharging them into natural streams.

14.3 Minimum flow should be ensured in the perennial streams for maintaining ecology and social considerations.

14.4 Principle of 'polluter pays' should be followed in management of polluted water.

14.5 Necessary legislation is to be made for preservation of existing water bodies by preventing encroachment and deterioration of water quality.

Water Zoning

15. Economic development and activities including agricultural, industrial and urban development, should be planned with due regard to the constraints imposed by the configuration of water availability. There should be a water zoning of the country and the economic activities should be guided and regulated in accordance with such zoning.

Conservation of Water

16.1 Efficiency of utilisation in all the diverse uses of water should be optimised and an awareness of water as a scarce resource should be fostered. Conservation consciousness should be promoted through education, regulation, incentives and disincentives.

16.2 The resources should be conserved and the availability augmented by maximising retention, eliminating pollution and minimising losses. For this, measures like selective linings in the conveyance system, modernisation and rehabilitation of existing systems including tanks, recycling and re-use of treated effluents and adoption of traditional techniques like mulching or pitcher irrigation and new techniques like drip and sprinkler may be promoted, wherever feasible.

Flood Control and Management

17.1 There should be a master plan for flood control and management for each flood prone basin.

17.2 Adequate flood-cushion should be provided in water storage projects, wherever feasible, to facilitate better flood management. In highly flood prone areas, flood control should be given overriding consideration in reservoir regulation policy even at the cost of sacrificing some irrigation or power benefits.

17.3 While physical flood protection works like embankments and dykes will continue to be necessary, increased emphasis should be laid on non-structural measures such as flood forecasting and warning, flood plain zoning and flood proofing for the minimisation of losses and to reduce the recurring expenditure on flood relief.

17.4 There should be strict regulation of settlements and economic activity in the flood plain zones along with flood proofing, to minimise the loss of life and property on account of floods.

17.5 The flood forecasting activities should be modernised, value added and extended to other uncovered areas. Inflow forecasting to reservoirs should be instituted for their effective regulation.

Land Erosion by Sea or River

18.1 The erosion of land, whether by the sea in coastal areas or by river waters inland, should be minimised by suitable cost-effective measures. The States and Union Territories should also undertake all requisite steps to ensure that indiscriminate occupation and exploitation of coastal strips of land are discouraged and that the location of economic activities in areas adjacent to the sea is regulated.

18.2 Each coastal State should prepare a comprehensive coastal land management plan, keeping in view the environmental and ecological impacts, and regulate the developmental activities accordingly.

Drought-prone Area Development

19.1 Drought-prone areas should be made less vulnerable to drought-associated problems through soil-moisture conservation measures, water harvesting practices, minimisation of evaporation losses, development of the ground water potential including recharging and the transfer of surface water from surplus areas where feasible and appropriate. Pastures, forestry or other modes of development which are relatively less water demanding should be encouraged. In planning water resource development projects, the needs of drought-prone areas should be given priority.

19.2 Relief works undertaken for providing employment to drought-stricken population should preferably be for drought proofing.

Monitoring of Projects

20.1 A close monitoring of projects to identify bottlenecks and to adopt timely measures to obviate time and cost overrun should form part of project planning and execution.

20.2 There should be a system to monitor and evaluate the performance and socio-economic impact of the project.

Water Sharing / Distribution amongst the States

21.1 The water sharing / distribution amongst the states should be guided by a national perspective with due regard to water resources availability and needs within the river basin. Necessary guidelines, including for water short states even outside the basin, need to be evolved for facilitating future agreements amongst the basin states.

21.2 The Inter-State Water Disputes Act of 1956 may be suitably reviewed and amended for timely adjudication of water disputes referred to the Tribunal.

Performance Improvement

22. There is an urgent need of paradigm shift in the emphasis in the management of water resources sector. From the present emphasis on the creation and expansion of water resources infrastructures for diverse uses, there is now a need to give greater emphasis on the improvement of the performance of the existing water resources facilities. Therefore, allocation of funds under the water resources sector should be re-prioritised to ensure that the needs for development as well as operation and maintenance of the facilities are met.

Maintenance and Modernisation

23.1 Structures and systems created through massive investments should be properly maintained in good health. Appropriate annual provisions should be made for this purpose in the budgets.

23.2 There should be a regular monitoring of structures and systems and necessary rehabilitation and modernisation programmes should be undertaken.

23.3 Formation of Water Users' Association with authority and responsibility should be encouraged to facilitate the management including maintenance of irrigation system in a time bound manner.

Safety of Structures

24. There should be proper organisational arrangements at the national and state levels for ensuring the safety of storage dams and other water-related structures consisting of

specialists in investigation, design, construction, hydrology, geology, etc. A dam safety legislation may be enacted to ensure proper inspection, maintenance and surveillance of existing dams and also to ensure proper planning, investigation, design and construction for safety of new dams. The Guidelines on the subject should be periodically updated and reformulated. There should be a system of continuous surveillance and regular visits by experts.

Science and Technology

25. For effective and economical management of our water resources, the frontiers of knowledge need to be pushed forward in several directions by intensifying research efforts in various areas, including the following:

- hydrometeorology;
- snow and lake hydrology;
- surface and ground water hydrology;
- river morphology and hydraulics;
- assessment of water resources;
- water harvesting and ground water recharge;
- water quality;
- water conservation;
- evaporation and seepage losses;
- recycling and re-use;
- better water management practices and improvements in operational technology;
- crops and cropping systems;
- soils and material research;
- new construction materials and technology (with particular reference to roller compacted concrete, fiber reinforced concrete, new methodologies in tunneling technologies, instrumentation, advanced numerical analysis in structures and back analysis);
- seismology and seismic design of structures;
- the safety and longevity of water-related structures;
- economical designs for water resource projects;
- risk analysis and disaster management;
- use of remote sensing techniques in development and management;
- use of static ground water resource as a crisis management measure;
- sedimentation of reservoirs;
- use of sea water resources;
- prevention of salinity ingress;
- prevention of water logging and soil salinity;
- reclamation of water logged and saline lands;
- environmental impact;
- regional equity.

Training

26. A perspective plan for standardised training should be an integral part of water resource development. It should cover training in information systems, sectoral planning, project planning and formulation, project management, operation of projects and their physical structures and systems and the management of the water distribution systems. The

training should extend to all the categories of personnel involved in these activities as also the farmers.

Conclusion

27. In view of the vital importance of water for human and animal life, for maintaining ecological balance and for economic and developmental activities of all kinds, and considering its increasing scarcity, the planning and management of this resource and its optimal, economical and equitable use has become a matter of the utmost urgency. Concerns of the community need to be taken into account for water resources development and management. The success of the National Water Policy will depend entirely on evolving and maintaining a national consensus and commitment to its underlying principles and objectives. To achieve the desired objectives, State Water Policy backed with an operational action plan shall be formulated in a time bound manner say in two years. National Water Policy may be revised periodically as and when need arises.

LAKE 2000 Recommendations

A number of scientific papers had been presented by scientists from India and abroad on different aspects of wetlands, including energetics, nutrient cycling, biodiversity, disease and health of the biota (particularly the fishes), sustainable utilization, management and conservation of the wetlands and their biota, reclamation & restoration of the wetlands & their modeling.

On the basis of discussions and deliberations held in the Symposium, the following recommendations are unanimously adopted:

1. The Symposium recommends integration of different Government Agencies for effective implementation of activities related to restoration of wetlands, their sustainable utilization & conservation.
2. It is recommended that a National Committee for Lakes and Wetlands reclamation, restoration & development be formed to formulate a National Policy to evolve strategies for their sustainable utilization and c conservation (Funds be made available from National & International sources to the Centre for Ecological Sciences, Indian Institute of Science, to go ahead with the restoration of the Lakes in collaboration with National & International Organizations in view of the importance of Lakes and Wetlands in rural development).
3. A Comprehensive Plan be prepared to study selective, representative Wetlands in a phased manner to create database with regard to their present status, sustainable use, management and conservation and to formulate strategies for their long term management. Regular monitoring of ecosystems through the involvement of Schools, Colleges & Universities. (For this purpose, funds be made available to Centre for Ecological Sciences, Indian Institute of Science, Bangalore to implement proposal in collaboration with National and International Organizations.).
4. A Comprehensive Action Plan be chalked out immediately for taking care of health, disease and quarantine aspects of the aquatic biota. The aspects assume importance in view of the still persisting virulent disease like Epizootic Ulcerative Syndrome (EUS) among the freshwater fishes of India . A National Committee be formed to tackle such health and disease problems among the aquatic biota which has been a concern to the society as a whole. The committee is entrusted to find ways and means to control the epidemic.
5. India being a Megadiversity region, with hotspots in Western Ghats and North Eastern regions, a comprehensive action plan be chalked out to study the aquatic biodiversity of the inland water bodies of the country. Centre for Ecological Sciences (CES) be entrusted to co-ordinate the aspect with collaboration at National and International levels.
6. Mass awareness programme be chalked out and implemented through Governmental and Non-Governmental Organisations(NGO)for popularization of the importance of the lakes, wetlands and rivers, and their role in the aquatic biodiversity and sustenance of human civilization. CES be entrusted to co-ordinate the aspect with collaboration from Governmental and Non Governmental Organization at National and International levels.
7. Lakes & Ponds in each Zilla Panchayath area be identified and their streams recharged through peoples participation. People should be made aware of

their significance so that reclamation and conservation of these water bodies be taken up effectively.

8. Temporary ponds be identified and their diversity explored to delineate their contribution to the society.
9. People's watchdog team to stop the dumping of wastes into water bodies and the catchment area protection. Steps should be taken to bring in aesthetic sense among the public which will help protect the lakes.
10. Fishermen's socio - economic aspects to be taken into consideration while formulating wetland policies.
11. Student's involvement including curriculum development concerning the protection of the ecosystem.
12. Ownership and legal status of lakes and the inhabitants around to be properly defined.
13. Easy access for scientists and students to investigate the status of wetlands in protected areas. Free access of data, Survey of India toposheets, along with GIS and Remote Sensing data be made available.
14. Introduction of exotic fishes into lakes to be permitted only after clearance from Fishery experts.
15. Education and training: Participants strongly felt that the public needs to be better informed about the rationale, goals and methods of aquatic ecosystem restorations. In addition, scientists and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation are in short supply. Lake 2000 recommends are following :

    Public education and outreach should be components of aquatic ecosystem restorations. Lake Associations and citizen monitoring groups have proved helpful in educating the general public, and effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

    Funding is needed for both undergraduate and graduate programmes in aquatic ecosystem restorations. Training programmes should cause traditional disciplinary boundaries such as those between basic and applied ecology : between water quality management and fisheries or wildlife management : among lakes, streams, river, coastal wetlands and wetland ecology. In this regard Lake 2000 recommends:

    - Organizing three to four week training course in the year 2001. Training modules include aspects of,
        - Limnology of lakes, reservoirs and wetlands
        - Coastal wetlands
        - Watershed hydrology/Urban hydrology.
        - Ground water and hydrogeology
        - Monitoring and modeling
        - Restoration methodologies and conservation strategies.
        - Remediation measures.
        - Integrated management of water quality and quantity with ecosystem protection.
        - Land use, urban planning, Geographic Information System, Remote sensing.
        - Sustainable water resources management and water resources policy.

Organizing an International Symposium in November/December 2002 to discuss Research needs for the restoration conservation and management of wetlands.

16. The National and State Governments should support research and development, watershed-scale restorations that integrate lake, stream and wetland components. State agencies, Non-Governmental organizations and University researchers should participate in planning, implementing and evaluating restoration projects. In addition, an inter-agency programme under Karnataka State Council for Science and Technology could be formed to co-ordinate the selection, planning and evaluation of these pilot projects. The research and implementation of the projects could be managed by the participating agencies.
17. Lake 2000 believes that goals for restoration of lakes need to be realistic and should be based on the concept of expected conditions for individual eco-regions. Further development of project selection and evaluation technology based on eco-region definitions and description should be encouraged and supported by the national and state government agencies.

Research and development are needed in several areas of applied limnology, and this programme should take an experimental approach which emphasizes manipulation of whole ecosystems. Improved techniques for littoral zone and aquatic microphytes management need to be developed. Research should go beyond the removal of nuisance microphytes to address the restoration of native species that are esse ntial for waterfowl and fish habitat . Basic research is necessary to improve understanding of fundamental limnological processes in littoral zones and the interactions between littoral and pelagic zones of lakes.

Biomanipulation (foodweb management) has great potential for low-cost and long-term management of lakes, and research in this emerging field must be stimulated. Innovative and low-cost approaches to contaminant clean up in lakes need to be developed.

The relations between loadings of stress-causing substances and responses of lakes need to be understood more precisely. Research should be undertaken to improve predictions of trophic state and nutrient loading relationships.

Improved assessment programmes are needed to determine the severity and extent of damage in lakes and wetlands and a change in status over time. Innovative basicresearch is required to improve the science of assessment and monitoring. There is a great need for cost effective, reliable indicators of ecosystems function, including those that would reflect long-term change and response to stress. Research on indicators should include traditional community and ecosystem measurements, paleoecological trend assessments and remote sensing. Effective assessment and monitoring programme would involve network of local schools , colleges and

Procedures such as food web manipulation, introduction of phytophagous, insects and fish lining, and reintroduction of native species show promise for effective and long-lasting results when used alone or in combination with other restoration measures. Further research and development needs to be undertaken on these aspects.

Paleolimnological approaches should be used to infer the past trophic history of lakes and wetlands and to decide whether these systems should be restored. Paleolimnological approaches also could be used to infer whether a lake has been restored to its predisturbance condition.

Wetland Policy Guidelines

The objective of policy with respect to wetland conservation is:
To promote the conservation of wetlands to sustain their ecological and socio-economical functions , now and in the future. Towards this end, the goals are,

- Maintenance of the functions and values derived from wetlands;
- No net loss of wetland functions on regional lands and water;
- Enhancement and rehabilitation of wetlands where the continued loss or degradation of wetlands or their functions have reached critical levels;
- Recognition of wetland functions in resource planning, management and economic decision making with regard to all national/state programmes, policies and activities;
- Securement of wetlands of significance;
- Recognition of sound, sustainable management practices in sectors such as forestry and agriculture that make positive contribution to wetland conservation while also achieving wise use of wetland resources;
- Utilization of wetlands in a manner that enhances prospects;

The proposed strategies in this regard are,

i. Developing public awareness.
ii. Managing wetlands on State lands and water,and in other State programmes.
iii. Promote the wetland conservation in State protected areas.
iv. Enhancing co-operation among State, District, Regional and Non Government partners.
v. Conserving wetlands of significance.
vi. Ensuring a sound scientific basis for policy.

The wetland policy at State level provides:

- A signal of commitment to wetland conservation and adds as a catalyst for mutually supporting action across the region;
- A heightened profile for the issue to call attention to wetland, socio-economic and environmental benefits, to ensure that wetlands receive adequate consideration by the State government;
- Direction and support for individual decision makers to ensure that opportunity for the sustained wise use of wetlands is realized, to avoid or reserve wetland related conflicts;
- Clarification of specific State responsibility for wetlands, as well as a synthesis of existing legislation, policies and programmes which already contribute to wetland conservation;

- A consistent, co-ordinated approach among the many State agencies which influence wetlands, aimed at adjusting activities which conflict with wetland conservation and ensuring progress towards specific objectives and goals.

A comprehensive policy on wetlands needs to be formulated to enhance the quality and increase spatial coverage specific to the region, to offer some of the most environmentally productive and cost effective opportunities for wetland conservation . The objectives should focus on addressing the following aspects,

* To reverse the current decline in the wetland base, ensuring no net loss and long term net gain in the quality, quantity and permanence of wetlands.
* To encourage partnerships in restoration, management, usage, through co-operative planning efforts with the primary focus on wetland conservation.
* Draft procedures for administration of wetland usage and its conservation.

The emphasis is placed on the formation of Regional Wetlands Forum,involving local educational,public and private organization (involved in wetland issue). For effective functioning, the forum should consist researchers, school and college-students and teachers , economists , policy makers, representatives from agricultural community, developmental concerns , conservation organizations, state and local agencies under the collaboration efforts from the Ministry of Forest and Environment, Ministry of Science and Technology, Indian Council for Agricultural Research and planning departments with the following responsibilities. The policy should address,

1. Defining wetlands, classification (based on degree of saturation, type of vegetation,usage,soil etc),inventory, planning, wetland regulation , and conservation approaches (i.e., acquisition, restoration, management and education).
2. Establish regional and state-wide goals to achieve long term increase in wetland acreage,functions and values in emphasizing the economic uses(fishing,agriculture,drinking water supply,etc).
3. Draft programs for preservation, conservation, restoration, and enhance wetlands acreage and provide technical and adequate funding for wetlands program.
4. In the formulation/development of consistent standards and guidelines concerning wetland water quality, mitigation and monitoring of mitigation and restoration efforts.
5. Encourage actions that promote efficiency of wetlands-related Permitting processes for the varied usage of wetlands for economic purposes (as fisheries, irrigation etc) by suitable policies and creation of concurrent permit review procedures.
6. Enhancing co-ordination of governmental (state, federal) and non- governmental organizations responsible in wetland development. Action oriented restoration and conservation programs could be initiated and monitored through discussion meetings of academicians, planning and implementing agencies for providing a platform for exchange of ideas.
7. Help in the development of internal policies within state agencies like irrigation departments, public works department, forest department, urban development and others that will encourage wetland conservation activities

which are compatible with programmatic goals of flood control, ground water recharge, water management,water pollution control, recreation and others.

8. Establishment of inter-agency task force responsible for co-ordinating and information exchange among the agencies, boards, and departments as necessary to ensure co-ordinated development and implementation of wetland conservation program
9. Integrate wetland policy and planning with other environmental and land use processes.
10. Cost-benefit analyses of the wetland resources derived by the society and economic evaluation caused due to the loss of wetlands.
11. The forum could act as an advisory to the government in providing funds for wetland research and conservation programs.
12. Formulate Wetland Protection Act as a legislative vehicle to restrict any disturbance of wetlands leading to loss in biodiversity dependent on them.

LAKE 2002 Recommendations

With firm confidence that the recommendations will lay a strong foundation for watershed conservation and restoration efforts in the days to come, Lake 2002 was successful in collecting/concluding the recent trends in conservation and restoration of lentic and lotic water system, including peoples' participation and the role of NGO's, educational and government organizations. Based on the presentations, active interaction of the presenter and the audience, and the views of the panelists at the panel discussion on 13th Dec 2002, the following recommendations were proposed:

1. Water is `life' and it is to be `conserved'. A clean aquatic ecosystem with a healthy biological community is an indicator of the condition of the terrestrial habitats in the watershed.

2. Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such as monitoring of water quality, socio-economic dependency, biodiversity and other activities, as an indispensable tool for formulating long term conservation strategies. This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at rising the levels of public awareness of aquatic ecosystems' restoration, goals and methods. Actively participating schools and colleges in the vicinity of the water bodies may value the opportunity to provide hands-on environmental education, which could entail setting up of laboratory facilities at the site. Regular monitoring of water bodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

3. Government Agencies, Academies, Institutions and NGO's must co-ordinate grass-root level implementation of policies and activities related to conservation of wetlands (both Inland and Coastal), their sustainable utilization, restoration and development including human health. There is also a need for management and conservation of aquatic biota including their health aspects. Traditional knowledge and practices have to be explored as remedial measures. Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of the wetlands.

4. National water policy shall recognize the ecological, environmental, economic and socio-cultural values of the aquatic systems.

5. To be cost effective, lake quality classification using appropriate parameters and values assigned on the best designated use of lake or lake system shall be prescribed as a policy guideline.

6. Line Agencies at the National level, like UGC, DST, DBT, MoEF, ICAR, CSIR, etc.; and at the State level, like departments of Education, Science and Technology, Forest, Agriculture, Irrigation, etc.; be suggested to integrate their activities

among themselves seeking assistance from the educational institutions and NGO's.

7. A National Committee be constituted consisting of Experts, Representatives of Stakeholders (researchers, students, industrialists, agriculturists, fishermen, etc.) and Line Agencies, in addition to the existing Committee(s), if any, in order to evolve policies and strategies for reclamation, development, sustainable utilization and restoration of the wetlands and socio-economic development of the local people.

8. At local level, Lake Management Authority (LMA) having stakeholders-representatives from central and state and local body authorities, NGO's and eminent people and experts shall be constituted with autonomy, corpus funds from plan allocations of state and center and responsibility and accountability for avoiding excessive cost and time over runs.

9. Generous funds shall be made available for such developmental works through the National Committee, as mentioned above. Local stakeholders be suggested to generate modest funds for immediate developmental needs in the aquatic systems in their localities.

10. Centre for Ecological Sciences (CES) be the Nodal Agency for capacity building at all levels: Formal and Non-formal and Govt. officials. Students should be involved in participatory management of the wetlands. Due impetus be given on equipping the institutions with qualified environmental specialists. Teachers of the local institutions shall be trained for in-turn capacity building in their own areas, in which, aquatic ecosystems especially wetlands could serve as `field laboratories'.

11. It was felt among the participants that public needs to be better informed about the rational, goal and methods of aquatic ecosystem conservation and restoration. In addition, the need was realized for scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation. In this regard Lake 2002 proposes:

    - Public education and outreach should be components of aquatic ecosystem restoration. Lake associations and citizen monitoring groups have proved helpful in educating the general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

    - Funding is needed for both undergraduate and graduate programmes in aquatic ecosystem conservation and restorations. Training programmes should cross traditional disciplinary boundaries such as those between basic and applied ecology: water quality management and fisheries or wildlife management: among lakes, streams, rivers, coastal and wetland ecology. This could be achieved through capacity building exercises and in this regard Lake 2002 suggests

- ☞ Organising two weeks training course on "Integrated watershed management with emphasis on conservation and restoration of aquatic ecosystems".
- ☞ Organising an International symposium (sequel to Lake 2002) and a national seminar to prioritise research needs for the conservation, restoration and sustainable management of aquatic ecosystems.

12. Promote documentation of aquatic biodiversity and ensure the implementation of the recommendation towards protection of wetlands through network of schools, colleges and locals.

13. Provisions be made for adoption of wetlands by the NGO's and Self-help groups for their conservation, management, sustainable utilization and restoration.

14. Aquatic ecosystem restoration works taken up by any agency, Govt. or NGO's should have 10% of restoration costs (per annum) spent or set off for awareness building, research and monitoring compulsorily in future.

15. Aquatic sanctuaries be created and tanks of religious places be declared as heritage centers for *in situ* conservation.

16. Appropriate technologies for point and non-point sources of pollution and *in situ* measures for lake restoration shall be compatible to local ethos and site condition as well as objectives of Aquatic Ecosystem Restoration Action Plan (AERAP).

17. Conservation and management of the `rain water' and `ground water' including maintenance of water table elevation is recommended for integrated development. Appropriate technology including encouragement of `aeration process' be evolved and implemented for efficient effluent treatment.

18. There is an urgent need for creating a `Data Bank' through inventorisation and mapping of the aquatic biota. This task be networked through Centre for Ecological Sciences (CES) in collaboration with the sister organisations.

19. All kinds of introduction of Exotic species and Quarantine measures be done in consultation with the concerned Authorities and the data bank.

20. Continuous integrated monitoring of the Ecosystem health of the Aquatic domains and their biota to be made by the Working Groups. There should be strict enforcement of the existing laws not to use the wetlands as `dumping grounds' for wastes, or for land-filling. Developmental activities should not be taken-up at the cost of the wetlands including their original open areas.

21. It is suggested that, an ecologically sound approach be practiced in reservoir / dam construction, keeping in view, the consequences to be faced by the rivers, wetlands, coastal areas, migrating aquatic biota and the beneficiaries.

22. Beneficiary participation from planning to operational stage be ensured including financial contribution.

23. Ecosystem approach in aquatic ecosystem restoration endeavour should consider catchment land use plan as of pre-project status and optimal land use plan shall first be prepared for short term (10 years and 30 years) and long term periods keeping in view developmental pressure over time span.

24. Soil conservation measures should be based on designated and actual land use plans, compatible to climate, topography, soil type and hydro-geology of the catchment and impact of siltation on productivity of land and lake values.

25. Appropriate cropping pattern, water harvesting, urban development, water usage, and waste generation data shall be utilized and projected for design period for arriving at preventive, curative and maintenance of Aquatic Ecosystem Restoration Action Plan (AERAP).

26. Ecological values of lands and water within the catchment / watershed shall be internalised into economic analysis and not taken for granted. Pressure groups shall play as watchdogs in preventing industrial and toxic and persistent pollutants by agencies and polluters.

27. A mechanism to disseminate information on wetlands, through publications be initiated. Print and electronic media be suggested to give wide coverage of environmental issues pertaining to aquatic ecosystem. Exposition of plans of maintenance and expansions be made mandatory for all industries.

28. Legislations be formulated at the earliest for efficient and sustainable management of aquatic ecosystems. Sustainable aquatic resources development and management depends mainly on proper planning, implementation, operation and maintenance, which is possible with GIS and Remote Sensing techniques, complementing and supplementing ground data collection in various facets of different kinds of water resource projects. Provisions should be made for easy access and transfer of accurate information to researchers working in the Aquatic systems including Survey of India maps, GIS software and Remote Sensing data.

29. It is recommended to maintain the sediment regime under which the aquatic ecosystems evolve including maintenance, conservation of spatial and temporal connectivity within and between watersheds.

30. Intersectoral systems approach is suggested for decision making regarding river basin management and integrated catchment / watershed development.

31. Greater role and participation of women in management and sustainable utilisation of resources of aquatic ecosystems.

32. Based on the concept of **polluter pays,** a mechanism be evolved to set up efficient effluent treatment plants [ETP], individual or collective, to reduce the

pollution load. Polluting industries be levied **Environmental Cess,** which can be utilised for conservation measures by the competent authorities. A `waste audit' must be made compulsory for all the industries and other agencies.

33. A project must be initiated to assess the practicality of using the information available for increasing the oxygen content by aerating raw sewage, which encourages proliferation of phyto and zoo species (hygienic agents of nature) and the eventual cleanup process. It is necessary to see how these processes can be expedited. The situation in Bangalore offers an ideal opportunity to try out the linear treatment plants along the channels flowing out from the city.

34. Regularly monitored "Ambient water quality stations" need to be immediately established and run by responsive and responsible group or agencies.

35. Long-term multidisciplinary team monitoring of at least some representative wetlands from geographically different micro regions be initiated.

36. As far as possible, eco-friendly and cost effective technologies such as Phyto-remediation, Bio-manipulation and in-lake engineered system could be considered for AERAP, provided land constraints are taken care of.

37. Energy intensive, high cost mechanized systems for pollution control shall be weighed based on cost effectiveness vis-à-vis viability of operation and maintenance on a sustainable manner.

38. In view of the immense importance of mangroves and salt pan estuaries, the following measures have to be taken for their protection and restoration.

- Qualitative and quantitative survey and regular monitoring of the mangrove resources would help in
  - Listing of endangered, threatened, at risk, near extinct and extinct species.
  - Understanding composition, structure (forest inventories) and function of the habitat.
  - Long term data collections for growth biomass increase and removal of biomass for individual species from localities.
  - Alterations in the mangrove land use pattern.

- Panchayat Raj institutions may be involved in the development of mangrove nurseries, afforestation, and protecting the luxuriant mangrove areas from illegal felling and poaching. High density plantation programme can be developed in the barren coastal wetlands which are under regular inundation for fodder, fuel and wood, for creating awareness. The necessary incentives may be provided for such people.
- Compensatory mangrove rehabilitation for reclaimed mangrove habitats be made compulsory for the organizations involved.
- Disaster management plans for accidental damage to the mangrove ecosystem should be made mandatory for the concerned organizations.
- It is necessary to create awareness regarding the importance of mangroves at schools, colleges, post-graduate and other appropriate educational levels. The

local people should be educated through various media like booklets, audio, video, documentary films, lectures, exhibitions, posters, postal stamps, stickers etc. of the mangroves.

- A mangrove information center could be established at each coastal district. These centers would collect various types of information on mangroves such as area, composition, endangered species, fisheries, land-use pattern, reclamation etc. These centers would also be made responsible for educating and training the locals and creating awareness.

39. Project reports should be subject to public access and public hearings before approved by competent authority.

40. The goals for restoration of aquatic ecosystems need to be realistic and should be based on the concept of expected conditions for individual eco-regions. Further development of project selection and evaluation technology based on eco-region definitions and description should be encouraged and supported by the national and state government agencies.
    - Research and development is needed in several areas of applied limnology, and this programme should take an experimental approach which emphasizes manipulation of whole ecosystems.
    - Improved techniques for littoral zone and aquatic microphytes management need to be developed. Research should go beyond the removal of nuisance microphytes to address the restoration of native species that are essential for waterfowl and fish habitat. Basic research is necessary to improve the understanding of fundamental limnological processes in littoral zones and the interactions between littoral and pelagic zones of lakes.
    - Biomanipulation (foodweb management) has great potential for low-cost and long-term management of lakes, and research in this emerging field must be stimulated.
    - Innovative and low-cost approaches to contaminant clean up in lakes need to be developed.
    - The relations between loadings of stress-causing substances and responses of lakes need to be understood more precisely. Research should be undertaken to improve predictions of trophic state and nutrient loading relationships.
    - Improved assessment programmes are needed to determine the severity and extent of damage in lakes and wetlands and a change in status over time. Innovative basic research is required to improve the science of assessment and monitoring. There is a great need for cost effective, reliable indicators of ecosystems function, including those that would reflect long-term change and response to stress. Research on indicators should include traditional community and ecosystem measurements, paleoecological trend assessments and remote sensing. Effective assessment and monitoring programme would involve network of local schools, colleges and universities.
    - Procedures such as food web manipulation, introduction of phytophagous insects and fish lining, and reintroduction of native species show promise for effective and long-lasting results when used alone or in

combination with other restoration measures. Further research and development needs to be undertaken on these aspects.

- Paleolimnological approaches should be used to infer the past trophic history of lakes and wetlands and to decide whether these systems should be restored. Paleolimnological approaches could also be used to infer whether a lake has been restored to its predisturbance condition.

41. Integrated aquatic ecosystem management needs to be implemented to ensure sustainability, which requires proper study, sound understanding and effective management of water systems and their internal relations (soil, groundwater, surface water and return water; quantity and quality; biotic components; upstream and downstream). The aquatic systems should be managed as part of the broader environment and in relation to socio-economic demands and potentials, acknowledging the political and cultural context. Sustainable management helps in conservation that sustains the ecological and socio-economic functions, which depends on the following aspects:

    - Should be applied at catchment level: The catchment is the smallest complete hydrological unit of analysis and management. Integrated catchment management (ICM), therefore, becomes the practical operating approach. Although this approach is obviously sound and finds wide acceptance, too narrow an interpretation should be avoided.
    - Decentralised: Decentralisation should be pursued as much as possible in order to bring river basin management as close as possible to the individual citizens and facilitate local variation in response to differing local conditions and preferences. Decentralisation is also possible in case of tasks with a supra-local scope if the decentralised governments concerned co-operate (e.g. panchayaths in a river basin) or if they are supervised by a higher-level government body. The process should be transparent, phased and planned.
    - It is critical to integrate water and environmental management: This principle is widely and strongly supported. Integrated aquatic ecosystem management can be strengthened through the integration of Environmental Impact Assessments (EIA's), water resources modeling and land use planning. It should also be understood that a catchment or watershed approach implies that water should be managed alongside the management of codependent natural resources, namely soil, forests, air and biota.
    - Through a systems approach: A true systems approach recognizes the individual components as well as the linkages between them, and that a disturbance at one point in the system will be translated to other parts of the system. Sometimes the effect on another part of the system may be indirect, and may be damped out due to natural resilience and disturbance. Sometimes the effect will be direct, significant and may increase in degree as it moves through the system. While systems analysis is appropriate, analyses and models that are too complex to be translated into useful knowledge should be avoided.
    - Operational management: The only form of river basin management that directly affects the river basin and its users is operational management (the

application of regulatory, economic and communicative policy instruments and concrete activities such as infrastructure management). Consequently, it should play a pivotal role in any river basin management strategy. Planning, policies, analytical tools and institutional systems play an essential role as deciders and facilitators. They can improve operational management, promote a basin-wide, intersectoral long-term approach, and in this way further the sustained multi-functional use of the basins concerned.

- Full participation by all stakeholders, including workers and the community: This will involve new institutional arrangements. There must be a high level of autonomy, but this must at the same time be associated with transparency and accountability for all decisions. Care should be taken to ensure that those participating in any catchment management structure do indeed represent a designated group or sector of society. It is also important to ensure that representatives provide feedback to the constituencies they represent Integrated Aquatic Ecosystem Management (IAEM) seeks to combine interests, priorities and disciplines as a multi-stakeholder planning and management process for natural resources within the catchment ecosystem, centered on water. Driven bottom-up by local needs and priorities, and top-down by regulatory responsibilities, it must be adaptive, evolving dynamically with changing conditions.

- Attention to social dimensions: This requires attention to, amongst other things, the use of social impact assessments, workplace indicators and other tools to ensure that the social dimension of a sustainable water policy is implemented. This will include the promotion of equitable access, enhanced role of women, and the employment and income implications of change.

- Capacity building: At many levels in the process – even at the governmental level - stakeholders lack the necessary knowledge and skills for full application of Integrated Aquatic Ecosystem Management. Community stakeholders may not be familiar with the concept of water resource management, catchment management, corporate governance, and their role in these. Capacity building categories include education and raising awareness about water; information resources for policy making; regulations and compliance; basic infrastructure; and market stability. Early and ongoing stakeholder collaboration and communication in capacity building is also important from the view point of “leveling the playing field” in anticipation of disputes that may arise. Filling strategic skills/capacity gaps supports integrated aquatic ecosystem management, facilitates dispute resolution, and builds practical understanding of the scope of sustainable natural resource development challenges and opportunities.

- Capacity mangement: The capacity of all institutions needs to be maintained and/or developed by means of short-term and long-term programmes (including postgraduate education and curricula development).

- Availability of information and the capacity to use it to make policy and predict responses: This implies, firstly, sufficient information on hydrological, bio-physical, economic, social and environmental characteristics of a catchment to allow informed policy choices to be made; and secondly, some ability to predict the most important responses of the catchment system to factors such as effluent discharges, diffuse pollution, changes in agricultural or other land use practices and the building of water retaining structures. The latter hinges on the adequacy of scientific models. It is recognized that predicting ecosystem response to perturbation with reasonable confidence stimulates current scientific capabilities and hence ongoing research.

- Full-cost pricing complemented by targeted subsidies: This is essential as users do not value water provided free or almost free and have no incentives to conserve water. Wide support for this principle was engendered, but also significant opposition from those who felt that the interests of the poor might not be sufficiently protected, even under an associated subsidy system, however well designed. Opposing views held that full-cost pricing, when applied in its narrowest sense, offends the principle that water is a public good, a human right, and not simply an economic good.

- Effective Pricing: Charges are effective and efficient means to finance aquatic ecosystem management (cost recovery) and reduce water use and pollution if the basic water needs of the poor are safeguarded, e.g. by means of block tariffs.

- Central Government support through the creation and maintenance of an enabling environment: The role of central government in integrated catchment management should be one of leadership, aimed at facilitating and coordinating the development and transfer of skills, and assisting with the provision of technical advice and financial support, to local groups and individuals. Where specific areas of responsibility fall outside the mandate of a single government department, appropriate institutional arrangements are required to ensure effective inter-departmental collaboration.

- Traditional regimes and institutions should be recognised and integrated in aquatic ecosystem management.

- Adoption of the best existing technologies and practices - BMPs (best management practices).

- Equitable allocation of water resources: This implies improved decision-making, which is technically and scientifically informed, and can facilitate the resolution of conflicts over contentious issues. There are existing tools (e.g. multi-criteria analysis) to help decision-making in terms of balancing social, ecological and economic considerations. These should be tested and applied.

- The recognition of water as an economic good: The recognition of water as an economic good is central to achieving equitable allocation and sustainable usage. Water allocations should be optimized by benefit and cost, and aim to maximize water benefits to society per unit cost. For example, low value uses could be reallocated to higher value uses such as basic drinking water supplies, if water quality permits. Similarly, lower quality water can be allocated to agricultural or industrial use.

- Strengthening the role of women in water management: Women's participation in decision-making positively affects both project quality and sustainability.

- Floods not only cause suffering but also support life: Flood management should not be based solely on building dykes and dams. It needs to be based on strategies that use both structural and non-structural methods. The strategy should balance all interests involved and be based on an integrated assessment, of the environmental, economic and human costs and benefits of these alternatives, including their potential contribution to drought mitigation and including the possibilities that they offer for nature.

- Pollution prevention: The ultimate goal of pollution control is to close substance cycles and in this way prevent pollution. A mix of instruments for regulation and compliance can be used to move into this direction and solve urgent pollution problems: waste control, process and emission standards, and a water quality approach. The exact mix should reflect inter-alia the local management capacity and the availability of water quality data and other data.

- Analytical model: To support aquatic ecosystem management, a new analytical model should be developed that can aggregate socio-economic, political, institutional and technological potentials and hydrological constraints. This model should furthermore be capable of evaluating the actual management capacity.

- Strategic planning: To support strategic planning, methods for analytical support should be developed that:
    - ✓ cover the whole basin and all significant impacts;
    - ✓ specifically consider the socio-economic processes that affect the basin;
    - ✓ predict the socio-economic effects of alternate strategies; and
    - ✓ present the issues in such a way that people can understand them.

- Information systems: There is a large role for appropriate decentralised information systems and networks that can promote interaction among sectors, provide a basis for consistent technical studies, help communication with the public, and stimulate participation.

- Cyclic policy: To implement the general principles of the integrated aquatic ecosystem management requires a cyclic policy development approach. Such an approach would include the following steps - Assessment of institutions, needs and resources, planning, implementation, compliance monitoring and evaluation.

Experts involved in formulating and finalising Lake 2002 Recommendations are: Dr. Devashish Kar, Dr. Rajasekara Murthy, Dr. T.V. Ramachandra, Dr. S.N. Balasubramanyam, Dr. T. Ananda Rao, Dr. Madhyastha, Dr. H.S. Patil, Dr. K.Mohan, Dr. S.P. Hosmani, Dr. J. Pasupathi, Dr. B.K. Chakrapani, Dr. M.B. Krishna, Dr. Rajan Nair, Dr. S.A. Hussain, Dr. H.N. Chanakya, Dr. M.K. Ramesh, Dr. Yellappa Reddy, Mr. Vijay Kumar Gogi, Mr. S. Sridhar and Mr. Raushan Kumar.

LAKE 2004 Recommendations

- Action oriented conservation and protection plan for Chilika Lake
- Declare Chilika Lake, with its watershed, the national heritage site and strict implementation of time bound conservation and restoration measures. Integrated water resource management of Chilika watershed and integrated coastal management.
- Interdisciplinary, intensive monitoring and modeling of hydrological, meteorological, limnological and coastal oceanographic studies be taken by CDA.
- Declare a buffer zone of wetlands as a protected area devoid of any developmental activities.
- Ecosystem approach with integrated holistic approaches in the management considering all biotic and abiotic components of the ecosystem, with its functional aspects to ensure sustainability.
- Establish a permanent laboratory with research facilities at wetlands site (with the sensors to characterize: biological, physical and chemical, hydrological, meteorological) and encourage local college and school students to carry out the dissertation work (part of the curriculum at degree and post graduate levels). Fully equipped live labs would help the younger generation to understand and learn the importance of the ecosystem.
- Capacity building - environment education by establishing eco-schools. Inclusion of field oriented environmental education in the school curriculum.
- Training of all stakeholders (at regular intervals - about wetlands importance, biotic and abiotic factors, sustainable management practice…..).
- Biological studies and regular stock assessment of important fauna (dolphin, shell fish, fin fish, etc.) needs to be undertaken for a better understanding and utilization of natural resources. Developing a biodiversity register involving schools and colleges for Chilika.
- Reconstitution of CDA involving all stakeholders - local people (who depend on the lake for their livelihood), academicians and researchers. Constitution of a task force involving local people for regular monitoring.
- Reduction of siltation: improvement in land cover in a phased manner with appropriate land use practices. Catchment treatment with the species locally preferred (or could meet the food, fodder and fuel requirement of the local population as well as fauna).
- Measures to protect coral reefs and other aquatic flora and fauna.
- Improvement in riparian vegetation based on local hydrology and native species.
- Protection of breeding grounds of fauna (fish, birds, etc.) - banning hunting, fishing in breeding area. (Captive breeding of Dolphins.)
- Pollution prevention (through an appropriate design of sewage treatment plant up to tertiary level, if possible).

- Ban on use of plastics and implementation of integrated solid waste management as per the guidelines of the national SWM committee (constituted as per the Supreme Court verdict).
- Implementation of best engineered wetlands: prevention of non point source pollution.
- Rehabilitation of the local population (with proper housing, drinking water, drainage and sanitation systems).
- Ban on encroachment (illegal occupants to be evicted).
- Ban on aquaculture (that is unsustainable from the ecosystem point of view).
- The constitution of cooperative societies involving all local fishermen and ban on over harvesting of fish resources (restriction on the size of the net, number of licenses, immediate removal of non local fishermen with unsustainable harvesting practices). Removal of contract system (middle men) and sharing of resources equitably by local people. Constitution of local self help groups.
- Prevention of oil spillage (motor boats, etc.).
- Restoration of mangroves ecosystems in the coastal belt to avert the impact of natural calamities.
- Inventory, mapping and monitoring of the coastal and marine biodiversity.
- Conservation of forests and restoration of natural forests (deforestation is the prime cause for declining water resources, etc.).
- Strict law enforcement to our waters for their preservation (life).

LAKE 2006 Recommendations

Lake 2006 was organised from 28th to 30th December 2006 at Rustum Choksi Hall, Indian Institute of Science, Bangalore. This symposium focused on Environmental Education and Ecosystem Conservation to bring in awareness among school students, teachers and the public. The symposium was organised by the Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science in collaboration with the Commonwealth of Learning (COL), Canada, Karnataka Environment Research Foundation (KERF), Bangalore, K.K. English School , Varthur and Vidya Niketan Public School , Ullal upanagara, Bangalore. As a part of the symposium there were paper and poster presentations and model displays from school and college students apart from many presentations from research scholars across the country. The symposium attracted more than 200 participants from different walks of life. This provided a forum for 120 students along with 80 researchers, technologists, economists, sociologists and others to meet and discuss issues regarding ecosystem conservation.

The main objective of the symposium was to bring out the current trends in aquatic ecosystem conservation, restoration and management including the hydrological and the biophysical aspects, peoples' participation and the role of non-governmental, educational and governmental organisations and future research needs for the restoration, conservation and management.

As a part of the symposium a panel discussion was held with about 22 panelists who came out with the following key recommendations:

Environmental education program should be more proactive, field oriented and experiential (with real time examples) for effective learning

- Environmental education should be made mandatory for teachers and teacher educators at the teachers' training institutes (Tch, B Ed, D Ed)
- Experts to be involved in the preparation of resource material related to ecosystem studies and the same to be disseminated to educational institutions for monitoring surrounding ecosystems through electronic or print form in local/bilingual language

(materials need to be in self learning format with the objective of learning need to move away from content centric approach)

- Implement solid waste management effectively at educational institutions level towards zero waste
- A taxonomic inventory of taxa like birds, fishes, amphibians, reptiles, aquatic plants and insects of wetlands to be prepared and periodically revised for respective wetlands through local schools and colleges and this is to be made available as reference for each wetlands
- Ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such as monitoring of ecosystems, socio-economic dependency, biodiversity and other activities, as an indispensable tool for formulating long term conservation strategies. This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at raising the levels of public awareness of aquatic ecosystems' restoration, goals and methods. Actively participating schools and colleges in the vicinity of the water bodies may value the opportunity to provide hands-on environmental education, which could entail setting up of laboratory facilities at the site. Regular monitoring of water bodies (with permanent laboratory facilities) would provide vital inputs for conservation and management. Potential of students in educational institutions to be tapped for interacting and contributing to monitor the status of ecosystem, in and around their locality

- Government Agencies, Academics, Institutions and NGO's must co-ordinate grass-root level implementation of policies and activities related to conservation of ecosystems (both Inland and Coastal), their sustainable utilisation, restoration and development including human health. There is also a need for management and conservation of aquatic and terrestrial biota including their health aspects. Traditional knowledge and practices have to be explored as remedial measures.

Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of ecosystems.

- Ecosystem approach in aquatic ecosystem restoration endeavour considering catchment land use plan as of pre-project status and optimal land use plan shall first be prepared for short term (10 years and 30 years) and long term periods keeping in view developmental pressure over time span.
- Soil conservation measures based on designated and actual land use plans, compatible to climate, topography, soil type and hydro-geology of the catchment and impact of siltation on productivity of land and ecosystem values.
- Catchment areas of wetlands in general with lakes and riverine ecosystems in particular, to be protected. Land cover / land use changes should be curtailed / minimized with immediate effect
- Impact of pesticide or fertilisers on wetlands in the catchment areas to be checked
- Regulate illegal sand and clay mining around the wetlands
- Immediate steps to conserve endangered wetlands such as Myristica swamps
- National Wetlands Policy both at state and national level to be formulated and enforced
- Identify water bodies of biodiversity importance and declare them as Wetland Conservation Reserves (WCR)
- Marine and Coastal areas to be considered as fragile ecosystems and hence should be comprehensively protected from any industrial and power generation activities
- Lake management should involve all stakeholders like public, local non-governmental agencies, etc.
- Management and maintenance of lakes to be decentralised involving stakeholders, local bodies, institutions and community participation without any commercialization or commoditization of lakes.

- Lake monitoring and management to be assigned to neighborhood schools so that school children can learn the ecological process
- All wetlands to be considered as Common Property Resources and hence custodians should carefully deal with these ensuring security
- Urban wetlands, mostly lakes to be regulated from any type of encroachments

- Lake privatised recently to be taken over and handed over to locals immediately thus restoring the traditional access to these lakes by the stakeholders
- Restore surviving lakes in urban areas strengthening their catchment area and allowing sloping shorelines for fulfilling their ecological function
- Alteration of topography in lake / river catchments should be banned
- Provisions to be made for adoption of wetlands by the NGO's and self-help groups for their conservation, management, sustainable utilisation and restoration.
- Centre for Ecological Sciences (CES) be the Nodal Agency for capacity building at all levels: Formal and Non-formal and Govt. officials. Students should be involved in participatory management of the wetlands. Due impetus be given on equipping the institutions with qualified environmental specialists. Teachers of the local institutions shall be trained for in-turn capacity building in their own areas, in which, aquatic ecosystems especially wetlands could serve as `field laboratories'.
- It was felt among the participants that public needs to be better informed about the rational, goal and methods of ecosystem conservation and restoration. In addition, the need was realized for scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation. In this regard Lake 2006 proposes:

➢ Public education and outreach should include all components of ecosystem restoration. Lake associations and citizen monitoring groups have proved helpful in educating the general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

➢ Funding is needed for both undergraduate and graduate programmes in ecosystem conservation and restorations. Training programmes should cross traditional disciplinary boundaries such as those between basic and applied ecology: water quality management and fisheries or wildlife management: among lakes, streams, rivers, coastal and wetland ecology. This could be achieved through capacity building exercises and in this regard Lake 2006 suggests Organising two weeks training course on "Integrated watershed management with emphasis on conservation and restoration of aquatic ecosystems". Organising an International symposium (sequel to Lake 2006) and a national seminar to prioritise research needs for the conservation, restoration and sustainable management of ecosystems.

LAKE 2008 Recommendations

Introduction

Water, the elixir of life, is the most precious resource on the planet earth. Life originated and evolved in water before it appeared on the land. The unit of life whether on land or water is the living cell, the major bulk of which is water itself. Ultimately it is the delicate balance of chemicals within the cellular water that determines the quality of life and forms a fragile barrier between life and death itself. No wonder, water as an element and water bodies in general have been revered as holy by traditional human societies all over the world.

The elemental water is venerated as one of the *Panchabhuthas* in the scriptures of India. Water- bodies ranging from springs, streams, ponds and lakes to the mighty ocean are sacred in the Indian culture. *Tirthayatra*, literally pilgrimage to the holy waters, became an important part of Indian life through millennia to this day; and it causes major movements and congregations of humans within this country and is one of the most unifying factors of the society.

India is basically an agricultural country; bulk of the Indian population in one way or the other is connected with growing of an amazing variety of crops, domestication of animals, trading in the agricultural and dairy products, and in allied industries such as cotton textiles, sugar, soaps and oils and scores of others. Despite the tremendous technological progress the country has achieved, water and soil still form the core of the Indian life and have given the much needed resilience and strength to the Indian economy in these days of global economic crisis.

Recent times, sadly enough, have witnessed a drastic change in our attitude towards water and water-bodies, the reverence towards which is more becoming a matter of ritualism. Water is being used with gay abandon and water-bodies are being destroyed for alternative uses or have turned out to be receptacles of filth and pollutants including of life threatening chemicals and deadly pesticides. These pollutants through the process of bio-magnification have turned out to be major threats to the very fabric of life on the planet.

The Scope:

The symposium has covered water-bodies of all kinds on the land including the estuaries, which are the places where the freshwater of the rivers mingle with the saltwater of the sea and create unique habitats of intermediate salinity and high productivity. Over 200 persons from all over the country, from scientists, hydrologists, policy makers, legal experts and NGO's to students and teachers participated in the symposium, which saw the presentation of around 100 research papers. These papers encompassed an array of topics related to the past and present status of water-bodies, biodiversity associated with them ranging from bacteria and diatoms to the endangered mighty trees in the Myristica swamps of the Western Ghats and from protozoans to fishes, birds and aquatic mammals. The value of sacred groves in watershed conservation, the importance of preparing management plans for individual estuaries, rainwater harvesting, sedimentation in water-bodies, water chemistry etc were among the notable topics discussed.

Recommendations:

Lake 2008 reviewed the Draft Notification 2008 Regulatory Framework for Wetlands Conservation (Wetland Conservation Rules) of the Ministry of Environment and Forests of the Government of India and has recommended the following:

1. **Mapping of water-bodies:** The mapping of water bodies should also include smaller wetlands, particularly hill streams, Myristica swamps of the Western Ghats, springs etc. The neglect of these hydrological systems could cause considerable impoverishment of water flow in the river systems as well as turn out to be threats to rare kinds of biodiversity. As most of the streams originate in forest areas they come under the legal authority of the forest departments. At the same time the waters of many of these streams are being diverted for private uses. This causes diminished water flow especially in the non Himalayan Rivers during the summer months. A judicious water sharing mechanism has to be worked out at the local level taking into account also the broader national interest as well as conservation of dependent biodiversity. The mapping of these smaller water-bodies, along with their catchments needs to be conducted involving also the local Biodiversity Management Committees. The jurisdictional agreements on the water usage and watershed protection need to be arrived at on a case to case basis involving all the stakeholders.

2. **Documentation of biodiversity:** The biodiversity of every water body should form part of the People's Biodiversity Registers (PBR). The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity. The presence of endemic, rare, endangered or threatened species and economically important ones should be highlighted. A locally implementable conservation plan has to be prepared for such species.

3. **Preparation of management plans for individual water bodies:** Most large water bodies have unique individual characteristics. Therefore it is necessary to prepare separate management plans for individual water bodies.

4. **Preparation of estuary based management plans:** Estuaries are ranked among the highest productive ecosystems of the world. These are dynamic ecosystems of highly variable environmental factors and therefore require preparation of management plans for individual estuary.

5. **Demarcation of the boundary of water bodies:** The existing regulations pertaining to boundary demarcations within different states need to be reviewed according to updated norms and based on geomorphology and other scientific aspects pertaining to individual water bodies. Maximum Water Level mark

should form the boundary line of the water body. In addition, a specified width, based on historical records/ survey records etc. may be considered for marking a buffer zone around the water body. In case such records are not available, the buffer zones may be marked afresh considering the flood plain level and also maximum water levels. The width of the buffer zone should be set considering the geomorphology of the water body, the original legal boundaries, etc. The buffer zone should be treated as inviolable in the long term interests of the water body and its biodiversity.

6. **Implementation of sanitation facilities:** It was noted with grave concern that the water bodies in most of India are badly polluted with sewage, coliform bacteria and various other pathogens. To preserve the purity of waters and to safeguard the biodiversity and productivity, dumping of waste has to be prohibited. In addition to this, all the settlements alongside the water body should be provided with sanitation facilities so as not to impinge in anyway the pristine quality of water.

7. **Management of polluted lakes:** This programme needs priority attention. Bioremediation method may be preferred for detoxification of polluted water bodies. The highly and irremediably polluted water bodies may be fenced off to prevent fishing, cattle grazing and washing, bathing and collection of edible or medicinal plants to prevent health hazards. Warning boards should be displayed around such water bodies. Collection of any biomaterials from such water bodies should be prohibited.

8. **Valuation of goods and services:** Goods and services provided by the individual water bodies to be documented, evaluated through participatory approach and be made part of the People Biodiversity Registers (PBR). If in any case the traditional fishing rights of the local fishermen are adversely affected by lake conservation or by declaring it as a bird sanctuary, etc they should be adequately compensated.

9. **Regulation of boating:** Operation of motorized boats should not be permitted within lakes of less than 50 ha. In larger lakes the number of such boats should be limited to carrying capacity of the water body. In any case boating during the periods of breeding and congregations of birds should be regulated.

10. **Protection of riparian and buffer zone vegetation:** Any clearances of riparian vegetation (along side rivers) and buffer zone vegetation (around lakes) have to be prohibited.

11. **Restoration of linkages between water bodies:** The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities. Wherever such disruptions have taken place alternative arrangements should be provided to establish the lost linkages.

12. **Rainwater harvesting:** Intensive and comprehensive implementation of rain water harvesting techniques can reduce taxation of water bodies and also minimize electricity requirements. The country needs in principle a holistic rainwater harvesting policy aimed at directing water literally from "roof-tops to lakes" after catering to the domestic needs.

13. **Protection of sacred grove-water body system:** Sacred groves have been integral part of traditional watershed protection systems. Ponds, lakes, springs, streams and rivers associated with the sacred groves were integral to the landscape management systems of traditional societies of especially Indian highlands. Most of these groves lost their significance due to merger of them with the state reserved forests or due to cultural changes. There still exist thousands of sacred groves along the Indian countryside. If these groves are recognized, ecologically restored and brought under appropriate management mechanisms in collaboration with local communities, a fresh revival can happen of the water bodies associated with them.

14. **Carrying capacity studies for all macro cities:** Unplanned concentrated urbanisation in many cities has telling impacts on local ecology and biodiversity, evident from decline of waterbodies, vegetation, enhanced pollution levels (land, water and air), traffic bottlenecks, lack of appropriate infrastructure, etc. There is a need to adopt holistic approaches in regional planning considering all components (ecology, economic, social aspects). In this regard, Lake 2008 recommends carrying capacity studies before implementing any major projects in macro cities.

These recommendations are in addition to or supplementing the Prohibited and Regulated activities given in the Rule 4 - Restriction on activities within wetlands of the Draft Notification of 2008 of Ministry of Environment and Forests, Govt. of India 'REGULATORY FRAME WORK FOR WETLAND CONSERVATION'. The wetlands considered under the symposium recommendations are also applicable to wetland categories other than A, B and C given in the Draft Notification.

Aquatic Ecosystems: Conservation, Restoration and Management

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INTRODUCTION

Aquatic ecosystems contribute to a large proportion of the planet's biotic productivity as about 30% of the world's primary productivity comes from plants living in the ocean. These ecosystems also include wetlands located at lake shores, river banks, the ocean shoreline, and any habitat where the soil or vegetation is submerged for some duration. When compared to terrestrial communities, aquatic communities are limited abiotically in several different ways (http://www.usgs.gov).

- Organisms in aquatic systems survive partial to total submergence. Water submergence has an effect on the availability of atmospheric oxygen, which is required for respiration, and solar radiation, which is needed in photosynthesis.
- Some organisms in aquatic systems have to deal with dissolved salts in their immediate environment. This condition has caused these forms of life to develop physiological adaptations to deal with this problem.
- Aquatic ecosystems are nutritionally limited by phosphorus and iron, rather than nitrogen and
- These are generally cooler than terrestrial systems which limit metabolic activity.

Global Scenario

The earth, two-thirds of which is covered by water, looks like a blue planet—the planet of water—from space (Clarke, 1994). The world's lakes and rivers are probably the planet's most important freshwater resources. But the amount of fresh water constitutes only 2.53% of the earth's water. On the earth's surface, fresh water is the habitat of a large number of species. These aquatic organisms and the ecosystem in which they live represent a substantial sector of the earth's biological diversity. The association of man and aquatic ecosystem is ancient. It is not surprising that the first sign of civilization is traced to wetland areas. The flood plains of the Indus, the Nile delta, and the Fertile Crescent of the Tigris and Euphrates rivers provided man with all his basic necessities. Water may be required for various purposes like drinking and personal hygiene, fisheries, agriculture, navigation, industrial production, hydropower generation, and recreational activities. The wide variety of wetlands, like marshes, swamps, bogs, peat land, open water bodies like lakes and rivers, mangroves, tidal marshes, and so forth, can be profitably used by humans for various needs and for environmental amelioration. Ever-increasing population and the consequent urbanization and industrialization have mounted serious environmental pressures on these ecosystems and have affected them to such an extent that their benefits have declined significantly.

It is interesting to know that there are nearly 14×10^8 cubic km of water on the planet, of which more than 97.5% is in the oceans, which covers 71% of the earth's surface. Wetlands are estimated to occupy nearly 6.4% of the earth's surface. Of those wetlands, nearly 30% is made up of bogs, 26% fens, 20% swamps, and 15% flood plains. Of the earth's fresh water, 69.6% is locked up in the continental ice, 30.1% in underground aquifers, and 0.26% in rivers and lakes. In particular, lakes are found to occupy less than 0.007% of world's fresh water (Clarke, 1994). This amount of water is found in lakes, rivers, reservoirs, and those underground sources that are shallow enough to be tapped at an affordable cost. Only this amount is regularly renewed by rain and snowfall, and is therefore available on a sustainable basis.

Indian Scenario

India by virtue of its geography, varied terrain, and climate is blessed with numerous rivers and streams that support a rich diversity of inland and coastal wetland habitats. Major river systems in the north are Ganga, Yamuna, and Brahmaputra (perennial rivers from the Himalayas) and in the south, Krishna, Godavari, and Cauvery (not perennial, as they are mainly rain-fed). The central part of India has the Narmada and the Tapti. The Indo-Gangetic floodplain is the largest wetland regime of India. Most of the natural wetlands of India are connected with the river systems. The lofty Himalayan mountain ranges in northern India accommodate several well-known lakes, especially the palaearctic lakes of Ladakh and the Vale of Kashmir, which are sources of major rivers. In the northeastern and eastern parts of the country are located the massive floodplains of Ganga and Brahmaputra along with the productive system of swamps, marshes, and oxbow lakes. Apart from this, there exists a number of man-made wetlands for various multipurpose projects. Examples are Harike Barrage at the confluence of the Beas and the Sutlej in Punjab, Bhakra Nangal Dam in Punjab and Himachal Pradesh, and the Cosi Barrage in Bihar-Nepal Border. India's climate ranges from the cold, arid Ladakh to the warm, arid Rajasthan, and India has over 7,500 km of coastline, major river systems, and mountains. Terrestrial ecosystems range from wet evergreen to deciduous forests in the Western ghats and north-east, scrub/plains in deccan plateau and gangetic plains amidst the mountain ranges.

There are 67,429 wetlands in India, covering about 4.1 million hectares. Out of these, 2,175 wetlands are natural, covering about 1.5 million hectares, and 65,254 wetlands are man-made, occupying about 2.6 million hectares.

According to Forest Survey of India, mangroves cover an additional 6,740 sq km. Their major concentrations are Sunderbans, and Andaman and Nicobar Islands, which hold 80% of the country's mangroves. The rest are in Orissa, Andhra Pradesh, Tamilnadu, Karnataka, Maharashtra, Gujarat, and Goa.

Wetlands have been drained and transformed due to anthropogenic activities, like unplanned urban and agricultural development, industries, road construction, impoundments, resource extraction, and dredge disposal, causing substantial economic and ecological losses in the long term. They occupy about 58.2 million hectares, of which 40.9 million hectares are under paddy cultivation. About 3.6 million hectares are suitable for fish culture. Approximately 2.9 million hectares are under capture fisheries (brackish and freshwater). Mangroves, estuaries, and backwaters occupy 0.4, 3.9, and 3.5 million hectares respectively. Man-made impoundments constitute 3 million hectares. Nearly 28,000 km are under rivers, including main tributaries and canals. Canal and irrigation channels constitute another 113,000 km (Rajinikanth, R. and Ramachandra, T.V., 2000).

Though accurate results on wetland loss in India are not available, the Wildlife Institute of India's survey reveals that 70-80% of individual fresh water marshes and lakes in the Gangetic flood plains have been lost in the last five decades. Indian mangrove areas have decreased by half from 700,000 ha in 1987 to 453,000 ha in 1995.

Karnataka Scenario of Aquatic Ecosystems

Karnataka state situated between 11° 31' and 18° 45' N latitude and 74° 12' and 78° 40' E longitude is endowed with numerous rivers, lakes, and streams, and has a coastline of about 320 km. Spatial extent of the state is 1,92,204 sq km (5.35% of the country's total geographical area) with a population of 52 million. Mean annual rainfall varies from 3,932 (Dakshina Kannada) to 140 mm (Bijapur). The wetlands of Karnataka are classified into inland and coastal categories, both natural and man-made. Natural inland wetlands include lakes, ox-bow lakes, and marshes/swamps; man-made inland wetlands include reservoirs and tanks. Natural coastal wetlands include estuaries, creeks, mudflats, mangroves, and marshes; while man-made coastal wetlands includes salt pans. Wetlands cover about 2.72 million hectares, of which inland wetlands cover 2.54 million hectares, and coastal wetlands 0.18 million hectares. The area of 682 wetlands, scattered throughout the state of Karnataka, is about 2,718 sq km, of which seven are natural inland wetlands (581.25 ha), 615 are man-made inland wetlands (253,433.75 ha), 56 are natural coastal wetlands (16,643.75 ha) and four are man-made coastal wetlands (1,181.75 ha). Inland wetlands cover 93.43% (254,015 ha) of the total wetland area while coastal wetlands cover only 6.57 % (17,825.5 ha). Tanks (561) account for 79,088 ha; followed by reservoirs (53), which cover about 174,290 ha; lakes, which occupy about 438 ha; and mangroves, which account for 550 ha. Karnataka includes the basins of Krishna (58.9%), Cauvery (18.8%), Godavari (2.31%), North Pennar (3.62 %), South Pennar (1.96%), Palar (1.55%), and west flowing rivers (12.8%) with drainage of 191,770 sq km. (Rege et al., 1996).

The total water spread area during pre-monsoon is about 204,054 ha, and 246,643 ha in post-monsoon. Out of the total wetlands in the state, 71 have shown water spread less than 56.25 ha (Rege et al., 1996). Water-spread area of lakes/ponds in post-monsoon is about 437.50 ha, and 368.75 ha in pre-monsoon. Reservoirs have shown considerable variations from post-monsoon (167,268 ha) to pre-monsoon (138,684.25 ha). Tanks also vary from 46,975.25 ha (post-monsoon) to 60,912.25 ha (pre-monsoon). Coastal wetlands, under constant influence from the sea, have no variation in terms of water spread area in all seasons. Most of the tanks dry up during pre-monsoon.

Ancient human societies have traditionally recognised water resources in practical as well as symbolic ways. Failure by modern societies to deal with water as a finite resource is leading to unnecessary destruction of rivers, lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need for

- *Restoring and conserving the actual source of water*—the water cycle and the natural ecosystems that support it—is the basis for sustainable water management;
- *Environmental degradation is preventing us from reaching goals* of good public health, food security, and better livelihoods world-wide;

- *Improving the human quality of life* can be achieved in ways that also maintain and enhance environmental quality;
- *Reducing greenhouse gases to avoid the dangerous effects of climate change* is an integral part of protecting freshwater resources and ecosystems.

AQUATIC ECOSYSTEMS: CATEGORIES

Aquatic ecosystems could be categorised as

1. Open Sea which occupies about 90% of the total surface area of the ocean, and contains about 10% of all marine plant and animal species.
2. Coastal Zone which is the area of the ocean where water depth is less than 200 metres. Within the coastal zone are several unique habitats, such as
   - Estuaries—the saline waters of the ocean meet with fresh water from streams and rivers and these habitats are very productive due to accumulation of nutrients from fresh water runoff.
   - Tidal marshes—common in temperate areas, and are dominated by sedges and grasses.
   - Mangroves—common in tropical areas and have tree species.
   - Coral reefs—supported by warm shallow tropical water and comparable with tropical forests in density of individuals, species diversity, and types of life-forms. Corals are tiny organisms that build a calcium carbonate chamber for a home. Over long periods of time, the continued building of these homes creates a large accumulation of coral skeletons (http://www.geog.ouc.bc.ca).
3. Lakes and Reservoirs: Lakes are natural features formed from the accumulation of fresh water in depressions. Sources for the water include precipitation, runoff, stream flow, and groundwater flows while reservoirs are bodies of fresh water that are artificially created by humans. Lakes are categorised according to their nutrient status as:
   - Eutropic: rich in nutrients – nitrogen and phosphorous. These have usually large populations of plankton and zooplankton, have less diverse populations of fish, and are often depleted of dissolved oxygen during periods of warm temperatures. Humans have altered the nutrient status of many lakes through the addition of nitrates, urea, and phosphates. This process results in physical, chemical and biological changes in the system.
   - Oligotrophic: these are nutrient poor, often crystal clear and have low biotic productivity.
4. Rivers and Streams: These are created by the accumulation of runoff and groundwater into low lying channels. These constitute important components of the hydrologic system and move water from areas where precipitation exceeds evapotranspiration to lakes and oceans.

5. Fresh Water Wetlands: These are terrestrial habitats that are partially submerged by fresh water and include habitats like marshes, swamps, ponds, etc. These habitats support many different species of fish, birds, and animals. Plants and animals present in wetlands are more than terrestrial habitats, thus making them highly productive environments. Wetlands function as *ecotones*, transitions between different habitats, and have characteristics of both aquatic and terrestrial ecosystems.

Wetlands have often been described as the kidneys of the landscape because of the role they play in water and chemical cycles. Wetlands filter out sediment and pollution from the surrounding environment so that the water they discharge to rivers and lakes is cleaner. In this manner, wetlands act as both a sink and source, storing and passing on vital resources to their local environment.

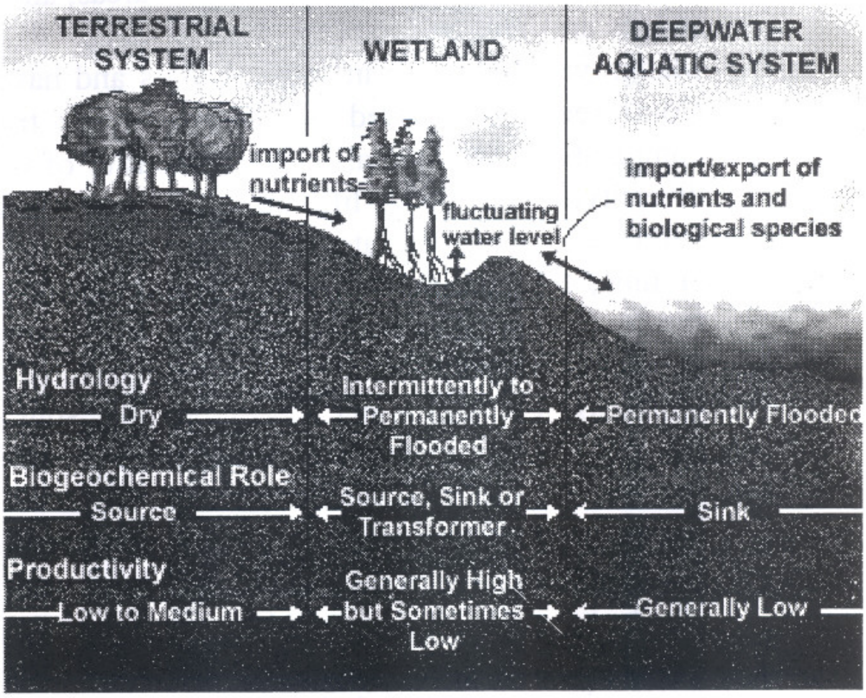

Fig. 1 Wetlands: Transition zone between aquatic and terrestrial ecosystems.

WATERSHED

River, pond, wetlands, lake or estuary is an ultimate destination of all water running downhill through an area of land, which is referred as watershed. A watershed is a catchment basin that is bound by topographic features, such as ridge tops and perform primary functions of the ecosystem (http://www.gdrc.org). It plays a critical role in the natural functioning of the ecosystem (Ahalya, N. and Ramachandra, T.V., 2002) such as:

- Hydrologically, watersheds integrate the surface water run-off of an entire drainage basin. It captures water from the atmosphere. Ideally, all moisture received from the atmosphere, whether in liquid or solid form, has the maximum opportunity to enter the ground where it falls. The water infiltrates the soil and percolates downward. Several factors affect the infiltration rate, including soil type, topography, climate, and vegetative cover. Percolation is also aided by the activity of burrowing animals, insects, and earthworms.
- It stores rainwater once it filters through the soil. Once the watershed's soils are saturated, water will either percolate deeper, or runoff the surface. This can result in freshwater aquifers and springs. The type and amount of vegetation, and the plant community structure, can greatly influence the storage capacity in any one watershed. The root mass associated with healthy vegetative cover keeps soil more permeable and allows the moisture to percolate deep into the soil for storage. Vegetation in the riparian zone affects both the quantity and quality of water moving through the soil.
- Finally, water moves through the soil to seeps and springs, and is ultimately released into streams, rivers, and the ocean. Slow release rates are preferable to rapid release rates, which result in short and severe peak instream flow. Storm events which generate large amounts of run-off can lead to flooding, soil erosion and siltation of streams.
- Ultimately, the moisture will return to the atmosphere by way of evaporation. The hydrologic cycle (the capture, storage, release, and eventual evaporation of water) forms the basis of watershed function. Economically, they play a critical role as sources of water, food, hydropower, recreational amenities, and transportation routes.
- Ecologically, watersheds constitute a critical link between land and sea; they provide habitat — within wetlands, rivers, and lakes — for 40 percent of the world's fish species, some of which migrate between marine and freshwater systems.
- Watersheds also provide habitat within the terrestrial ecosystems such as forests and grasslands for most terrestrial plant and animal species; and they provide a host of other ecosystem services — from water purification and retention to flood control to nutrient recycling and restoration of soil fertility — vital to human civilizations.

Hence, watershed should be managed as a single unit. Each small piece of the landscape has an important role in the overall health of the watershed. Paying attention primarily to the riparian zone, an area critical to a watershed's release function, will not make up for lack of attention to the watershed's uplands. They play an equally important role in the watershed, the capture and storage of moisture. It is seamless management of the entire watershed, and an understanding of the hydrologic process, that ensures watershed health.

Watershed-Based Approach to Resource Management

Each river system — from its headwaters to its mouth — is an integrated system and must be treated as such. The focus of water resource management is on wise and efficient use of water resources for such purposes as energy production, navigation, flood control, irrigation, and drinking water (Rajinikanth, R. and Ramachandra, T.V., 2001). It also places emphasis on improving ambient water quality. Watershed approach can provide benefits to individual citizens, the public sector, and the private sector. Individual citizens benefit when watershed protection improves the environment and the livability of an area. The watershed-wide participation of local citizens and organizations ensures that those who are most familiar with a watershed, its problems and possible solutions, play a major role in watershed stewardship. The private sector can benefit because the burden of water resource protection is distributed more equitably among pollution sources.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from non-point and point sources as well as from habitat degradation. Watershed based planning and resource management is a strategy for more effective protection and restoration of aquatic ecosystems and for protection of human health. The watershed approach emphasizes all aspects of water quality, including chemical water quality (e.g., toxins and conventional pollutants), physical water quality (e.g., temperature, flow, and circulation), habitat quality (e.g., stream channel morphology, substrate composition, and riparian zone characteristics), and biological health and biodiversity (e.g., species abundance, diversity, and range).

To deal with non-point source pollution in an effective manner, a smaller and more comprehensive scale of analysis and management is required. While point source pollution control programmes encourage identifying isolated polluters, non-point source strategies recognize that small sources of pollution are widely dispersed on the landscape and that the cumulative impacts of these pollutants on water quality and habitat are great. A whole basin approach to protecting water quality has proved most effective because it recognizes connected sub-basins (Ahalya, N. and Ramachandra, T.V., 2002). This includes:

- Addressing issues of water quantity, protection of riparian areas, control of aquatic non-native species, and protection of water quality.
- Protecting the integrity of permanent and intermittent seeps, streams, rivers, wetlands, riparian areas, etc.
- Prioritising watersheds for protection and restoration and focus available resources on highest priorities. Also, identify subwatersheds in which to emphasize high water quality.
- Not implementing any timber management in riparian areas without proof that these activities actually increase coarse woody debris above natural

levels and the benefits outweigh the risks (sedimentation, oil and fuel runoff, etc).
- Conducting a comprehensive all seasons water quality monitoring.
- Eliminating commercial logging and unrestrained recreation in municipal watersheds.

Watershed Management Practices

Non-point source pollution poses a serious threat to the health of watersheds. It results from an accumulation of many small actions, and, although the individual impacts may seem minor, the combined cumulative effects are significant. Control measures and best management practices (BMPs) exist that can be utilized for improved watershed health (Kiran and Ramachandra, T.V., 1999). The effectiveness of the measures varies, depending on the specific pollutants addressed; the watershed hydrology and characteristics, such as soils, slopes, type of vegetative cover, and the nature and extent of area development; the waterbodies in the watershed; and the sources of the pollution. Effectiveness also depends on correct application of the control measure or practice. All types of land uses have the potential to create non-point source pollution. Most of this pollution results from changes and disturbances on the land. Some key sources include residential areas, agricultural activities and forest practices.

Residential problems stem from neighbourhoods containing typical single- or multi-family dwelling units. The problems arise from impervious surfaces that increase the flow and volume of runoff causing stream channel erosion and flooding, and from sedimentation from eroded lawns and gardens. Runoff can become contaminated by household chemicals such as fertilizers, pesticides and herbicides, paints, solvents, and street/auto contaminants like oil. The most effective control measures to address residential non-point source pollution include:

- public education
- use of vegetated swales and wetlands for contaminate filtration before runoff enters receiving streams
- sediment traps in stormwater systems
- stormwater retention (e.g. detached downspouts)
- landscape design for erosion control
- recycling and proper disposal of household chemicals and wastes
- proper maintenance of on-site septic systems to reduce nutrient loading
- combined sewer overflow management
- vegetative planting and riparian enhancement of neighbourhood streams
- street sweeping to reduce suspended solid loading and decrease heavy metals and phosphorus contamination to receiving streams
- planned development on steep slopes
- limited amount of impervious surface

- increased use of cluster developments
- utilization of erosion control ordinances, especially on construction sites.

Agricultural activities include land uses such as orchards, nurseries, crop production, feedlots, and grazing. Most non-point source pollution from agricultural practices comes from erosion or chemical contamination of receiving waters. The most effective control measures to address agriculture-related non-point source pollution include:

- riparian area protection and enhancement
- revised management practices for livestock grazing and manure handling.

Forestry practices generally lead to nonpoint source pollution problems of soil erosion and chemical contamination. The most effective control measures to address these problems include:

- technical assistance to landowners
- limits on road building and management
- use of erosion control standards
- chemical application controls (pesticides and herbicides)
- riparian area protection and enhancement.

This accentuates the need for healthier watersheds. Healthier watersheds would slow the runoff, increase percolation into underground aquifers, decrease siltation of waterways, and lengthen the flow period for the rivers.

Watershed management has worked for over a century in Tirunelvelli, where watershed recovered resulting in improved stream flow in less than five years when cattle grazing and fuelwood harvest were removed. The Palni Hills Conservation Council (PHCC) found that the watersheds of the Karavakurichi Reserve Forest improved in mere two years when fuelwood harvesters were given alternate employment in tree nurseries. Similar success stories are reported from dry arid districts like Ananthpur.

AQUATIC ECOSYSTEM: CONSERVATION STRATEGY

While rivers, lakes, and wetlands contain a mere 0.01% of the Earth's water, these ecosystems support a disproportionately large part of global biodiversity. Freshwater fishes alone account for approximately one quarter of all living vertebrate species and it is estimated that there are 44,000 scientifically named species of freshwater biota. Tallies of endangered species indicate that freshwater biodiversity is generally more threatened than terrestrial biodiversity. For example, of those species considered in the World Conservation Union's (IUCN) Red List for 2000, 20% of amphibians and 30% of fishes (mostly freshwater) were considered threatened. Freshwater biodiversity faces a broad range of threats. These include the direct impacts of dams, exotic species, overfishing, pollution, stream channelisation, water withdrawals, and diversions, as well as the indirect consequences of terrestrial activities such as logging, agriculture, industry, housing development, and mining (Prasad et al., 2002). Conservation strategies need to be evolved and implemented to protect freshwater biodiversity. The Aquatic Conservation Strategy focuses on conservation and maintaining the ecological health of watersheds and aquatic ecosystems so as to (Ramachandra, T.V. et al., 2002):

- Maintain and conserve the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations, and communities are uniquely adapted.
- Maintain and conserve spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include flood plains, wetlands, up slope areas and headwater tributaries. These linkages must provide chemically and physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.
- Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.
- Maintain and preserve water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain in the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.
- Maintain the sediment regime under which an aquatic ecosystem evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.
- Maintain in stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing (i.e., movement of woody debris through the aquatic system). The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.
- Maintain the timing, variability, and duration of flood plain inundation and water table elevation in meadows and wetlands.
- Maintain and conserve the species composition and structural diversity of plant communities in riparian zones and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration, and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.
- Maintain and conserve habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.
- Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding the various components, such as monitoring of water quality, socio-economic dependency, biodiversity, and other activities, as an

indispensable tool for formulating long term conservation strategies (Kiran & Ramachandra, 1999). This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at raising the levels of public awareness and comprehension of aquatic ecosystem restoration, goals, and methods. Actively participating schools and colleges in the vicinity of the waterbodies may value the opportunity to provide hands-on environmental education which could entail setting up laboratory facilities at the site. Regular monitoring of waterbodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

Watershed restoration should be an integral part of the conservation programme to aid recovery of habitat, riparian habitat, and water quality. The most important components of an aquatic restoration programme are control and prevention of pollution and sediment production, restoration of the condition of riparian vegetation, and restoration of in-stream habitat complexity (Ahalya, N. & Ramachandra, T.V., 2001).

RESTORATION OF AQUATIC ECOSYSTEMS

Due to various anthropogenic activities to cater the needs of growing population, the degradation of freshwater ecosystems by a variety of stressors has increased logarithmically. As a result, many aquatic ecosystems are in need of some drastic corrective measures/restoration. Restoration is the "return of an ecosystem to a close approximation of its condition prior to disturbance" or the reestablishment of predisturbance aquatic functions and related physical, chemical and biological characteristics (Gwin et al., 1999; Lewis, 1989; NRC, 1992; Race, M.S. & M.S. Fonseca, 1996). It is a holistic process not achieved through the isolated manipulation of individual elements. The objective is to emulate a natural, self-regulating system that is integrated ecologically with the landscape in which it occurs. Often, restoration requires one or more of the following processes: reconstruction of antecedent physical conditions, chemical adjustment of the soil and water; and biological manipulation, including the reintroduction of absent native flora and fauna (Zedler, J., 1996).

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values is to be considered. Coordination with the local people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with all stakeholders can also add useful resources, ranging from finance and technical expertise to volunteer help with implementation and monitoring (Ramachandra T.V., 2001). Restoration principles are:

- *Preserve and protect aquatic resources:* Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems.
- *Restore ecological integrity:* Ecological integrity refers to the condition of an ecosystem — particularly the structure, composition, and natural processes of its biotic communities and physical environment.
- *Restore natural structure:* Many aquatic resources in need of restoration have problems that originated with harmful alteration of channel form or other physical characteristics, which in turn may have led to problems such as habitat degradation, changes in flow regimes, and siltation.
- *Restore natural function:* Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions.
- *Work within the watershed and broader landscape context:* Restoration requires a design based on the entire watershed, not just the part of the waterbody that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. By considering the watershed context in this case, restoration planners may be able to design a project for the desired benefits of restoration, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and non-point source pollution.
- *Understand the natural potential of the watershed:* Restoration planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.
- *Address ongoing causes of degradation:* Identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible.
- *Develop clear, achievable, and measurable goals:* Goals direct implementation and provide the standards for measuring success. The chosen goals should be achievable ecologically, given the natural potential of the area, and socio-economically, given the available resources and the extent of community support for the project.
- *Focus on feasibility* taking into account scientific, financial, social and other considerations.
- *Anticipate future changes:* As the environment and our communities are both dynamic, many foreseeable ecological and societal changes can and should be factored into restoration design.
- *Involve the skills and insights of a multi-disciplinary team:* Universities, government agencies, and private organizations may be able to provide useful information and expertise to help ensure that restoration projects are based on well-balanced and thorough plans.
- *Design for self-sustainability:* Ensure the long-term viability of a restored area by minimizing the need for continuous maintenance of the site. In

addition to limiting the need for maintenance, designing for self-sustainability also involves favouring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.

- *Use passive restoration, when appropriate:* Simply reducing or eliminating the sources of degradation and allowing recovery time will allow the site to naturally regenerate. For some rivers and streams, passive restoration can reestablish stable channels and floodplains, regrow riparian vegetation, and improve in-stream habitats without a specific restoration project. Passive restoration relies mainly on natural processes and it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.
- *Restore native species and avoid non-native species:* Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls.
- *Use natural fixes and bioengineering techniques, where possible:* Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants, and provide habitat. These techniques would be successful for erosion control and bank stabilisation, flood mitigation, and even water treatment.
- *Monitor and adapt where changes are necessary:* Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked. The presence or absence of public support for a restoration project can be the difference between positive results and failure. Coordination with the people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area (Ramachandra, T.V. et al., 2002). Thus, a sustainable water system encompasses issues such as:

- Environment: watershed protection, ecosystem balance, waste-water and bio-solids.
- Community: sufficient and reliable water supply, participation in planning and recreational use to water.
- Economy: Evolution and diversification, sustainable and long-term growth.

Within this overall vision, water management system will require, among other steps, the following action to be taken:

- Through strategic partnerships among national agencies, provincial agencies and local/city departments.
- Developing alternate water sources—reclaimed/treated water, desalination, rainwater and water reuse.
- Implementing new technologies for water fees/metering, leak detection and water auditing systems.
- Engage the community through education, local and regional planning processes and outreach to cultural and community groups.
- Scientific investigations involving aquifer monitoring, coastal marine environment study, supply-demand forecasting and pollution prevention.

The principal components of water management system include:

- *Supply optimization*, including assessments of surface and groundwater supplies, water balances, wastewater reuse, and environmental impacts of distribution and use options.
- *Demand management*, including cost-recovery policies, water use efficiency technologies, and decentralized water management authority.
- *Equitable access* to water resources through participatory and transparent management, including support for effective water users association, involvement of marginalized groups, and consideration of gender issues.
- *Improved policy, regulatory and institutional frameworks*, such as the implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.
- *Intersectoral approach* to decision-making, and combining authority with responsibility for managing the water resource.

Water quality and quantity are becoming increasingly critical factors of socioeconomic development in many parts of the world. One of the milestones in managing international and transnational water resources and boundaries was the meeting and agreement on transboundary water management signed in Helsinki in 1966 (ILC Helsinki, 1966).

Helsinki rule evolved by the International Law Association in 1966 (see Annexure) are:

i) the geography of the basin including, in particular, the extent of the drainage area in the territory of each basin state;
ii) the hydrology of the basin including, in particular, the contribution of water by each basin state;
iii) the climate affecting the basin;
iv) the past utilization of the waters of the basin, including in particular, existing utilization;
v) the economic and social needs of each basin state;
vi) the population dependent on the waters of the basin of each state;

vii) the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
viii) the availability of other resources;
ix) the avoidance of unnecessary waste in the utilization of the waters of the basin;
x) the practicability of compensation to one or more of the co-basin states as a means of adjusting conflicts among users; and
xi) the degree to which the needs of a basin state may be satisfied without causing substantial injury to a co-basin state.

POLICY OPTIONS

Burgeoning human populations coupled with agricultural and industrial developments increase the water requirements. As escalating need for food in dry climate areas increases the need for irrigation, water and water supply systems are increasingly becoming reasons for conflict. The development and implementation of a comprehensive forward-looking integrated water resources management scheme must include water law as an integral component. This is especially important in upstream/downstream situations where conflicts of water use are increasingly inevitable.

It is evident from recent water disputes/conflicts, that what has to be shared between those upstream and those downstream in a river basin is not the water currently going in the river (as suggested by the concerned authorities), but rather the rainfall over the river basin (which takes into account scarce rainfall period) and solutions should be based on sound economics, science, and enlightened and enhanced political commitment. In summary, policy:

1. Defines the legal entitlement to water and identifies the rights and obligations tied to water use and thus provides the prescriptive parameters for its development.
2. Provides the framework to ensure the ongoing integrity of the regime (i.e. monitoring, regulation, compliance, dispute avoidance and settlement).
3. Permits the rational modification of existing regimes (i.e. to meet changing needs).

Water development issues must be viewed in an overall context. In conflicts between upstream and downstream users, the scenario at all levels (national, regional and international) is much the same: the downstream user generally develops first and is keen to preserve into perpetuity these senior-in-time uses. The upstream user is thus placed in the unenviable situation of justifying the legitimacy of new uses, which almost certainly will adversely affect the existing uses downstream. Planning (the formulation of plans and policies) is an important and often indispensable means to support and improve operational management. Planning has six related functions, such as:

a) To assess the current situation (including the identification of conflicts and priorities), formulate visions, set goals and targets, and thus orient operational management.
b) To provide a framework for organising policy relevant research and public participation.
c) To increase the legitimacy, public acceptance of, or even support for operational management.
d) To facilitate the interaction and discussion among managers and stakeholders, offer a common point of reference (the plan or policy), and thus provide co-ordination. Planning should involve, in a systems framework, all phenomena, institutions and issues that affect the allocation and protection of inland waters. It should not result in negative effects on other natural resources and should consider linkages to plans for biodiversity management, coastal protection, ocean health, and human health and well being.
e) Planning should be focussed and coherent and be in proportion to the resources available for implementation. Planning should be rooted in the real problems to be solved and be realistic.
f) Planning systems should be evaluated to check whether they serve their purpose; planning systems should not be taken for granted; given the differences in problem situations and cultures, planning systems should reflect the local situation.

INTEGRATED AQUATIC ECOSYSTEM MANAGEMENT

Integrated aquatic ecosystem management requires proper study, sound understanding and effective management of water systems and their internal relations (groundwater, surface water and return water; quantity and quality; biotic components; upstream and downstream). The water systems should be studied and managed as part of the broader environment and in relation to socio-economic demands and potentials, acknowledging the political and cultural context. The water itself should be seen as a social, environmental, and economic resource, and each of these three aspects must be represented in the political discourse. This discourse should reflect the interests of local communities and people, their livelihoods and their aquatic environments. Users and managers at all levels must be allowed to have an input. The aim of integrated aquatic system management is to ensure the sustained multi-functional use of the system. The basic water needs of people and ecosystems should be fulfilled first. Essential ecological and physical processes should be protected. Moreover, the effects on the receiving water bodies (seas, lakes, deltas, coastal zones) should be paid full attention. The following points (Ramachandra, T.V. et al., 2002) need to be stressed as crucial for sustainable management:

- Should be applied at catchment level. The catchment is the smallest complete hydrological unit of analysis and management. Integrated catchment management (ICM), therefore, becomes the practical operating approach. Although this approach is obviously sound and finds wide acceptance, too narrow an interpretation should be avoided.

- Decentralisation should be pursued as much as possible in order to bring river basin management as close as possible to the individual citizens and facilitate local variation in response to differing local conditions and preferences. Decentralisation is also possible in case of tasks with a supra-local scope if the decentralised governments concerned co-operate (e.g. panchayaths in a river basin) or if they are supervised by a higher-level government body. The process should be transparent, phased and planned.
- It is critical to integrate water and environmental management. This principle is widely and strongly supported. Integrated aquatic ecosystem management can be strengthened through the integration of Environmental Impact Assessments (EIA's), water resources modeling and land use planning. It should also be understood that a catchment or watershed approach implies that water should be managed alongside the management of codependent natural resources, namely soil, forests, air and biota.
- Through a systems approach. A true systems approach recognizes the individual components as well as the linkages between them, and that a disturbance at one point in the system will be translated to other parts of the system. Sometimes the effect on another part of the system may be indirect, and may be damped out due to natural resilience and disturbance. Sometimes the effect will be direct, significant and may increase in degree as it moves through the system. While systems analysis is appropriate, analyses and models that are too complex to be translated into useful knowledge should be avoided.
- The only form of river basin management that directly affects the river basin and its users is operational management (the application of regulatory, economic and communicative policy instruments and concrete activities such as infrastructure management). Consequently, it should play a pivotal role in any river basin management strategy. Planning, policies, analytical tools and institutional systems play an essential role as deciders and facilitators. They can improve operational management, promote a basin-wide, intersectoral long-term approach, and in this way further the sustained multi-functional use of the basins concerned (Rajinikanth, R. & Ramachandra, T.V., 2001).
- Communicative instruments for operational management, such as voluntary agreements, can help to improve the implementation of river basin plans and policies, but they only work in relation to regulation and compliance mechanisms.
- Tradable water rights can be an important tool for river basin management, but they are only effective if a number of conditions are met:
  a) The basic water demands of citizens and ecosystems are safeguarded.
  b) The rights should be defined and agreed upon.

c) Utilisation of the rights should be physically possible.
d) Monopoly is to be prevented.

- Full participation by all stakeholders, including workers and the community. This will involve new institutional arrangements. There must be a high level of autonomy, but this must at the same time be associated with transparency and accountability for all decisions. Care should be taken to ensure that those participating in any catchment management structure do indeed represent a designated group or sector of society. It is also important to ensure that representatives provide feedback to the constituencies they represent. Integrated aquatic ecosystem management seeks to combine interests, priorities and disciplines as a multi-stakeholder planning and management process for natural resources within the catchment ecosystem, centered on water. Driven bottom-up by local needs and priorities, and top-down by regulatory responsibilities, it must be adaptive, evolving dynamically with changing conditions.
- Attention to social dimensions. This requires attention to, amongst other things, the use of social impact assessments, workplace indicators and other tools to ensure that the social dimension of a sustainable water policy is implemented. This will include the promotion of equitable access, enhanced role of women, and the employment and income implications of change.
- Capacity building. At many levels in the process—even at the governmental level—stakeholders lack the necessary knowledge and skills for full application of integrated aquatic ecosystem management. Community stakeholders may not be familiar with the concept of water resource management, catchment management, corporate governance, and their role in these. Capacity building categories include education and awareness raising about water; information resources for policy making; regulations and compliance; basic infrastructure; and market stability. Early and ongoing stakeholder collaboration and communication in capacity building is also important from the view point of "leveling the playing field" in anticipation of disputes that may arise. Filling strategic skills/capacity gaps supports integrated aquatic ecosystem management, facilitates dispute resolution, and builds practical understanding of the scope of sustainable natural resource development challenges and opportunities.
- The capacity of all institutions needs to be maintained and/or developed by means of short-term and long-term programmes (including postgraduate education and curricula development).
- Availability of information and the capacity to use it to make policy and predict responses. This implies, firstly, sufficient information on hydrological, bio-physical, economic, social and environmental characteristics of a catchment to allow informed policy choices to be made; and secondly, some ability to predict the most important responses of the catchment

system to factors such as effluent discharges, diffuse pollution, changes in agricultural or other land use practices and the building of water retaining structures. The latter hinges on the adequacy of scientific models. It is recognized that predicting ecosystem response to perturbation with reasonable confidence is severely taxing current scientific capabilities, stimulating ongoing research.

- Full-cost pricing complemented by targeted subsidies. This principle was strongly urged by the World Water Council at The Hague, the rationale being that users do not value water provided free or almost free and have no incentives to conserve water. Wide support for this principle was engendered, but also significant opposition from those who felt that the interests of the poor might not be sufficiently protected, even under an associated subsidy system, however well designed. Opposing views held that full-cost pricing, when applied in its narrowest sense, offends the principle that water is a public good, a human right, and not simply an economic good. Reiterating: The economic sustainability of water and sanitation services depends largely and appropriately on the recovery of costs through user fees or tariffs that are equitably assigned based on ability-to-pay. Under-served or unserved, marginalized users in many places already pay high financial costs of not having safe piped water, for example, because they are forced to pay for water trucked-in by suppliers. This water may be of dubious quality yet is expensive.
- Charges are effective and efficient means to finance aquatic ecosystem management (cost recovery) and reduce water use and pollution if the basic water needs of the poor are safeguarded, e.g. by means of block tariffs.
- Central government support through the creation and maintenance of an enabling environment. The role of central government in integrated catchment management should be one of leadership, aimed at facilitating and coordinating the development and transfer of skills, and assisting with the provision of technical advice and financial support, to local groups and individuals. Where specific areas of responsibility fall outside the mandate of a single government department, appropriate institutional arrangements are required to ensure effective inter-departmental collaboration.
- Traditional regimes and institutions should be recognised and integrated in aquatic ecosystem management. Adoption of the best existing technologies and practices—BMPs (best management practices).
- Reliable and sustained financing. In order to ensure successful implementation of integrated aquatic ecosystem management approaches, there should be a clear and long-term commitment from government to provide financial and human resources support. This is complemented by income from a healthy water and sanitation market, especially when local providers of goods and services that support the water sector are active players, and when there is active reinvestment in the sector.

- Equitable allocation of water resources. This implies improved decision-making, which is technically and scientifically informed, and can facilitate the resolution of conflicts over contentious issues. There are existing tools (e.g. multi-criteria analysis) to help decision-making in terms of balancing social, ecological and economic considerations. These should be tested and applied.
- The recognition of water as an economic good. The recognition of water as an economic good is central to achieving equitable allocation and sustainable usage. Water allocations should be optimized by benefit and cost, and aim to maximize water benefits to society per unit cost. For example, low value uses could be reallocated to higher value uses such as basic drinking water supplies, if water quality permits. Similarly, lower quality water can be allocated to agricultural or industrial use.
- There may be a distinct role for private entities (publicly or privately owned) in the provision of water services and water management. Private ownership of water infrastructure is a controversial issue that needs to be carefully explored.
- Strengthening the role of women in water management. A review by the World Bank of 121 water projects showed that ensuring women's participation in decision-making positively affects both project quality and sustainability (http://www.gdrc.org/uem/water).
- Floods not only cause suffering but also support life. Flood management should not be based solely on building dykes and dams. It needs to be based on strategies that use both structural and non-structural methods. The strategy should balance all interests involved and be based on an integrated assessment, of the environmental, economic and human costs and benefits of these alternatives, including their potential contribution to drought mitigation and including the possibilities that they offer for nature.
- The ultimate goal of pollution control is to close substance cycles and in this way prevent pollution. A mix of instruments for regulation and compliance can be used to move into this direction and solve urgent pollution problems: waste control, process and emission standards, and a water quality approach. The exact mix should reflect inter-alia the local management capacity and the availability of water quality data and other data (Ramachandra T.V. et al., 2001).
- Effective aquatic ecosystem management requires sound data, information and knowledge, including both data on surface and groundwater (quantity and quality) and social and economic data. Collection and processing of relevant data, easy accessibility and broad dissemination are eminent tasks of river basin management. To increase policy relevance, data should be aggregated into meaningful information, for example in the form of indicators and systems for benchmarking. Compliance monitoring (reporting, reviewing and evaluating) is very important for promoting the implementation of plans.

- Sustainable aquatic resources development and management depends mainly on proper planning, implementation, operation and maintenance, which is possible with Geographic Information System (GIS) and Remote Sensing techniques, complement and supplement ground data collection in various facets of different kinds of water resources projects. The synoptic large area repetitive coverage provided by satellite sensors provide appropriate database.
- To support aquatic ecosystem management, a new analytical model should be developed that can aggregate socio-economic, political, institutional and technological potentials and hydrological constraints. This model should furthermore be capable of evaluating the actual management capacity.
- To support strategic planning, methods for analytical support should be developed that:
  - ✓ cover the whole basin and all significant impacts;
  - ✓ specifically consider the socio-economic processes that affect the basin;
  - ✓ predict the socio-economic effects of alternative strategies; and
  - ✓ present the issues in such a way that people can understand them.
- Methods for analytical support should furthermore reflect the fact that policy analysis can never rely on quantitative information only. Moreover, these methods should be transparent and flexible, promote policy learning by all actors, and facilitate negotiation processes. Appropriate methods may include argumentative policy analysis and role-playing supported by a computer model of the natural system and the socio-economic effects.
- There is a large role for appropriate decentralised information systems and networks that can promote interaction among sectors, provide a basis for consistent technical studies, help communication with the public, and stimulate participation.
- To implement the general principles of the integrated aquatic ecosystem management requires a cyclic policy development approach. Such an approach would include the following steps — Assessment of institutions, needs and resources, planning, implementation, compliance monitoring and evaluation.

Acknowledgements: The financial assistance from the Ministry of Environment and Forests, Government of India, Commonwealth of Learning, Canada and Indian Institute of Science is acknowledged. I thank Mr. H.S. Sudhira for reading this manuscript and providing useful suggestions.

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ANNEXURE

Guiding Principles for Water Management

Issues that have come up as a result of global consultations include the promotion of a greater focus on water demand management, and conservation within the framework of integrated water resources management; encouraging a shift from the supply driven approach to meet demand on water to the demand management approach and greater efficiency to match available resources; promoting greater focus on pollution control policies within the framework of integrated water resources management to safeguard the quality of water and to maximize the safe reintegration of recycled wastewater into the water cycle as a non-conventional water source; reviewing water demand and pollution control experience across the region and identify and examine replicable strategies and models; and demonstrating the viability of water demand management and efficiency policies (*http://www.idrc.org/wem/water*).

Event	*Guiding Principles*
Global Consultation on Safe Water and Sanitation for the 1990s, New Delhi, 1990	The New Delhi Statement formalised the need to provide, on a sustainable basis, access to safe water in sufficient quantities and proper sanitation for all, emphasising the "some for all rather than more for some" approach. Four guiding principles were postulated: • Protection of the environment and safeguarding of health through the integrated management of water resources and liquid and solid wastes • Institutional reforms promoting an integrated approach • Community management of services • Sound financial practices.
International Conference on Water and the Environment, Dublin 1992	Four guiding principles were formulated: • Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment • Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels • Women play a central part in the provision, management and safeguarding of water • Water has an economic value in all its competing uses and should be recognised as an economic good.
United Nations Conference on Environment and Development, Rio de Janeiro, 1992	Agenda 21 emerged from this Conference, with Chapter 18 dealing with water issues. Chapter 18 was titled: "Protection of the quality and supply of freshwater resources: Application of integrated approaches to the development, management and use of water resources". Seven programme areas were proposed for the freshwater sector:

- Integrated water resources development and management
- Water resources assessment
- Protection of water resources, water quality and aquatic ecosystems
- Drinking-water supply and sanitation
- Water and sustainable urban development
- Water for sustainable food production and rural development
- Impacts of climate change on water resources.

Second World Water Forum and Ministerial Conference in The Hague, March 2000

The World Water Vision which was presented at the Forum, defined three primary objectives: (1) to empower people and communities to decide how to use water, (2) To get more crops and jobs per drop and (3) to manage use to conserve freshwater and terrestrial ecosystems. It deemed five actions critical to the achievement of the objectives:

- Involving all stakeholders in integrated management
- Moving to full-cost pricing
- Increasing public funding for research and innovation
- Cooperating to manage international basins
- Massively increasing investments in water

The World Water Council which organized the Second World Water Forum, formulated the following Messages for a water secure world:

- A holistic, systemic approach relying on integrated water resources management must replace the current fragmentation in managing water
- Participatory institutional mechanisms must be put in place to involve all sectors of society in decision-making
- Fresh water must be recognised as a scarce commodity and managed accordingly.
- Full cost pricing of water services with targeted subsidies for the poor
- Fresh water must be recognised as a basic need, with adequate access ensured for the poor
- Incentives for resource mobilisation and technology change are needed
- Institutional, technological and financial innovation is needed
- Private investment and community action
- Political will is needed to go beyond Dublin and Rio
- Governments are key actors — as enablers and regulators
- Behavioural change is needed by all — no more business as usual

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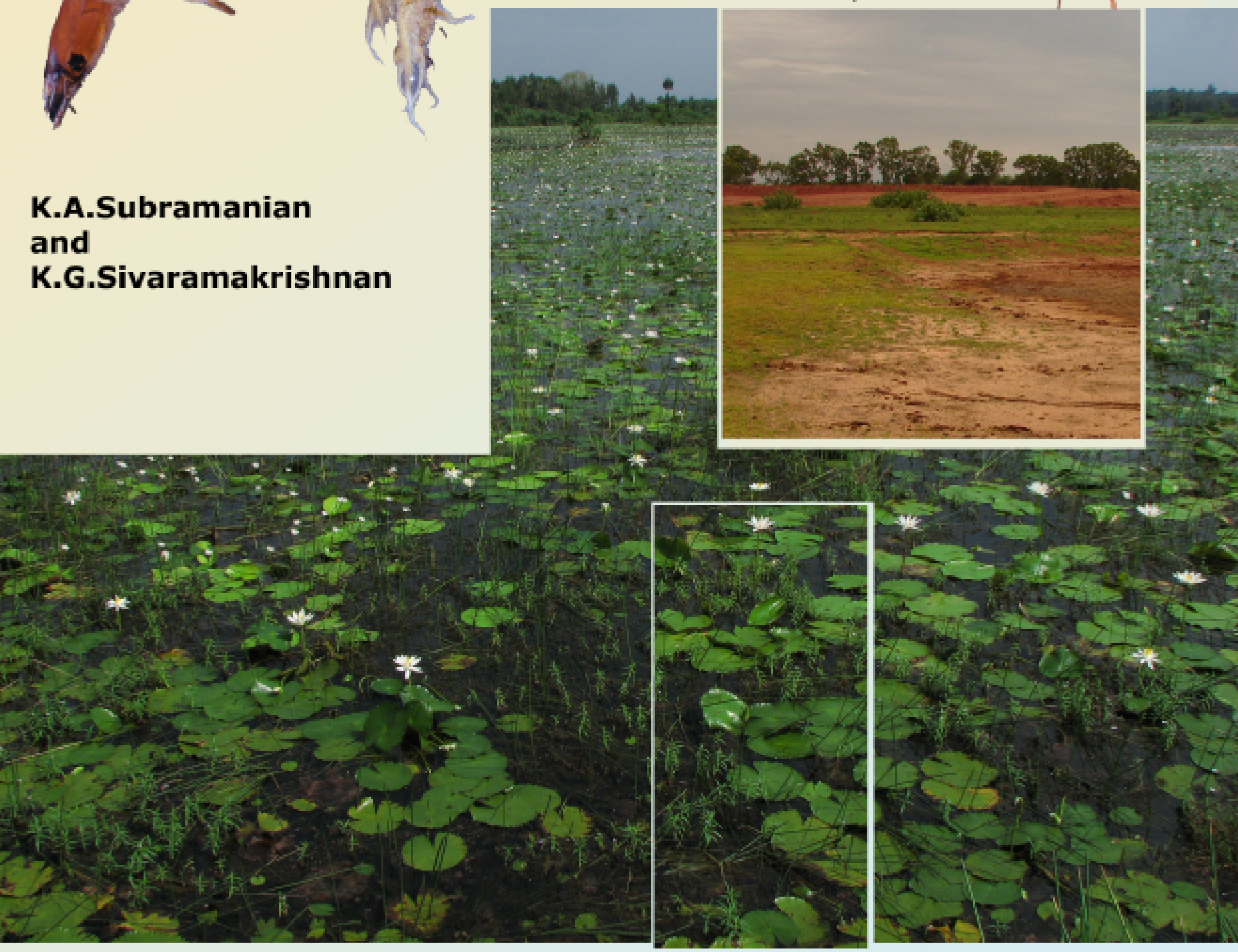

Ashoka Trust for Research in Ecology and Environment (ATREE)
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2007

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Acknowledgements: This field guide would not have achieved this shape without the support of ATREE through its Small Grants Programme to K.A.Subramaninan. Authors sincerely thank friends and colleagues for valuable comments and suggestions on earlier drafts of this guide. We sincerely thank the Karnataka and Kerala forest departments for their field support.

Citation: Subramanian, K.A. and Sivaramakrishnan, K.G. (2007). Aquatic Insects for Biomonitoring Freshwater Ecosystems-A Methodology Manual. Ashoka Trust for Ecology and Environment (ATREE), Bangalore, India. 31pp.

Aquatic Insects for Biomonitoring Freshwater Ecosystems- A Methodology Manual

1. Introduction

Around the world, freshwater habitats are being subjected to increased levels of human disturbance (Saunders *et al.,* 2002). A recent assessment of the status of inland water ecosystems shows that globally most threatened river catchments are to be found in the Indian subcontinent (WCMC, 2000). A study based on 195 animal species of inland water ecosystems indicates that on average monitored populations have declined by 54% during 1970-2000. This compares with a decline over the same period of some 35% in 217 marine and coastal species, 15% in 282 terrestrial species. Though, not conclusive, these provide strong indications that inland water ecosystems are suffering the greatest negative impact from human activities at present (WWF 2002 & WCMC, 2000). In this juncture, it is imperative to identify, monitor and conserve important areas biodiversity especially of the riverine ecosystems (Dudgeon, 1994).

Dudgeon *et al.,* (1994, 2000) stresses the importance of biomonitoring and identifying areas of riverine biodiversity for long term conservation. Biological assessment of the freshwater habitats aims at characterizing and monitoring the conditions of the aquatic resources (Sivaramakrishnan, *et al.,* 1996a). The assessments are commonly associated with human impact (Resh, *et al.,* 1995). The use of living organism for monitoring water quality originated in Europe early in this century and it is widely used (Cairns and Pratt, 1993; Metcalfe-Smith, 1994). A spectrum of biological communities including plankton, periphyton, microphytobenthos, macrozoobenthos, aquatic macrophytes and fish has been used in the assessment of the water quality (De Pauw *et al.,* 1992). However, experiences from USA and European programmes have demonstrated that benthic macroinvertebrates are most useful in monitoring freshwater ecosystems (De Pauw *et al.,* 1992; Hellawell, 1986; Rosenberg and Resh, 1993).

Anisocentropus and *Chironomus* are indicators of unpolluted and polluted waters respectively.

1.1. Assumptions: Biological assessment methods using macroinvertebrates are based on the assumptions that with increasing pollution, change will occur in

(1) the species present (e.g., appearance of tolerant species)

(2) the number of species and

(3) change in abundance of species.

1. 2.Advantages: Current monitoring techniques detect one or more of these changes to identify water quality problems at a site (Sivaramakrishnan *et al.,* 1996a). Traditionally, qualitative and quantitative approaches are employed for biomonitoring of freshwater ecosystems. The analytical methods used for quantitative biomonitoring methods require replicate sampling. The problem with this approach is only few sites can be sampled and most of the time will be expended on identification of the whole sample (Sivaramakrishnan *et al.,* 1996). In contrast, the qualitative sampling requires only few samples from a site and various measures (or metrics) are easily calculated (Resh and Jackson, 1993; Metcalfe-Smith, 1994). The level of impairment is estimated by comparing the deviation of the test site values from the reference site (Sivaramakrishnan *et al.,* 1996).

Biomonitoring can not entirely replace standard physic-chemical water quality methods. Standard physico-chemical water quality measures provide information on water quality at a particular spatial unit during the time of sampling. It cannot provide historical information on water quality. On the other hand, by knowing the ecology of aquatic insect community, biomonitoring tools provide some historic insights into the water quality. Standard physico-chemical water quality methods need to be carried out in conjunction with biomonitoring tools to comprehensively evaluate the health of freshwater ecosystems. This is particularly important when heavy metal or pesticide contamination is suspected.

1. 3. Historic background: The biotic index approach adopted by many European programmes integrates the indicator species concept with elements of diversity. A biotic index is a “scoring system” and assigns scores to taxonomic groups based on assumed tolerance of the taxa to pollution and habitat disturbance (Cairns and Pratt, 1993). The basis for modern day biotic indices is the Trent Biotic Index (TBI), which was originally developed in 1964 for the Trent River in England (Metcalfe-Smith, 1994). Currently, for biomonitroing the Biological Monitoring Working Party (BMWP) score (Armitage *et al.,* 1983) and the "Average Score per Taxon" (ASPT) modification of this index is frequently used (Sivaramakrishnan *et al.,* 1996). In India various studies have presented spatial and temporal trends in diversity or biotic index of streams, rivers and lakes (Chattopadhyay *et al.,* 1987; Jhingran *et al.,* 1989; Khanna, 1993; Verma *et al.,* 1978, Bhat, 2002). The biomonitoring system developed for the temperate streams was tested and found to be useful for the river Cauvery (Sivaramakrishnan, 1992; Sivramakrishnan *et al.,* 1996). The biomonitoring scores for the river Cauvery was developed by using, the modified form of standard table of Armitage *et al.,* (1983) developed for the Yamuna River (Trivedi, 1991; Sivaramakrishnan, 1992; Sivramakrishnan *et al.,* 1996).

2. Methods

2. 1.Tools for Sampling

A checklist of tools for sampling aquatic insects is provided in the **Appendix-1** and figure-1. Most of the materials for sampling can be locally fabricated or procured.

2. 2.Selecting Study sites

A reconnaissance visit to the proposed study site is necessary to select sampling locations, design sampling protocol and work out the logistics. It is better to take one or two local persons who are familiar with the area during the reconnaissance tour. You can particularly request them to show most polluted and least disturbed areas of your study site. You may even hold a small meeting of local residents and explain them the purpose of your study and inform about your proposed study locations. Try to involve local schools/ colleges in your study. If your study site falls under any forest/defence/private/panchayat/ municipality/ corporation area take written permissions from concerned authority.

Topographic maps (Survey of India Topo sheets 1:2, 50,000 and 1:50,000) is necessary to understand the ecological setting of the study locations. SOI topo sheets of 1:2, 50,000 scales are easily available for general public and would serve most of the practical purpose. It is advisable to carry the topo sheets during reconnaissance tour and mark changes in the water bodies after the publication of the map. Note down the local names of water bodies from local residents. This will help in communicating the results of your findings to locals.

It is very important to select reference site(s) within the study site. Reference site(s) are locations which are assessed to be least disturbed or represent natural or near natural condition of the freshwater ecosystem under study. It is advisable to select the reference site(s) within the same catchment (Fig.2). However, if the suitable reference site(s) are not available within the catchment, sites from neighbouring catchment can be selected.

3.Sampling Protocol

3. 1.Identifying Freshwater Habitat: The inland freshwaters encompass a diverse array of ecosystems as varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs and even pools of water that collect in the leaf axils of certain plants. This is a small fraction of world's water resource. Despite this, inland aquatic habitats show far more variety in their physical and chemical characteristics than marine habitats and contain a disproportionately high fraction of the world's biodiversity.

Inland water habitats can be classified into stagnant (*lentic)* and flowing (*lotic*)*.* They may also be classified into perennial or transient. Each of these has its own set of distinctive ecology and biological community. Lentic systems comprise lakes and ponds. Manmade lentic habitats such as irrigation tanks, ponds and reservoirs are predominant landscape features in many parts of Asia.

Lotic system encompasses rivers and streams. A river system is essentially a linear body of water draining under the influence of gravity. Most of the river systems discharge intose the sea and some into lakes. A few watercourses in arid regions enter inland basins where no permanent lakes exist and disappear into the dry plains. Large rivers such as Ganges and Brahmaputra cross over many degrees of latitude and traverse a wide range of climatic conditions. Variations in water flow and underlying geology also create a wide range of habitats, often within a short distance. Because of this change in habitats, different organisms are typically present in different parts of any given river system. Even though rivers are physically very dynamic, large rivers rarely disappear, and there are indications that some of the large rivers are in existence for tens of millions of years. This is reflected in the fact that, all the taxonomic groups are found in running waters, and some invertebrate taxa are exclusive or attain greatest diversity there.

Widely accepted classification scheme for inland aquatic habitats is given in **Appendix-2.**

3. 2. How many samples? This is a recurring question in biomonitoring studies. As a guideline, widely accepted taxa/family accumulation curve (across samples) can be used to determine the efficacy of the sampling. Figure-2 shows family accumulation curve across samples. It shows that most of the families have been encountered by 39 sampling sessions. This graph can be easily prepared in MS Office Excel and it is better to plot this graph after few sampling (about 10) to know the taxa accumulation trend and to decide on future sampling.

3.3.When to sample? This is a very important sampling issue. Many aquatic insects show clear seasonality and community composition changes across seasons. So it is better to sample the study sites across seasons. Studies in peninsular India have shown that sampling during post monsoon (August-December) gives a reasonable picture of community composition. However, this may not be applicable to other parts of India and more data is required to design appropriate sampling schedule for those parts.

3.4.Where to sample? It is better to stratify the study area before sampling. The study area can be stratified based on broad ecological variables (altitude, rainfall gradient, vegetation type, riparian landuse etc.), or disturbance regime (polluted, unpolluted, dams, canalized etc.). Topographic and thematic maps are essential at this stage to decide on sampling spot.

3.5.Are water quality parameters necessary? Basic water quality parameters (water temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Turbidity, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) provides useful information and helps in analyzing biological data. Protocols for these methods are standardized. The methods standardized by American Public Health Association (APHA) (Clescerl et al., 1999) are universally accepted and followed.

3.6. What other data to collect? Data on aquatic plants and observations on disturbances are quite useful. Interviewing local residents, fisher folks, and other indigenous communities who are depending on the water body will provide interesting insights on the history of the ecosystem. This is very important to understand the stake holder perception on the ecosystem and design future conservation strategies.

3.7. Sampling Data Sheet:

A sample data sheet is provided in **Appendix-3.**

4 .Collection and Preservation of Samples:

Different methods are employed to sample aquatic insects from the target habitats. The methods employed for collecting aquatic insects from different habitats are outlined below. In all the methods, collected samples are stored in 70% ethanol and labeled separately in the field for each sampling session.

4.1. Lotic habitats (Streams and Rivers):

In streams where the water flows through boulders and cobbles with high turbulence using nets is extremely difficult owing to its physical nature. An “all out search” method can used to collect the aquatic insects. The effort in sampling is standardized by restricting the collection of aquatic insects from 10 sq.m area for one hour. Within the sampling area, aquatic insects are searched in all the possible substrata collected from substrata such as bedrocks, boulders, cobbles, leaf litter and dead wood. A sable hairbrush or forceps is used to collect all samples.

In stretches of streams and rivers where the water flows with little turbulence over gravel and sand, physical nature permits to use nets. Aquatic insects were sampled by taking three, 1-minute kick-net samples (mesh opening: 180µm; area 1m^2). The kick-net is held against water current and an area of 1m^2 in front of the net is disturbed for one minute. Contents of the net is pooled and preserved in 70% ethanol.

Pools are stretches of streams and rivers where the water flow is minimum with least turbulence. Aquatic insects on water surface are collected using a nylon pond net (mesh opening: 500µm; diameter: 30cm; depth: 15cm). All out search method mentioned earlier is also employed to collect aquatic insects from the substratum in the shallow pools.

4.2. Lentic habitats (Ponds and lakes):

In ponds and lakes aquatic insects can be sampled using a pond net mentioned earlier. A bigger pond net (mesh opening: 500µm; diameter: 60cm; depth: 50cm) with adjustable handle is quite useful in large lakes and ponds. Many aquatic beetles and bugs use aquatic vegetation as a shelter. Aquatic vegetation can be taken out to the shore with the pond net and vigorously searched for aquatic insects using a forceps. Make a special effort to sample shores of the water body to collect semi aquatic insects.

5.Analyzing samples

5.1. Identification of Samples:

Collected samples should be examined under a dissection or stereozoom microscope (10X and above) and identified using standard taxonomic literature. Samples can be assigned to a family or genus using taxonomic keys for that particular group. Following keys are useful for identification: *Ephemeroptera* (Dudgeon, 1999); *Odonata, Plecoptera, Hemiptera, Megaloptera, Coleoptera, Diptera* and *Lepidoptera* (Fraser, 1933-36; Morse *et al.,* 1994; Dudgeon, 1999); *Hemiptera* (Thirumalai 1989, 1999; Morse *et al.,* 1994), *Trichoptera* (Wiggins, 1975, 1996).

5.2. Data organization:

Data collected can be organized for future analysis using spread sheets such as MS Office Excel 2003-2007. It is better to make to master list of taxa with corrected spelling for before entering the data. This will eliminate problem of "pseudo taxa" while creating the data matrix using the software. Data in matrix is used to calculate biodiversity indices and biomonitoring scores. Pivot table function of MS Office Excel is useful in creating data matrix.

5.3. Basic data analysis:

There are many free softwares in Windows platform to estimate basic biodiversity parameters. Programs such as **Past**, **EstimateS** and **BiodiversityPro** will meet most of the basic analytical requirement.

6.Calculating Biomonitoring Scores

6.1. Assigning BMWP Scores:

The determination of Biomonitoring Working Party (BMWP) scores was based on the standard table of Armitage *et al.,* (1983). Trivedi (1991) adopted this in a modified form for the biomonitoring studies of Yamuna River. For calculation of BMWP score, identification to family is sufficient. The biomonitoring scores can be obtained by summing the individual scores of all families present (**Appendix-4**). Score values for individual families reflect their pollution tolerance based on the current knowledge of distribution and abundance. Pollution intolerant families have high BMWP scores, while pollution tolerant families have low scores (Sivaramakrishnan, 1992).

6.2. BMWP-ASPT: The Average Score per Taxon (ASPT) is calculated by dividing the score by the total number of scoring taxa. A high ASPT usually characterizes clean sites with relatively large numbers of high scoring taxa. Disturbed sites generally have low ASPT values and do not support many high scoring taxa (Sivaramakrishnan, 1992).

6.3. Percent Ephemeroptera, Plecoptera and Trichoptera (%EPT):

Propotion of Ephemeroptera, Plecoptera and Trichoptera in total number of individuals collected gives a fairly descent picture of water quality in rivers and streams. These groups prefer clear, unpolluted fast flowing streams and are sensitive to pollution.

7. Interpreting and Presenting Results

Results of impacted site should be compared with reference site to know how the aquatic insect community has responded to habitat change. The results thus obtained can be presented as simple tables and charts. It is advisable to prepare charts in black and white for easy reproduction. Key results should be highlighted and presented in simple language. Graphical representation of results through maps and charts are powerful tools for communicating the results to general public.

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Softwares

1. **EstimateS 8.0**: http://viceroy.eeb.uconn.edu/estimates
2. **PAST:** http://folk.uio.no/ohammu/past/
3. **BiodiversityPro:** www.sams.ac.uk/research/software

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Appendix-1. Tools for Sampling Aquatic Insects

1. Pencil
2. Alcohol proof pen
3. Field note book
4. Fine forceps
5. Blunt forceps
6. Hand lens
7. Watch glass
8. Plastic tray
9. Plastic jars (various sizes)
10. Leak proof vials (vaious sizes)
11. Measuring tape
12. Rope
13. Twine
14. Blade
15. Scissors
16. Knife
17. Box for keeping samples
18. Map of the study area
19. Magnetic compass
20. Geographic Position System (GPS) if available
21. Altimeter
23. Thermometer
24. Kicknet
25. Pond net
26. Small sieve
27. Brushes-various sizes
28. Torch
29. Polythene covers
30. Camera
31. Data sheets
32. Permission letters
33. Contact addresses
34. First aid kit

Essential Equipments for Sampling Aquatic Insects

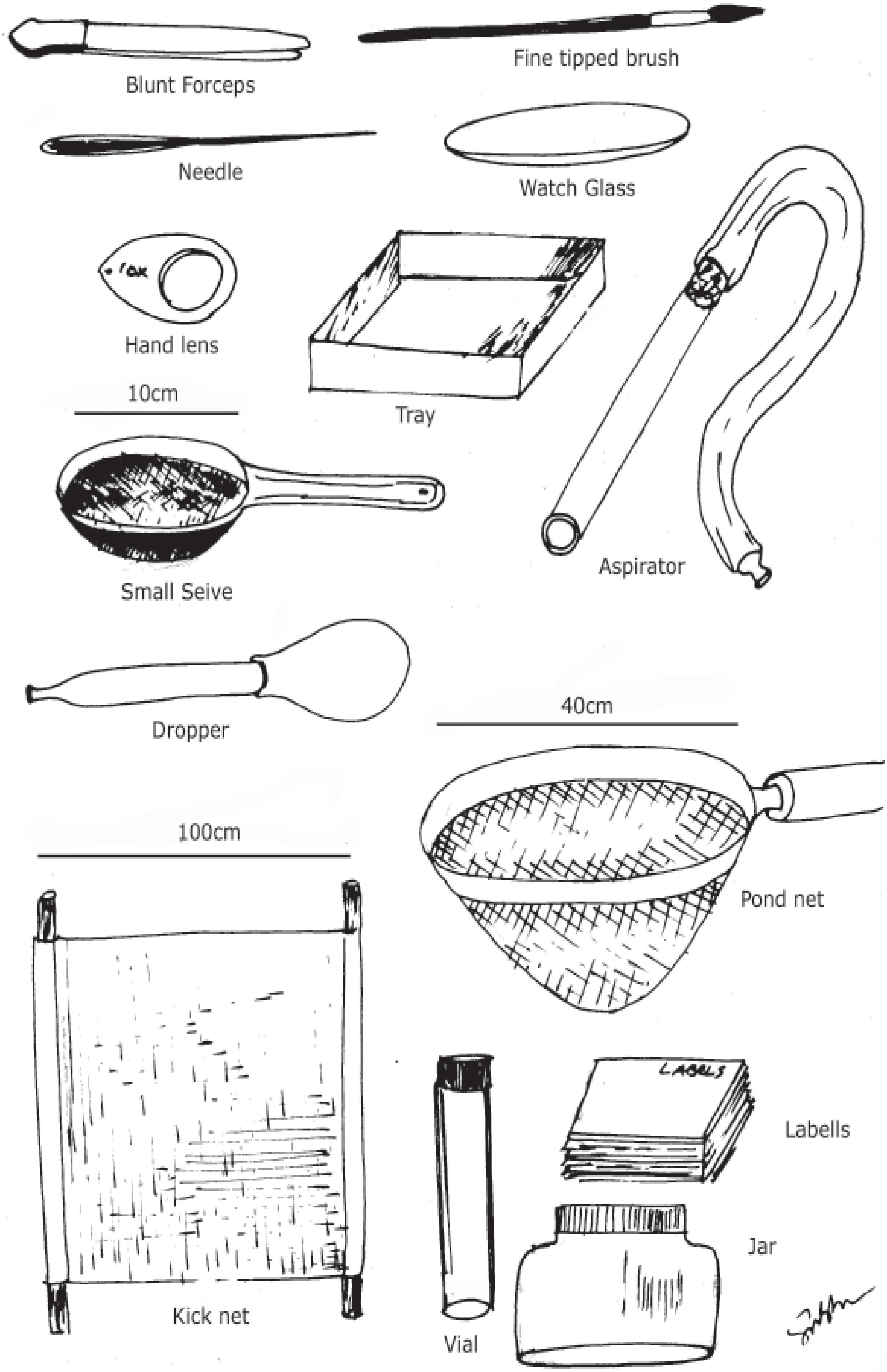
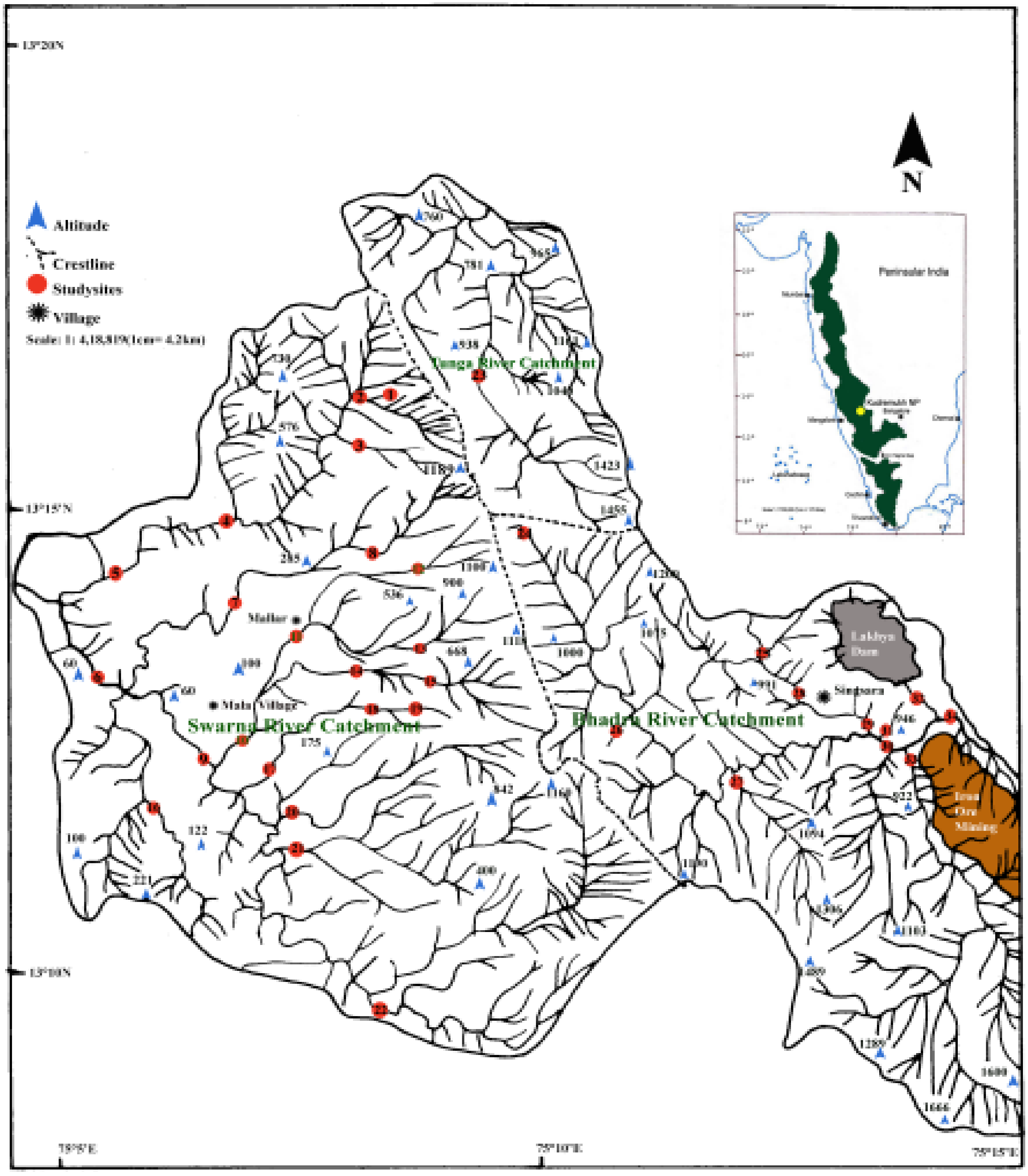


Figure-2. An example for distributing study sites within a landscape



(Ref: K.A.Subramanian et.al., (2005). *Journal of Insect Science* 5:49)

Appendix-2 Classification of Freshwater Habitats (Dugan, 1993)

1.0. Freshwater

1.1 Riverine

1.Perennial

i) Permanent rivers and streams, including waterfalls.
ii) Inland deltas.

2.Temporary

i) Seasonal and irregular rivers and streams
ii) Riverine floodplains, including river flats, flooded river basins, seasonally flooded grassland.

1.2 Lacustrinel

1.Permanent

i) Permanent freshwater lakes (> 8ha), including shores subject to seasonal of irregular inundataion
ii) Permanent freshwater ponds (< 8ha).

2.Seasonal

i) Seasonal freshwater lakes (> 8ha), including floodplain lakes.

1.3 Palustrinel

1.Emergent

i) Permanent freshwater marshes and swamps on inorganic soils, with emergent vegetation whose bases ie. below the water table for at least most of the growing season.
ii) Permanent peat-forming freshwater swamps,including tropical upland valley swamps dominated by Papyrus or Typha.
iii) Seasonal freshwater marshes on inorganic soil, including sloughs, potholes, seasonally flooded meadows, sedge marshes, and dambos.
iv) Peatlands, including acidophilous, ombrogenous, or soligenous mires covered by moss, herbs or dwarf shrub vegetation, and fens of all types.
v) Alpine and polar wetlands, including seasonally flooded meadows moistened by temporary waters from snowmelt.
vi) Freshwater springs and oases with surrounding vegetation.
vii) Volcanic fumaroles continually moistened by emerging and condensing water vapour.

2.Forested

i) Shrub swamps, including shrub-dominated freshwater marsh, shrub and thickets, on inorganic soils.

ii) Freshwater swamp forest, including seasonally flooded forest, wooded swamps on inorganic soils.
iii) Forested peatlands, including peat swamp forest.3. Man-Made Wetlands

3.Manmade wetlands

3.1Aquaculture/ Mariculture

i)Aquaculture ponds, including fish ponds and shrimp ponds.

3.2 Agriculture

i) Ponds, including farm ponds, stock ponds, small tanks.
ii) Irrigated land and irrigated channels, including rice fields, canals and ditches.
iii) Seasonally flooded arable lands.

3.3 Urban/ Industrial

i) Excavations, including gravel pits, borrow pits and mining pools.
ii) Wastewater treatment areas, including sewage farms, settling ponds and oxidation basins.

3.4 Water-storage areas

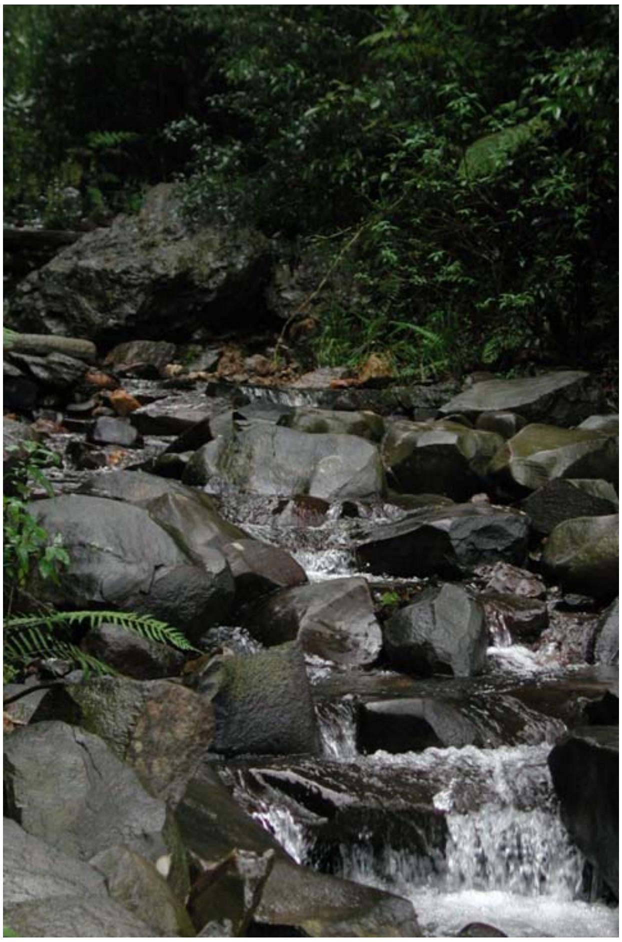
i) Reservoirs holding water for irrigation and/ or human consumption with a pattern of gradual, seasonal, draw down of water level.
ii) Hydro-dams with regular fluctuations in water level on a weekly or monthly basis.

Plate-1. Some Freshwater Ecosystems

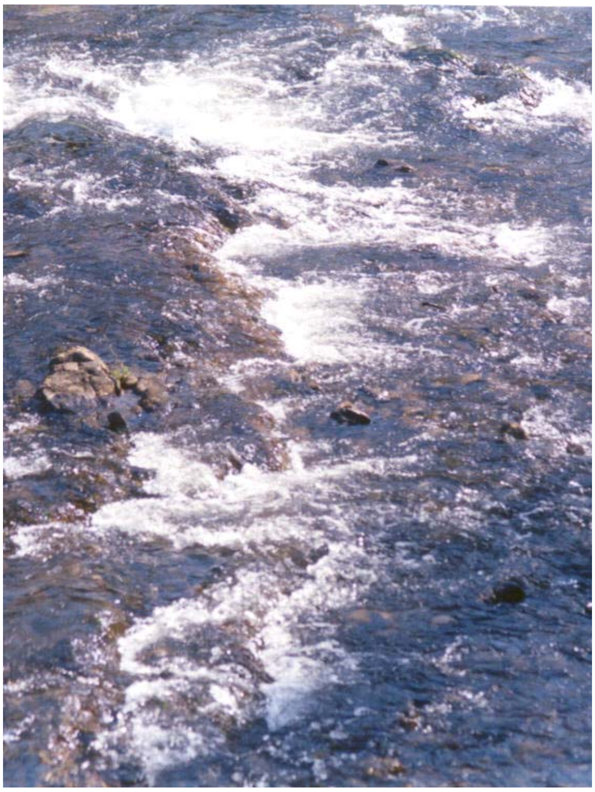
Ecosystem	Suggested Methodology
(1) Pond..	Pond net and sweep net
(2) Lake..	Pond net and sweep net
(3) Reservoir..................................	Pond net and sweep net
(4) Stream.....................................	Kicknet, Pond net and all out search
(5) River...	Kicknet, Pond net and all out search
(6) Myristica Swamp....................	All out search

Plate-2. Major Lotic Habitats

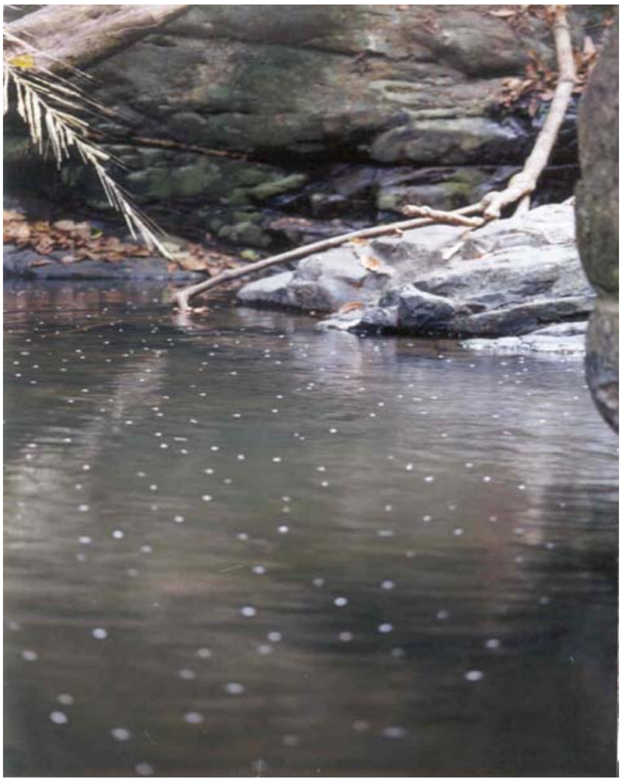
Waterfalls



Cascades



Riffles



Pools

Plate-3. Use of Kicknet and unsorted beetle samples

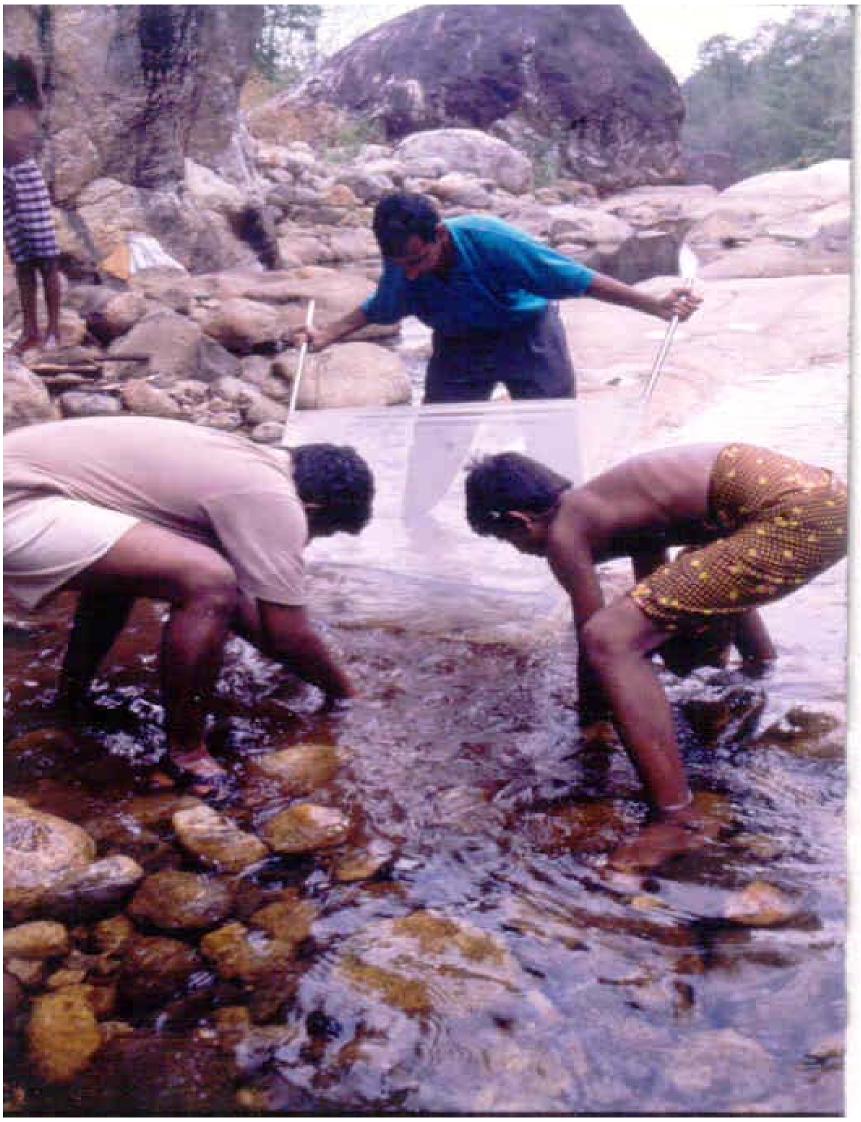


Plate-4.Some Common Aquatic Insects

Thalerosphyrus (Heptageniidae)

Euphaea (Euphaeidae)

Cybister (Dytiscidae)

Leptonea (Hydropsychidae)

Anisocentropus (Calamoceratidae)

Glossosoma (Glossosomatidae)

Aulocodes (Pyralidae)

Philorus (Blephariceridae)

Photos: K.A.Subramanian

Plate-5.Some Common Aquatic Insects

Isonychia (Oligoneuridae)

Caenis (Caenidae)

Neoperla (Perlidae)

Eubrianax (Psephenidae)

Macronema (Hydropsychidae)

Hydropsyche (Hydropsychidae)

Simulium (Simulidae)

Ephydridae

Photos: K.A.Subramanian

Plate-6.Some Common Aquatic Insects

Baetis (Baetidae)

Tenagogonus (Gerridae)

Metrocoris (Gerridae)

Rhagovelia (Velidae)

Dineutus (Gyrinidae)

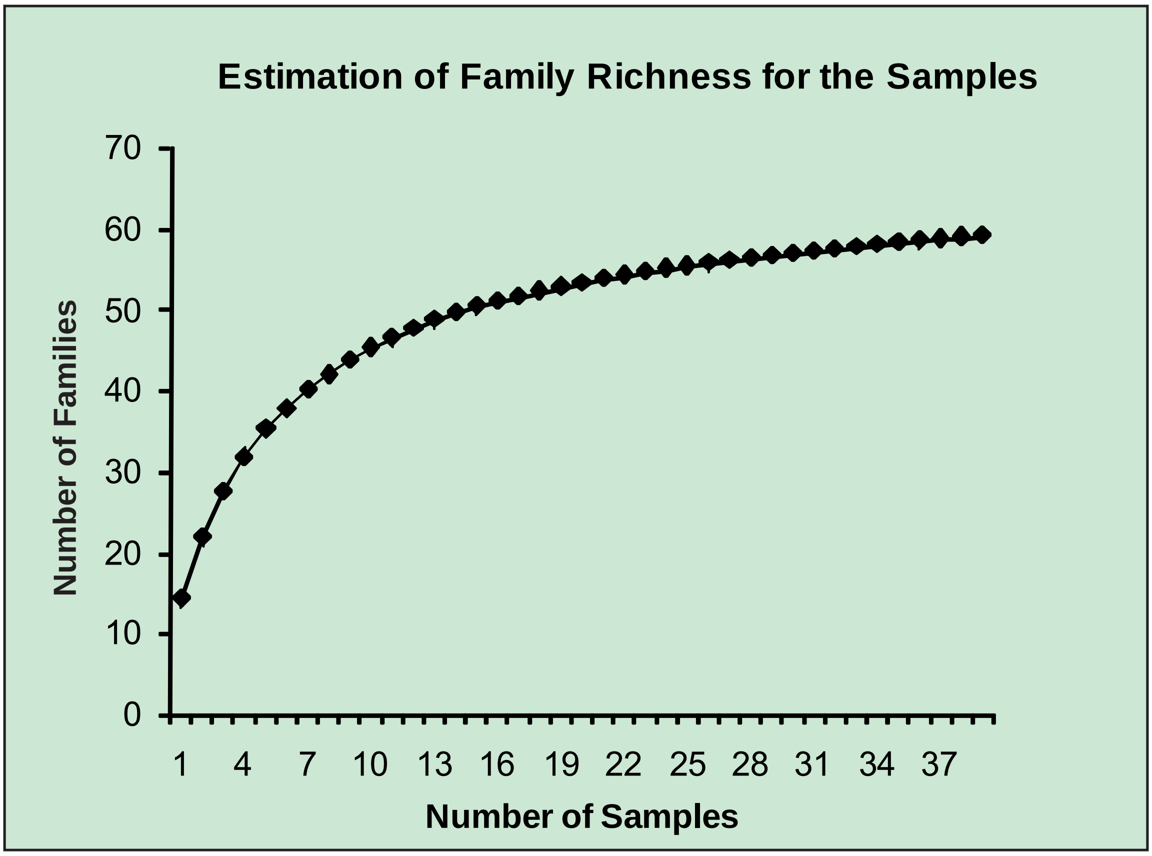
Sandracottus (Dytiscidae)

Goerodes (Lepidostomatidae)

Helicopsyche (Helicopsychidae)

Photos: K.A.Subramanian

Figure-3. Family accumulation curve across samples in Kudremukh Streams, Karnataka



The graph indicates that by 37 sampling sessions, most of the families are encountered in the study site.

Appendix-3. Basic Details of Sampling Localities and sample data

State: Karnataka
River Basin: Sharavathi

Sl.No	Site Name	District	Altitude(m)	Latitude(°N)	Longitude(°E)	AARF(mm)	NDM
1	Hosanagara	Shimoga	513	13.8833	75.05	2500	6
2	Nagodi	Shimoga	550	13.91299	74.85861	2500	6
3	Nittur	Shimoga	550	13.9333	75.9	2500	6
4	Nellibedu	Shimoga	550	13.93822	74.8497	2500	6
5	Mavinahole	Uttara Kannada	550	13.9666	75.1	3500	6
6	Nandihole	Shimoga	530	14	75.1333	981	6
7	Haridravathi	Shimoga	525	14.1	75.1333	981	6
8	Malemanne	Uttara Kannada	500	14.2833	74.7333	4000	6
9	Kathlekan	Uttara Kannada	525	14.2833	74.75	4000	6

AARF: Average Annual Rainfall; NDM: Number of Dry Months

Sample Data from Kudremukh National Park, Karnataka

SNo	Sample Number	Site code	Order	Family	Genus	Number of individuals
24	40	7	Ephemeroptera	Baetidae	Baetis	3
537	40	7	Coleoptera	Elmididae	Leptelmis	6
532	40	7	Odonata	Euphaeidae	Euphaea	3
531	40	7	Odonata	Gomphidae	Lamelligomphus	1
147	40	7	Trichoptera	Hydropsychidae	Hydropsyche	10
148	40	7	Trichoptera	Hydropsychidae	Leptonema	2
142	40	7	Trichoptera	Lepidostomatidae	Goerodes	1
143	40	7	Trichoptera	Limnephilidae	Moselyana	1
535	40	7	Plecoptera	Perlidae	Neoperala	3
144	40	7	Trichoptera	Polycentropodidae	Polycentropus	2
536	40	7	Coleoptera	Psephenidae	Eubrianax	5
132	41	7	Ephemeroptera	Baetidae	Baetis	5
131	41	7	Ephemeroptera	Heptagaeniidae	Epeorus	8
132	41	7	Trichoptera	Hydropsychidae	Hydropsyche	12
152	41	7	Trichoptera	Hydropsychidae	Hydropsyche	25

Appendix-4 BMWP Scores of families

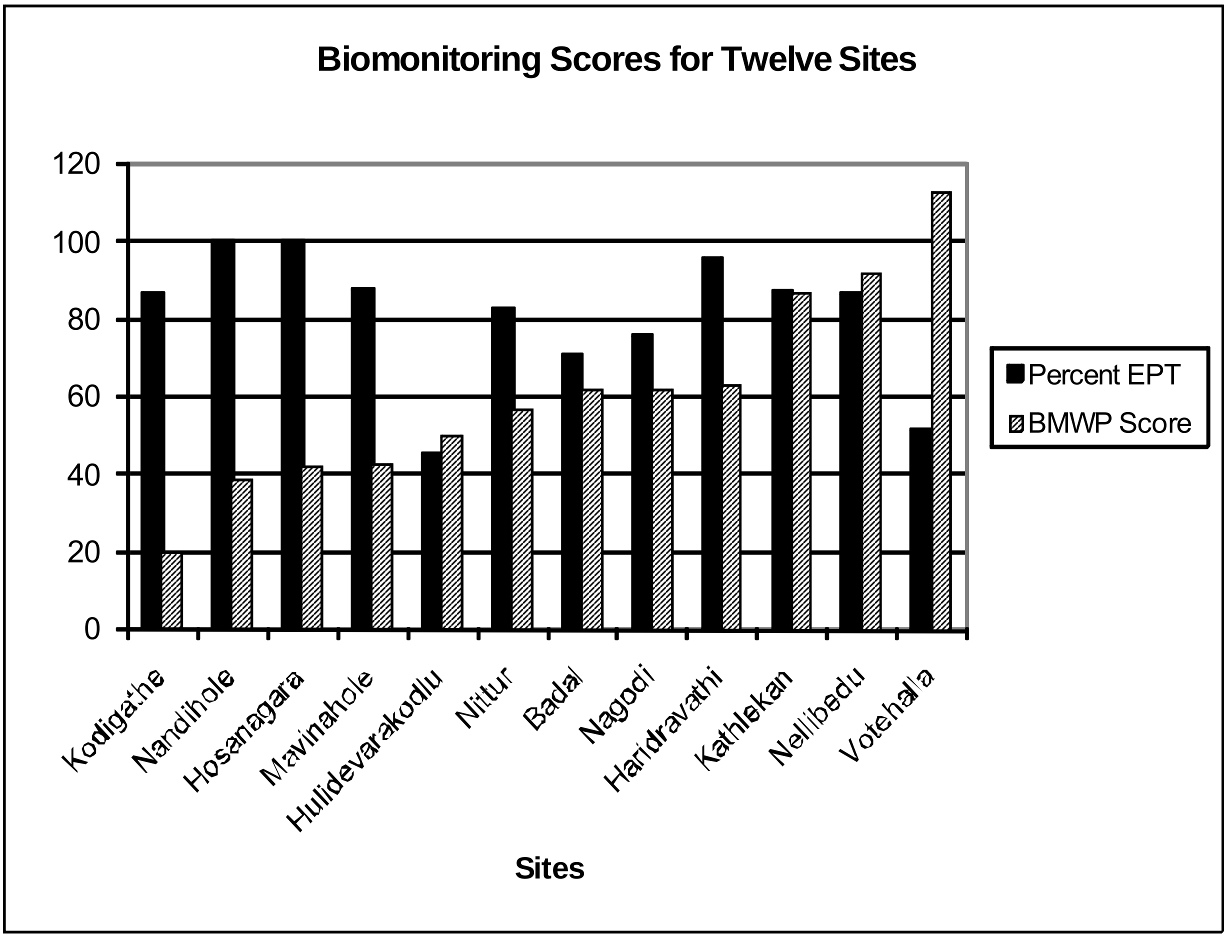
SlNo	Order	Family	BMWPScore
I	**Ephemeroptera (Mayflies)**		
1		Baetidae	04
2		Caenidae	07
3		Ephemerellidae	10
4		Heptageniidae	10
5		Oligoneuridae	10
6		Leptophlebiidae	10
7		Potamanthidae	10
8		Trichorythidae	10
II	**Odonata (Dragonflies and Damselflies)**		
9		Chlorocyphidae	10
10		Euphaeidae	09
11		Gomphidae	08
12		Libellulidae	08
13		Protoneuridae	08
III	**Plecoptera (Stoneflies)**		
14		Perlidae	10
IV	**Orthoptera (Grasshoppers and Crickets)**		
15		Tetrigidae	10
V	**Blattodea (Semiaquatic Cockroach)**		
16		Blaberidae	07
VI	**Hemiptera (Aquatic Bugs)**		
17		Corixidae	05
18		Gerridae	05
19		Hebridae	05
20		Naucoridae	05
21		Notonectidae	05
22		Pleidae	05
23		Veliidae	10
VII	**Megaloptera (Alderflies)**		
24		Corydalidae	10
VIII	**Coleoptera (Aquatic Beetles)**		
25		Curculionidae	05
26		Dytiscidae	05
27		Elmidae	05
28		Gyrinidae	05
29		Haliplidae	05
30		Hydrophilidae	05
31		Noteridae	07
32		Psephenidae	08

33		Staphylinidae	05
IX	**Trichoptera (Caddiesflies)**		
34		Calamoceratidae	10
35		Glossosomatidae	10
36		Helicopsychidae	10
37		Hydropsychidae	05
38		Lepidostomatidae	10
39		Limnephilidae	07
40		Philopotamidae	08
41		Polycentropodidae	07
42		Rhyacophilidae	07
43		Stenopsychidae	10
X	**Lepidoptera (Aquatic Moths)**		
44		Pyralidae	08
XI	**Diptera (Flies)**		
45		Blephariceridae	10
46		Chironomidae	02
47		Ephydridae	07
48		Simuliidae	05
49		Tabanidae	06
50		Tipulidae	06

Appendix-5: Biomonitoring Scores for study sites in Sharavathy River, Karnataka

Site	Gen.Richness	%EPT	BMWP	ASPT
Kodigathe	2	86	20	10
Nandihole	5	100	39	8
Sharavathy	6	100	42	7
Huledevarakudulu	8	88	43	5
Markatehole	9	45	50	6
Badal	10	83	57	6
Mavinahole	10	71	62	6
Kathlekan	11	76	62	6
Haridravathi	11	96	63	6
Nagodihole	11	87	87	8
Nellibedu	12	86	92	8
Votehalla	18	51	113	6

Legends: (1) **%EPT**: Percent of Ephemeroptera, Plecoptera and Trichoptera (2) **BMWP**: Biomonitoring Working Party Score (3) **ASPT**: Average Score Per Taxon



Space for Notes


Photo:K.A.Subramanian
Ashoka Trust for Research in Ecology and Environment (ATREE),
Bangalore, India
Small Grants Programme
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Aquatic Insects of India-A Field Guide

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Acknowledgements: This field guide would not have achieved this shape without the support of ATREE through its Small Grants Programme to K.A.Subramaninan. Authors sincerely thank friends and colleagues for valuable comments and suggestions on earlier drafts of this guide. We sincerely thank the Karnataka and Kerala forest departments for their field support.

Citation: Subramanian, K.A. and Sivaramakrishnan, K.G. (2007). Aquatic Insects of India-A Field Guide. Ashoka Trust for Ecology and Environment (ATREE), Bangalore, India. 62pp.

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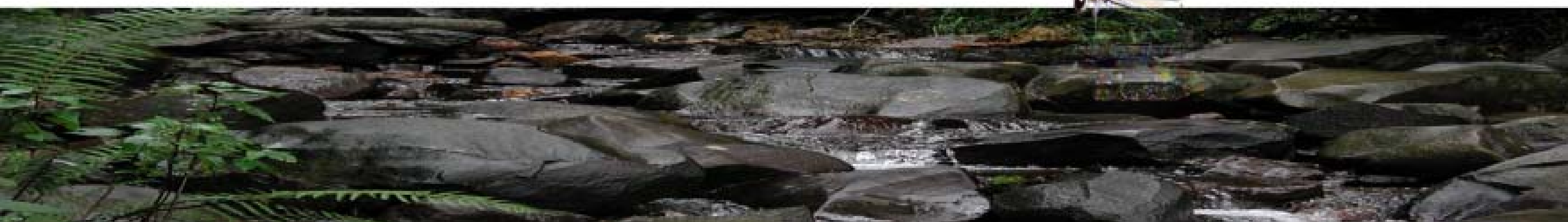


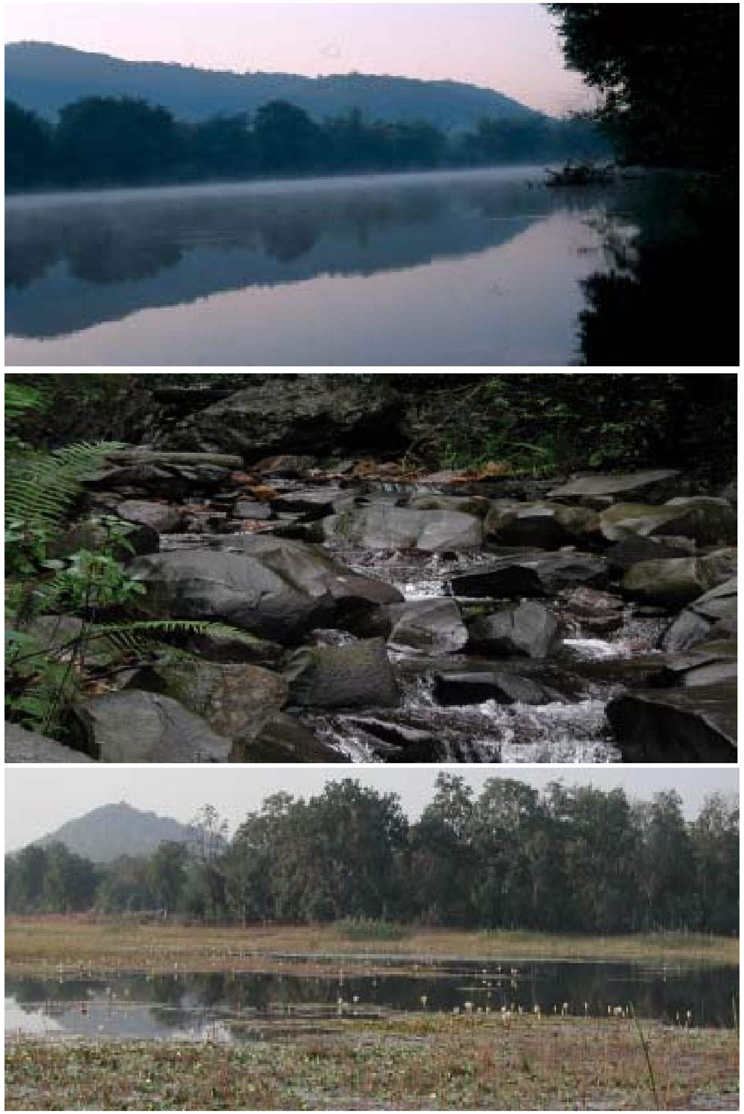
Freshwater Biodiversity

The inland freshwaters encompass a diverse array of ecosystems as varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs and even pools of water that collect in the leaf axils of certain plants. This is a small fraction of world's water resource. Despite this, inland aquatic habitats show far more variety in their physical and chemical characteristics than marine habitats and contain a disproportionately high fraction of the world's biodiversity.

Inland water habitats can be classified into stagnant (*lentic)* and flowing (*lotic*). They may also be classified into perennial or transient. Each of these has its own set of distinctive ecology and biological community. Lentic systems comprise lakes and ponds. Majority of large lakes are formed either by glacial or tectonic activity. Most of the glacial lakes are geologically young and were formed during Holocene, 11,500 years before present. Manmade lentic habitats such as irrigation tanks, ponds and reservoirs are historically recent and predominant landscape features in India.

Lotic system encompasses rivers and streams. A river system is essentially a linear body of water draining under the influence of gravity. Most of the river systems discharge into the sea and some into lakes. A few water courses in arid regions enter inland basins where no permanent lakes exist and disappear into the dry plains.

Large rivers such as Ganges and Brahmaputra cross over many degrees of latitude and traverse a wide range of climatic conditions. Variations in water flow and underlying geology also create a wide range of habitats, often within a short distance. Because of this change in habitats, different organisms are typically present in different parts of any given river system. Even though



The inland freshwaters encompass a diverse array of ecosystems as varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs and even pools of water that collect in the leaf axils of certain plants.

rivers are physically very dynamic, large rivers rarely disappear, and there are indications that some of the large rivers are in existence for tens of millions of years. This is reflected in the fact that, all the taxonomic groups are found in running waters and some invertebrate taxa are exclusive or attain greatest diversity there.

Biodiversity at higher taxonomic levels such as Phylum, Class or Order in freshwater systems are much narrower than those in the terrestrial or marine systems. The overall number of species (species richness) is also low compared to marine and terrestrial groups. However, species richness in relation to habitat extent may be very high. For example, about 10, 000 (40%) of the 25,000 known fish species are freshwater forms. This high diversity of freshwater fishes relative to habitat extent is promoted by isolation between freshwater systems. The species richness in the freshwater systems increases towards the equator as in the case with terrestrial habitats. There are many more species in the tropical freshwater systems than in temperate regions, but in some specific groups such as freshwater crayfishes this trend appears to be reversed.

Animal species are far more diverse and numerous in inland waters than plants. Apart from fishes, invertebrates form an important group. The important groups include sponges, flatworms, mollusks, polychaete worms, oligochaete worms, crustaceans, insects and numerous parasitic species in various groups. As on land, insects are the most diverse group of organisms in inland waters. Unlike terrestrial faunas, where beetles (Order Coleoptera) are the most diverse, flies (Order Diptera) appear to be by far, the most abundant group in inland waters.

Animal species are far more diverse and numerous in inland waters than plants. As on land, insects are the most diverse group of organisms in inland waters.

Introduction to aquatic insects

Insects are the most diverse group of organisms in freshwater. Estimates on the global number of aquatic insect species derived from the fauna of North America, Australia and Europe is about 45,000, of this about 5,000 species are estimated to inhabit inland wetlands of India. Aquatic insects of inland wetlands comprise some well-known groups like mayflies (Ephemeroptera), dragonflies (Odonata) and caddiesflies (Trichoptera). Aquatic insects such as dragonflies and damselflies (Odonata) are very colourful and prominent insects of the wetlands. Different functional feeding groups of aquatic insects such as shredders, scrapers, filter feeders and predators are important links in nutrient recycling. Aquatic insects primarily process wood and leaf litter reaching the wetland from the surrounding landscape. Nutrients processed by aquatic insects are further degraded into absorbable form by fungal and bacterial action. Plants in the riparian zone absorb this nutrient soup transported through the wetlands. In addition to this significant ecosystem function, aquatic insects are also a primary source of food for fishes and amphibians.

Evolution of aquatic insects: The origin of aquatic insects has been controversial and doubts still exist as to whether or not insects are primarily or secondarily adapted to aquatic environments. The widely accepted view is that the ancestor of myriapod-insect group (millipedes, centipedes, and insects) lived in leaf litter areas along margins of pond like environment. Primitive insects of this moist environment were ancestors of aquatic insects. Their fossil record extends to Devonian in the Paleozoic era. Among extend aquatic insects, dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive and only insects with aquatic juveniles. The understanding of aquatic insect evolution and phylogeny has been hampered by poor fossil record of freshwater animals.
Living aquatic insects represent 12 insect orders.

About 5,000 species of insects are estimated to inhabit inland wetlands of India. Dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive insects.

Of this, larvae of species of mayflies (Ephemeroptera), dragonflies and damselflies (Odonata), stoneflies (Plecoptera), alderflies (Megaloptera), lacewings (Neuroptera), flies (Diptera), caddiesflies (Trichoptera), moths (Lepidoptera) and wasps (Hymenoptera) are aquatic with terrestrial adults. Larval or nymphal and adult stages of aquatic beetles (Coleoptera) and bugs (Hemiptera) are fully aquatic.

Morphological and physiological adaptations: Aquatic insects have tackled the problem of living in aquatic environment by evolving various morphological and physiological modifications. These include air-tubes to obtain atmospheric oxygen, cutaneous and gill respiration, the extraction of air from plants, hemoglobin pigments, air bubbles and plastrons. Air-tubes are present in aquatic bugs (Hemiptera) and files (Diptera) restricting their activity to water surface. Cutaneous and gill respiration is widespread in the immature stages of most of the aquatic insects. This helps them to live among submerged substrates. Adult beetles and bugs often respire by the use of an air bubble. Some species use plastron (a system of microhairs or papillae) that hold an air film. Plastron respiration helps these insects to stay longer under water. Chironomid (Diptera) larvae living in eutrophic aquatic habitats survive in low oxygen levels through the use of hemoglobin pigments.

One of the major physical forces faced by aquatic insects of running waters is water current. In running waters, aquatic insect morphology are closely related to hydraulic stress and the necessity to remain in close contact with the substrate. A diverse range of body modifications are present in aquatic insects. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects. Morphological adaptations are closely followed by behaviour adaptations. Aquatic insects avoid

A diverse range of body modifications are present in aquatic insects to survive in running waters. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects.

water current by burrowing into the substrate or occupying a space in the substrate with minimum hydraulic stress such as rock crevices or under the rock.

Lifecycle adaptations: Aquatic insects have evolved diverse lifehistory strategies to suit their environment. Many temporary pool breeding species have egg stage which can remain in total dry condition (eg: *Aedes)*. In many species of caddiesflies a gelatinous egg mass matrix protect the eggs and larvae from desiccation and freezing for months together. Some species have staggered hatching which prevents over crowding of newly hatched larvae.

Very few aquatic insects have adapted to a completely submerged life cycle. Most of the aquatic insects spend atleast one part of their life cycle in terrestrial habitat. A major problem in being completely submerged is respiration. Many species have developed morphological and physiological adaptations to survive in particular oxygen concentration. The distinction is being very evident in running and standing water, where the former is very well oxygenated than the latter. This is one important factor that determines the distribution of groups like mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddiesflies (Trichoptera). These groups depend upon dissolved oxygen and achieve their maximum diversity in running water. Among holometabolous aquatic insects, aquatic pupa is found in caddiesflies (Trichoptera), flies (Diptera) and aquatic moths (Lepidoptera). Aquatic beetles, alderflies (Megaloptera) and lacewings (Neuroptera) have semi aquatic or terrestrial pupa.

During the course of life, aquatic insects encounter diverse physical environmental conditions, the most pronounced being temperature. The temperature varies daily and seasonally. This variation in temperature affects emergence pattern of aquatic insects. In tropics because of relatively constant temperature, many pool breeding species show continuous emergence throughout the year. However, in the Western Ghats, most of the stream breeding species emerge during pre and post monsoon months. Some species in tropics follow an emergence pattern coinciding with phases of moon.

The presence of diapausing egg and pupa are important life history evolutions that help insects to survive unfavourable conditions. Aquatic insects complete single or multiple generations during a year. Some tropical species have life cycle greater than a year. Life cycle completion time for a species varies with altitude and latitude.

Feeding strategies: Essentially all aquatic insects are omnivorous, atleast in their early instars. Species which use similar morpho-behavioural mechanisms for food acquisition have evolved similar mouth parts. This has facilitated classification of aquatic insects to functional feeding groups, which is equivalent of guild. The “functional group” approach reflects both convergent and parallel evolution leading to functionally similar organisms. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional groups are shredders, collectors, scrappers, predators and piercers. The shredders feed on woody debris and leaf litter, and collectors filter feed or gather suspended organic matter from water column. Scrappers graze algae and other plants growing on substrate. Predators feed on other aquatic invertebrates and small vertebrates. Piercers obtain liquid food from plants or other animals.

Aquatic insects and their habitats: Aquatic insects are adapted to either running waters (streams and rivers) or standing waters (ponds and lakes). These habitats can also be viewed as erosional (streams and rivers) or depositional (ponds and lakes). Both stream/ river currents and lake shoreline waves create erosional habitats while lake basins, river flood plain pools and stream/river backwaters provide depositional conditions. Species adapted to erosional habitats frequently colonize lake shorelines. Similarly many species of depositional habitats are common in flood plain pools and backwaters.

The habitats for the aquatic insects can be visualized within the framework of various spatial -temporal scales. At a spatial scale, it ranges in size from particles of few millimeters to the entire drainage basin, which extends to squares of kilometers. Temporally, the changes in the habitats can be visualized from days to thousands of years. The permanence of the physical structures of the habitats varies with the spatial scale. This ranges from few days for individual grain and microhabitat to thousands of years for the drainage network. Insect communities of the wetlands respond to this spatial-temporal variation as well.

Within a given habitat, aquatic insects maintain their location by clinging, swimming, skating or burrowing into the habitat. Distribution of aquatic insects within a habitat is determined by intricate interplay between substrate, flow, turbulence and food availability. The habit (mode of locomotion, attachment or concealment) of a given species determines the frequency of movement within the habitat

Substrate, an important physical component of habitat is very complex. The water current and the nature of the available parental material determine the physical nature of the substrate. The organic detritus adds complexity to the substrata and can strongly influence the organism's response to the substrate. It has been established across continents and biomes that the faunal composition changes with the substrate. Sand is a relatively poor habitat with low

Species which use similar morpho-behavioural mechanisms for food acquisition have evolved similar mouth parts. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional feeding groups are shredders, collectors, scrappers, predators and piercers.

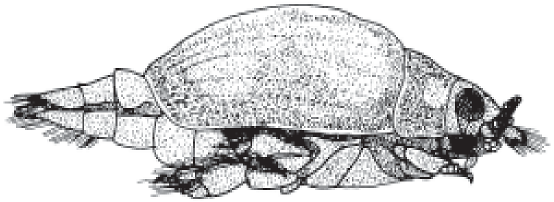
abundance and diversity. Relatively, the diversity is high in silty-sand and biomass may be high and diversity low in muddy substrata. The presence of sand and silt reduces and changes fauna. Atleast in stony substrata it is known that the space available for colonization determines species abundance. In general, diversity and abundance increase with substrate stability and the presence of organic detritus.

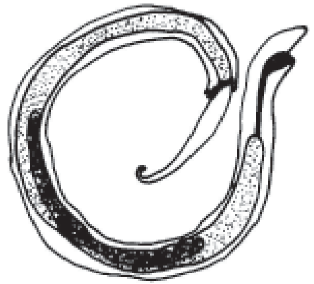
Aquatic insects in biomonitoring: Biological monitoring or biomonitoring is the systematic use of living organism or their responses to determine the health of aquatic ecosystem. Fish, algae, protozoans, and other groups of organisms is being used in water quality assessment but macroinvertebrates which largely consist of insects are more frequently used. They are suitable and sensitve indicators of water quality and ecosystem health because: (1) they are ubiquitous and, consequently affected by perturbations in many different aquatic habitats; (2) the large number of species respond to a range of environmental stress; (3) their sedentary nature relative to other aquatic organisms permits effective determination of spatial extend of perturbation; and (4) long life cycles allow to examine temporal changes in abundance and age structure.

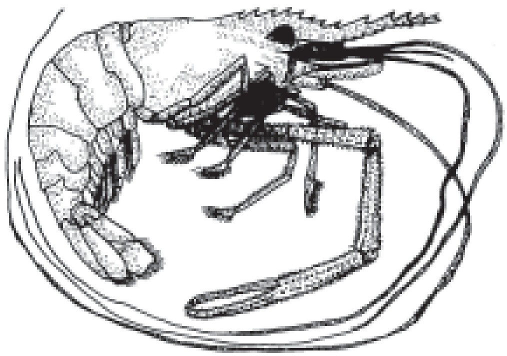
Traditional physico-chemical analysis of water quality provides a snap shot of water quality at the time of sample collection. In contrast, biomonitoring adds a temporal component to the sample and provides a history of the perturbation if any. However, physico-chemical measurements and biomonitoring are not mutually exclusive and an ideal water quality monitoring programme should involve both approaches.

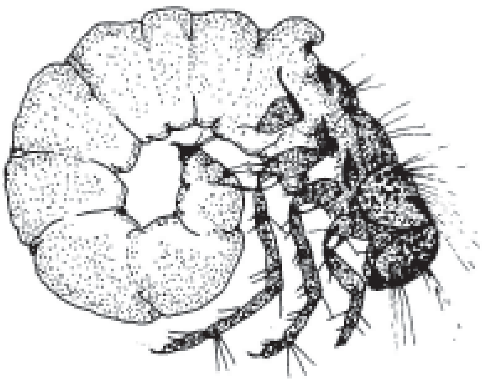
Macroinvertebrates which largely consist of insects are frequently used for biomonitoring. They are suitable and sensitive indicators of water quality and ecosystem health. Biomonitoring adds a temporal component to the sample and provides a history of the perturbation if any.

Key to Aquatic Macroinvertebrates



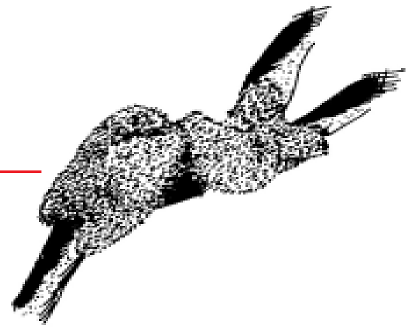






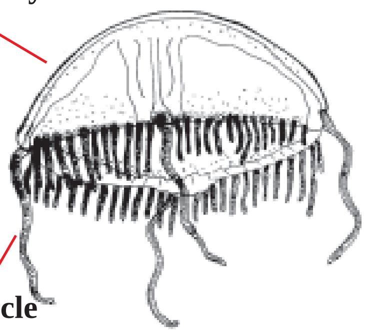
Key to Aquatic Macroinvertebrates

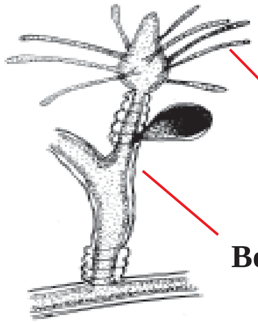
1. Encrusting forms with an irregular, asymmetric shape, lacking discrete organs or tentacles; spongy to touch…………..**Freshwater Sponges(Phylum: Porifera)**



Without the above characters; bilaterally symmetrical with organ-systems……………..**2**

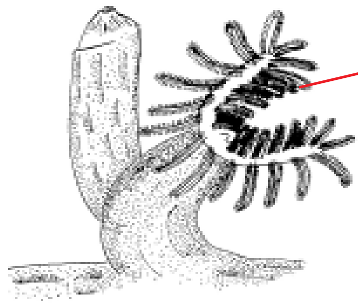
2. Either free-floating and transparent, like an umbrella shaped disc (< 30 mm diameters); or sessile and rather small (generally < 5 mm, but individuals may be solitary or colonial) with a short stem and several tentacles arising from it; rare…………..**Coelentrates (Phylum: Cnidaria)**





Without the above characters…………………………...........................**3**

3. Sessile, colonial forms made up of numerous small individuals each bearing several retractile tentacles on a horse-shoe shaped structure around the mouth; the rest of the body is enclosed in a gelatinous structure; the colony may be encrusting, compact, or branching, and twig-like………………......**Moss Animals (Phylum: Polyzoa (Ectoprocta))**



Form not as above; free-living and not colonial…………….........……**4**

4. Body segmented, or with joint legs, or bearing a shell, or any combination of these features…………………………..……**8**

Body unsegmented, lacking jointed legs or a shell………..……………**5**

5. Small (< 30 mm) elongate flattened body pressed to the substratum; moves with a gliding motion; often with a pair of anterior eyespots………**Flatworms or Planarians (Phylum: Platyhelminthes)**

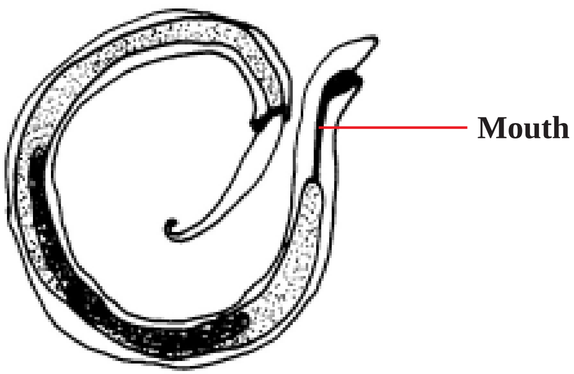
Without the above characters……………………........................…………..**6**

6. Body thin, flattened and ‘bootlace-like’; with a long, eversible proboscis (inconspicuous when retracted) and three pairs of eyes………….............**Ribbon or proboscis worm (Phylum: Nemertea)**

Body is long and thin it is approximately circular in cross-section.………………..……**7**

7. Body long (may be >20 cm long) and threadlike; anterior and posterior ends blunt (not tapering); usually dark brown......**Horsehair worms (Phylum: Nematomorpha)**

Worm-like cylindrical body tapering at both ends and lacking external segmentation; move in a ‘whip-like’ fashion; usually < 1 cm long………………..............................…**Nematodes (Phylum: Nematoda)**

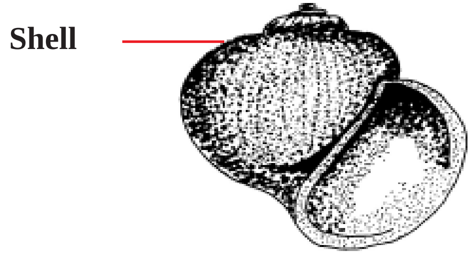


8. Body enclosed by an unsegmented calcareous shell which may be coiled, spherical or bi-valved; body is soft and unsegmented with a ventral muscular foot….**Snails, Clams and Mussels (Phylum Mollusca)**…….**9**

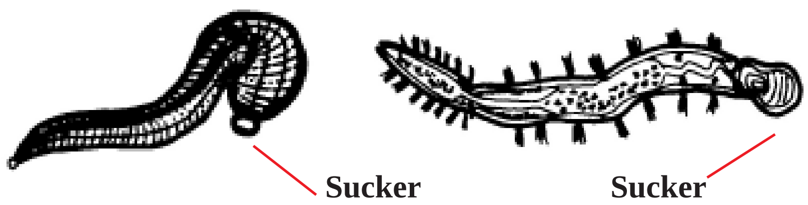
Body segmented and not enclosed in a calcareous shell……………….**10**

9. Body completely enclosed by a bi-valved shell………**Clams and Mussels (Bivalves) (Class: Bivalvia).**

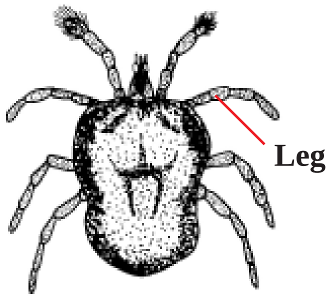
Shell not bi-valved, body may not be entirely enclosed by the shell …………...................................**Snails and Limpets (Class: Gastropoda)**

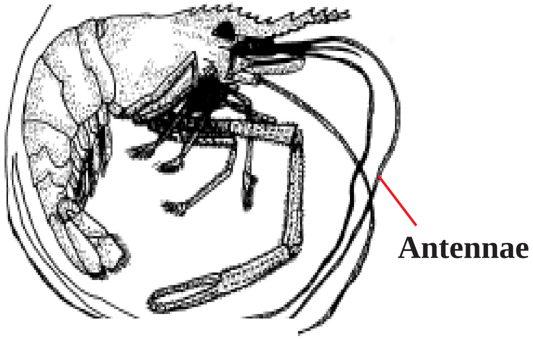


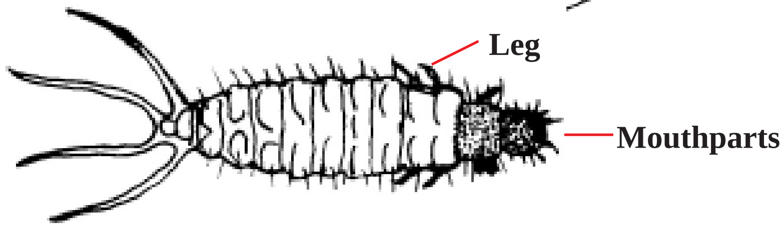
10. Body more or less elongated or worm-like with obvious segmentation and generally > 30 similar segments; may have anterior and posterior suckers; if suckers are lacking then the sements bear paired, fleshy, lateral outgrowths or bundles of fine bristles (chaetae)……….**True Worms and Leeches (Phylum: Annelida)**



Generally with jointed legs and a segmented body (which is often hardened) and usually divided into two or more discrete regions (e.g. head, thorax and abdomen); if legs are lacking then there are < 15 body segments and the head bears paried mandibles………..**Crustaceans, Arachinds and Insects (Phylum Arthropoda).**

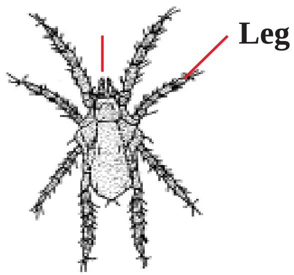






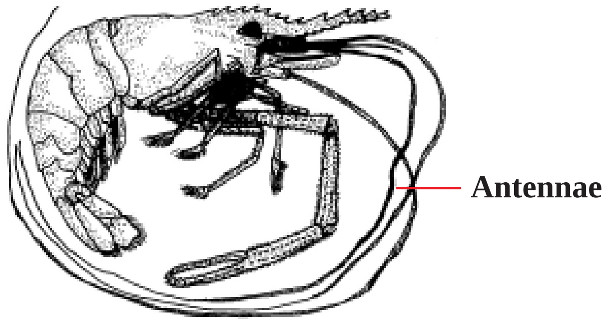
Key to Aquatic Arthropods

1. Four pairs of joined legs; antennae absent; body either globose or divided into two with indistinct segmentation (some minute forms [2 mm long] with globose bodies may have six legs only)………………**Water Mites and Spiders; (Class: Arachnida)**

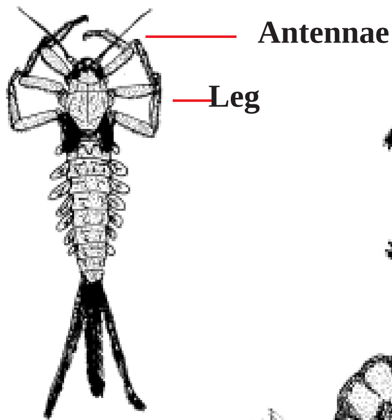


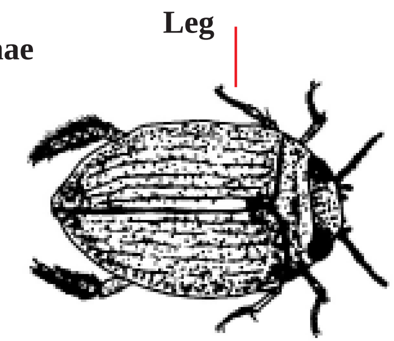
2. Body not as above; antennae present or inconspicuous......…………..**3**

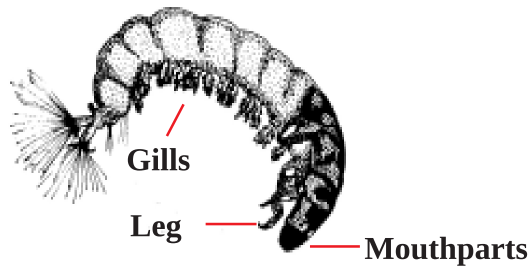
3. More than three pairs of jointed legs; two pairs of antennae…………....................**Crustaceans (Subphylum: Crustacea)**



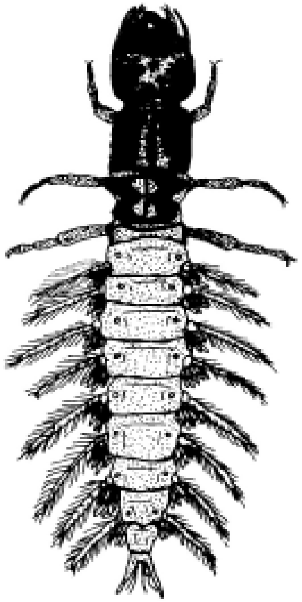
Either whith three pairs of jointed legs or legless; one pair of antennae…………..**Insects (Class: Insecta)**

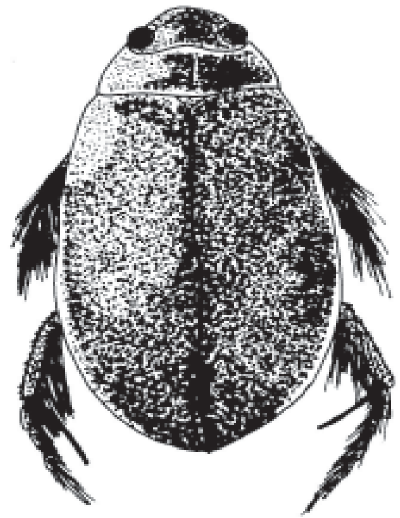


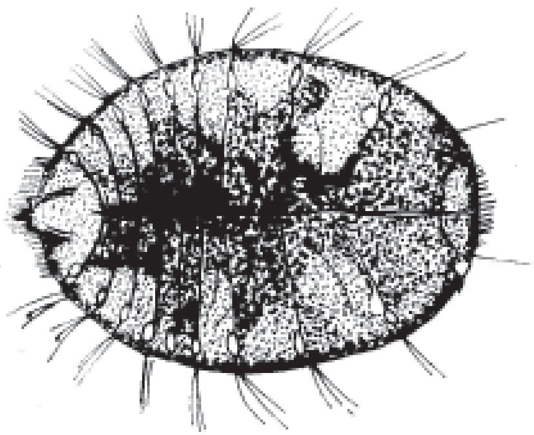




Key to Aquatic Insect Orders



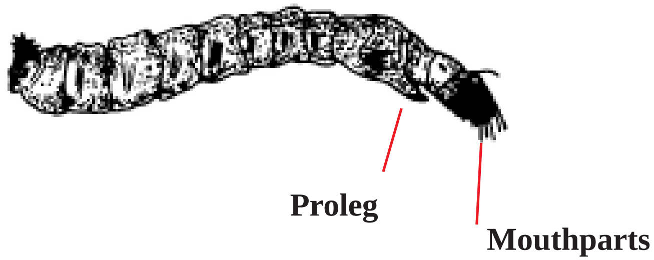




Key to Aquatic Insect Orders

1. Thorax bears three pairs of segmented legs; head fully formed……....**2**

Thorax lacks segmented legs (but unsegmented prolegs may be present); head may be fully formed but is often inconspicuous and incompletely formed or retracted into the thorax……… **Larval Flies (Order: Diptera)**
Page-43

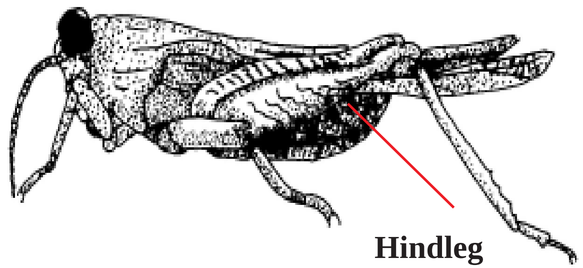


2. Minute insects (generally < 5 mm long), with a midventral forked appendage on the abdomen ……........**Springtails (Order:Collembola)**

Body generally considerably longer than 5 mm; ventral abdominal appendages absent but ventral gills may be present……......................**3**

3. Hind legs long with expanded femora and modified for jumping ………. ....**Crickets and Grasshoppers (Order: Orthopetra)**

Page-57

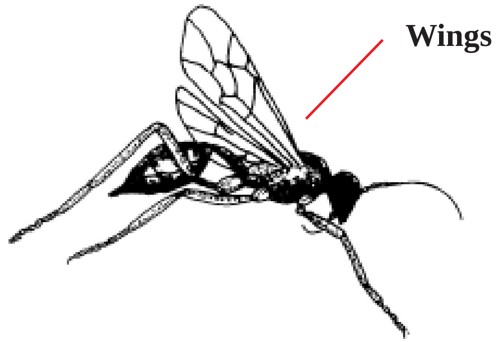


Hind legs not modified for jumping; femora not expanded…..........……**4**

4. Wings or wing pads present…...……..**5**

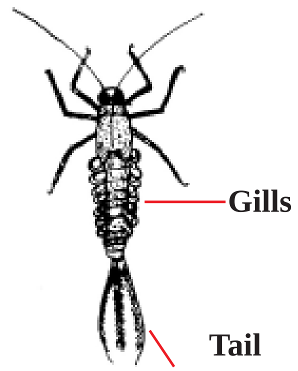
External wings or wing pads completely absent……..........................**12**

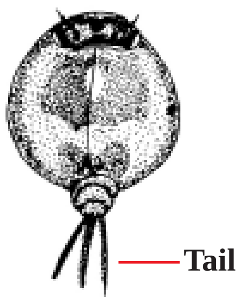
5. Two pairs of short membranous wings with few veins………..**Wasps (Order: Hymenoptera)**



Wings or wing pads present but, if wings are present, the first pair are leathery or hardened and overlie the second pair………………….........**6**

6. Abdomen ends in three long 'tails'……………….**Mayflies (Order: Ephemeroptera)**
Page-21

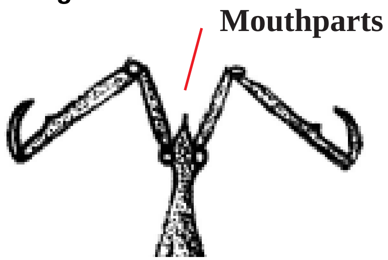


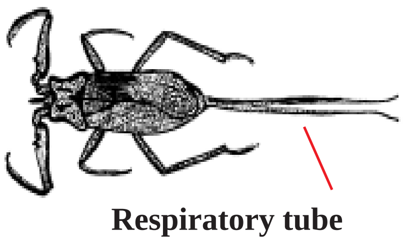


Abdomen ends in one, two or no such 'tails'……………………..............…7

7. Mouth in the form of an elongate beak, or tube or cone-like structure……......................…..……**Aquatic Bugs (Order: Hemiptera)**

Page-30





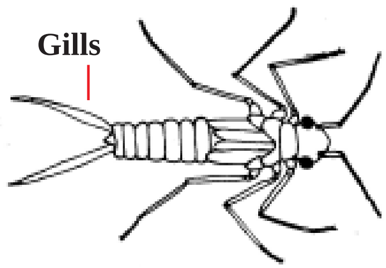
Mouth not as above………………...….**8**

8. Labium (lower 'lip') is modified into a large mask like structure which covers the other mouthparts when viewed from below….Damselflies and Dragonflies (Order: Odonata)……...…**9**

Labium not modified into a large mask-like structure………….........…**10**

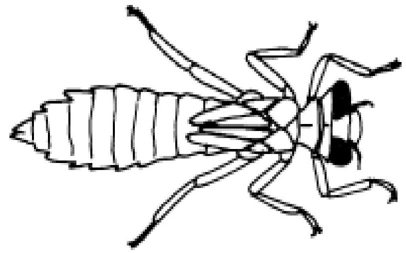
9. Abdomen ending in leaf-like gills…………..**Damselflies (Suborder: Zygoptera)**

Page-26



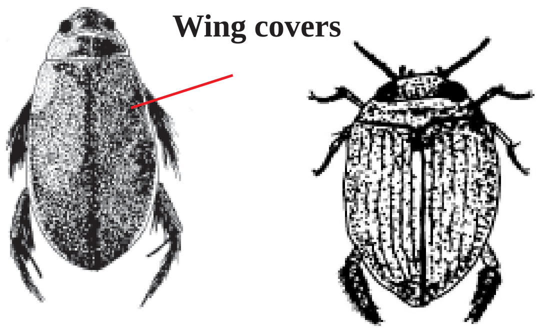
Abdomen without caudal lamellae……………………..**Dragonflies (Suborder: Anisoptera)**

Page-26



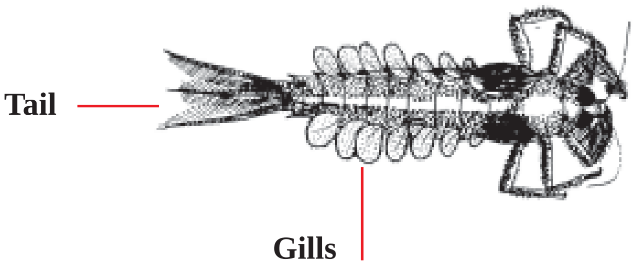
10. Forewings modified into hard protective coverings, concealing most of the dorsal surface……………......................**Beetles (Order: Coleoptera)**

Page-48

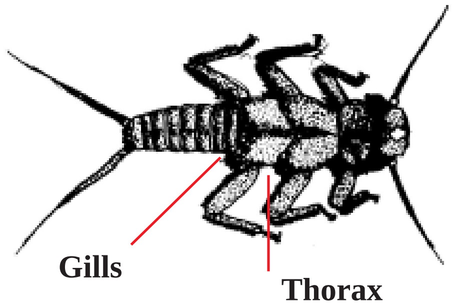


Forewings not thus modified; abdomen ends in a pair of segmented terminal filaments or 'tails'………………...**11**

11. Most abdominal segments possess lateral gills……………….**Mayflies (Order: Ephemeroptera) Page-21**



Lateral abdominal gills are absent but thoracic gills in the form of tracheal tufts present…………….........................**Stoneflies (Order: Plecoptera) Page-56**

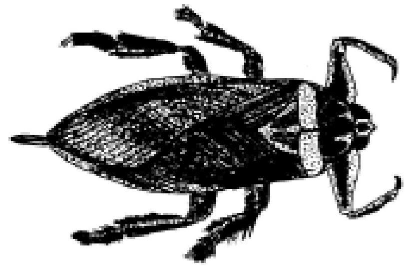


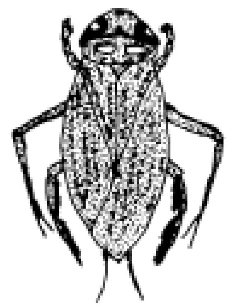
12. Mouth parts adapted for sucking……………………........................….**13**

Mouth parts adapted for chewing with mandibles ……….....................**14**

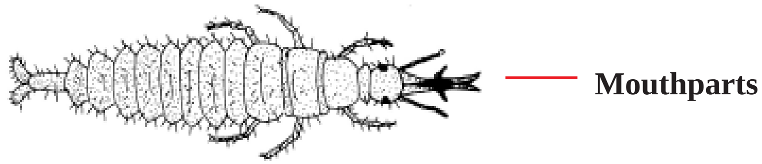
13. Mouth parts in the form of a tube, a beak or cone-like structure ……………...**Aquatic Bugs (Order: Hemiptera)**

Page-30

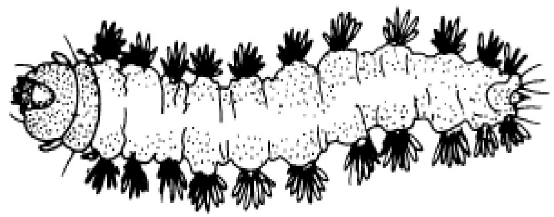




Mouthparts are a pair of long, needle-like stylets; associated with freshwater sponges…………**Spongilla Flies (Order: Neuroptera; Family: Sisyridae)**
Page-58

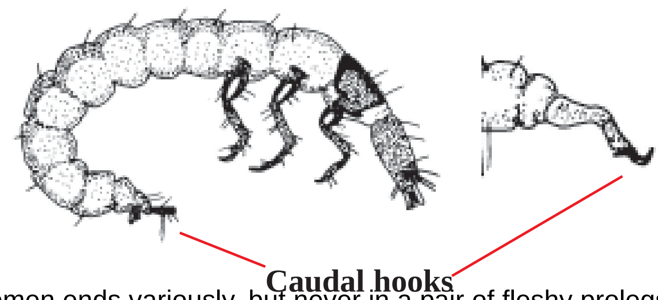


14. Abdomen on the underside of segments 3-6bears pairs of short, fleshy prolegs, each with a ring of tiny hooks……………..**Aquatic Moths (Order: Lepidoptera; Family: Pyralidae).**
Page-60



Abdomen lacks ventral prolegs (but may have lateral projections, or prolegs at the end of the abdomen)……………................……………**15**

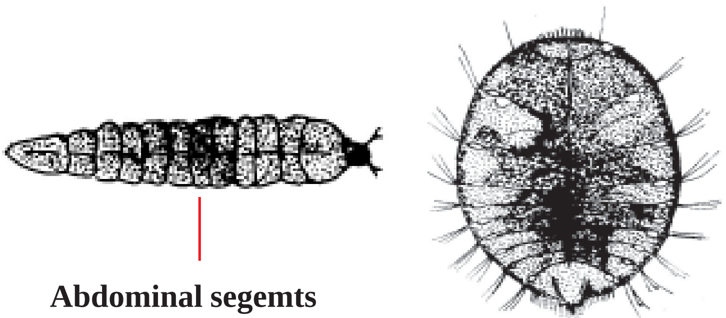
15. Abdomen ends in a pair of short or long, fleshy prolegs (sometimes fused together) that end in a single hook……………**Caddiesflies (Order: Trichoptera) Page-36**



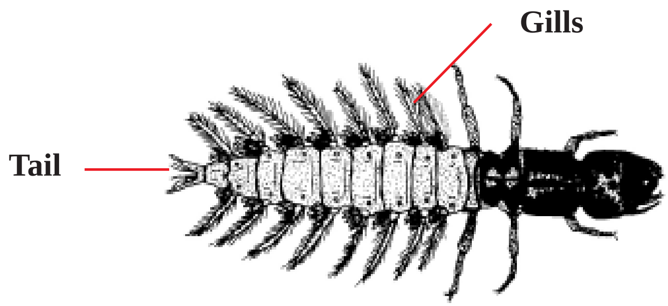
Abdomen ends variously, but never in a pair of fleshy prolegs each ending in a single hook…………..…**16**

16. Abdomen is fleshy with well-developed lateral filaments………………..**17**

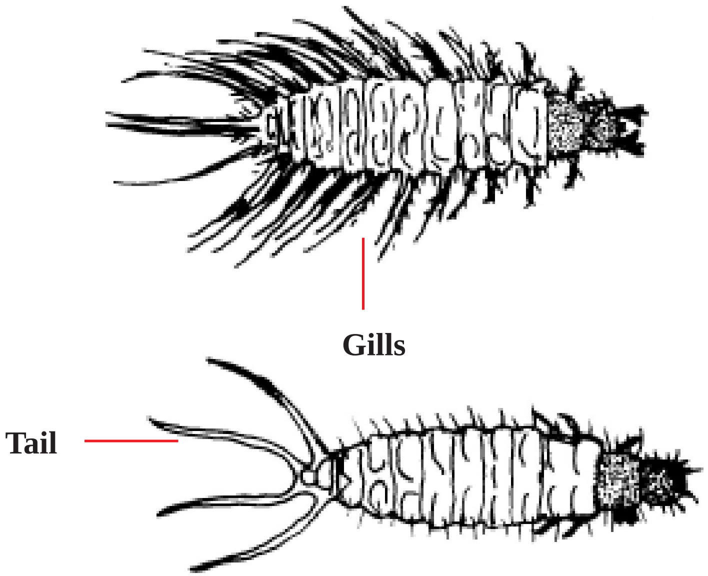
Abdomen hardened and lacks well developed lateral filaments……………..............................…**Larval Beetles (Order: Coleoptera) Page-48**



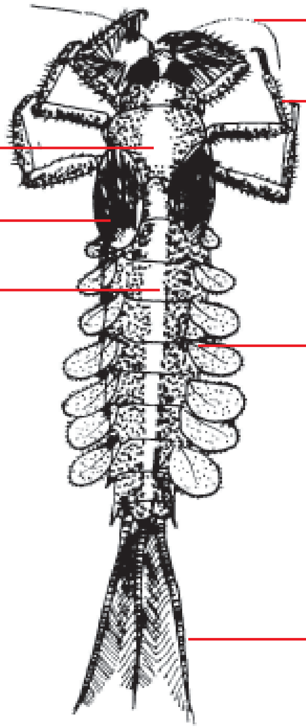
17. Abdomen ends in a pair of prolegs, each with a pair of hooks… .**Alderflies (Order: Megaloptera) Page-59**



Abdomen ends variously but never in a pair of prolegs each having a pair of hooks (although there may be two pairs of prolegs which each have hooks)……………........**Larval Beetles (Order: Coleoptera)Page-48**

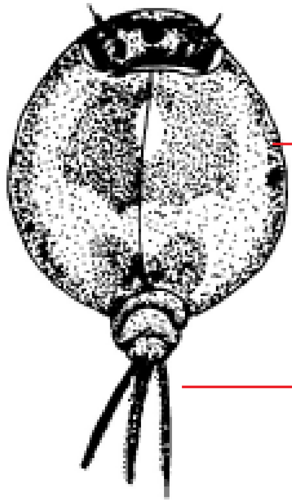


Key to Mayfly (Ephemeroptera)



Body parts of Mayfly Larvae

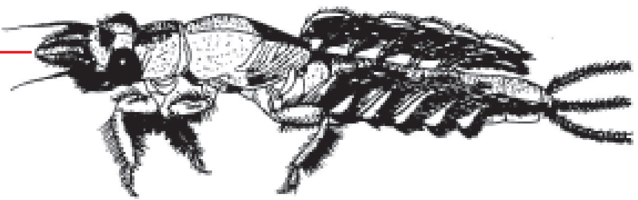
1.Body beetle like (smooth and hemispherical); a thoracic shield covers all of the gills (six pairs) and the abdomen ………….........…….**Prosopistomatidae**



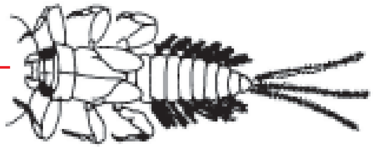
Body form not as above; abdominal gills partially or completely exposed; mandibles with tusk-like projections…………...….**2**

Mandibles without tusks like projections: gill form otherwise……....…………..**3**

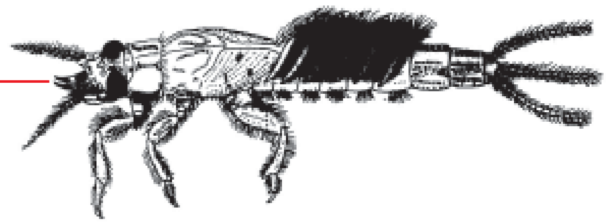
2a. Mandibular tusks long and sickle-shaped, with long setae; maxillary palp more than twice as long as the apical part of the maxilla ....…..**Polymitarcyidae**



2b. Mandibular tusks otherwise, bearing short bristles; maxillary palp as long or slightly longer than the apical part of the maxilla ………..........**Potamanthidae**



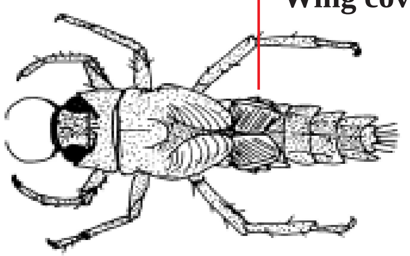
2c. Tusks curved outwards, inner edges convex……….............**Ephemeridae**



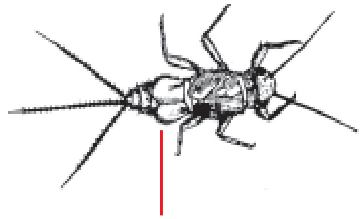
3.Second abdominal segment with large and plate-like (=operculate) gills, touching or overlapping along the dorsal midline and covering all or some of the gills arising posteriorly, gills III-VI with fringed margins…......……………….**4**

Second abdominal gills not as above…………………….............................……**5**

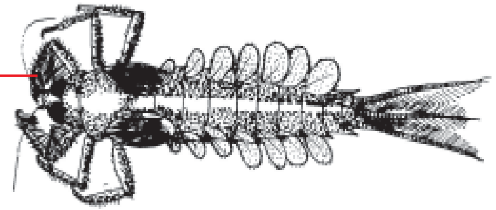
4a. Terminal gill filament densely clothed with setae on both margins, cerci (= lateral filaments) with setae on the inner margins only; mature larvae has small hindwing pads beneath the forewing pads on the metathorax ………………...………….**Neoephemeridae**



4b. Gills on abdominal segment II not fused but overlapping along the midline and covering all of the succeeding (III-VI) gills; cerci and terminal filament with short and sparse setae on the inner and outer margins; hindwing pads absent ………………...…**Caenidae**

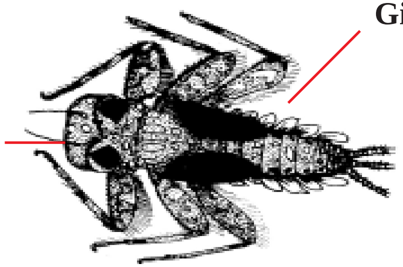


5.Inner margins of femora and tibiae of forelegs with conspicuous rows of long setae ………..……**Isonychidae**



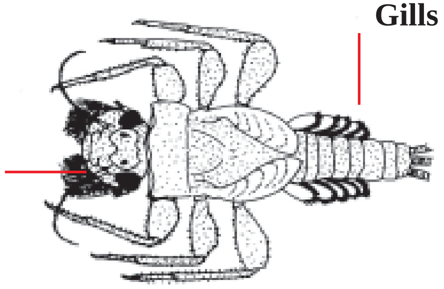
Inner margins of femora and tibiae of forelegs without rows of long setae ….**..6**

6.Head is flat and plate-like with dorsal eyes; body dorsoventrally compressed (flattened); gills plate-like and never doubled but may have a dorsal tuft of tracheae (= gill tufts) at the base of the lamellae……………….**Heptageniidae**



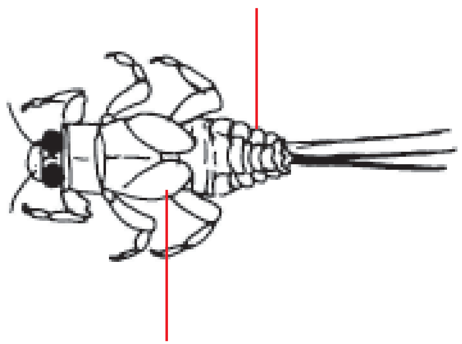
Head not plate-like; gill form various shapes but if plate-like then never with a dorsal tracheal tuft at the base of he lamellae……….............………………….**7**

7.Labium fused into a single semicircular structure, palps with long setae; gills on abdominal segments II-V or II-VII, gill II may overlay and partially conceal the rest of the series; a terminal filament is present; …………….**Tricorythidae**



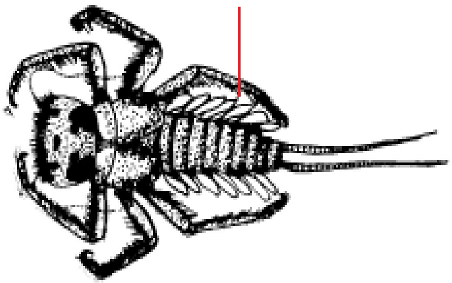
Mouthparts and gills not as above; terminal filament reduced or lacking………**8**

8. Gills lamellate on abdominal segments III-VII or IV-VII or more rarely, II-V, II-VI or I-V (gill on segment I rudimentary if present); gills usually consisting of a dorsal lamellae and a ventral pair of tufts or lamellules; first lamellate gill may conceal some or all of the posterior gills; forewing pads fused to the thoracic notum for more than half their length……………...............……**Ephemerellidae**

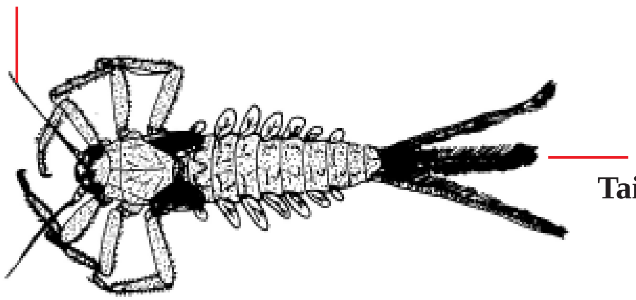


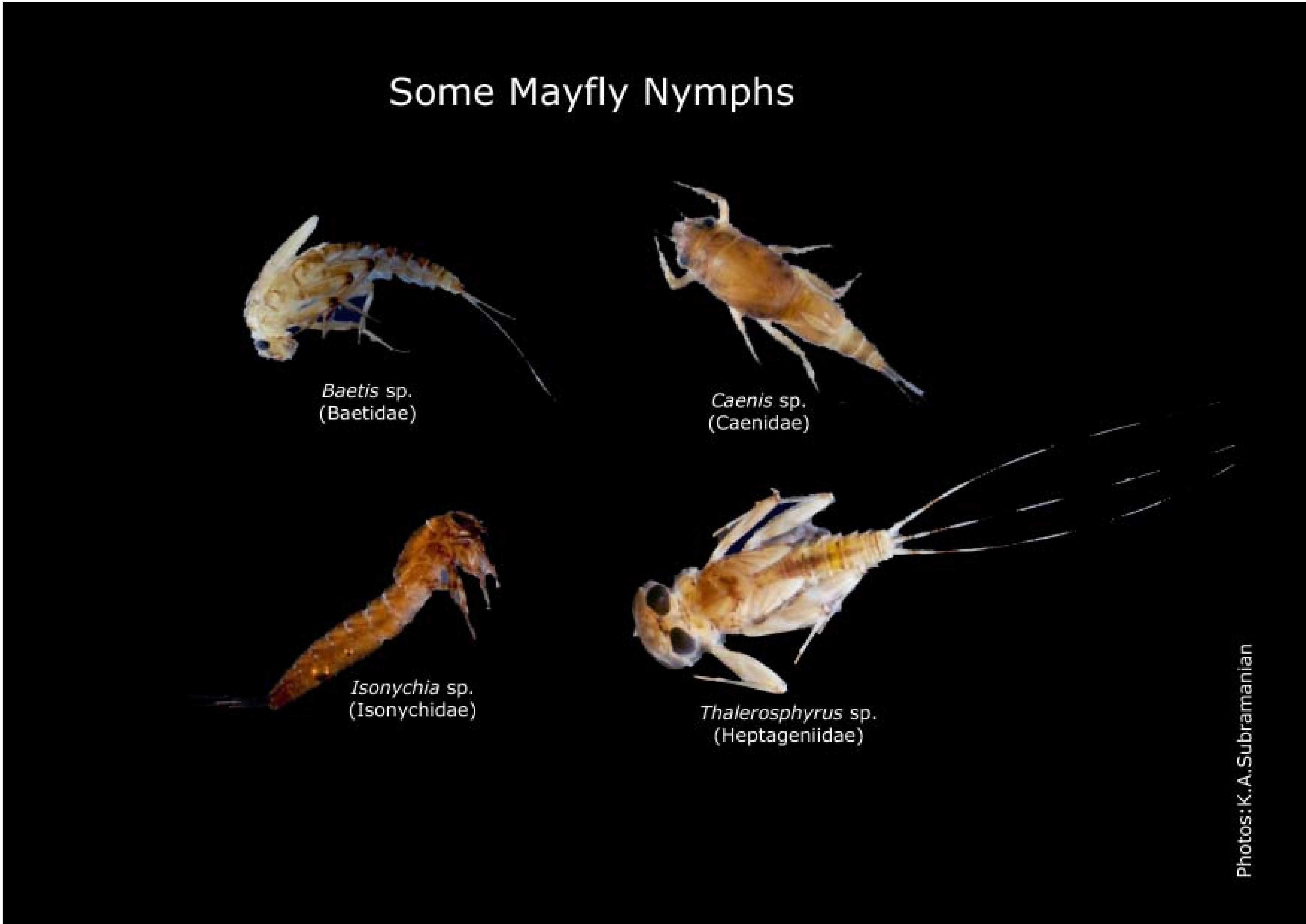
Gills lamellate or plate-like, rarely doubled, all members of the series rather similar in general form; terminal filament sometimes reduced or lacking …….**9**

9a. Gills are similar, long, slender and bifurcate (forked) in form or the first pair is rudimentary (thread-like) and others plate-like (usually with apical prolongations or fringes) and doubled; terminal filament is well-developed and similar to cerci (= lateral filaments)…………………......…………**Leptophlebiidae**



9b. Antennae long and twice the width of the head; median terminal filament often much reduced and always shorter than the cerci (lateral filaments); hind corners of the last few abdominal segments are not drawn out into spines;………………………...…..**Baetidae**



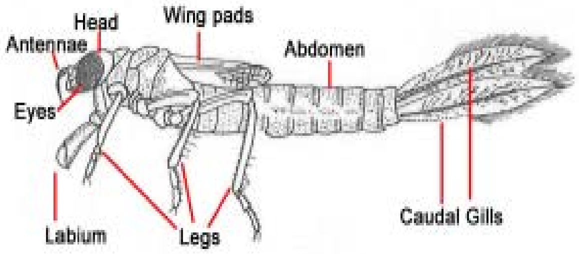

Some Mayfly Nymphs
Baetis sp.
(Baetidae)
Caenis sp.
(Caenidae)
Isonychia sp.
(Isonychidae)
Thalerosphyrus sp.
(Heptageniidae)
Photos: K.A.Subramanian

Space for Field Notes on Mayflies (Ephemeroptera)

Key to Dragonflies and Damselflies (Odonata)

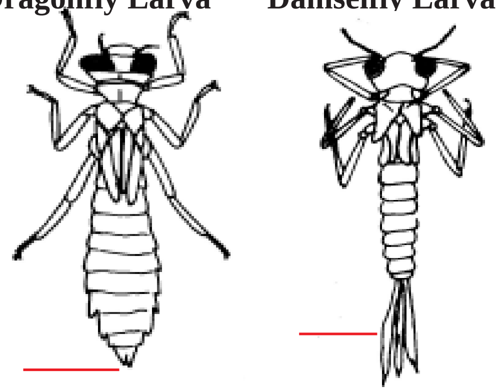
1.Abdomen short and stout, caudal gills absent and terminating in five short spine-like processes………......................................**Dragonflies (Anisoptera)-I**

2.Abdomen long and slender and terminating in three (rarely two) leaf or sac like caudal gills………………...................................**Damselflies(Zygoptera)-II**



Body Parts of Damselfly Larva

Dragonfly Larva Damselfly Larva



I. Dragonflies (Anisoptera)

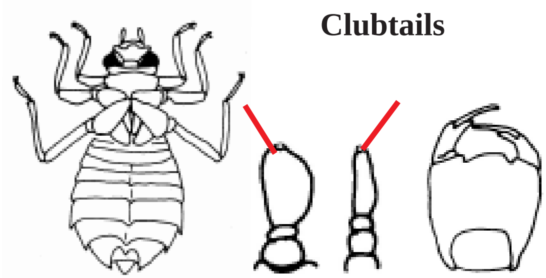
Prementum and palpal lobes of labium flat………………...................................**1**

Prementum and palpal lobes of labium scoop or spoon shaped...**2**

Labium Flat Labium Scoop Shaped

1a. Antennae four-segmented, 3rd segment enlarged and fourth vestigial…..…..**Clubtails (Gomphidae)**

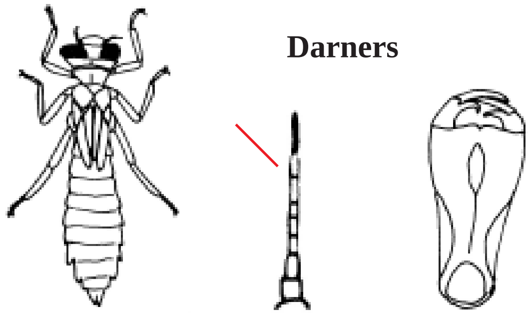
Clubtails



Larva Antenna Labium

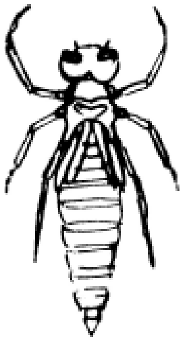
1b. Antennae six or seven segmented and filamentous…...**Darners (Aeshnidae)**

Darners



Larva Antenna Labium

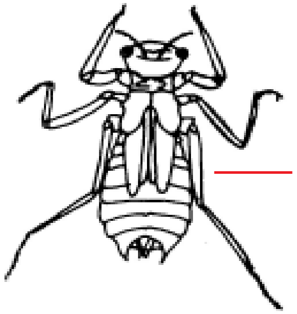
2a. Body elongate and covered with bristles or tufts of setae, labium with large irregular teeth…..................................**Mountain Hawks (Cordulegasterdiae)**



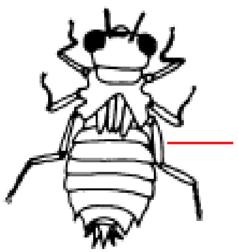
Mountain Hawks

2b. Hind femur does not extend beyond abdominal segment VIII, labium with small teeth…..**Torrent Hawks and Skimmers (Corduliidae and Libellulidae)**

Torrent Hawks



Skimmers



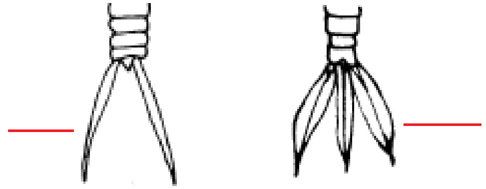
Labium

II. Damselflies (Zygoptera)

Two forceps like caudal gills………..**1**

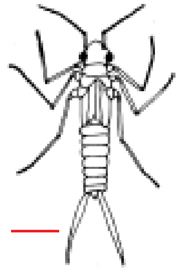
Three leaf, blade or sac like caudal gills..…..**2**

Caudal Gills of Damselfly Larva

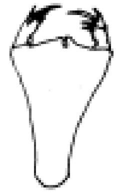


1a. Two forceps like caudal gills, which are triangular in cross section………...**Stream Jewels (Chlorocyphidae)**

Stream Jewels

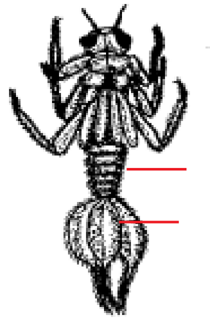


Labium

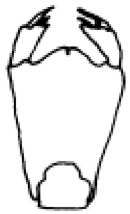


2a. Filamentous gills on the underside of abdominal segments II-VIII, caudal gills are sac like……………...............................**Torrent Darts (Euphaeidae)**

Torrent Darts



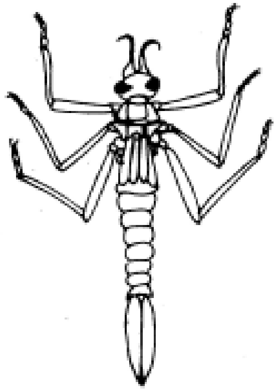
Labium

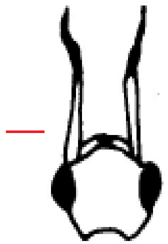


Without filamentous gills on abdominal segments II-VIII……….......................**3**

3a. First antennal segment longer than the combined length of other segments; body slender and long, caudal gills blade like with a distinct dorsal ridge………...**Glories(Calopterygidae)**

Glories **Antenna**

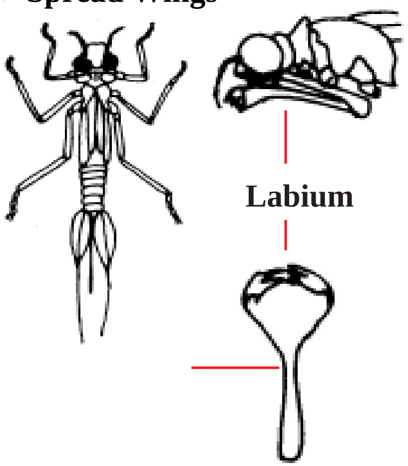




First antennal segment similar to other segments………….........................…..**4**

4a. Labium distinctly spoon shaped and strongly tapered posteriorly with large sharp teeth..**Spread Wings (Lestidae)**

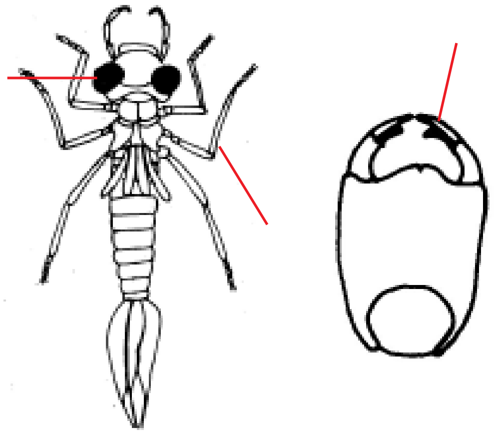
Spread Wings



Labium quadrate or more or less triangular in shape, but not spoon shaped; with movable hooks or spines at the tip…..….**5**

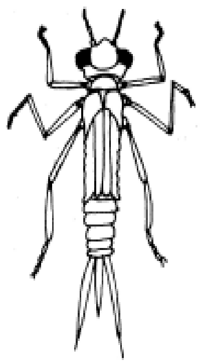
5a. Pale and lanky larvae with large bulbous eyes, labium with single spine and one movable hook...**Reedtails (Platystictidae)**

Reedtails **Labium**



5b. Gills clearly divided into a thickened dark proximal part and a thin, paler distal part......…...….**Bambootails (Protoneuridae)**

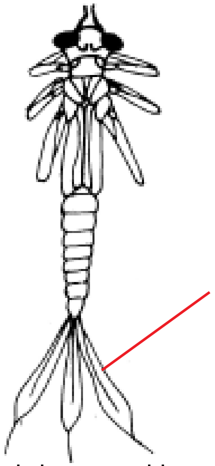
Bambootails



Gills not divided into proximal and distal parts…...…**6**

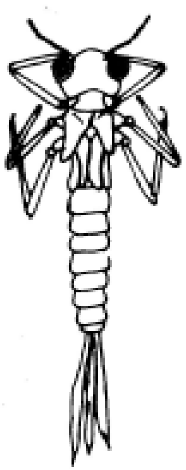
6a. Caudal gills long, about same length as the abdomen, apices pointed or tapering, third segment of antenna longer than the second ....**Bush Darts** (**Platycnemididae)**

Bush Darts

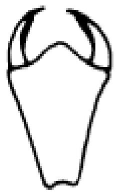


6b. Caudal gills shorter than the abdomen, with rounded apices third segment of antenna shorter than second........................**Marsh Darts (Coenagrionidae)**

Marsh Darts

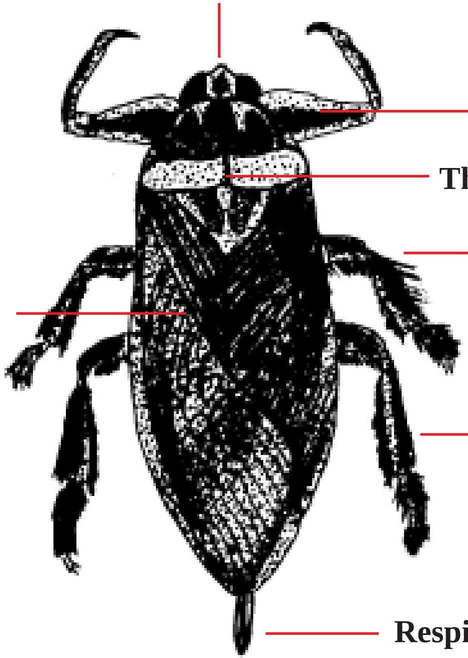


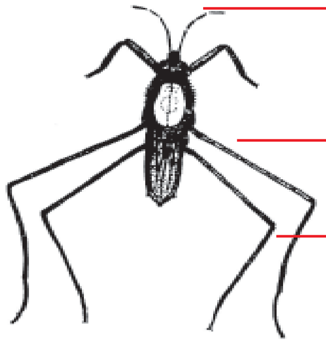
Head and Antenna



Labium

Key to Adult Aquatic Bugs (Hemiptera)

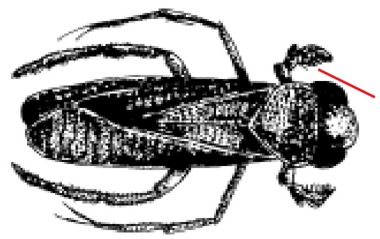




1.Antennae not visible from above; shorter than the head and inserted beneath the eyes …………………..**Suborder Nepomorpha**…………...........................**2**

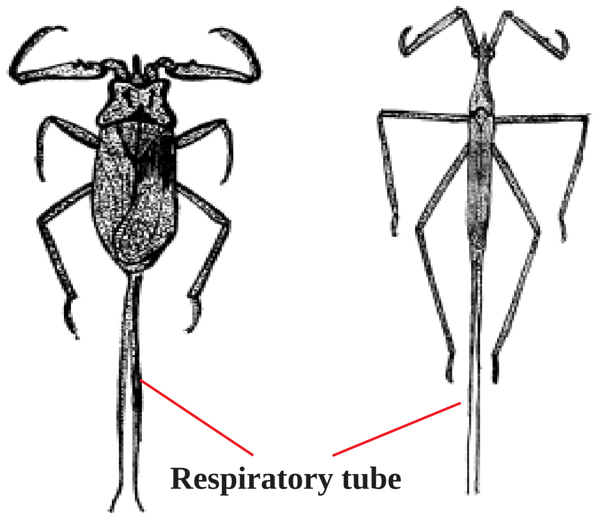
Antennae visible from above; longer than the head and inserted in front of the eyes ……………..…………**10**

2.Mouthparts blunt and triangular or beak-like; the tarsus of forelegs modified into a scoop-like structure …………..……**Corixidae**



Mouthparts elongate and cylindrical or cone-shaped, divided into segments and adapted for piercing; tarsi of fore legs not as above (often raptorial)……..**3**

3.A slender respiratory tube made up of two grooved filaments present at the apex of abdomen...……………..**Nepidae**



Respiratory tube either absent or very short…………...….**4**

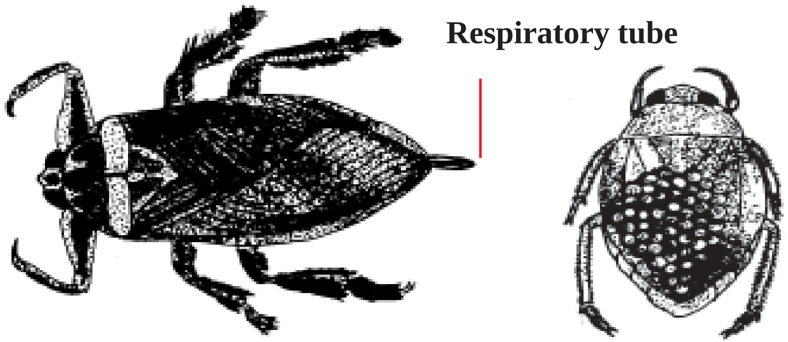
4.Swimming hairs present on the fringes of mid and hind legs; aquatic……….**5**

Swimming hairs absent on the fringes of mid and hind legs; riparian……..…**10**

5.Forelegs raptorial with broadened femora; body dorsoventrally flattened and oval insects...……………………**6**

Fore legs and femora not flattened; Elongate or hemispherical and distinctly ovid insects ………………………..……**8**

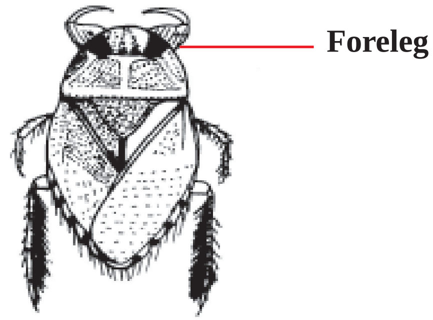
6.A pair of short, strap-like appendages at the tip of the abdomen; eyes protrude from margin of the head; mid- and hind legs somewhat flattened; anterior margin of the pronotum is not concave ……………….**Belostomatidae**



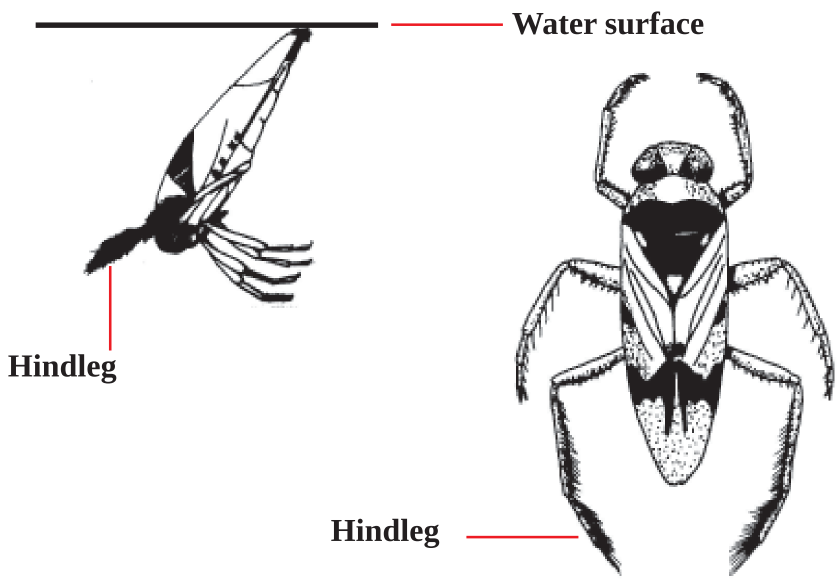
Strap like appendages absent at the tip of the abdomen; eyes do not protrude; mid- and hindlegs cylindrical; anterior margin of pronotum concave; ………………..**Naucoridae**…….**7**

7a. The tip of rostrum extends back to the base of the hindlegs; forefemora slightly broad …………...................….………**Naucoridae (Aphelocheirinae)**

7b. Rostrum short and stout with the tip extending back to the base of the forelegs; fore femora very broad………………..**Naucoridae (Cheirochelinae)**

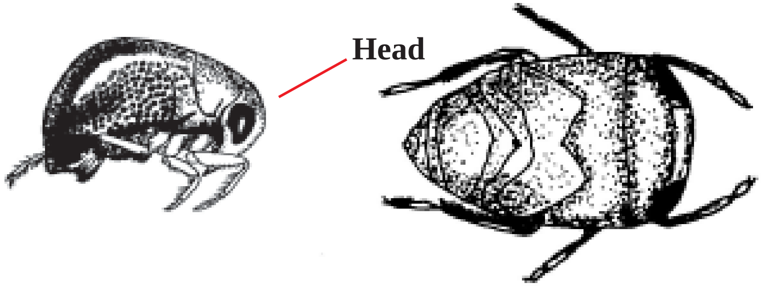


8. Hind legs long and oar-like and fringed with hairs; body elongate ……………………..…………**Notonectidae**



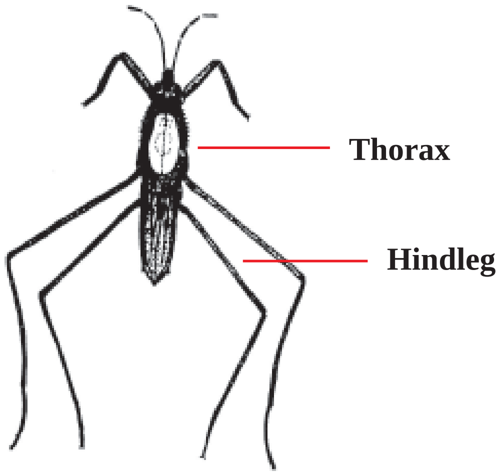
Mid- and hind legs of similar length; body hemispherical and ovoid (the head and thorax are fused) …………...………………**9**

9. Antennae with three segments; Body very small, laterally compressed with convex round face……..…..**Pleidae**

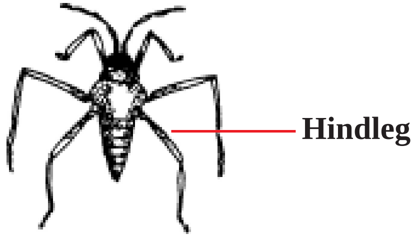


10. Body elongate or very slender; mid- and hind legs unusually long; ……….….**suborder Gerromorpha**……..**11**

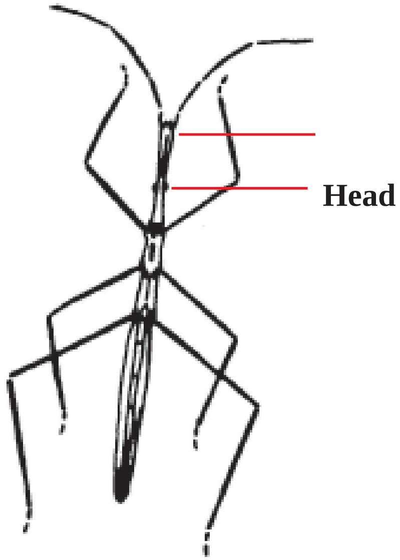
11a. Mesothorax longer than the other thoracic segments; Femora of hind legs longer than the abdomen………..……**Gerridae**



11b. Thoracic segments of approximately equal length; Femora of hind legs not longer than the abdomen ………...…..**Veliidae**

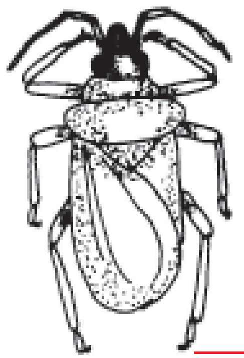


11c. Body delicate and stick like; head is as long as the thorax with eyes set halfway...…………**Hydrometridae**

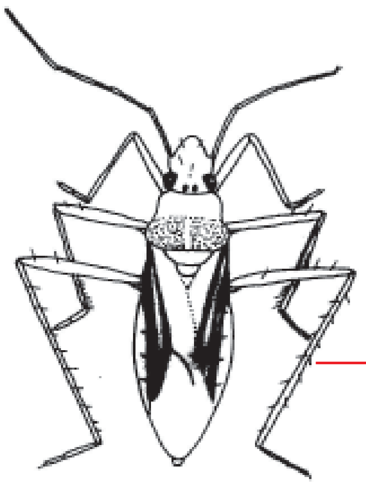


Without the above combination of characters…………………...................……**12**

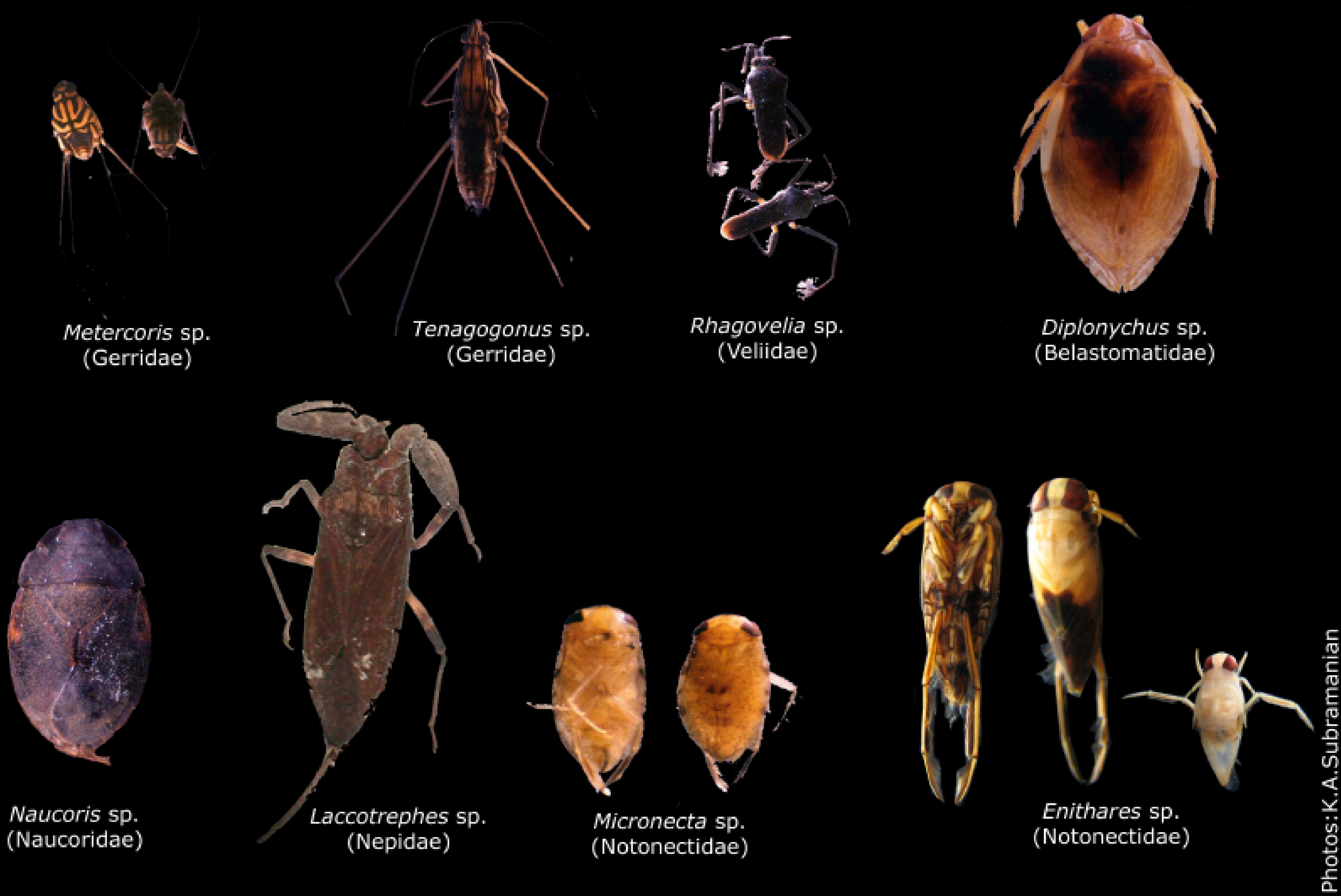
12a. Tarsi with two segments; hind legs without spines; ventral surface of the head grooved with a pair of prominent vertical plates covering the base of the rostrum…..…………..**Hebridae**



12b. Tarsi with three segments; hind legs armed with spines; ventral surface of head not as above;; ……......................................……………………**Mesoveliidae**

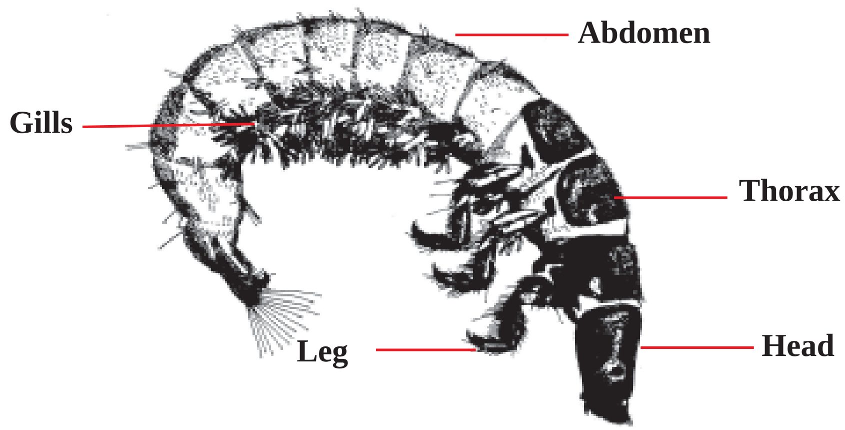


Some Aquatic Bugs (Nymphs and adults)

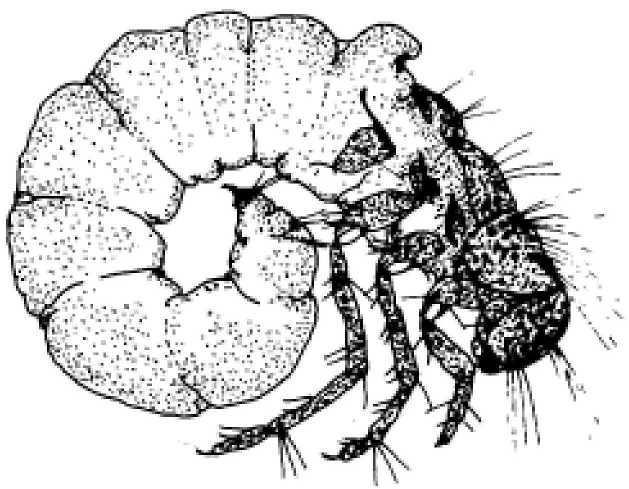


Space for Field Notes on Aquatic Bugs (Hemiptera)

Key to Larval Caddiesflies (Trichoptera)



1.Larval case is made up of sand grains resembling a snail shell; body strongly curved; anal claw comb-like ………………………......................**Helicopsyche**



Larval case not spiral or larvae free-living; anal claw generally hook-like.……**2**

2.Dorsal surface of all three thoracic segments covered with sclerotized plates …………...……..**9**

Dorsal surface of thorax membranous or fleshy and never entirely sclerotized …………...…………**3**

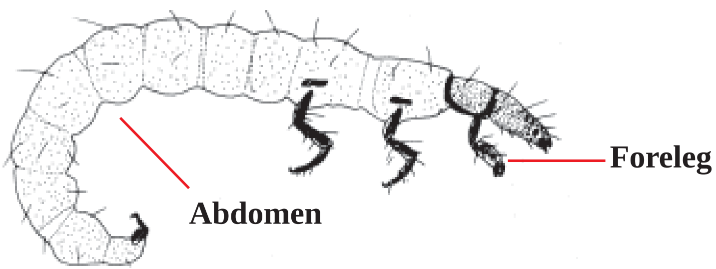
3.Second thoracic segment partly or largely covered by sclerotized plates (although these may be lightly pigmented); larvae construct portable cases of various materials………..…………**10**

Second thoracic segment without sclerotized plates but a few small sclerites and setae may be present; larvae without a portable case, but may construct a shelter or live within a net………...………………**4**

4.Dorsal surface of abdominal segment IX with sclerotized plate; tracheal gills may be present on the sides of the abdomen.……………..............……….…**5**

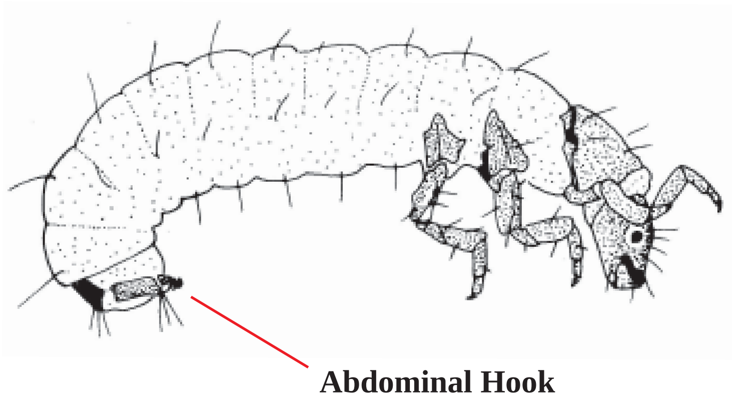
Dorsal surface of abdominal segment IX without sclerotized plate; tracheal gills absent on the sides of the abdomen.…………...…..**7**

5.Forelegs with modified tibia and tarsus (chelate, or pincer-like with an attenuated tarsus); abdomen without gills …….........…………..**Hydrobiosidae**

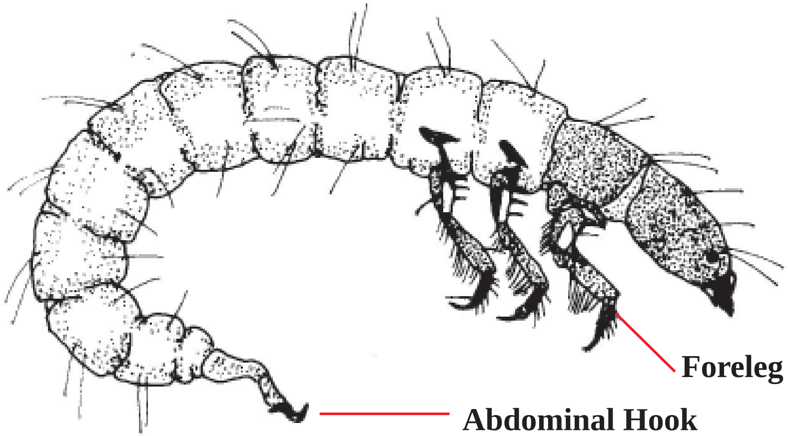


Forelegs not modified; limbs similar to each other in general form……………....**6**

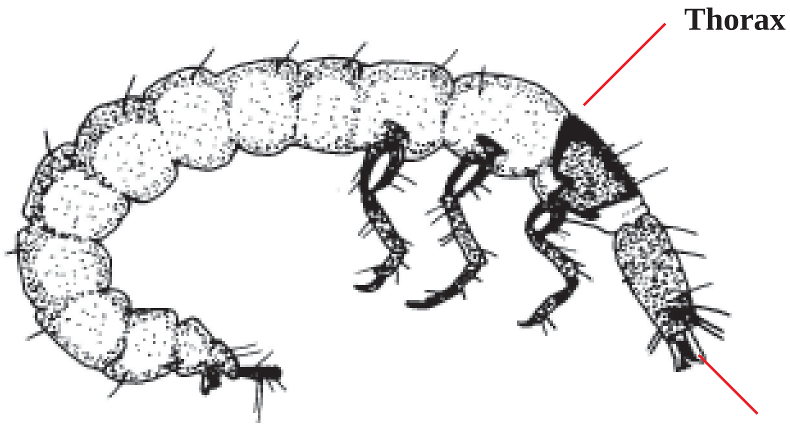
6a. Larvae live in a tortoise-like case made of small stones; anal prolegs short and broadly joined to abdominal segment IX; anal claws small with at least one dorsal accessory hook; forelegs not noticeably stouter than the other limbs; ………...……………**Glossosomatidae**



6b. Larvae free-living; anal prolegs free and rather long, with well-developed claws which may have accessory hooks on the inner margin; forelegs rather robust and raptorial; abdomen and thorax may bear lateral gills ……………..….**Rhyacophilidae**

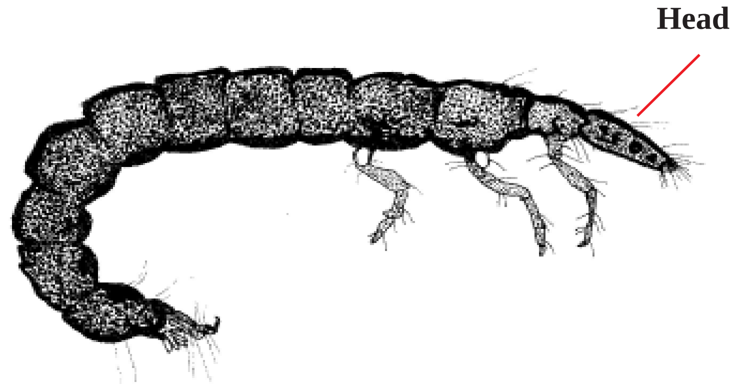


7.Larvae spine sac-like nets of fine silk; Labrum T-shaped and membranous, anterior margin densely fringed with fine setae; sclerotized parts usually yellow or orange and the posterior margin of the prothorax is rimmed with black ………..…………**Philopotamidae**



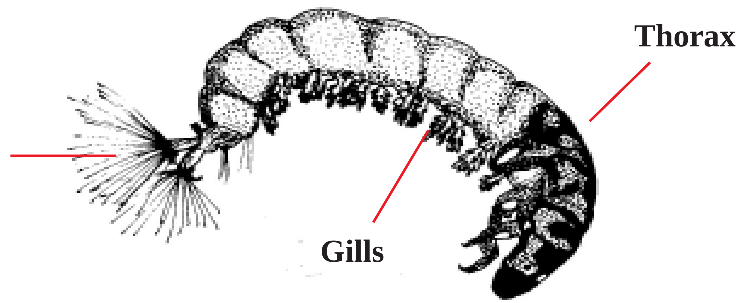
Labrum sclerotized, not T-shaped……………….......................……………….....**8**

8.Head at least twice as long as wide; larvae large and usually dark in colour; larvae spins an irregular net among stones and debris on the stream bed………...….**Stenopsychidae**

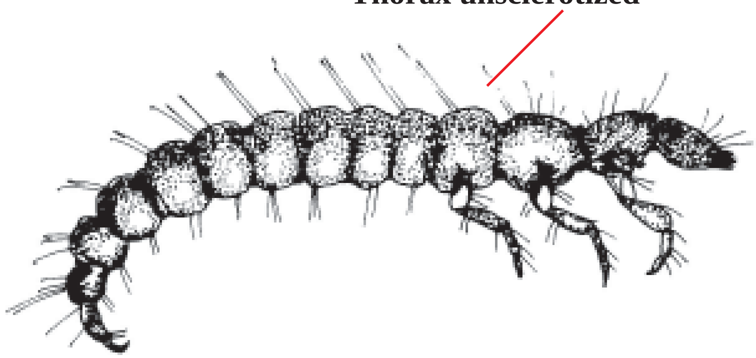


Head never twice as long as wide; larva usually small and pale; larvae spin fine-meshed nets or live in fixed tubes…………......................................……**9**

9a. Larvae lives within a silken net and fixed retreat; abdomen with conspicuous ventral and lateral gill tufts; anal prolegs with a distal brush of long setae; posterior margins of thoracic shield lobed ……………...……**Hydropsychidae**

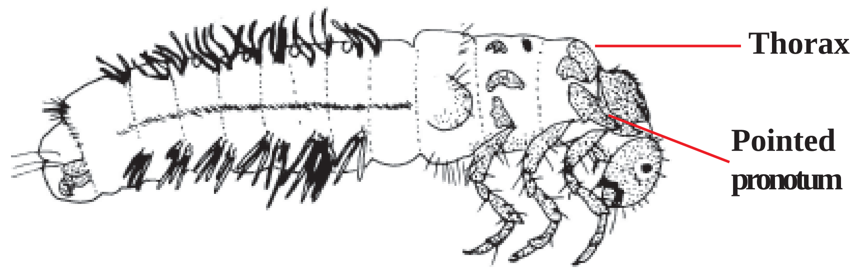


9b. Larvae spin nets or build tubes on hard surfaces; abdomen more- or less cylindrical and lacks gill tufts and lateral fringe of setae; last thoracic segment unsclerotized; labium short and not extend beyond the maxillary palps; margins of the labrum without dense fringe of setae; fore-trochantin relatively long; ………..….**Polycentropodidae**



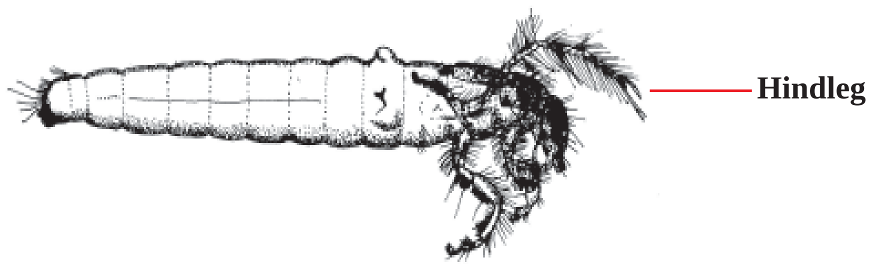
Ventral or lateral gills absent; anal prolegs lack a distal brush; posterior margins of thoracic nota straight…...…………**10**

10. Larval case of rock fragments with lateral ballast stones. Pronotum is thickened and the anterior margins are pointed and directed forward; mesonotum with four sclerites in addition to lateral projections that point forward; head can be retracted beneath the pronotum; ……………………...…………………**Goeridae**



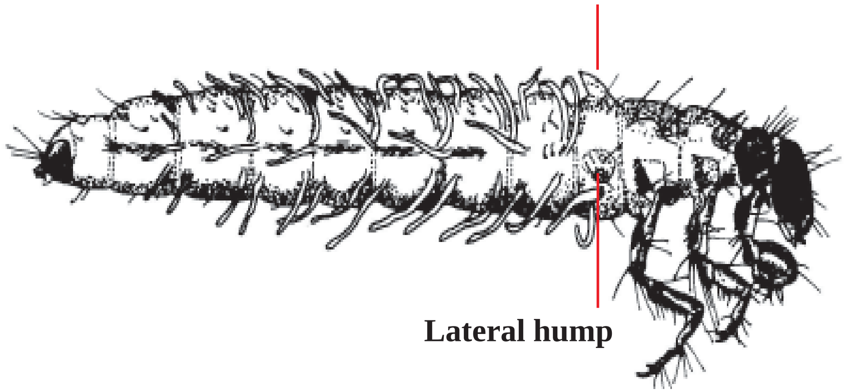
Pronotum and mesonotum not as above; head not retractable………………**11**

11. Antennae prominent; sclerotized plates on the mesonotum usually lightly-pigmented and sometimes have a pair of dark curved lines on the posterior half; hind legs longer than other limbs with the femur and tibia (and, in some cases the tarsi) subdivided into two 'pseudosegments'................**Leptoceridae**



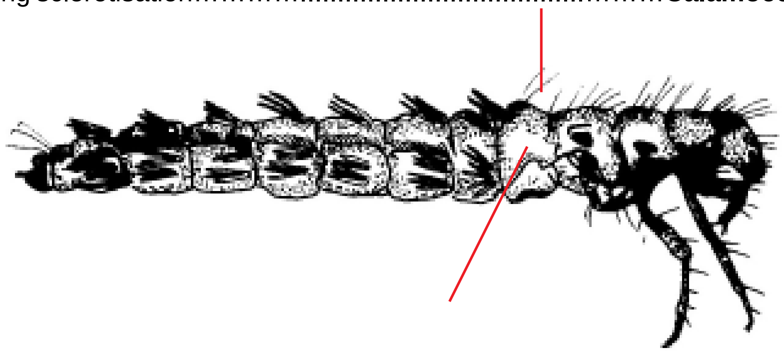
Abdominal segment I with membranous dorsum and lacks a shield-like sclerite, but setae or a dorsal hump or a small sclerite may be present; no sclerites on the meso- and metasterna and underside of abdominal segment I ……..….**12**

12. Larvae makes cases of plant material; large larvae with conspicuous head capsule; a membranous, finger-like projection (the prosternal horn) is present on the underside of the prothorax (prosternal horn); abdominal segment I with dorsal and lateral humps ………………….....................................…..**Phryganeidae**



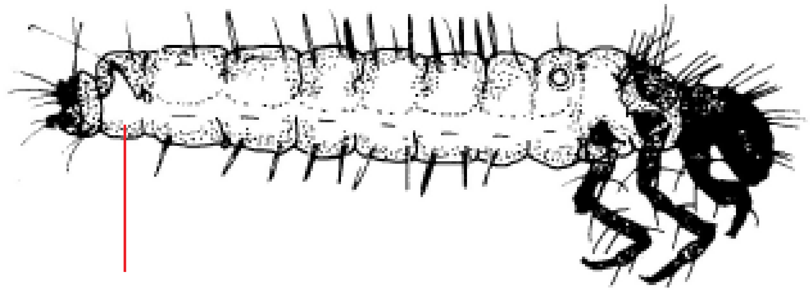
Thorax not as above…………...……..**13**

13. Larvae makes cases decaying leaves and twigs; abdominal segment I with dorsal and lateral humps; anterior corners of pronotum project forward; Labrum with a transverse row of 15-20 stout setae; mesonotum with a pair of anteriolateral sclerites and a larger central plate; metanotum almost entirely lacking sclerotisation…………...................................………**Calamoceratidae**



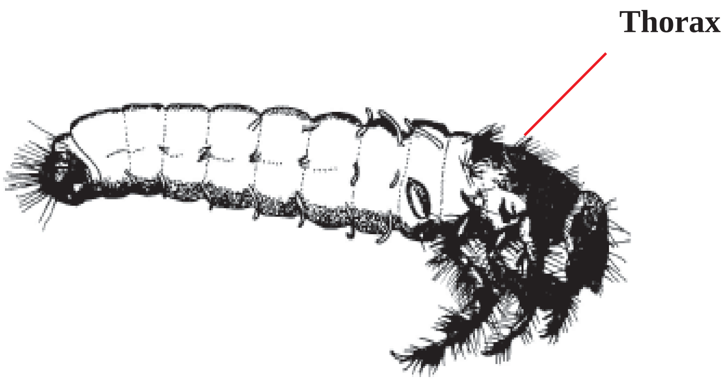
Labrum not like above; without the above combination of characters……….**14**

14a. Larval case square in cross-section and made of panels cut leaves; antennae situated close to the anterior margin of the eye; abdomen with out dorsal hump on segment I; prosternal horn present; abdominal segment VIII with a fleshy lateral lobe on either side……………………..**Lepidostomatidae**



Lateral fleshy lobe

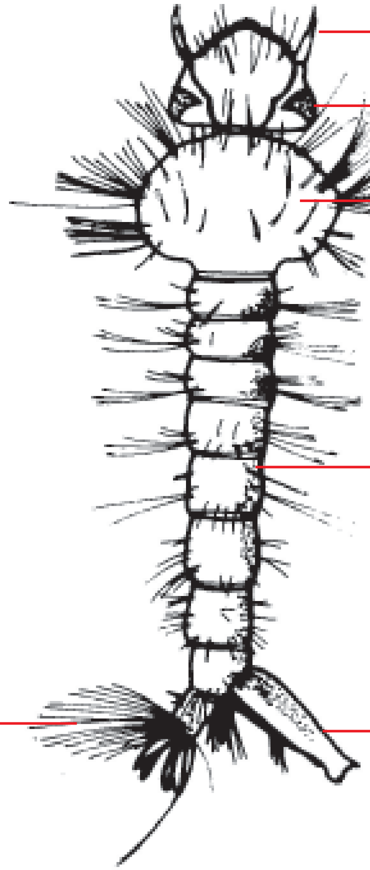
14b. Larval cases of rock fragments or detritus, often resembles pipe; anterior margin of the metanotum with a pair of sclerites; mandibles almost always toothed; gills consist of single or multiple filaments …………….**Limnephilidae**



Some Caddiesflies (Larvae)

Space for Field Notes on Caddiesflies (Trichoptera)

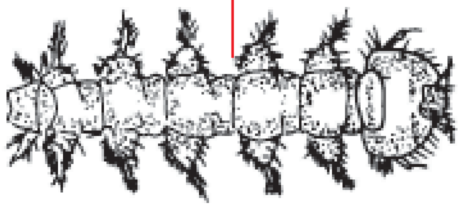
Key to Larval Flies (Diptera)



1.Larvae with a sclerotized head capsule; mandibles move laterally ……..**Suborder: Nematocera**…….**2**

Larvae without capsule or it is partially formed; mandibles move vertically and they are hook-like; prolegs sometimes (but not always) absent and body may be pale and maggot-like ……………..**Suborder: Brachycera**……..............….**6**

2. Body segments appears to be deeply constricted with seven segments; conspicuous ventral sucker present on first six 'segments**'**…..**Blephariceridae**



Abdomen without ventral suckers; prolegs present or absent...........................**3**

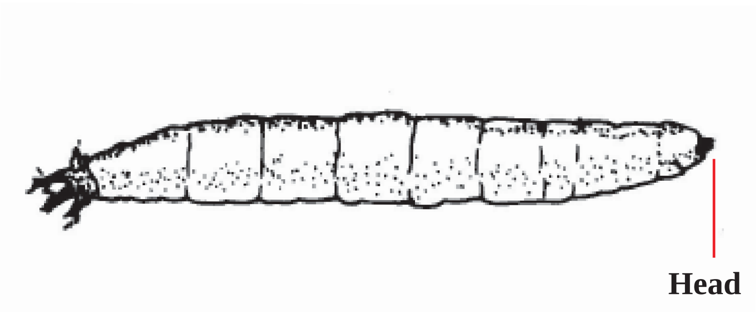
3. Prolegs absent...**4**

Prolegs present...**5**

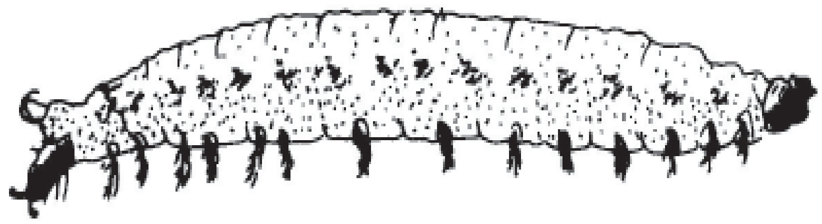
4a. Body segments secondarily segmented; head capsule strengthened only by sclerotized rods..**Ceratopogonidae**

Head capsule well sclerotized or, if strengthened only with sclerotized rods, then body segments not secondarily segmented

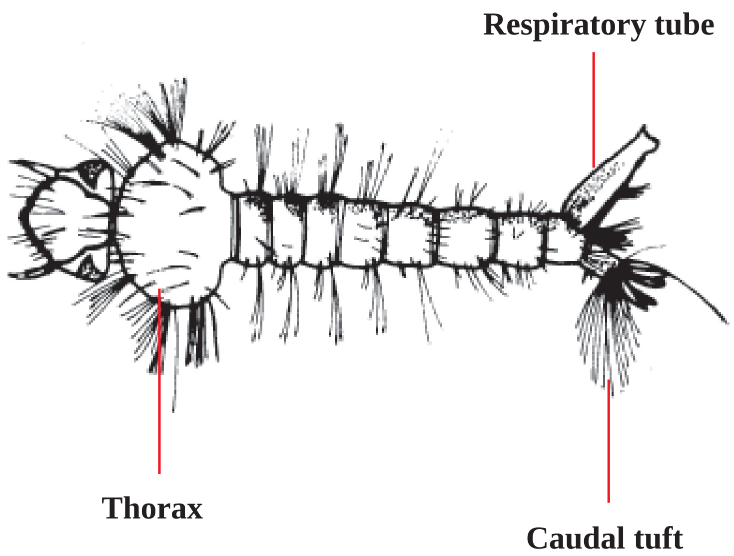
4b. Head capsule with incomplete posterior margins and retracted into body cavity..**Tipulidae**



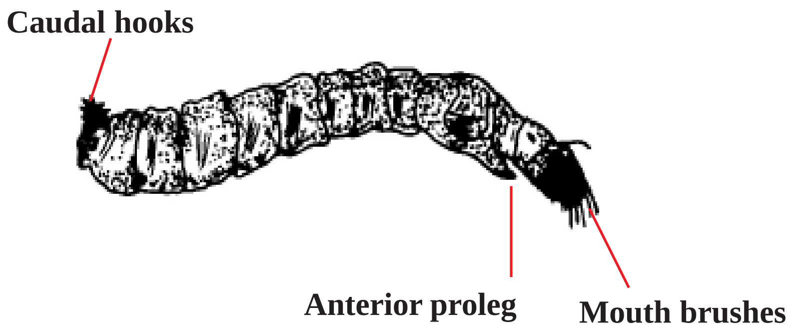
4c. Ventral suckers may be present; thoracic and abdominal segments divided up by one or more annuli; dorsal sclerites may be present.. .... **Psychodidae**



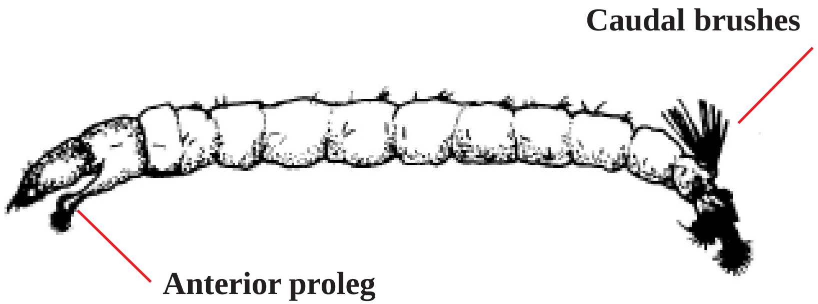
4d. Thorax disc like and wider than abdomen. Thoracic and abodminal segments with tufts of setae. Prominent mouth brushes present..........................**Culicidae**



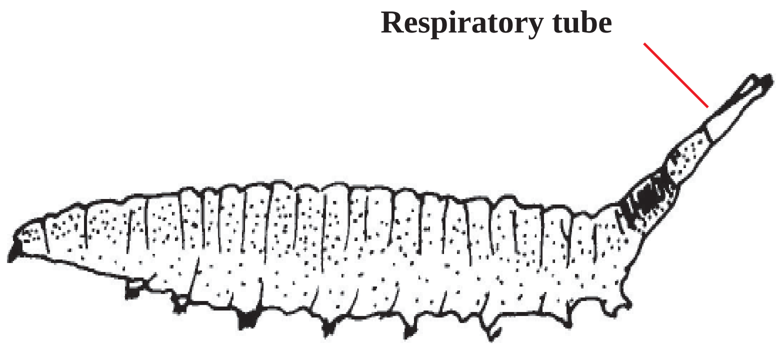
5a.A single proleg on the prothorax, and no posterior proleg(s); body club-shaped, posterior end swollen with a ring of tiny hooks at the tip….**Simuliidae**



5b. Posterior and anterior prolegs paired (although the anterior pair may be fused partially); widespread and abundant……………..............…**Chironomidae**

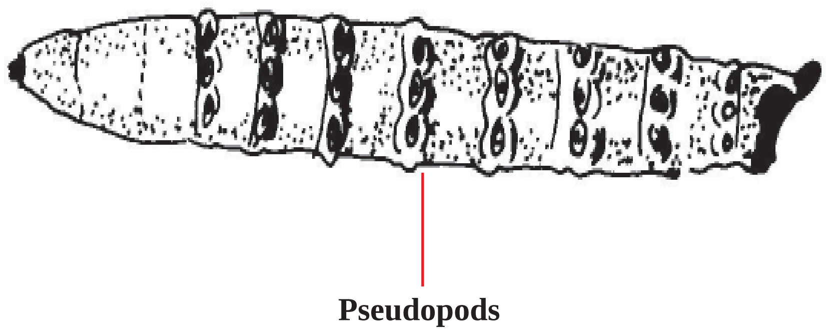


6.Body ends in a short respiratory tube that is divided at the apex..**Ephydridae**

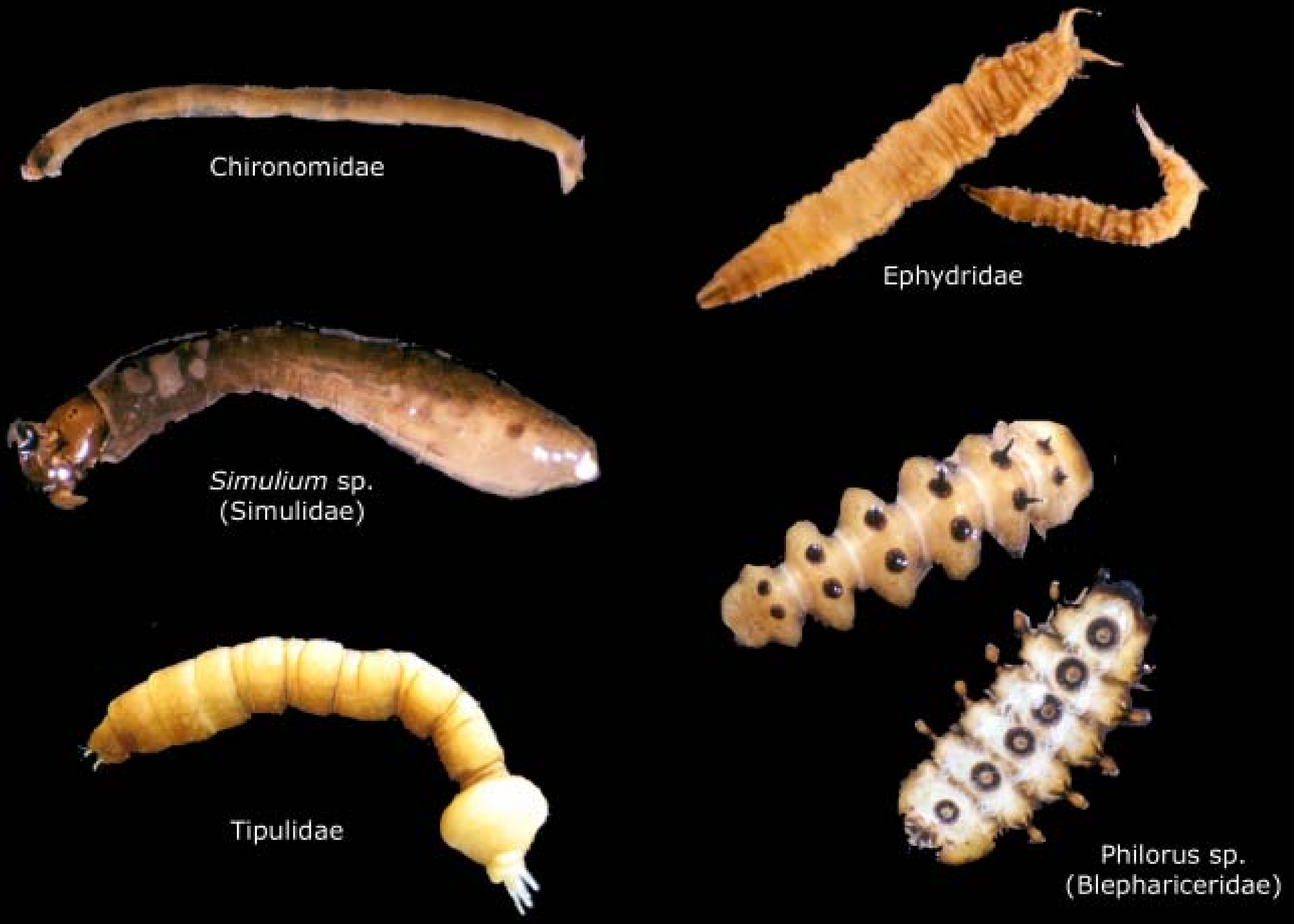


Respiratory tube lacking………..………….**7**

7. Abdomen without distinct prolegs but with a girdle of at least six pseudopods around each segment…..……**Tabanidae**



Some Aquatic Diptera (larvae)

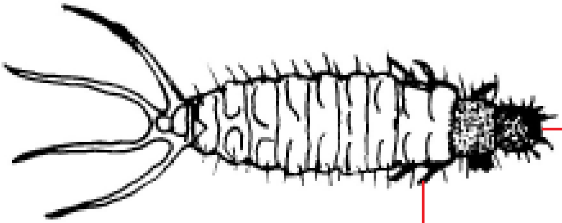


Photos:K.A.Subramanian

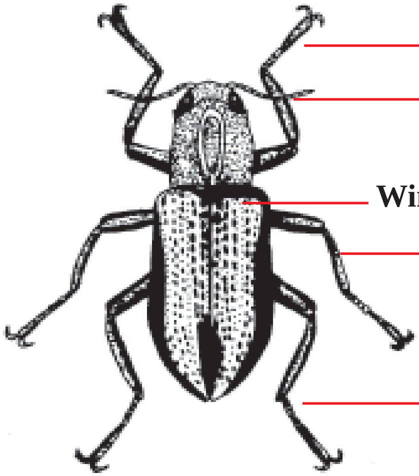
Space for Field Notes on Flies (Diptera)

Key to Aquatic Beetles (Coleoptera): Larvae and Adult

Larvae



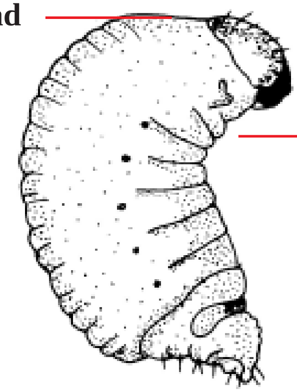
Adult



1.Membranous wings covered by hardened wing covers (elytra) which overlay the abdomen ………....................................…….. **Coleoptera- Adult** **10**

Wings and elytra absent……………........................……**Coleoptera- Larvae**.…..**2**

2.Associated with aquatic macrophytes; legs absent or minute; thorax and abdomen short………………………...….. **Curculionidae**

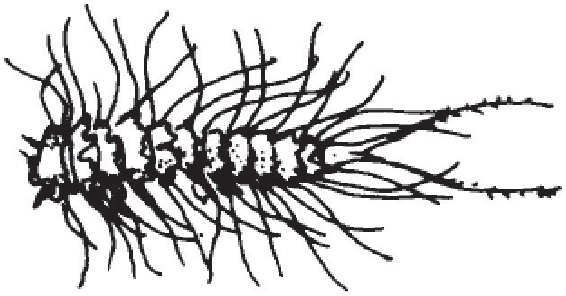


Not confined to aquatic macrophytes; Legs present and well defined.........…**3**

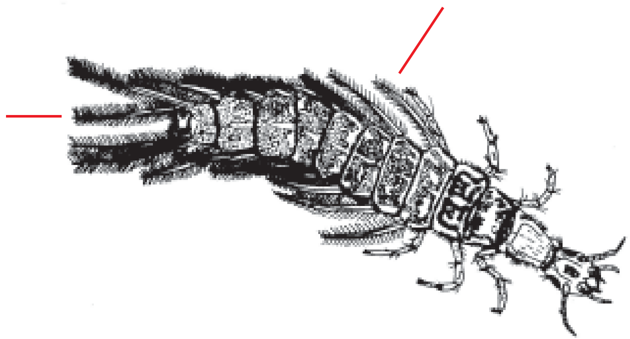
3. Legs with a single tarsal claw…...……………**4**

Legs with two tarsal claws………..………………**5**

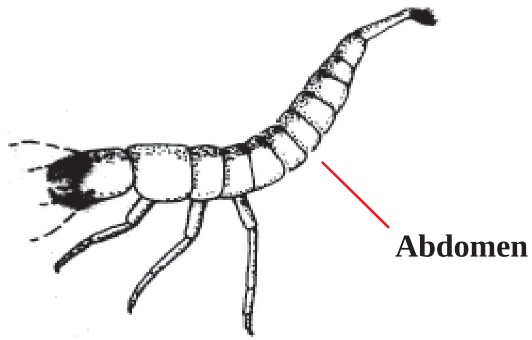
4. Body elongate and tapered posteriorly; legs with five segments (excluding claw) ....………………….**Haliplidae**



5a. Lateral gills present on abdominal segments I-IX; two pairs of stout hooks at the tip abdominal segment X …………………….........................……**Gyrinidae**

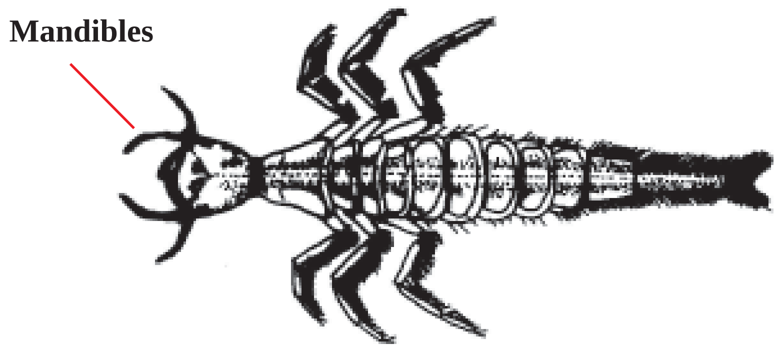


5b. Lateral gills are absent; abdomen eight segmented without terminal hooks; Abdominal segment VIII with a pair of large terminal spiracles; Cerci on the tip of the abdomen are slender and usually much longer than abdominal segment-I..………**Dytiscidae** (in part)

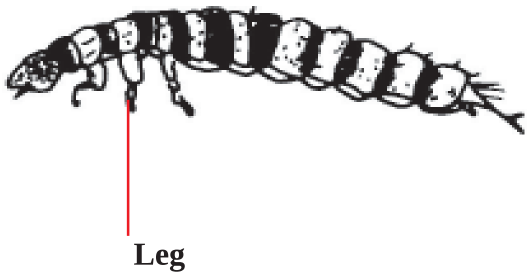


Cerci either short and stout or absent……………...……….**6**

6a. Legs short and slender, and may be adapted for swimming; mandibles sickle shaped…………..…………**Dytiscidae** (in part)

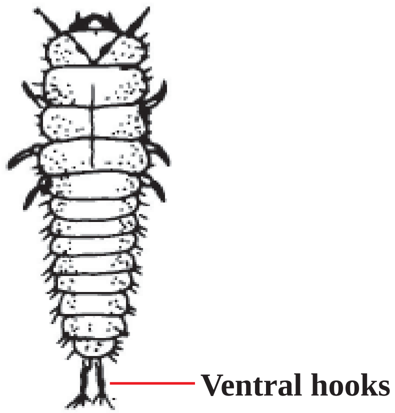


6b. Legs short and stout and adapted for digging; mandibles not sickle-shaped………...………………….**Noteridae**



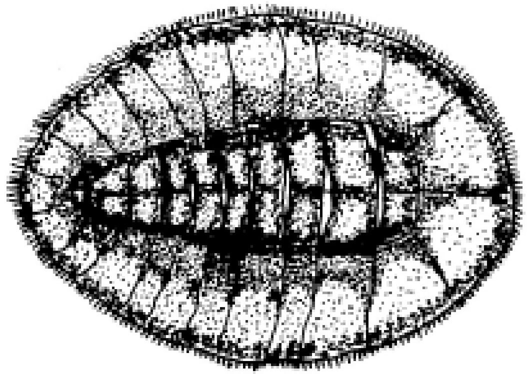
Without the above combination of characteristics ………….........................…….**7**

7. Abdominal segment X with a minute pair of recurved venteral hooks; segment IX has a pair of two segmented articulated cerci……….**Hydraenidae**

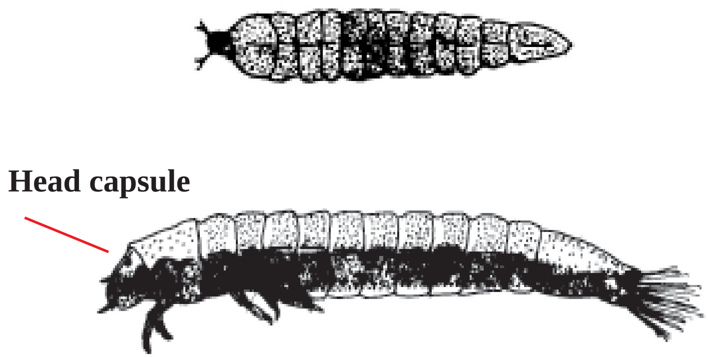


8.Head and legs visible when viewed from above; body cylindrical …………..**9**

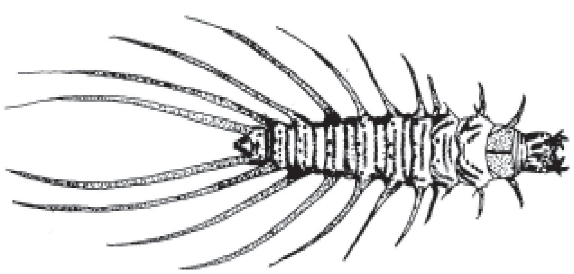
Head and legs not visible when viewed from above; body greatly flattened like a disc…………..………**Psephenidae**



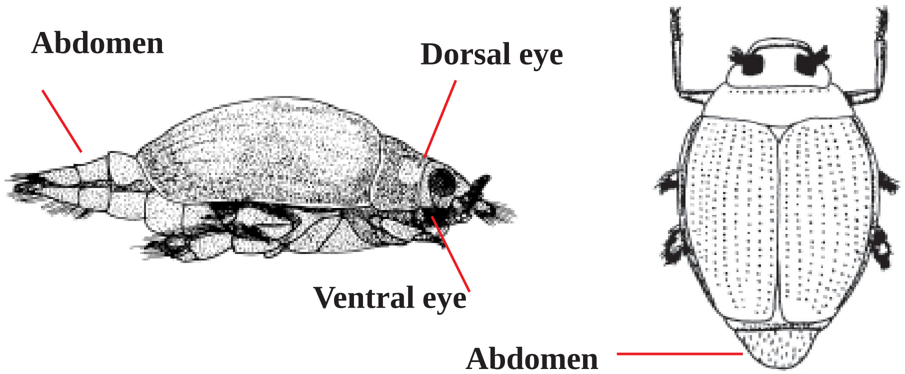
9a.Head capsule with groups of five lateral ocelli; abdominal tip distinctly pointed, bifid or notched with – often with– lateral ridges or longitudinal crests ………………..……………….**Elmidae**



9b. Head capsule with groups of six ocelli (five lateral and one ventral) or without ocelli; abdominal tip rounded; antennae arise behind the insertion point of the mandibles………...…….**Hydrophilidae**

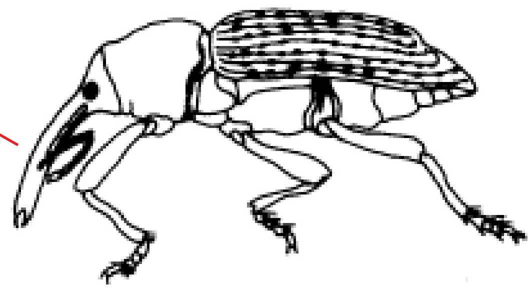


10. Eyes divided into dorsal and ventral portions; forelegs long and raptorial, mid- and hindlegs short and paddle- like; antennae stout and club-shaped; lives on water surface ……………………….......................................….**Gyrinidae**



Eyes undivided; form of legs and antennae various but not as above; aquatic or semiaquatic but never on water surface……....................…………………..**11**

11.Head with elephant's trunk like anterior prolongation or snout...**Curculionidae**

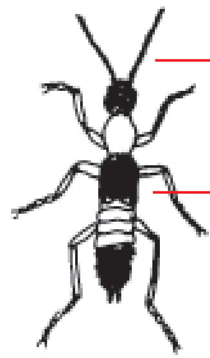


Head not produced into a snout………...…….**12**

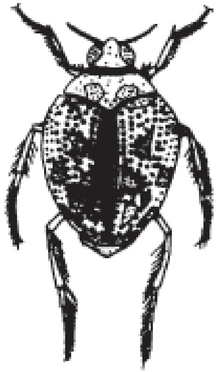
12.Elytra short and partially covers the dorsal surface of the abdomen…….**13**

Elytra covering entire dorsal surface of the abdomen……..............................…..**14**

13. Semi aquatic; metallic or iridescent beetles; antennae with more than eight segments…..………**Staphylinidae**

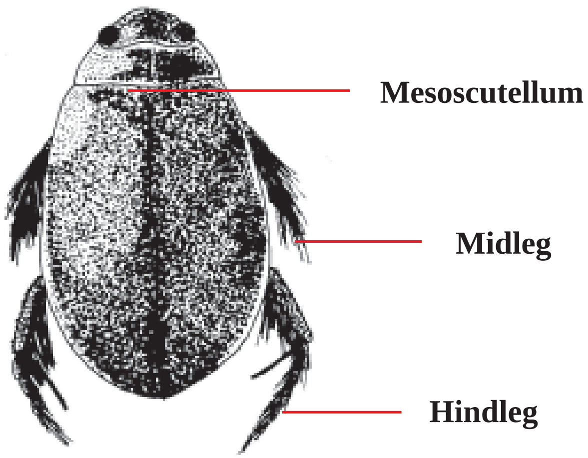


14. Abdominal segments I-III covered by plate like expansion of hind coxae ……………………………………………………………………………………… **Haliplidae**

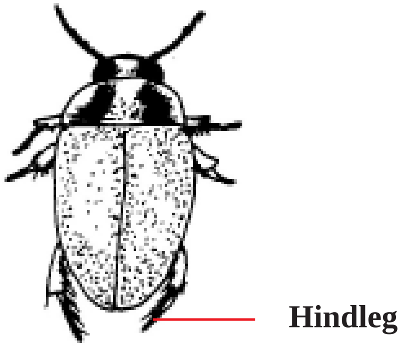


Hind coxae not expanded into plates but extend posteriorly to divide the first abdominal sternite…………………………………………………………………………….**15**

15a. Eyes do not protrude; body convex shaped in cross section; hind tarsus with a single claw, if two claws are present, the mesoscutellum (a triangular plate lying mid-dorsally on the mesothorax between the elytra) is large and exposed ……………………………………………………………………………**Dytiscidae**



15b. Hind tarsus with two claws; mesoscutellum concealed; dorsal surface more strongly convex than the ventral surface………………………………**Noteridae**

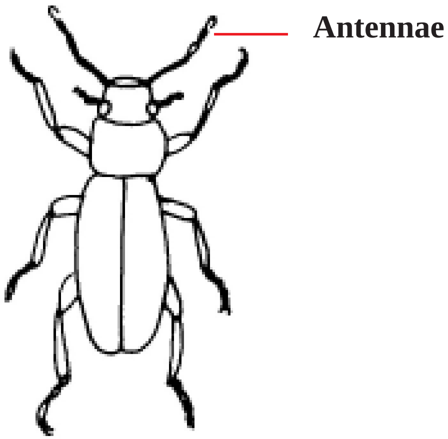


Not with above combination of characters…………………………………………**16**

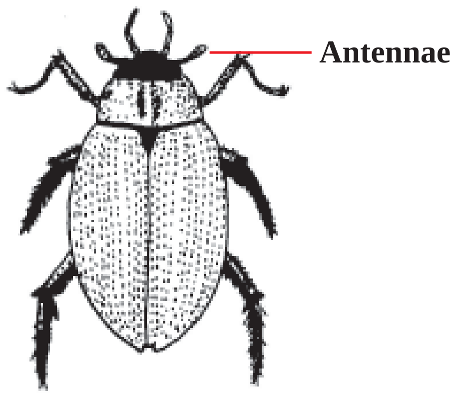
16. Tips of antennae an abrupt globular or elongate club……………………………**17**

Tips of antennae do not form a club………………………………………………………**18**

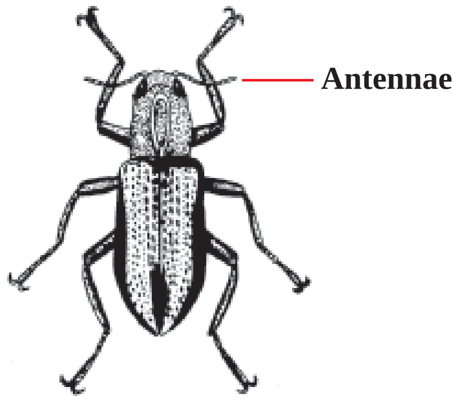
17a. Antennal club made up of five segments; abdomen with six or seven segments visible on the underside……………………………………………**Hydraenidae**



17b. Antennal club made up of three segments with five segments before the 'club'; abdomen with five segments visible on the underside; fore tarsi with five segments. Pronotum broadens posteriorly; eyes prominent or not……..…..**Hydrophilidae**

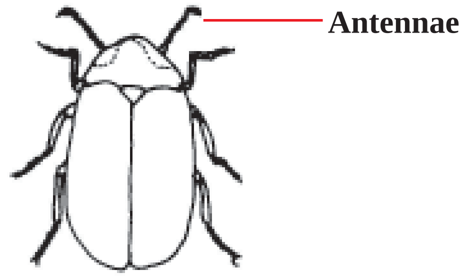


18. Abdomen with six or seven segments visible on the underside; antennae filiform and concealed within the prothroax and never longer than the combined length of head and prothorax; body heavily sclerotized……..**Elmidae**

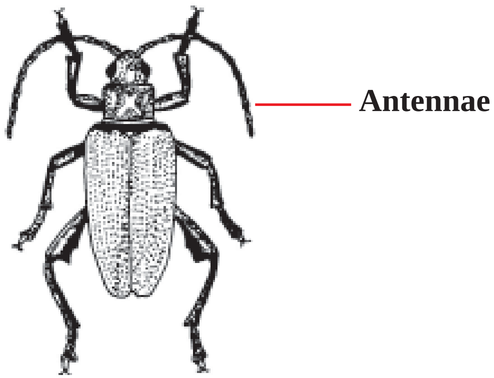


Antennae longer than the combined length of head and prothorax…..............**19**

19a. Antennae somewhat comb-like; broadly oval and somewhat flattened weakly-sclerotized beetles with less than 10 mm body length; antennae inserted between the eyes……...…..**Psephenidae**



19b. Antennae slender and longer; mandibles inconspicuous, directed venterally; brightly coloured, metallic or iridescent beetles; semiaquatic and associated with aquatic plants…………...................................…..**Chrysomelidae**



Some aquatic beetles (larvae and adults)

Cybister sp. (Dytiscidae)

Eubrianax sp. (Psephenidae)

Dineutus sp. (Gyrinidae)

Laccophilus sp. (Dytiscidae)

Sandracottus sp. (Dytiscidae)

Hydaticus sp. (Dytiscidae)

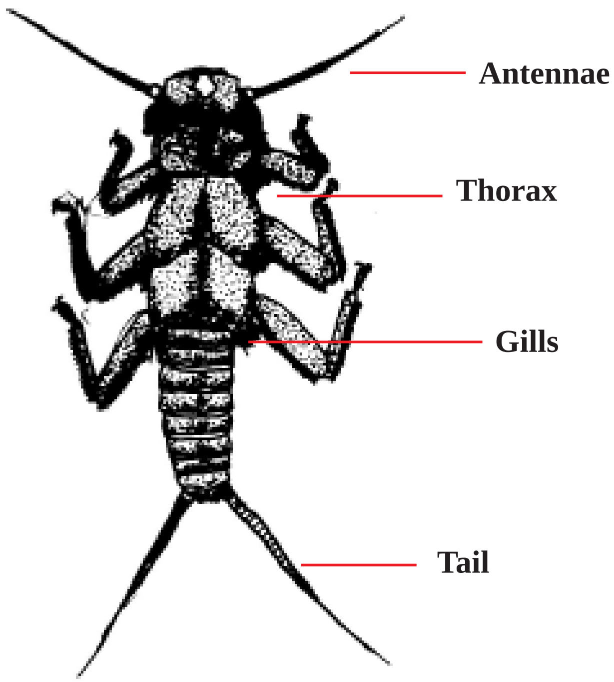
Noteridae

Photos:K.A.Subramanian

Space for Field Notes on Aquatic Beetles (Coleoptera)

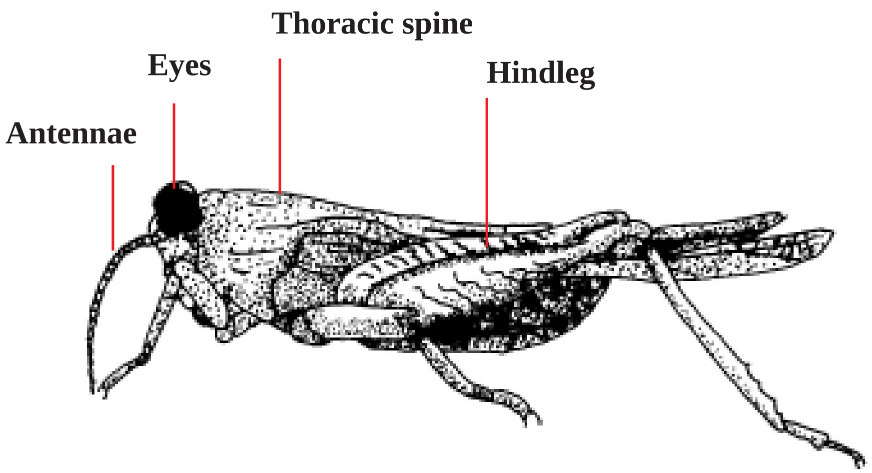
Key to Larval Stoneflies (Plecoptera)

1. Larvae generally brown with yellow markings; branched thoracic gills are present; abdomen terminates in two tails...............................**Perlidae**

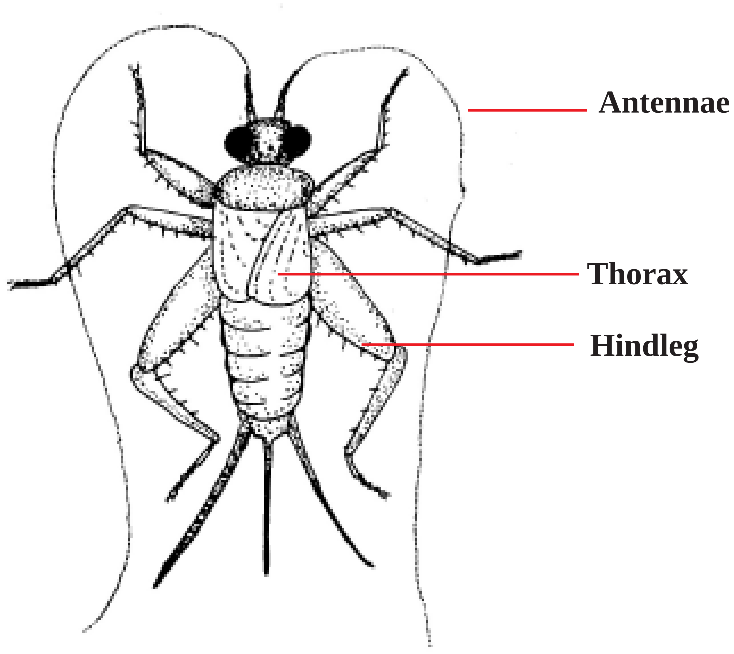


Key to Semi-aquatic Grasshoppers and Crickets (Orthoptera)

1. Hind femora enlarged and adapted for jumping; body laterally compressed; throax drawn into a long spine over the abdomen; eyes dorsally placed...**Tetrigidae**

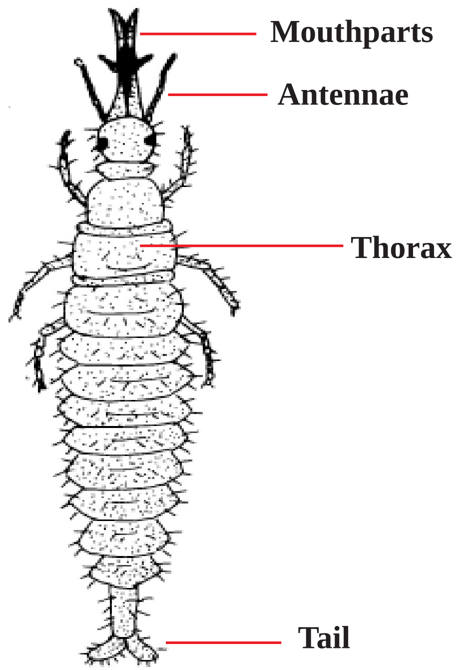


2. Body dorso ventrally compressed; antena longer than the body and thread like; wings absent or reduced...................**Gryllidae (Nemobinae)**



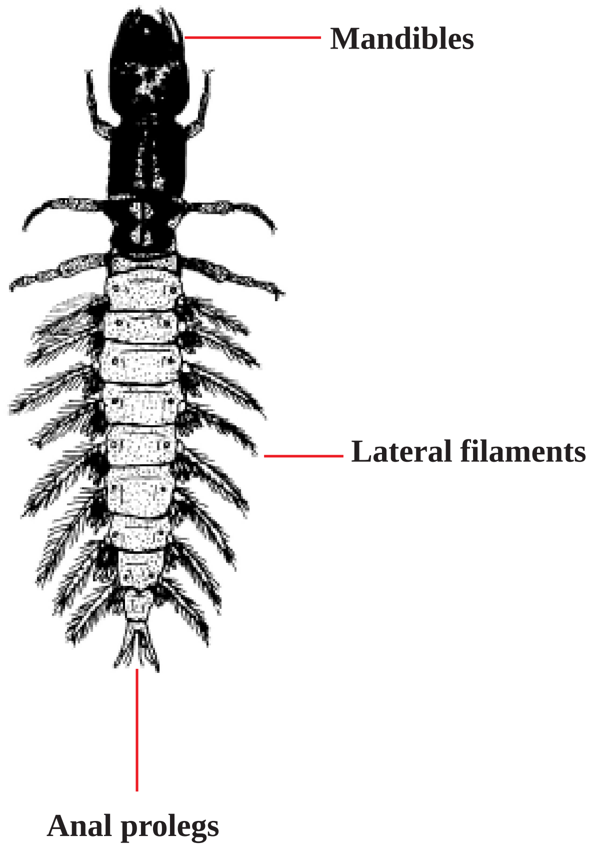
Key to Spongillaflies (Neuroptera)

1. Body covered with small bristles; antenna long; mouth parts needle like; wings pads and tails like structures are absent..................**Sisyridae**



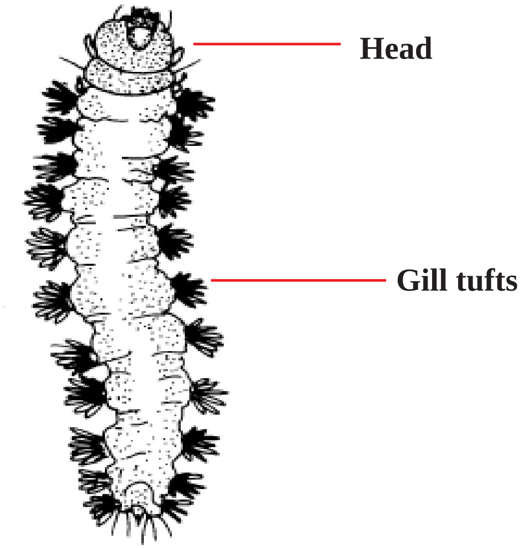
Key to Alderflies (Megaloptera)

1. Abdomen with eight pairs of lateral filament and hooked anal prolegs; mandibles large and conspicous...**Coridalidae**



Key to Aquatic Moths (Lepidoptera)

1. Abdomen with gill tufts and pseudo legs; associated with aquatic plants...**Pyralidae**



Other Aquatic Insects (Odonata, Plecoptera, Blattodea, Orthoptera and Lepidoptera)

Odonata: Libellulidae

Euphaea sp.
(Odonata: Euphaeidae)

Aulocodes sp.
(Lepidoptera: Pyralidae)

Neoperla sp.
(Plecoptera:Perlidae)

Blattodea:Blaberidae

Scelimenia sp.
(Orthoptera: Tetrigidae)

Space for Field Notes on other Aquatic Insects (Odonata, Plecoptera, Orthoptera etc.)

Ashoka Trust for Research in Ecology and Environment (ATREE), Bangalore, India

Small Grants Programme

2007

Photo:K.A.Subramanian

Aquatic Insects of India-A fieldguide

K.A.Subramanian and
K.G.Sivaramakrishnan

Ashoka Trust for Research in Ecology and Environment (ATREE)
Small Grants Programme

2007

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Acknowledgements: This field guide would not have achieved this shape without the support of ATREE through its Small Grants Programme to K.A.Subramaninan. Authors sincerely thank friends and colleagues for valuable comments and suggestions on earlier drafts of this guide. We sincerely thank the Karnataka and Kerala forest departments for their field support.

Citation: Subramanian, K.A. and Sivaramakrishnan, K.G. (2007). Aquatic Insects of India-A Field Guide. Ashoka Trust for Ecology and Environment (ATREE), Bangalore, India. 62pp.

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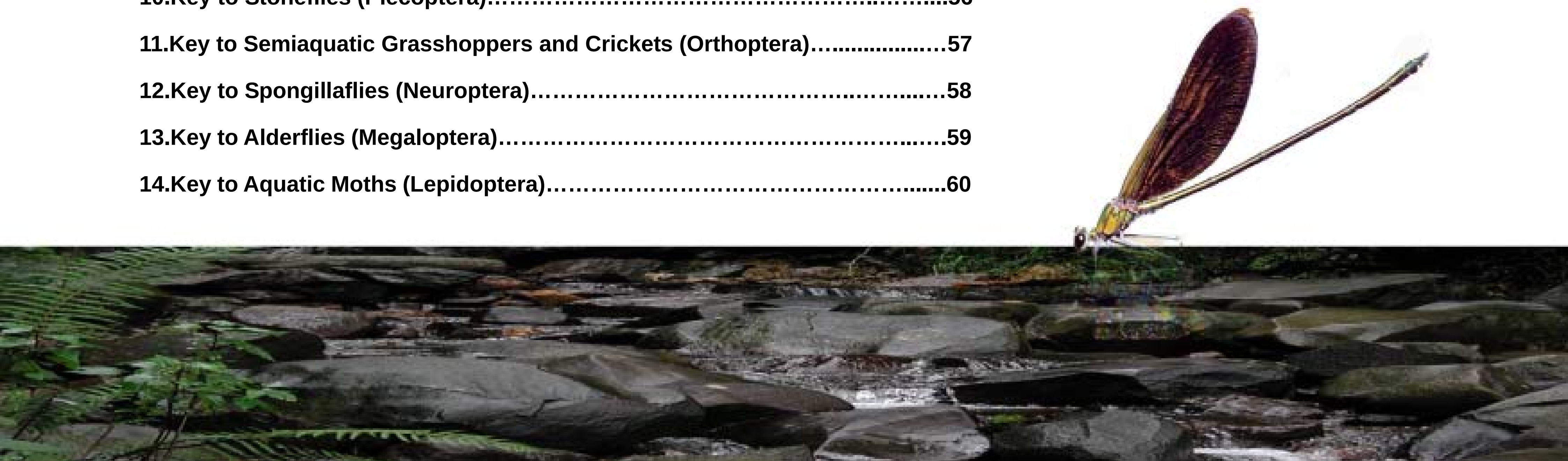


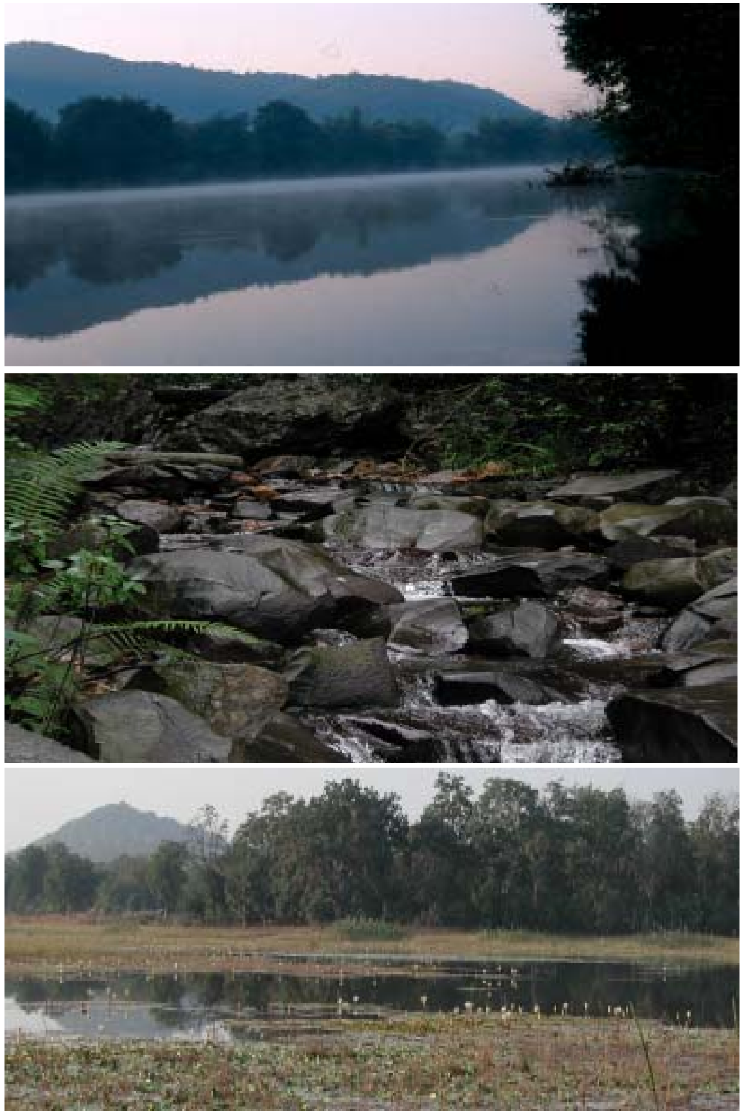
Freshwater Biodiversity

The inland freshwaters encompass a diverse array of ecosystems as varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs and even pools of water that collect in the leaf axils of certain plants. This is a small fraction of world's water resource. Despite this, inland aquatic habitats show far more variety in their physical and chemical characteristics than marine habitats and contain a disproportionately high fraction of the world's biodiversity.

Inland water habitats can be classified into stagnant (*lentic)* and flowing (*lotic*)*.* They may also be classified into perennial or transient. Each of these has its own set of distinctive ecology and biological community. Lentic systems comprise lakes and ponds. Majority of large lakes are formed either by glacial or tectonic activity. Most of the glacial lakes are geologically young and were formed during Holocene, 11,500 years before present. Manmade lentic habitats such as irrigation tanks, ponds and reservoirs are historically recent and predominant landscape features in India.

Lotic system encompasses rivers and streams. A river system is essentially a linear body of water draining under the influence of gravity. Most of the river systems discharge into the sea and some into lakes. A few water courses in arid regions enter inland basins where no permanent lakes exist and disappear into the dry plains.

Large rivers such as Ganges and Brahmaputra cross over many degrees of latitude and traverse a wide range of climatic conditions. Variations in water flow and underlying geology also create a wide range of habitats, often within a short distance. Because of this change in habitats, different organisms are typically present in different parts of any given river system. Even though



The inland freshwaters encompass a diverse array of ecosystems as varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs and even pools of water that collect in the leaf axils of certain plants.

rivers are physically very dynamic, large rivers rarely disappear, and there are indications that some of the large rivers are in existence for tens of millions of years. This is reflected in the fact that, all the taxonomic groups are found in running waters and some invertebrate taxa are exclusive or attain greatest diversity there.

Biodiversity at higher taxonomic levels such as Phylum, Class or Order in freshwater systems are much narrower than those in the terrestrial or marine systems. The overall number of species (species richness) is also low compared to marine and terrestrial groups. However, species richness in relation to habitat extent may be very high. For example, about 10, 000 (40%) of the 25,000 known fish species are freshwater forms. This high diversity of freshwater fishes relative to habitat extent is promoted by isolation between freshwater systems. The species richness in the freshwater systems increases towards the equator as in the case with terrestrial habitats. There are many more species in the tropical freshwater systems than in temperate regions, but in some specific groups such as freshwater crayfishes this trend appears to be reversed.

Animal species are far more diverse and numerous in inland waters than plants. Apart from fishes, invertebrates form an important group. The important groups include sponges, flatworms, mollusks, polychaete worms, oligochaete worms, crustaceans, insects and numerous parasitic species in various groups. As on land, insects are the most diverse group of organisms in inland waters. Unlike terrestrial faunas, where beetles (Order Coleoptera) are the most diverse, flies (Order Diptera) appear to be by far, the most abundant group in inland waters.

Animal species are far more diverse and numerous in inland waters than plants. As on land, insects are the most diverse group of organisms in inland waters.

Introduction to aquatic insects

Insects are the most diverse group of organisms in freshwater. Estimates on the global number of aquatic insect species derived from the fauna of North America, Australia and Europe is about 45,000, of this about 5,000 species are estimated to inhabit inland wetlands of India. Aquatic insects of inland wetlands comprise some well-known groups like mayflies (Ephemeroptera), dragonflies (Odonata) and caddiesflies (Trichoptera). Aquatic insects such as dragonflies and damselflies (Odonata) are very colourful and prominent insects of the wetlands. Different functional feeding groups of aquatic insects such as shredders, scrapers, filter feeders and predators are important links in nutrient recycling. Aquatic insects primarily process wood and leaf litter reaching the wetland from the surrounding landscape. Nutrients processed by aquatic insects are further degraded into absorbable form by fungal and bacterial action. Plants in the riparian zone absorb this nutrient soup transported through the wetlands. In addition to this significant ecosystem function, aquatic insects are also a primary source of food for fishes and amphibians.

Evolution of aquatic insects: The origin of aquatic insects has been controversial and doubts still exist as to whether or not insects are primarily or secondarily adapted to aquatic environments. The widely accepted view is that the ancestor of myriapod-insect group (millipedes, centipedes, and insects) lived in leaf litter areas along margins of pond like environment. Primitive insects of this moist environment were ancestors of aquatic insects. Their fossil record extends to Devonian in the Paleozoic era. Among extend aquatic insects, dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive and only insects with aquatic juveniles. The understanding of aquatic insect evolution and phylogeny has been hampered by poor fossil record of freshwater animals.

Living aquatic insects represent 12 insect orders.

About 5,000 species of insects are estimated to inhabit inland wetlands of India. Dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive insects.

Of this, larvae of species of mayflies (Ephemeroptera), dragonflies and damselflies (Odonata), stoneflies (Plecoptera), alderflies (Megaloptera), lacewings (Neuroptera), flies (Diptera), caddiesflies (Trichoptera), moths (Lepidoptera) and wasps (Hymenoptera) are aquatic with terrestrial adults. Larval or nymphal and adult stages of aquatic beetles (Coleoptera) and bugs (Hemiptera) are fully aquatic.

Morphological and physiological adaptations: Aquatic insects have tackled the problem of living in aquatic environment by evolving various morphological and physiological modifications. These include air-tubes to obtain atmospheric oxygen, cutaneous and gill respiration, the extraction of air from plants, hemoglobin pigments, air bubbles and plastrons. Air-tubes are present in aquatic bugs (Hemiptera) and files (Diptera) restricting their activity to water surface. Cutaneous and gill respiration is widespread in the immature stages of most of the aquatic insects. This helps them to live among submerged substrates. Adult beetles and bugs often respire by the use of an air bubble. Some species use plastron (a system of microhairs or papillae) that hold an air film. Plastron respiration helps these insects to stay longer under water. Chironomid (Diptera) larvae living in eutrophic aquatic habitats survive in low oxygen levels through the use of hemoglobin pigments.

One of the major physical forces faced by aquatic insects of running waters is water current. In running waters, aquatic insect morphology are closely related to hydraulic stress and the necessity to remain in close contact with the substrate. A diverse range of body modifications are present in aquatic insects. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects. Morphological adaptations are closely followed by behaviour adaptations. Aquatic insects avoid

A diverse range of body modifications are present in aquatic insects to survive in running waters. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects.

water current by burrowing into the substrate or occupying a space in the substrate with minimum hydraulic stress such as rock crevices or under the rock.

Lifecycle adaptations: Aquatic insects have evolved diverse lifehistory strategies to suit their environment. Many temporary pool breeding species have egg stage which can remain in total dry condition (eg: *Aedes)*. In many species of caddiesflies a gelatinous egg mass matrix protect the eggs and larvae from desiccation and freezing for months together. Some species have staggered hatching which prevents over crowding of newly hatched larvae.

Very few aquatic insects have adapted to a completely submerged life cycle. Most of the aquatic insects spend atleast one part of their life cycle in terrestrial habitat. A major problem in being completely submerged is respiration. Many species have developed morphological and physiological adaptations to survive in particular oxygen concentration. The distinction is being very evident in running and standing water, where the former is very well oxygenated than the latter. This is one important factor that determines the distribution of groups like mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddiesflies (Trichoptera). These groups depend upon dissolved oxygen and achieve their maximum diversity in running water. Among holometabolous aquatic insects, aquatic pupa is found in caddiesflies (Trichoptera), flies (Diptera) and aquatic moths (Lepidoptera). Aquatic beetles, alderflies (Megaloptera) and lacewings (Neuroptera) have semi aquatic or terrestrial pupa.

During the course of life, aquatic insects encounter diverse physical environmental conditions, the most pronounced being temperature. The temperature varies daily and seasonally. This variation in temperature affects emergence pattern of aquatic insects. In tropics because of relatively constant temperature, many pool breeding species show continuous emergence throughout the year. However, in the Western Ghats, most of the stream breeding species emerge during pre and post monsoon months. Some species in tropics follow an emergence pattern coinciding with phases of moon.

The presence of diapausing egg and pupa are important life history evolutions that help insects to survive unfavourable conditions. Aquatic insects complete single or multiple generations during a year. Some tropical species have life cycle greater than a year. Life cycle completion time for a species varies with altitude and latitude.

Feeding strategies: Essentially all aquatic insects are omnivorous, atleast in their early instars. Species which use similar morpho-behavioural mechanisms for food acquisition have evolved similar mouth parts. This has facilitated classification of aquatic insects to functional feeding groups, which is equivalent of guild. The “functional group” approach reflects both convergent and parallel evolution leading to functionally similar organisms. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional groups are shredders, collectors, scrappers, predators and piercers. The shredders feed on woody debris and leaf litter, and collectors filter feed or gather suspended organic matter from water column. Scrappers graze algae and other plants growing on substrate. Predators feed on other aquatic invertebrates and small vertebrates. Piercers obtain liquid food from plants or other animals.

Aquatic insects and their habitats: Aquatic insects are adapted to either running waters (streams and rivers) or standing waters (ponds and lakes). These habitats can also be viewed as erosional (streams and rivers) or depositional (ponds and lakes). Both stream/river currents and lake shoreline waves create erosional habitats while lake basins, river flood plain pools and stream/river backwaters provide depositional conditions. Species adapted to erosional habitats frequently colonize lake shorelines. Similarly many species of depositional habitats are common in flood plain pools and backwaters.

The habitats for the aquatic insects can be visualized within the framework of various spatial -temporal scales. At a spatial scale, it ranges in size from particles of few millimeters to the entire drainage basin, which extends to squares of kilometers. Temporally, the changes in the habitats can be visualized from days to thousands of years. The permanence of the physical structures of the habitats varies with the spatial scale. This ranges from few days for individual grain and microhabitat to thousands of years for the drainage network. Insect communities of the wetlands respond to this spatial-temporal variation as well.

Within a given habitat, aquatic insects maintain their location by clinging, swimming, skating or burrowing into the habitat. Distribution of aquatic insects within a habitat is determined by intricate interplay between substrate, flow, turbulence and food availability. The habit (mode of locomotion, attachment or concealment) of a given species determines the frequency of movement within the habitat

Substrate, an important physical component of habitat is very complex. The water current and the nature of the available parental material determine the physical nature of the substrate. The organic detritus adds complexity to the substrata and can strongly influence the organism's response to the substrate. It has been established across continents and biomes that the faunal composition changes with the substrate. Sand is a relatively poor habitat with low

Species which use similar morpho-behavioural mechanisms for food acquisition have evolved similar mouth parts. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional feeding groups are shredders, collectors, scrappers, predators and piercers.

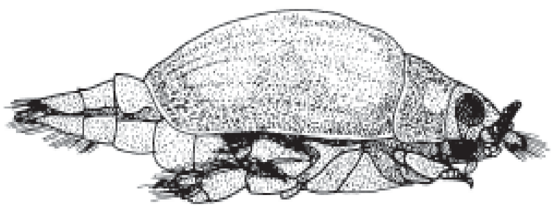
abundance and diversity. Relatively, the diversity is high in silty-sand and biomass may be high and diversity low in muddy substrata. The presence of sand and silt reduces and changes fauna. Atleast in stony substrata it is known that the space available for colonization determines species abundance. In general, diversity and abundance increase with substrate stability and the presence of organic detritus.

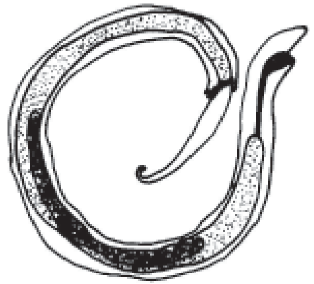
Aquatic insects in biomonitoring: Biological monitoring or biomonitoring is the systematic use of living organism or their responses to determine the health of aquatic ecosystem. Fish, algae, protozoans, and other groups of organisms is being used in water quality assessment but macroinvertebrates which largely consist of insects are more frequently used. They are suitable and sensitve indicators of water quality and ecosystem health because: (1) they are ubiquitous and, consequently affected by perturbations in many different aquatic habitats; (2) the large number of species respond to a range of environmental stress; (3) their sedentary nature relative to other aquatic organisms permits effective determination of spatial extend of perturbation; and (4) long life cycles allow to examine temporal changes in abundance and age structure.

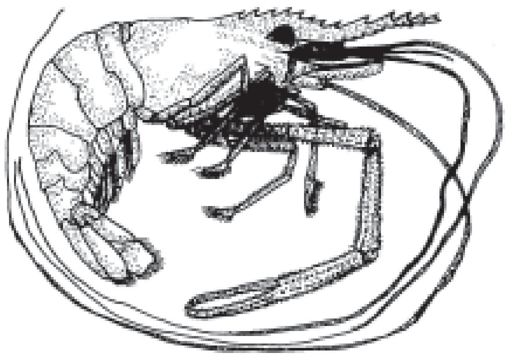
Traditional physico-chemical analysis of water quality provides a snap shot of water quality at the time of sample collection. In contrast, biomonitoring adds a temporal component to the sample and provides a history of the perturbation if any. However, physico-chemial measurements and biomonitoring are not mutually exclusive and an ideal water quality monitoring programme should involve both approaches.

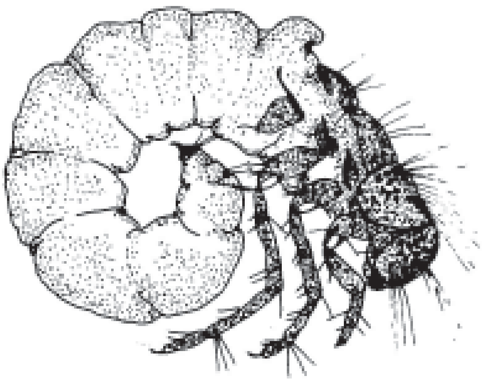
Macroinvertebrates which largely consist of insects are frequently used for biomonitoring. They are suitable and sensitive indicators of water quality and ecosystem health. Biomonitoring adds a temporal component to the sample and provides a history of the perturbation if any.

Key to Aquatic Macroinvertebrates



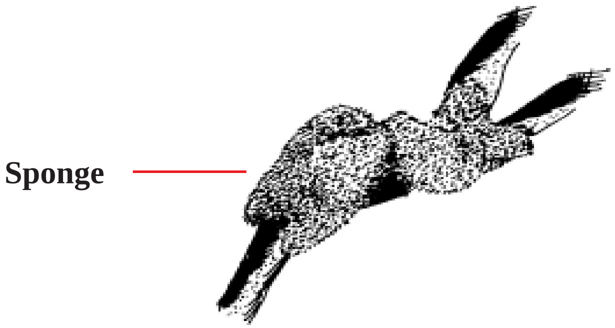






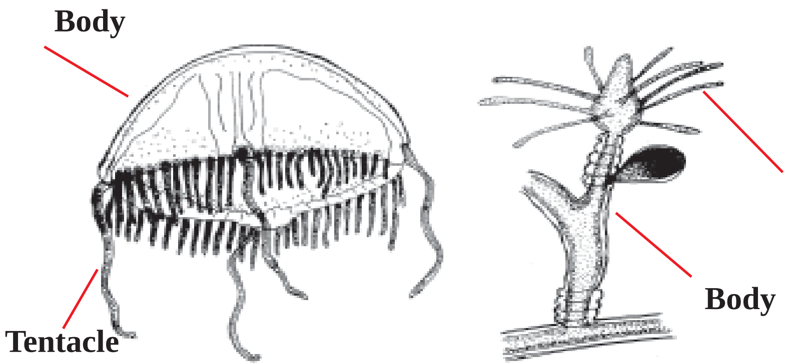
Key to Aquatic Macroinvertebrates

1. Encrusting forms with an irregular, asymmetric shape, lacking discrete organs or tentacles; spongy to touch………….**Freshwater Sponges(Phylum: Porifera)**



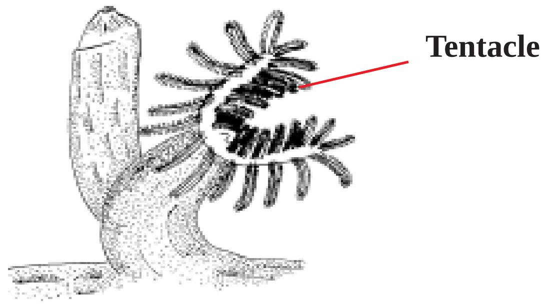
Without the above characters; bilaterally symmetrical with organ-systems……………..**2**

2. Either free-floating and transparent, like an umbrella shaped disc (< 30 mm diameters); or sessile and rather small (generally < 5 mm, but individuals may be solitary or colonial) with a short stem and several tentacles arising from it; rare………….**Coelentrates (Phylum: Cnidaria)**



Without the above characters……………………….........................**3**

3. Sessile, colonial forms made up of numerous small individuals each bearing several retractile tentacles on a horse-shoe shaped structure around the mouth; the rest of the body is enclosed in a gelatinous structure; the colony may be encrusting, compact, or branching, and twig-like………………......**Moss Animals (Phylum: Polyzoa (Ectoprocta))**

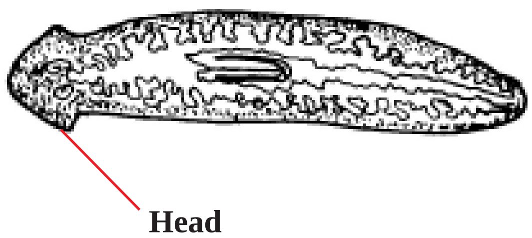


Form not as above; free-living and not colonial…………….........……**4**

4. Body segmented, or with joint legs, or bearing a shell, or any combination of these features…………………………...……**8**

Body unsegmented, lacking jointed legs or a shell………...……………**5**

5. Small (< 30 mm) elongate flattened body pressed to the substratum; moves with a gliding motion; often with a pair of anterior eyespots………**Flatworms or Planarians (Phylum: Platyhelminthes)**



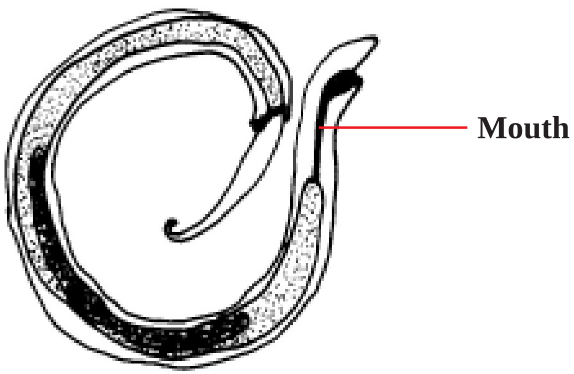
Without the above characters……………………..........................…………..**6**

6. Body thin, flattened and 'bootlace-like'; with a long, eversible proboscis (inconspicuous when retracted) and three pairs of eyes………….............**Ribbon or proboscis worm (Phylum: Nemertea)**

Body is long and thin it is approximately circular in cross-section………………...……**7**

7. Body long (may be >20 cm long) and threadlike; anterior and posterior ends blunt (not tapering); usually dark brown…...**Horsehair worms (Phylum: Nematomorpha)**

Worm-like cylindrical body tapering at both ends and lacking external segmentation; move in a 'whip-like' fashion; usually < 1 cm long……………...............................…**Nematodes (Phylum: Nematoda)**

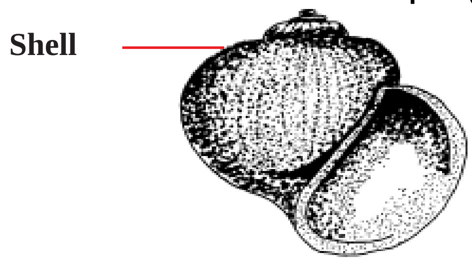


8. Body enclosed by an unsegmented calcareous shell which may be coiled, spherical or bi-valved; body is soft and unsegmented with a ventral muscular foot….**Snails, Clams and Mussels (Phylum Mollusca)**…….**9**

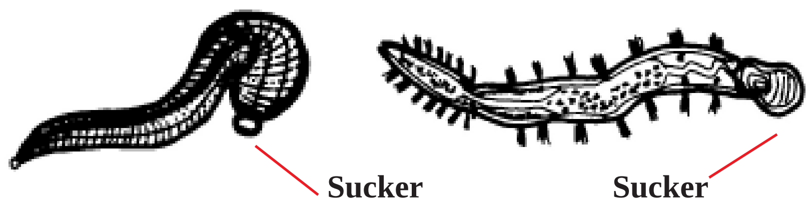
Body segmented and not enclosed in a calcareous shell………………..**10**

9. Body completely enclosed by a bi-valved shell………**Clams and Mussels (Bivalves) (Class: Bivalvia).**

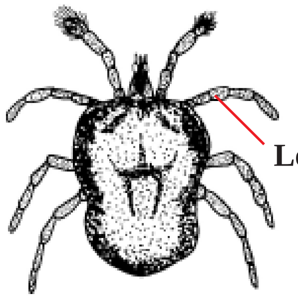
Shell not bi-valved, body may not be entirely enclosed by the shell …………...................................**Snails and Limpets (Class: Gastropoda)**

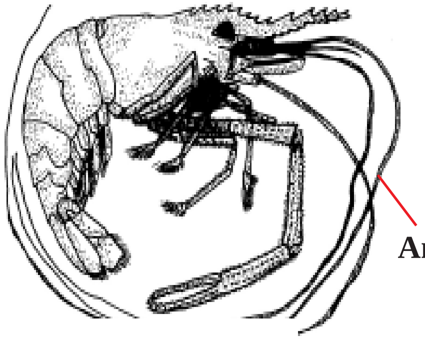


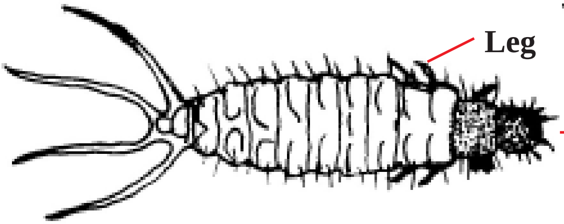
10. Body more or less elongated or worm-like with obvious segmentation and generally > 30 similar segments; may have anterior and posterior suckers; if suckers are lacking then the sements bear paired, fleshy, lateral outgrowths or bundles of fine bristles (chaetae)……….**True Worms and Leeches (Phylum: Annelida)**



Generally with jointed legs and a segmented body (which is often hardened) and usually divided into two or more discrete regions (e.g. head, thorax and abdomen); if legs are lacking then there are < 15 body segments and the head bears paried mandibles...........**Crustaceans, Arachinds and Insects (Phylum Arthropoda).**

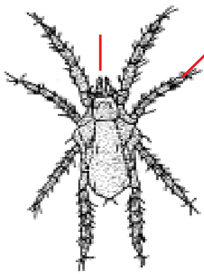






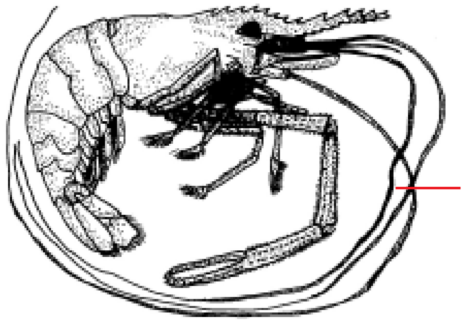
Key to Aquatic Arthropods

1. Four pairs of joined legs; antennae absent; body either globose or divided into two with indistinct segmentation (some minute forms [2 mm long] with globose bodies may have six legs only).................**Water Mites and Spiders; (Class: Arachnida)**

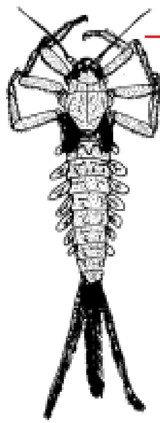


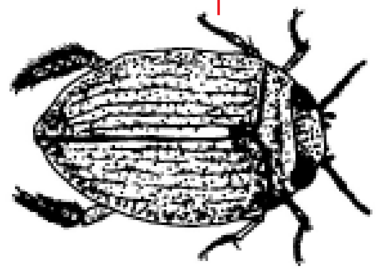
2. Body not as above; antennae present or inconspicuous.....................**3**

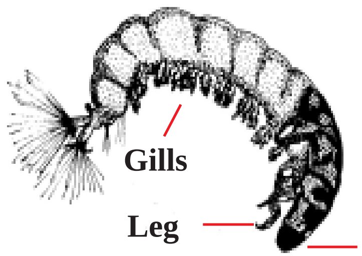
3. More than three pairs of jointed legs; two pairs of antennae..................................**Crustaceans (Subphylum: Crustacea)**



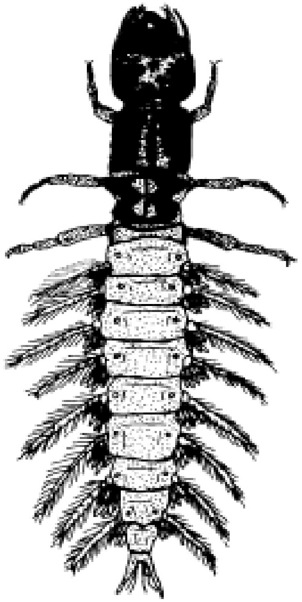
Either whith three pairs of jointed legs or legless; one pair of antennae..**Insects (Class: Insecta)**

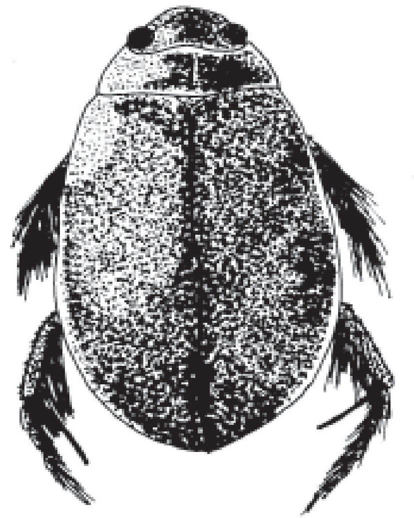


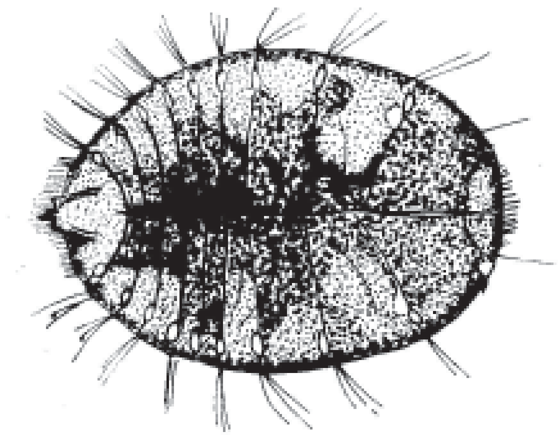




Key to Aquatic Insect Orders



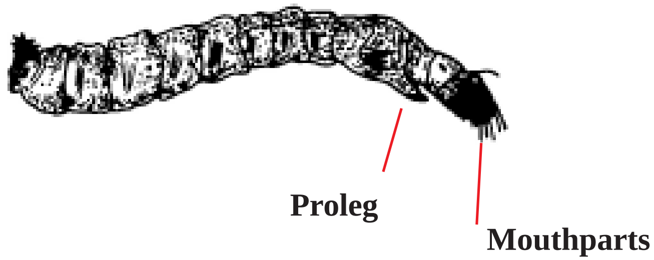




Key to Aquatic Insect Orders

1. Thorax bears three pairs of segmented legs; head fully formed……....**2**

Thorax lacks segmented legs (but unsegmented prolegs may be present); head may be fully formed but is often inconspicuous and incompletely formed or retracted into the thorax……… **Larval Flies (Order: Diptera)**
Page-43

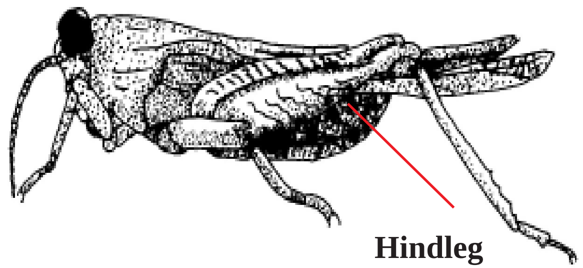


2. Minute insects (generally < 5 mm long), with a midventral forked appendage on the abdomen ……........**Springtails (Order:Collembola)**

Body generally considerably longer than 5 mm; ventral abdominal appendages absent but ventral gills may be present……......................**3**

3. Hind legs long with expanded femora and modified for jumping ………. ....**Crickets and Grasshoppers (Order: Orthopetra)**

Page-57

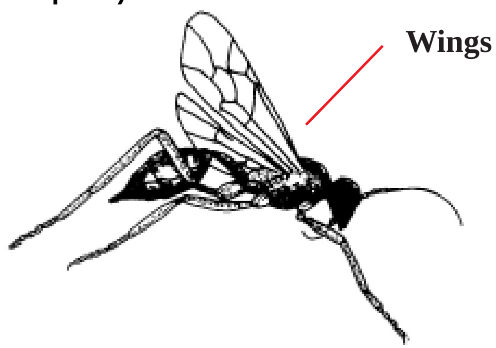


Hind legs not modified for jumping; femora not expanded…..........……**4**

4. Wings or wing pads present…..……..**5**

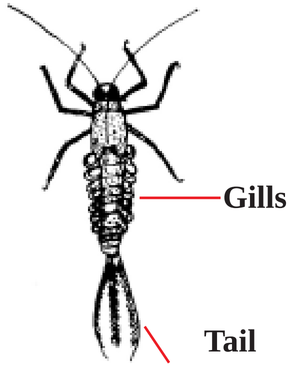
External wings or wing pads completely absent……..........................**12**

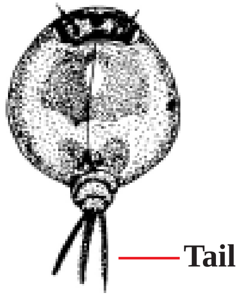
5. Two pairs of short membranous wings with few veins………..**Wasps (Order: Hymenoptera)**



Wings or wing pads present but, if wings are present, the first pair are leathery or hardened and overlie the second pair……………………........**6**

6. Abdomen ends in three long 'tails'………………**Mayflies (Order: Ephemeroptera)**
Page-21

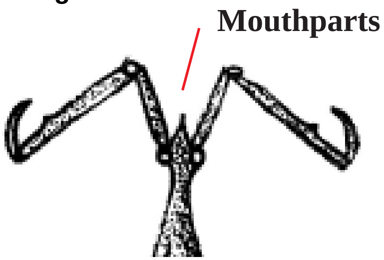


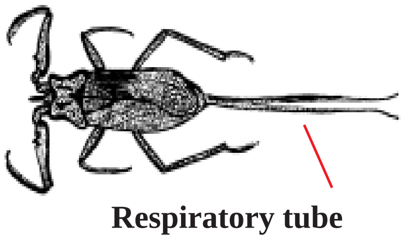


Abdomen ends in one, two or no such 'tails'……………………..............7

7. Mouth in the form of an elongate beak, or tube or cone-like structure……...................................…….**Aquatic Bugs (Order: Hemiptera)**

Page-30





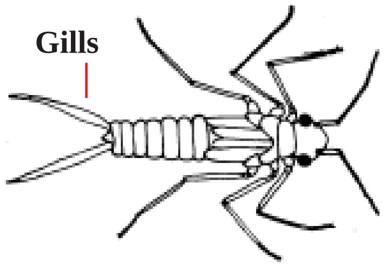
Mouth not as above………………..…….**8**

8. Labium (lower 'lip') is modified into a large mask like structure which covers the other mouthparts when viewed from below….Damselflies and Dragonflies (Order: Odonata)……...…**9**

Labium not modified into a large mask-like structure……………..........….**10**

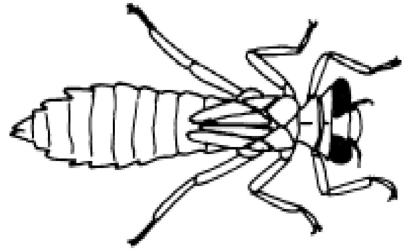
9. Abdomen ending in leaf-like gills…………..**Damselflies (Suborder: Zygoptera)**

Page-26



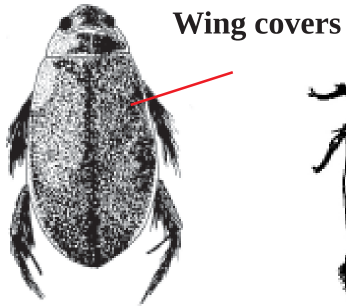
Abdomen without caudal lamellae……………………**Dragonflies (Suborder: Anisoptera)**

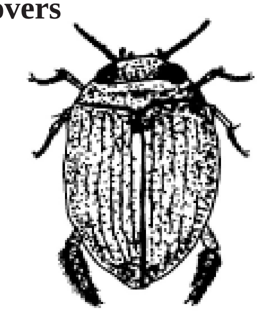
Page-26



10. Forewings modified into hard protective coverings, concealing most of the dorsal surface…………….....................**Beetles (Order: Coleoptera)**

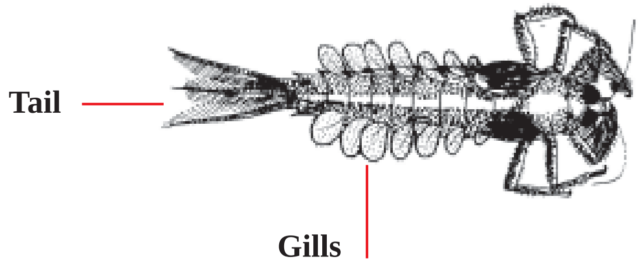
Page-48



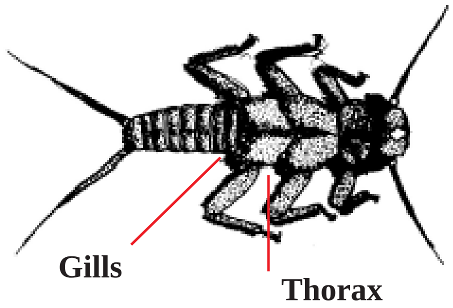


Forewings not thus modified; abdomen ends in a pair of segmented terminal filaments or 'tails'………………..**11**

11. Most abdominal segments possess lateral gills………………**Mayflies (Order: Ephemeroptera) Page-21**



Lateral abdominal gills are absent but thoracic gills in the form of tracheal tufts present…………….........................**Stoneflies (Order: Plecoptera) Page-56**

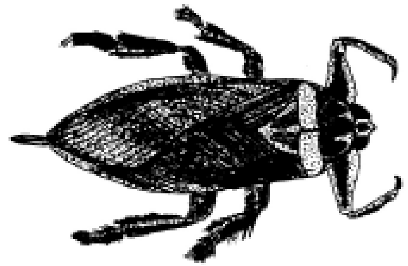


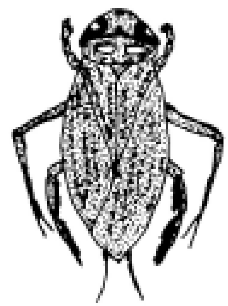
12. Mouth parts adapted for sucking…………………….........................…**13**

Mouth parts adapted for chewing with mandibles ……….....................**14**

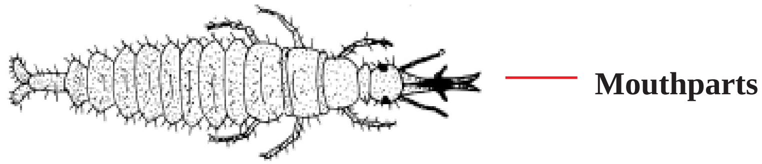
13. Mouth parts in the form of a tube, a beak or cone-like structure ……………..**Aquatic Bugs (Order: Hemiptera)**

Page-30

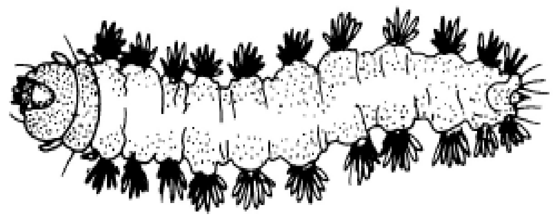




Mouthparts are a pair of long, needle-like stylets; associated with freshwater sponges…………**Spongilla Flies (Order: Neuroptera; Family: Sisyridae)**
Page-58

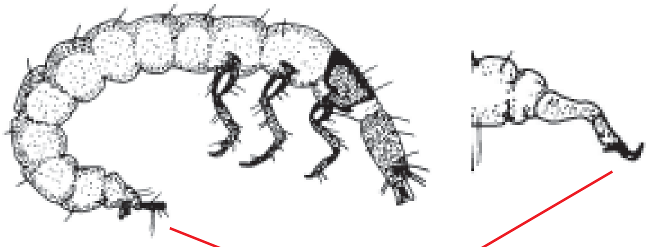


14. Abdomen on the underside of segments 3-6bears pairs of short, fleshy prolegs, each with a ring of tiny hooks………………**Aquatic Moths (Order: Lepidoptera; Family: Pyralidae).**
Page-60



Abdomen lacks ventral prolegs (but may have lateral projections, or prolegs at the end of the abdomen)……………..................……………**15**

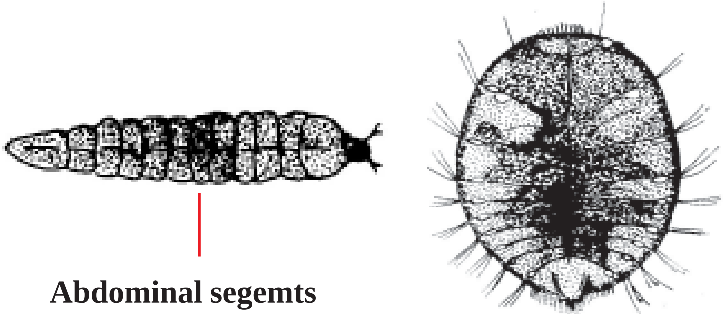
15. Abdomen ends in a pair of short or long, fleshy prolegs (sometimes fused together) that end in a single hook……………**Caddiesflies (Order: Trichoptera) Page-36**



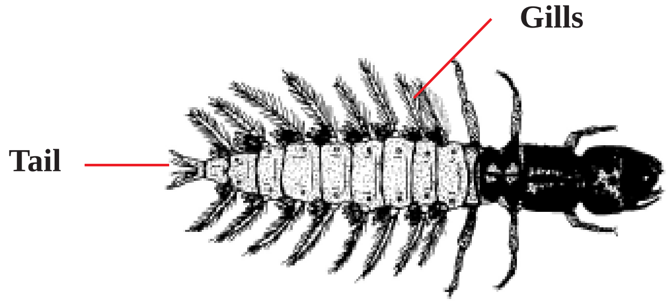
Abdomen ends variously, but never in a pair of fleshy prolegs each ending in a single hook…………...…**16**

16. Abdomen is fleshy with well-developed lateral filaments………………...**17**

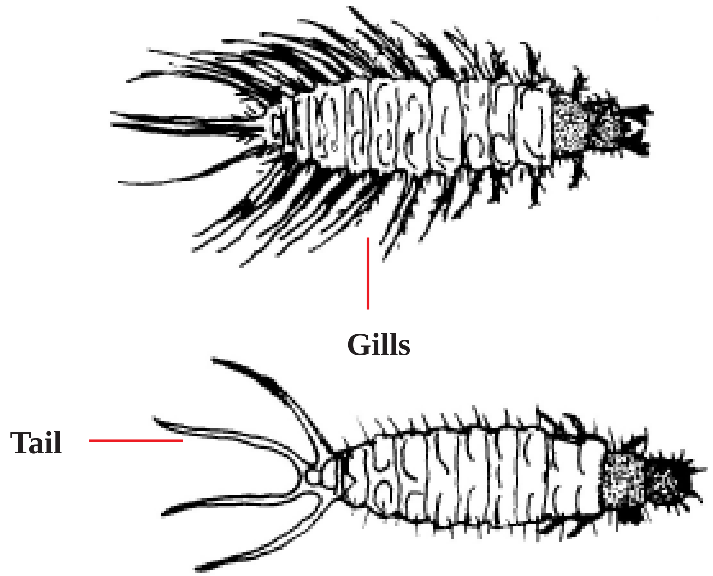
Abdomen hardened and lacks well developed lateral filaments……………...**Larval Beetles (Order: Coleoptera) Page-48**



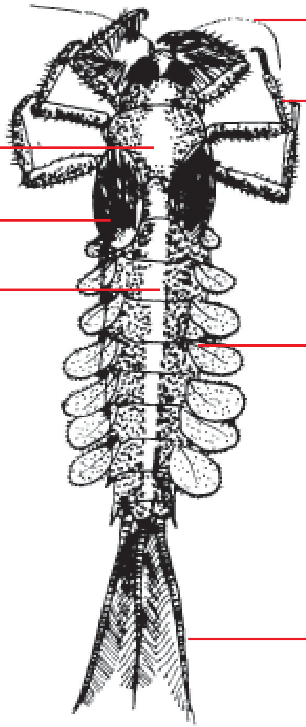
17. Abdomen ends in a pair of prolegs, each with a pair of hooks… .**Alderflies (Order: Megaloptera) Page-59**



Abdomen ends variously but never in a pair of prolegs each having a pair of hooks (although there may be two pairs of prolegs which each have hooks)…………….........**Larval Beetles (Order: Coleoptera)Page-48**

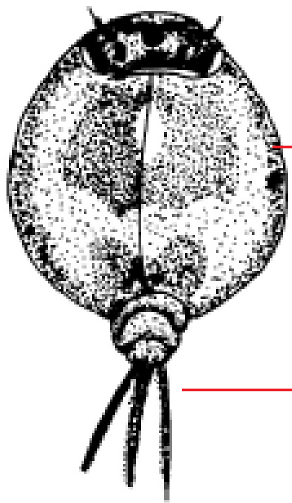


Key to Mayfly (Ephemeroptera)



Body parts of Mayfly Larvae

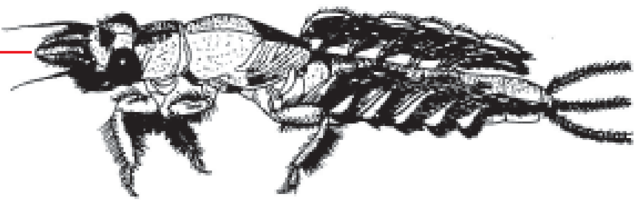
1.Body beetle like (smooth and hemispherical); a thoracic shield covers all of the gills (six pairs) and the abdomen …………..........……..**Prosopistomatidae**



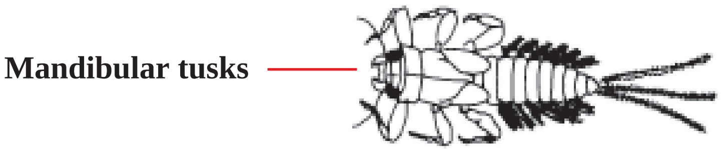
Body form not as above; abdominal gills partially or completely exposed; mandibles with tusk-like projections…………...….**2**

Mandibles without tusks like projections: gill form otherwise……......…………..**3**

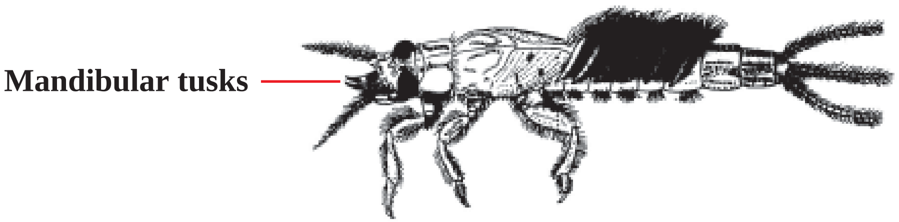
2a. Mandibular tusks long and sickle-shaped, with long setae; maxillary palp more than twice as long as the apical part of the maxilla ....…..**Polymitarcyidae**



2b. Mandibular tusks otherwise, bearing short bristles; maxillary palp as long or slightly longer than the apical part of the maxilla ……………........**Potamanthidae**



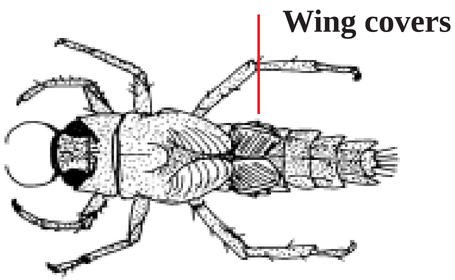
2c. Tusks curved outwards, inner edges convex……………............**Ephemeridae**



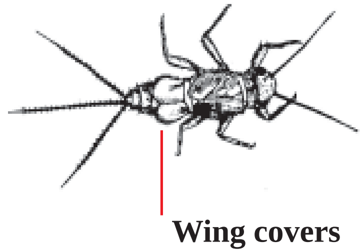
3.Second abdominal segment with large and plate-like (=operculate) gills, touching or overlapping along the dorsal midline and covering all or some of the gills arising posteriorly, gills III-VI with fringed margins…......…………………**4**

Second abdominal gills not as above…………………….................................……**5**

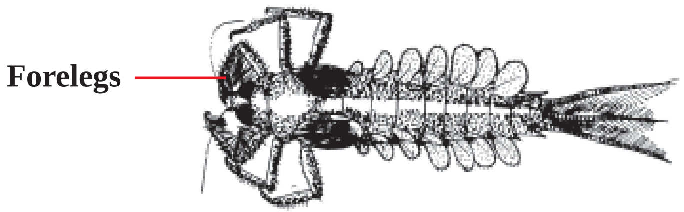
4a. Terminal gill filament densely clothed with setae on both margins, cerci (= lateral filaments) with setae on the inner margins only; mature larvae has small hindwing pads beneath the forewing pads on the metathorax ………………...………**Neoephemeridae**



4b. Gills on abdominal segment II not fused but overlapping along the midline and covering all of the succeeding (III-VI) gills; cerci and terminal filament with short and sparse setae on the inner and outer margins; hindwing pads absent ………………..…**Caenidae**

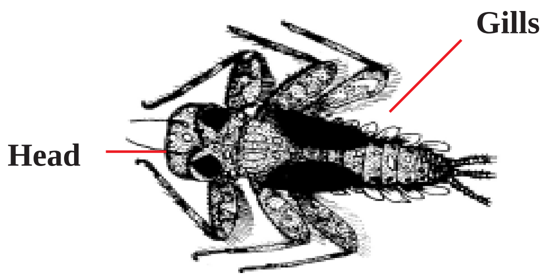


5.Inner margins of femora and tibiae of forelegs with conspicuous rows of long setae …………...……**Isonychidae**



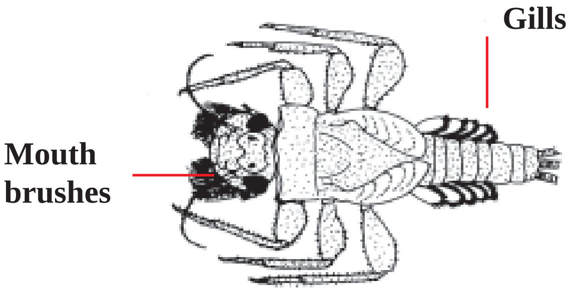
Inner margins of femora and tibiae of forelegs without rows of long setae …...**6**

6.Head is flat and plate-like with dorsal eyes; body dorsoventrally compressed (flattened); gills plate-like and never doubled but may have a dorsal tuft of tracheae (= gill tufts) at the base of the lamellae……………….**Heptageniidae**



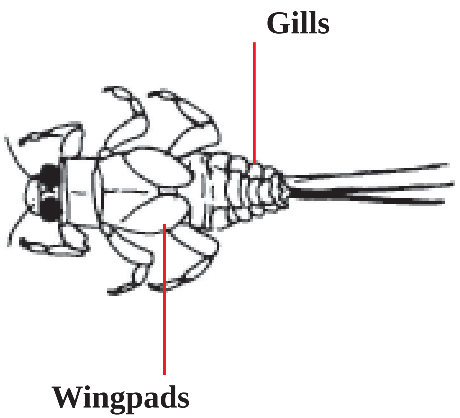
Head not plate-like; gill form various shapes but if plate-like then never with a dorsal tracheal tuft at the base of he lamellae…………...........………………….**7**

7.Labium fused into a single semicircular structure, palps with long setae; gills on abdominal segments II-V or II-VII, gill II may overlay and partially conceal the rest of the series; a terminal filament is present; …………….**Tricorythidae**



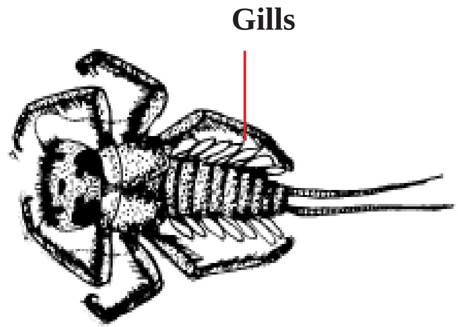
Mouthparts and gills not as above; terminal filament reduced or lacking……...**8**

8. Gills lamellate on abdominal segments III-VII or IV-VII or more rarely, II-V, II-VI or I-V (gill on segment I rudimentary if present); gills usually consisting of a dorsal lamellae and a ventral pair of tufts or lamellules; first lamellate gill may conceal some or all of the posterior gills; forewing pads fused to the thoracic notum for more than half their length……………..............……**Ephemerellidae**

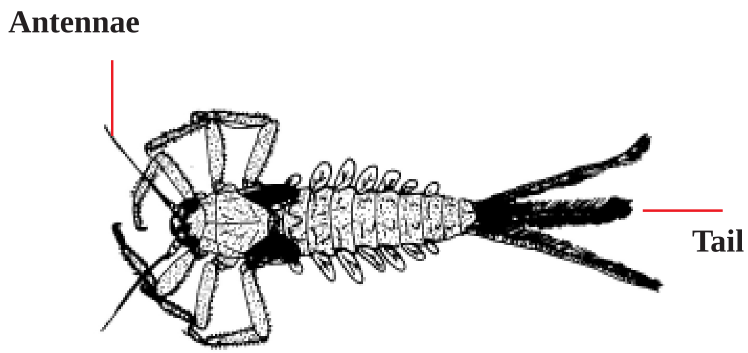


Gills lamellate or plate-like, rarely doubled, all members of the series rather similar in general form; terminal filament sometimes reduced or lacking …….**9**

9a. Gills are similar, long, slender and bifurcate (forked) in form or the first pair is rudimentary (thread-like) and others plate-like (usually with apical prolongations or fringes) and doubled; terminal filament is well-developed and similar to cerci (= lateral filaments)…………………......…………**Leptophlebiidae**



9b. Antennae long and twice the width of the head; median terminal filament often much reduced and always shorter than the cerci (lateral filaments); hind corners of the last few abdominal segments are not drawn out into spines;………………………...…..**Baetidae**

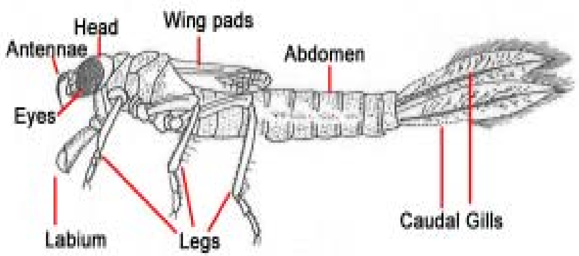


Space for Field Notes on Mayflies (Ephemeroptera)

Key to Dragonflies and Damselflies (Odonata)

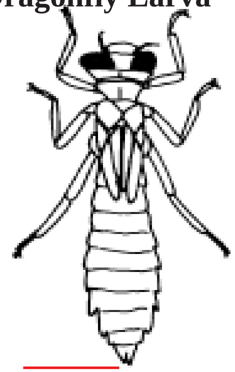
1.Abdomen short and stout, caudal gills absent and terminating in five short spine-like processes………....................................**Dragonflies (Anisoptera)-I**

2.Abdomen long and slender and terminating in three (rarely two) leaf or sac like caudal gills……………..................................**Damselflies(Zygoptera)-II**

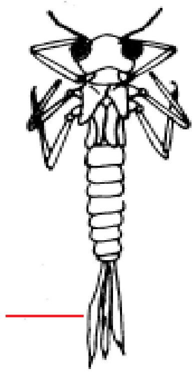


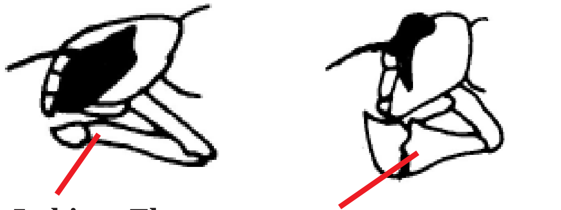
Body Parts of Damselfly Larva

Dragonfly Larva



Damselfly Larva

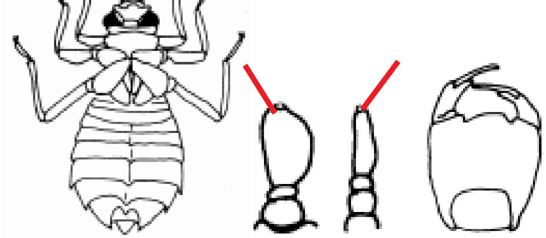




Labium Flat   Labium Scoop Shaped

1a. Antennae four-segmented, 3rd segment enlarged and fourth vestigial…..…..**Clubtails (Gomphidae)**

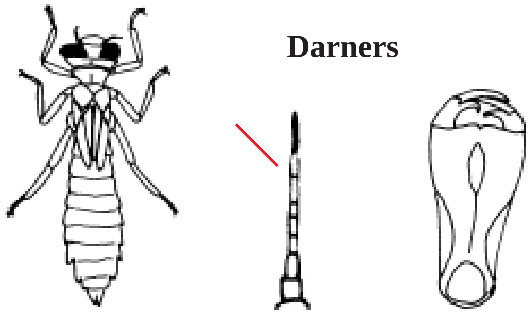
Clubtails



Larva   Antenna   Labium

1b. Antennae six or seven segmented and filamentous…...**Darners (Aeshnidae)**

Darners



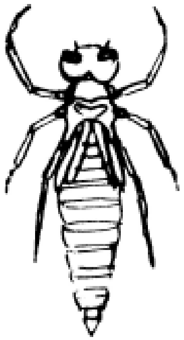
Larva   Antenna   Labium

<u>**I. Dragonflies (Anisoptera)**</u>

Prementum and palpal lobes of labium flat………………..................................**1**

Prementum and palpal lobes of labium scoop or spoon shaped...**2**

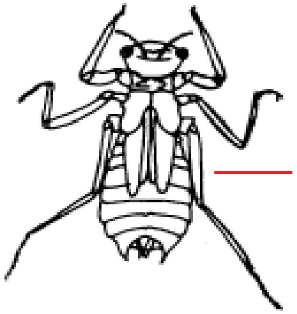
2a. Body elongate and covered with bristles or tufts of setae, labium with large irregular teeth…..................................**Mountain Hawks (Cordulegasterdiae)**



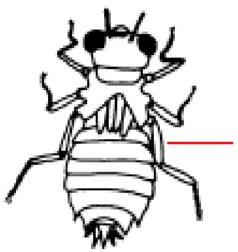
Mountain Hawks

2b. Hind femur does not extend beyond abdominal segment VIII, labium with small teeth…..**Torrent Hawks and Skimmers (Corduliidae and Libellulidae)**

Torrent Hawks



Skimmers



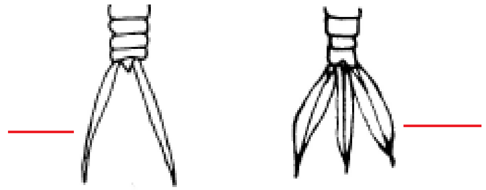
Labium

II. Damselflies (Zygoptera)

Two forceps like caudal gills………..**1**

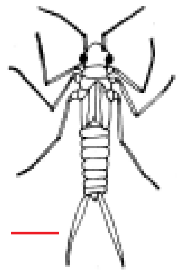
Three leaf, blade or sac like caudal gills..…...**2**

Caudal Gills of Damselfly Larva

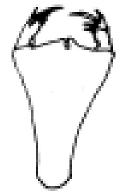


1a. Two forceps like caudal gills, which are triangular in cross section………...**Stream Jewels (Chlorocyphidae)**

Stream Jewels

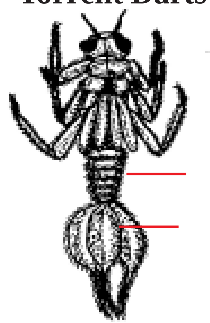


Labium

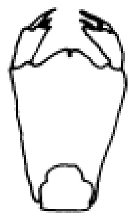


2a. Filamentous gills on the underside of abdominal segments II-VIII, caudal gills are sac like……………................................**Torrent Darts (Euphaeidae)**

Torrent Darts

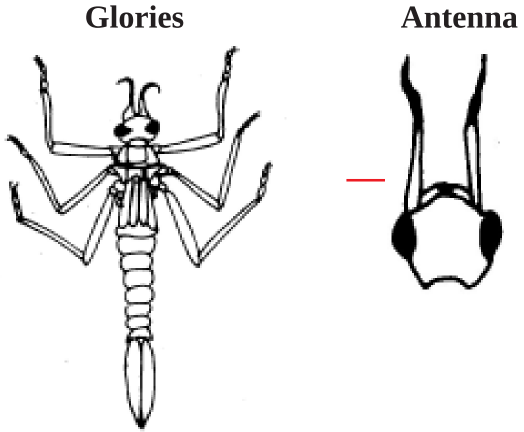


Labium



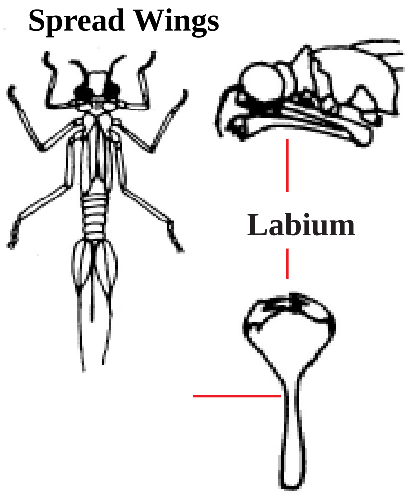
Without filamentous gills on abdominal segments II-VIII……….......................3

3a. First antennal segment longer than the combined length of other segments; body slender and long, caudal gills blade like with a distinct dorsal ridge………..**Glories(Calopterygidae)**



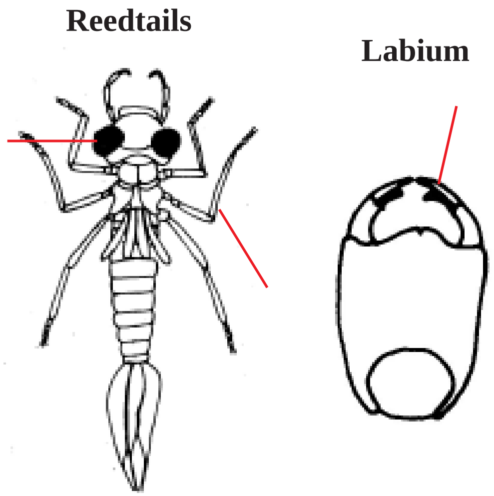
First antennal segment similar to other segments………….........................…..4

4a. Labium distinctly spoon shaped and strongly tapered posteriorly with large sharp teeth..**Spread Wings (Lestidae)**

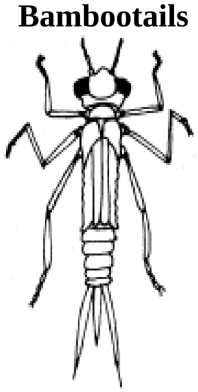


Labium quadrate or more or less triangular in shape, but not spoon shaped; with movable hooks or spines at the tip……..….5

5a. Pale and lanky larvae with large bulbous eyes, labium with single spine and one movable hook...**Reedtails (Platystictidae)**



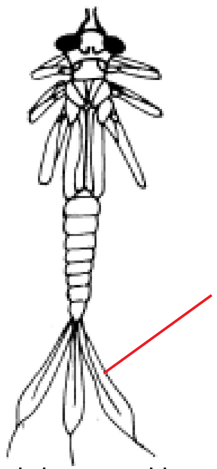
5b. Gills clearly divided into a thickened dark proximal part and a thin, paler distal part......…..…**Bambootails (Protoneuridae)**



Gills not divided into proximal and distal parts…...…**6**

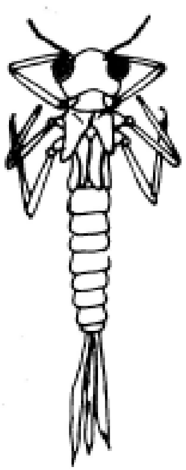
6a. Caudal gills long, about same length as the abdomen, apices pointed or tapering, third segment of antenna longer than the second ....**Bush Darts** (**Platycnemididae)**

Bush Darts

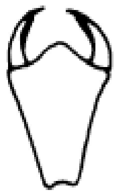


6b. Caudal gills shorter than the abdomen, with rounded apices third segment of antenna shorter than second.......................**Marsh Darts (Coenagrionidae)**

Marsh Darts

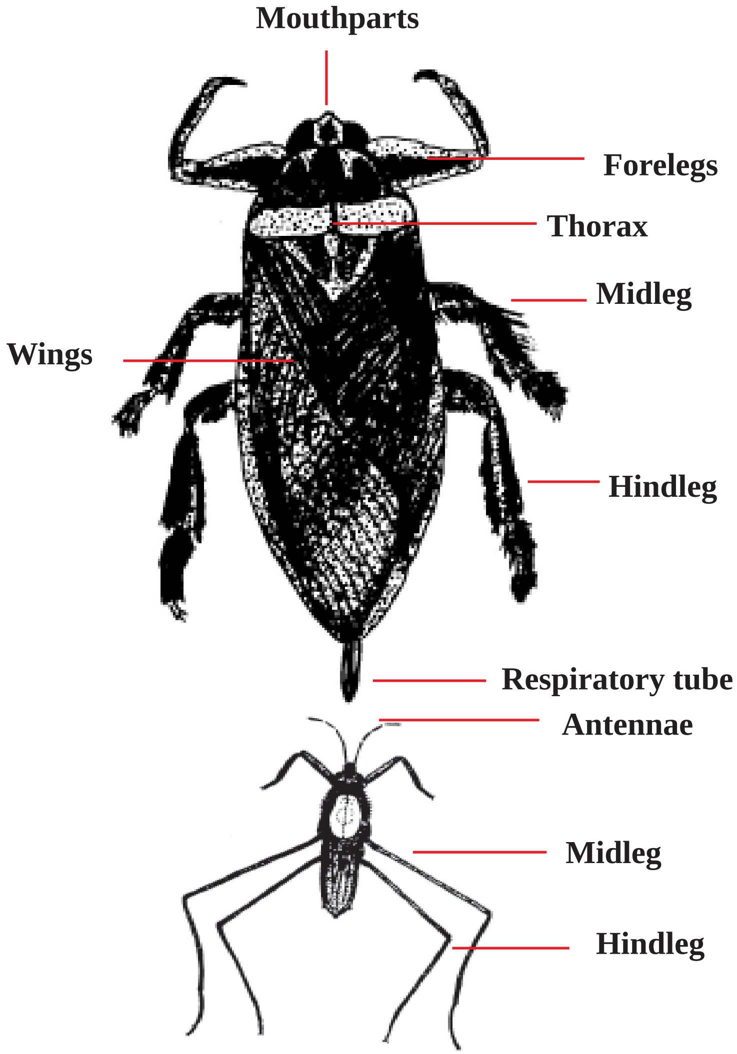


Head and Antenna



Labium

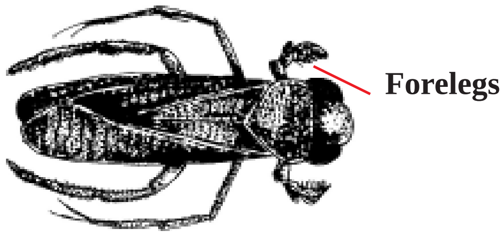
Key to Adult Aquatic Bugs (Hemiptera)



1.Antennae not visible from above; shorter than the head and inserted beneath the eyes ……………………**Suborder Nepomorpha**……………..........................**2**

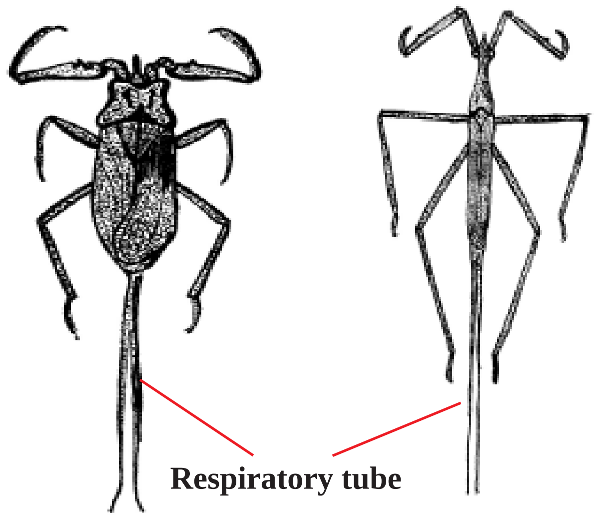
Antennae visible from above; longer than the head and inserted in front of the eyes ……………..……………**10**

2.Mouthparts blunt and triangular or beak-like; the tarsus of forelegs modified into a scoop-like structure …………..……**Corixidae**



Mouthparts elongate and cylindrical or cone-shaped, divided into segments and adapted for piercing; tarsi of fore legs not as above (often raptorial)……..**3**

3.A slender respiratory tube made up of two grooved filaments present at the apex of abdomen...………………**Nepidae**



Respiratory tube either absent or very short…………..….4

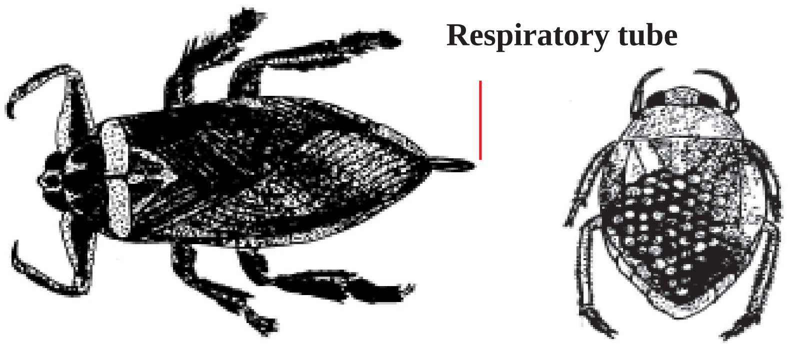
4.Swimming hairs present on the fringes of mid and hind legs; aquatic……….**5**

Swimming hairs absent on the fringes of mid and hind legs; riparian……..….**10**

5.Forelegs raptorial with broadened femora; body dorsoventrally flattened and oval insects..……………….….**6**

Fore legs and femora not flattened; Elongate or hemispherical and distinctly ovid insects ………………………...…….**8**

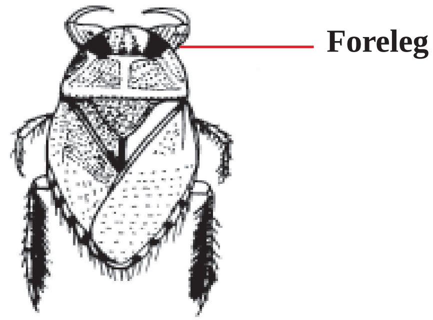
6.A pair of short, strap-like appendages at the tip of the abdomen; eyes protrude from margin of the head; mid- and hind legs somewhat flattened; anterior margin of the pronotum is not concave ……………….**Belostomatidae**



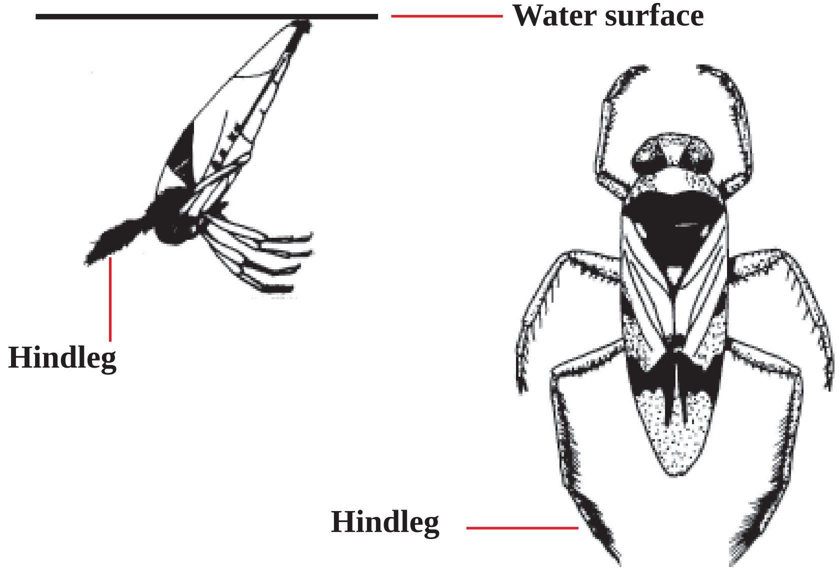
Strap like appendages absent at the tip of the abdomen; eyes do not protrude; mid- and hindlegs cylindrical; anterior margin of pronotum concave; ……………….**Naucoridae**…….**7**

7a. The tip of rostrum extends back to the base of the hindlegs; forefemora slightly broad …………...............................…………**Naucoridae (Aphelocheirinae)**

7b. Rostrum short and stout with the tip extending back to the base of the forelegs; fore femora very broad……………….**.Naucoridae (Cheirochelinae)**

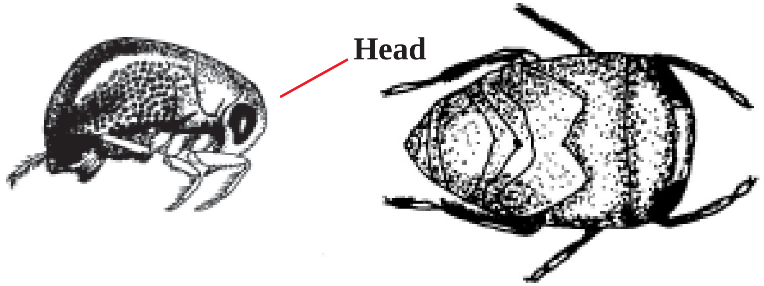


8. Hind legs long and oar-like and fringed with hairs; body elongate ……………………..……….**Notonectidae**



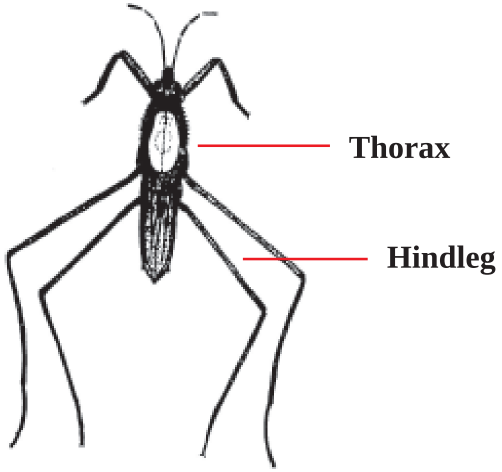
Mid- and hind legs of similar length; body hemispherical and ovoid (the head and thorax are fused) ……………..………………….9

9. Antennae with three segments; Body very small, laterally compressed with convex round face……...……**Pleidae**

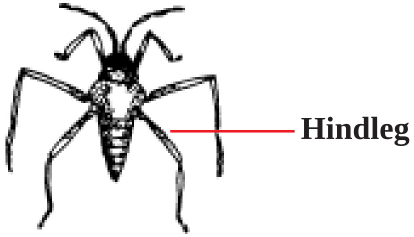


10. Body elongate or very slender; mid- and hind legs unusually long; …………..**suborder Gerromorpha**……..**11**

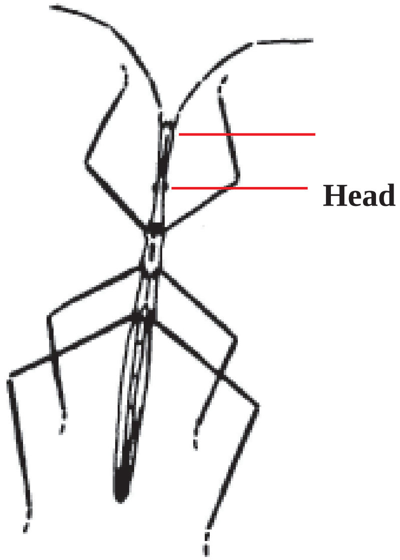
11a. Mesothorax longer than the other thoracic segments; Femora of hind legs longer than the abdomen………...……**Gerridae**



11b. Thoracic segments of approximately equal length; Femora of hind legs not longer than the abdomen ………...….**Veliidae**

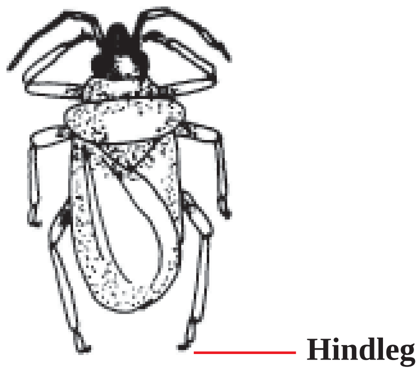


11c. Body delicate and stick like; head is as long as the thorax with eyes set halfway..…………**Hydrometridae**

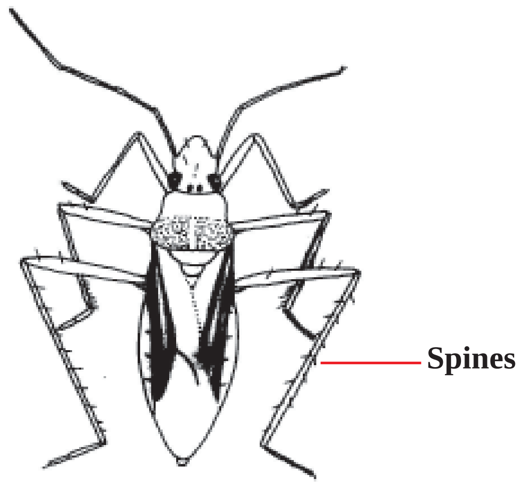


Without the above combination of characters………………….....................……**12**

12a. Tarsi with two segments; hind legs without spines; ventral surface of the head grooved with a pair of prominent vertical plates covering the base of the rostrum…..…………..**Hebridae**

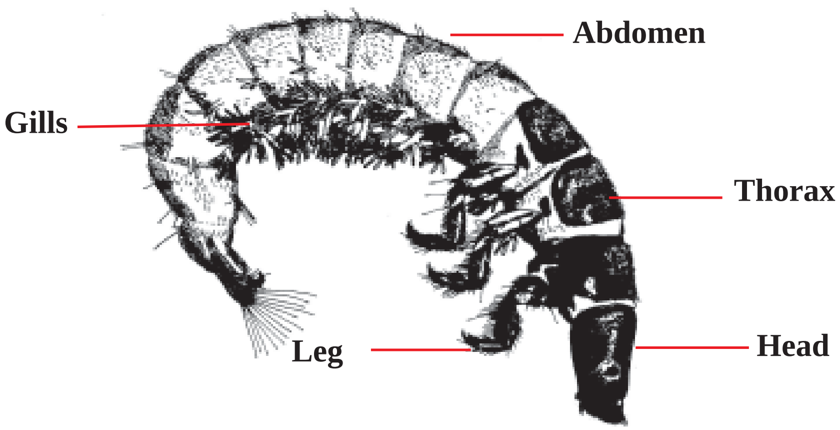


12b. Tarsi with three segments; hind legs armed with spines; ventral surface of head not as above;; ……......................................…………………..**Mesoveliidae**

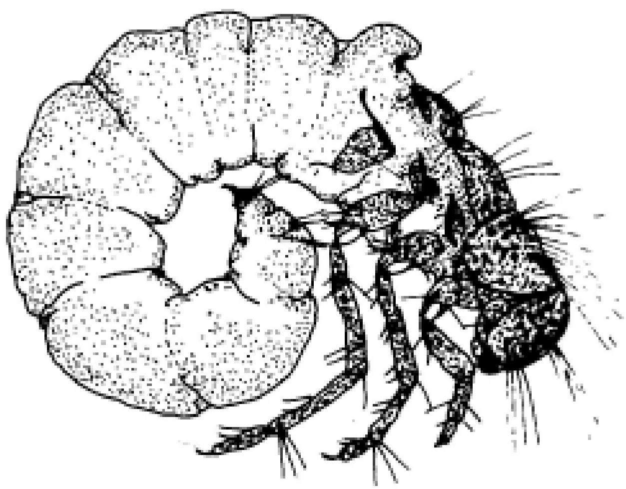


Space for Field Notes on Aquatic Bugs (Hemiptera)

Key to Larval Caddiesflies (Trichoptera)



1.Larval case is made up of sand grains resembling a snail shell; body strongly curved; anal claw comb-like ……………………….......................**Helicopsyche**



Larval case not spiral or larvae free-living; anal claw generally hook-like.……**2**

2.Dorsal surface of all three thoracic segments covered with sclerotized plates …………...……..**9**

Dorsal surface of thorax membranous or fleshy and never entirely sclerotized …………..…………**3**

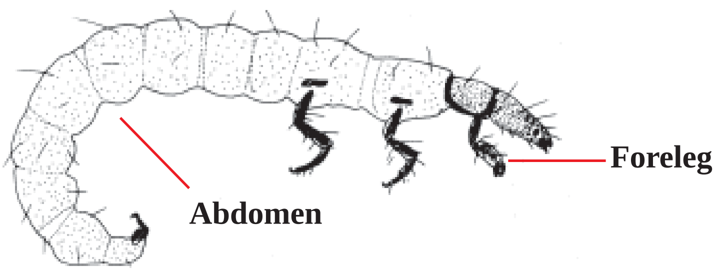
3.Second thoracic segment partly or largely covered by sclerotized plates (although these may be lightly pigmented); larvae construct portable cases of various materials………..…………**10**

Second thoracic segment without sclerotized plates but a few small sclerites and setae may be present; larvae without a portable case, but may construct a shelter or live within a net………...……………….**4**

4.Dorsal surface of abdominal segment IX with sclerotized plate; tracheal gills may be present on the sides of the abdomen.……………..................…………..**5**

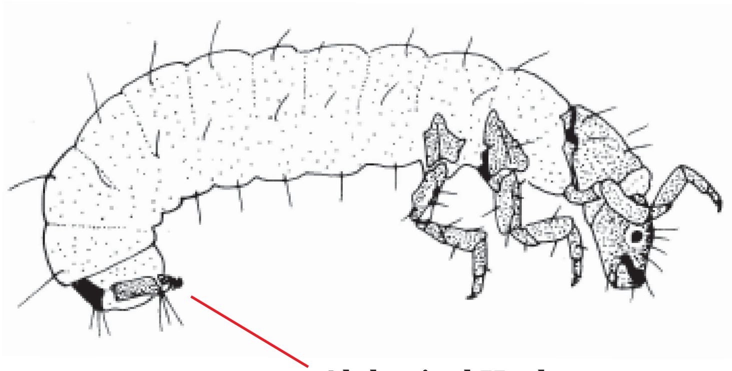
Dorsal surface of abdominal segment IX without sclerotized plate; tracheal gills absent on the sides of the abdomen.………...…..**7**

5.Forelegs with modified tibia and tarsus (chelate, or pincer-like with an attenuated tarsus); abdomen without gills …...........…………..**Hydrobiosidae**

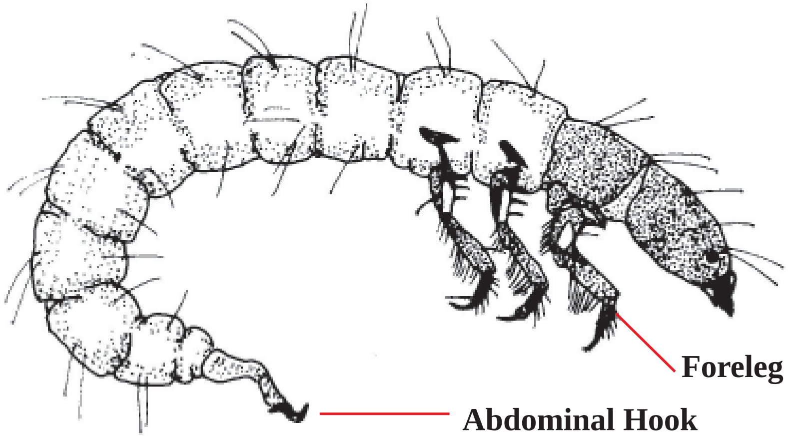


Forelegs not modified; limbs similar to each other in general form…………….....**6**

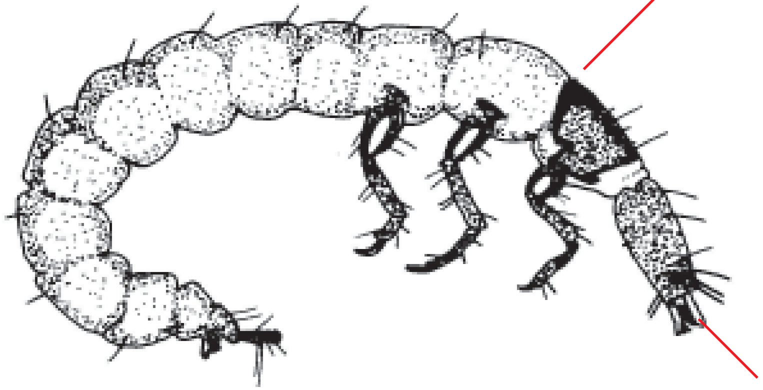
6a. Larvae live in a tortoise-like case made of small stones; anal prolegs short and broadly joined to abdominal segment IX; anal claws small with at least one dorsal accessory hook; forelegs not noticeably stouter than the other limbs; ………...……………**Glossosomatidae**



6b. Larvae free-living; anal prolegs free and rather long, with well-developed claws which may have accessory hooks on the inner margin; forelegs rather robust and raptorial; abdomen and thorax may bear lateral gills ……………..….**Rhyacophilidae**

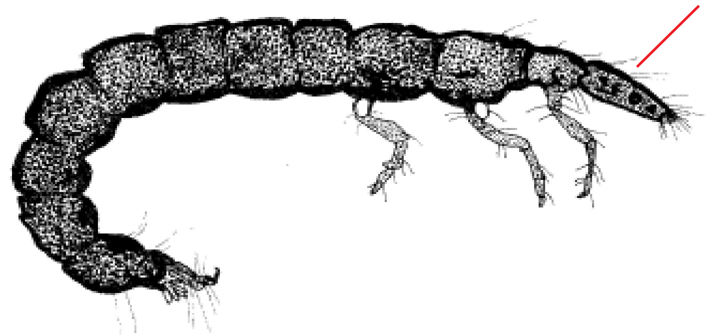


7. Larvae spine sac-like nets of fine silk; Labrum T-shaped and membranous, anterior margin densely fringed with fine setae; sclerotized parts usually yellow or orange and the posterior margin of the prothorax is rimmed with black ………...………**Philopotamidae**



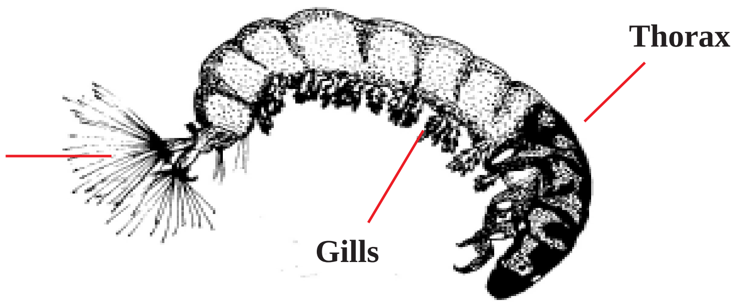
Labrum sclerotized, not T-shaped………………........................……………….**8**

8. Head at least twice as long as wide; larvae large and usually dark in colour; larvae spins an irregular net among stones and debris on the stream bed…………...….**Stenopsychidae**

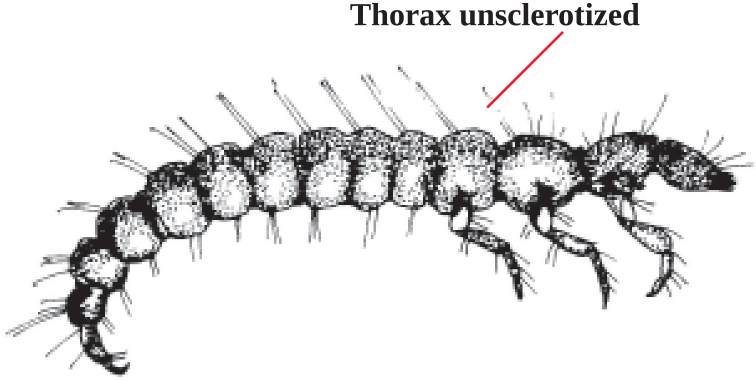


Head never twice as long as wide; larva usually small and pale; larvae spin fine-meshed nets or live in fixed tubes……..……**9**

9a. Larvae lives within a silken net and fixed retreat; abdomen with conspicuous ventral and lateral gill tufts; anal prolegs with a distal brush of long setae; posterior margins of thoracic shield lobed ……………...……**Hydropsychidae**

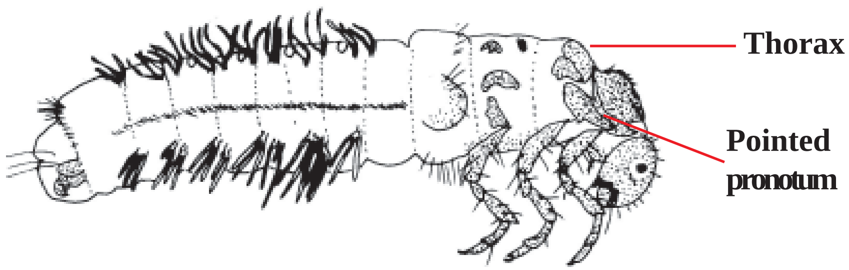


9b. Larvae spin nets or build tubes on hard surfaces; abdomen more- or less cylindrical and lacks gill tufts and lateral fringe of setae; last thoracic segment unsclerotized; labium short and not extend beyond the maxillary palps; margins of the labrum without dense fringe of setae; fore-trochantin relatively long; ………..….**Polycentropodidae**



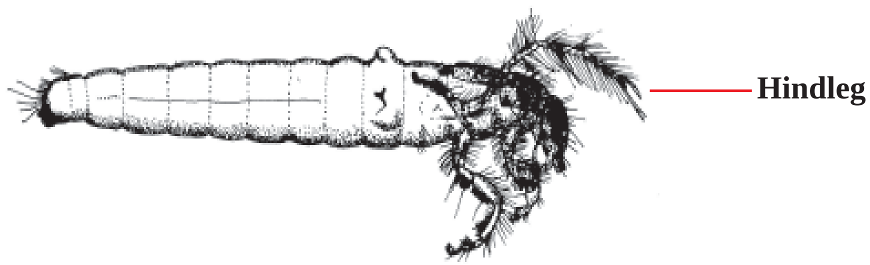
Ventral or lateral gills absent; anal prolegs lack a distal brush; posterior margins of thoracic nota straight…..…………**10**

10. Larval case of rock fragments with lateral ballast stones. Pronotum is thickened and the anterior margins are pointed and directed forward; mesonotum with four sclerites in addition to lateral projections that point forward; head can be retracted beneath the pronotum; ……………………..…………………**Goeridae**



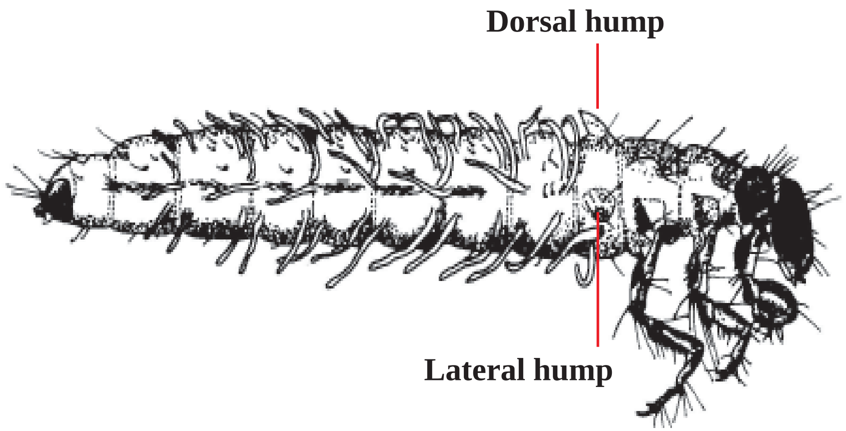
Pronotum and mesonotum not as above; head not retractable……………….**11**

11. Antennae prominent; sclerotized plates on the mesonotum usually lightly-pigmented and sometimes have a pair of dark curved lines on the posterior half; hind legs longer than other limbs with the femur and tibia (and, in some cases the tarsi) subdivided into two 'pseudosegments'.................**Leptoceridae**



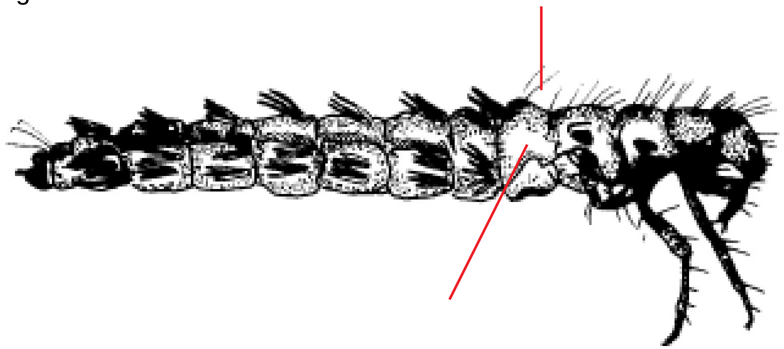
Abdominal segment I with membranous dorsum and lacks a shield-like sclerite, but setae or a dorsal hump or a small sclerite may be present; no sclerites on the meso- and metasterna and underside of abdominal segment I ……...….**12**

12. Larvae makes cases of plant material; large larvae with conspicuous head capsule; a membranous, finger-like projection (the prosternal horn) is present on the underside of the prothorax (prosternal horn); abdominal segment I with dorsal and lateral humps ………………….............................….….**Phryganeidae**



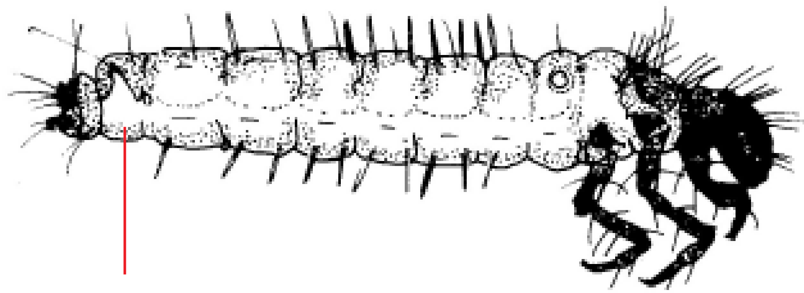
Thorax not as above…………..……..**13**

13. Larvae makes cases decaying leaves and twigs; abdominal segment I with dorsal and lateral humps; anterior corners of pronotum project forward; Labrum with a transverse row of 15-20 stout setae; mesonotum with a pair of anteriolateral sclerites and a larger central plate; metanotum almost entirely lacking sclerotisation…………..………**Calamoceratidae**



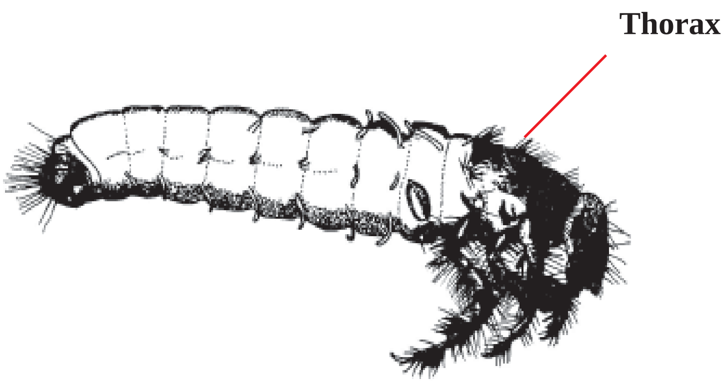
Labrum not like above; without the above combination of characters…..……**14**

14a. Larval case square in cross-section and made of panels cut leaves; antennae situated close to the anterior margin of the eye; abdomen with out dorsal hump on segment I; prosternal horn present; abdominal segment VIII with a fleshy lateral lobe on either side……………………..**Lepidostomatidae**



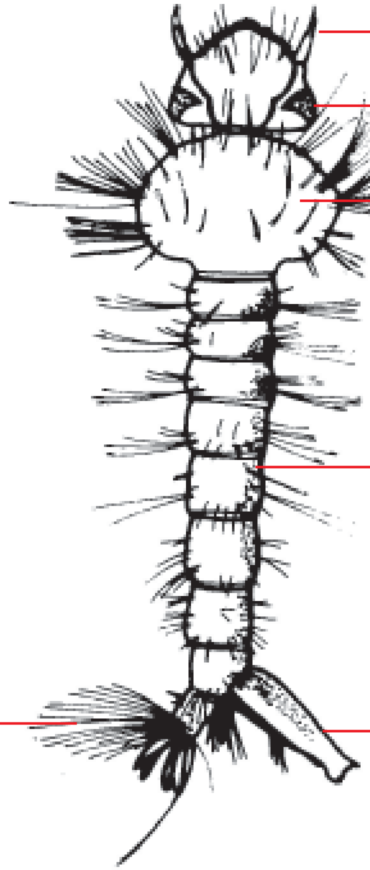
Lateral fleshy lobe

14b. Larval cases of rock fragments or detritus, often resembles pipe; anterior margin of the metanotum with a pair of sclerites; mandibles almost always toothed; gills consist of single or multiple filaments …………….**Limnephilidae**



Space for Field Notes on Caddiesflies (Trichoptera)

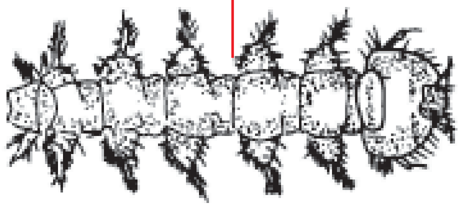
Key to Larval Flies (Diptera)



1.Larvae with a sclerotized head capsule; mandibles move laterally ……..**Suborder: Nematocera**…….**2**

Larvae without capsule or it is partially formed; mandibles move vertically and they are hook-like; prolegs sometimes (but not always) absent and body may be pale and maggot-like ……………..**Suborder: Brachycera**……..............….**6**

2. Body segments appears to be deeply constricted with seven segments; conspicuous ventral sucker present on first six 'segments**'**…..**Blephariceridae**



Abdomen without ventral suckers; prolegs present or absent...........................**3**

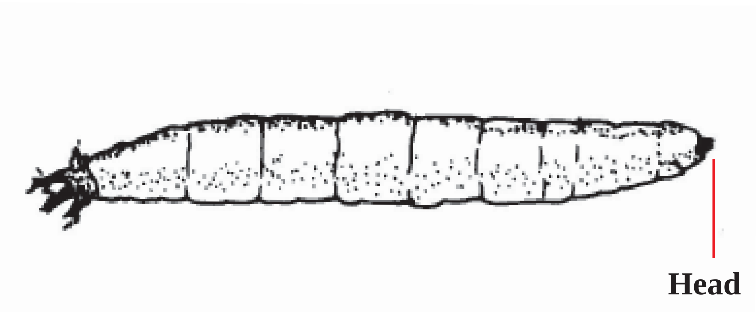
3. Prolegs absent..**4**

Prolegs present...**5**

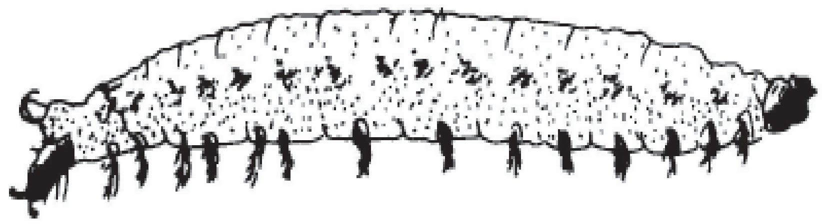
4a. Body segments secondarily segmented; head capsule strengthened only by sclerotized rods..................………...…..**Ceratopogonidae**

Head capsule well sclerotized or, if strengthened only with sclerotized rods, then body segments not secondarily segmented

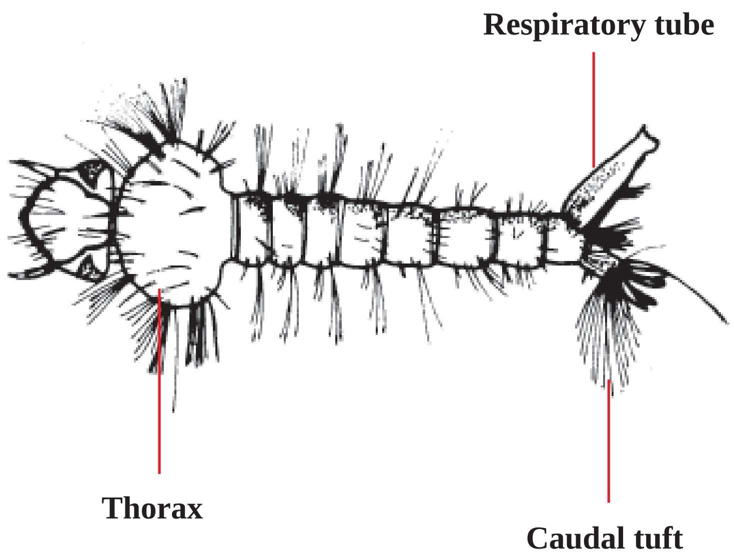
4b. Head capsule with incomplete posterior margins and retracted into body cavity.........................…..………**Tipulidae**



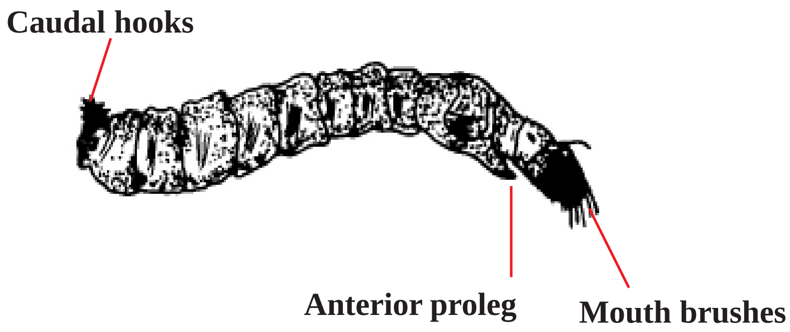
4c. Ventral suckers may be present; thoracic and abdominal segments divided up by one or more annuli; dorsal sclerites may be present.. ……. **Psychodidae**



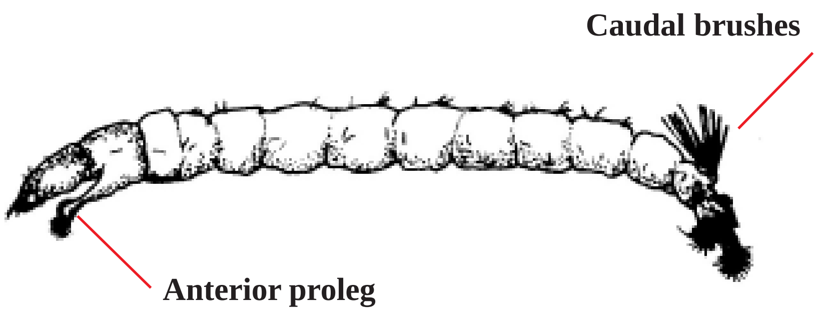
4d. Thorax disc like and wider than abdomen. Thoracic and abodminal segments with tufts of setae. Prominent mouth brushes present..........................**Culicidae**



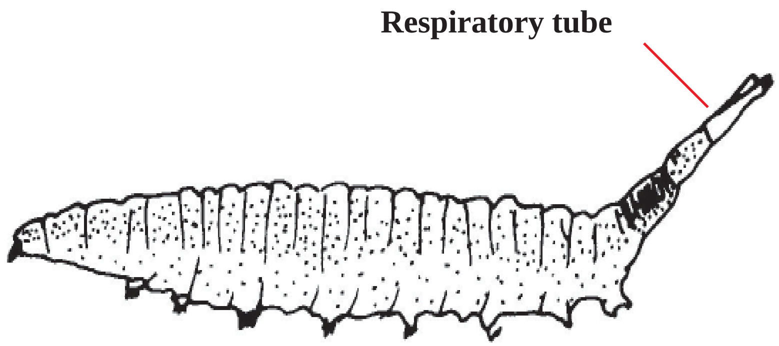
5a.A single proleg on the prothorax, and no posterior proleg(s); body club-shaped, posterior end swollen with a ring of tiny hooks at the tip….**Simuliidae**



5b. Posterior and anterior prolegs paired (although the anterior pair may be fused partially); widespread and abundant…………….............…**Chironomidae**

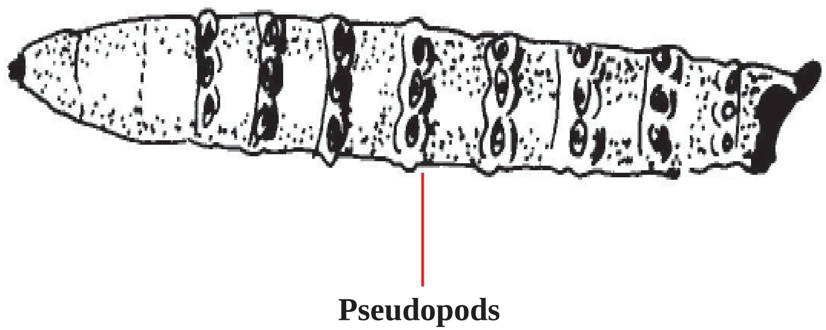


6.Body ends in a short respiratory tube that is divided at the apex..**Ephydridae**



Respiratory tube lacking………..………….**7**

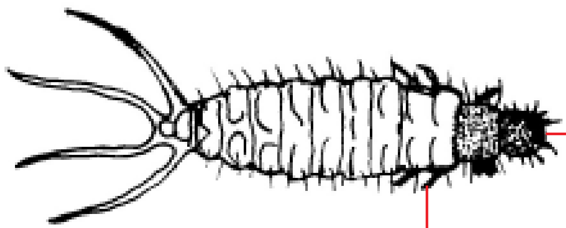
7. Abdomen without distinct prolegs but with a girdle of at least six pseudopods around each segment…...……**Tabanidae**



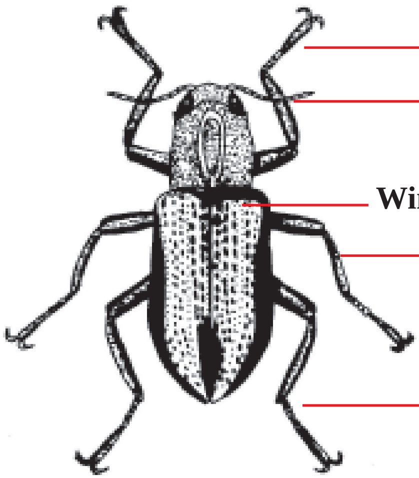
Space for Field Notes on Flies (Diptera)

Key to Aquatic Beetles (Coleoptera): Larvae and Adult

Larvae



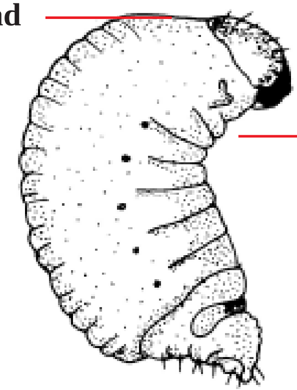
Adult



1.Membranous wings covered by hardened wing covers (elytra) which overlay the abdomen ……..……. **Coleoptera- Adult** **10**

Wings and elytra absent……………........................……**Coleoptera- Larvae**……**2**

2.Associated with aquatic macrophytes; legs absent or minute; thorax and abdomen short………………………..….. **Curculionidae**

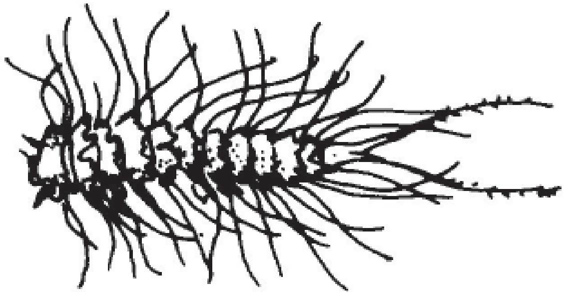


Not confined to aquatic macrophytes; Legs present and well defined........…..**3**

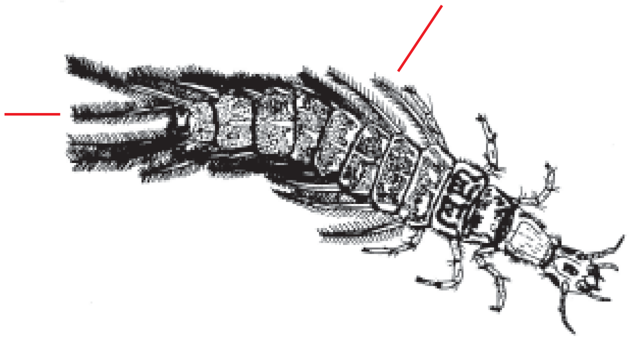
3. Legs with a single tarsal claw…..……………..**4**

Legs with two tarsal claws………...………………**5**

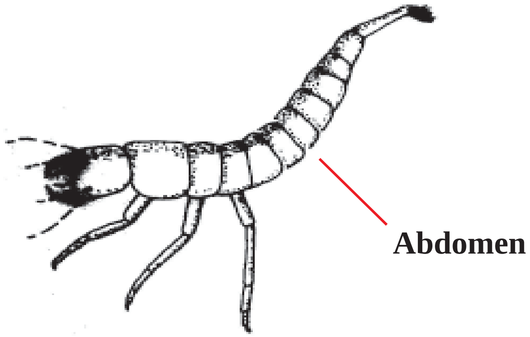
4. Body elongate and tapered posteriorly; legs with five segments (excluding claw) ....…………………**Haliplidae**



5a. Lateral gills present on abdominal segments I-IX; two pairs of stout hooks at the tip abdominal segment X …………………............................……**Gyrinidae**

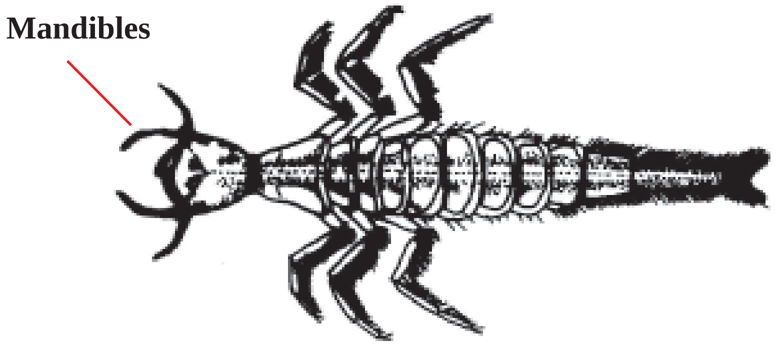


5b. Lateral gills are absent; abdomen eight segmented without terminal hooks; Abdominal segment VIII with a pair of large terminal spiracles; Cerci on the tip of the abdomen are slender and usually much longer than abdominal segment-I...………**Dytiscidae** (in part)



Cerci either short and stout or absent……………..………..**6**

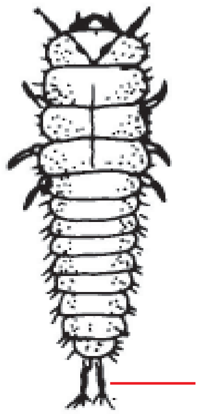
6a. Legs short and slender, and may be adapted for swimming; mandibles sickle shaped…………..…………..**Dytiscidae** (in part)



6b. Legs short and stout and adapted for digging; mandibles not sickle-shaped……..……………….**Noteridae**

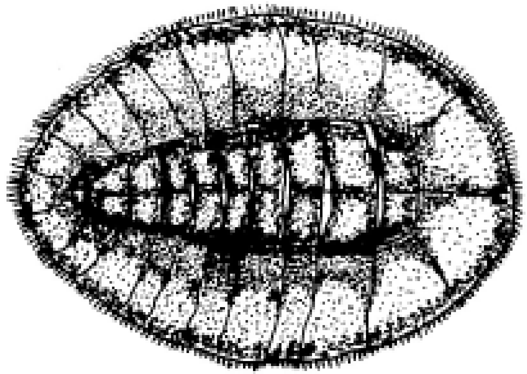
Without the above combination of characteristics ………….........................…….**7**

7. Abdominal segment X with a minute pair of recurved venteral hooks; segment IX has a pair of two segmented articulated cerci……….**Hydraenidae**

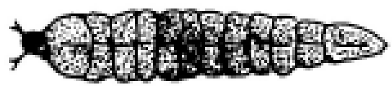


8.Head and legs visible when viewed from above; body cylindrical …………..**9**

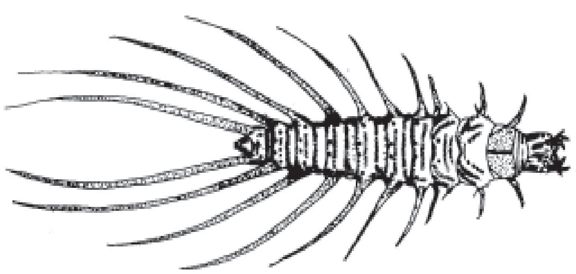
Head and legs not visible when viewed from above; body greatly flattened like a disc…………...………**Psephenidae**



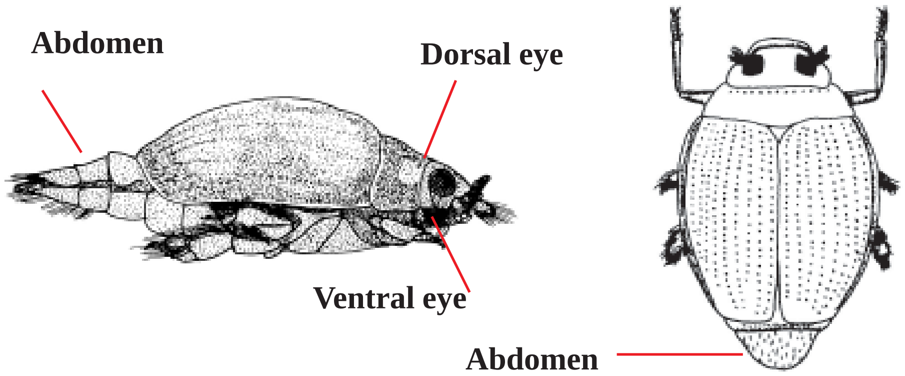
9a.Head capsule with groups of five lateral ocelli; abdominal tip distinctly pointed, bifid or notched with – often with– lateral ridges or longitudinal crests ………………...…………….**Elmidae**



9b. Head capsule with groups of six ocelli (five lateral and one ventral) or without ocelli; abdominal tip rounded; antennae arise behind the insertion point of the mandibles………...…….**Hydrophilidae**

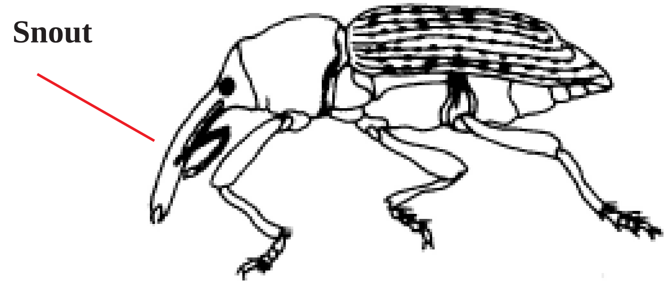


10. Eyes divided into dorsal and ventral portions; forelegs long and raptorial, mid- and hindlegs short and paddle- like; antennae stout and club-shaped; lives on water surface …………………….....................................….**Gyrinidae**



Eyes undivided; form of legs and antennae various but not as above; aquatic or semiaquatic but never on water surface……....................……………………..**11**

11.Head with elephant's trunk like anterior prolongation or snout...**Curculionidae**

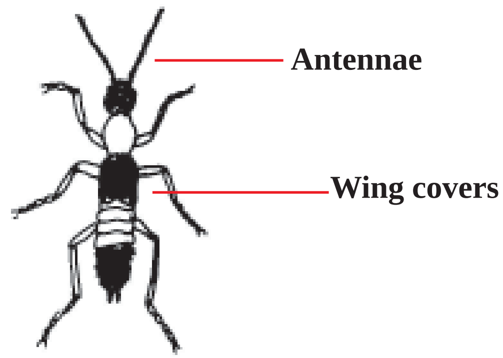


Head not produced into a snout………..…….**12**

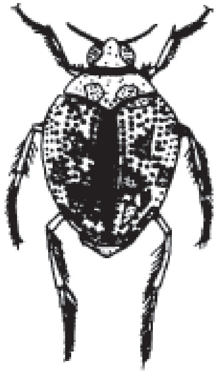
12.Elytra short and partially covers the dorsal surface of the abdomen…….**13**

Elytra covering entire dorsal surface of the abdomen……..............................….**14**

13. Semi aquatic; metallic or iridescent beetles; antennae with more than eight segments…..……….**Staphylinidae**

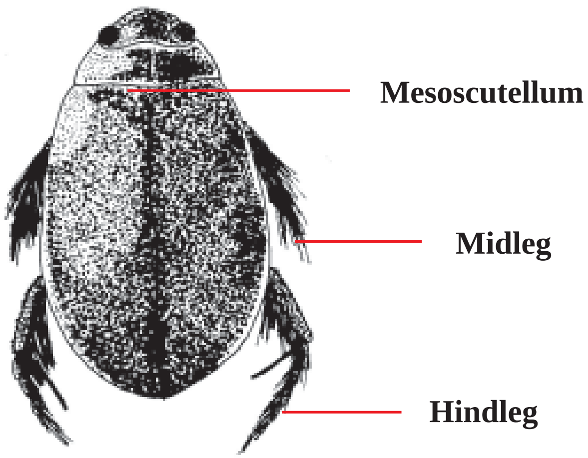


14. Abdominal segments I-III covered by plate like expansion of hind coxae ……………………………………………………………………………………… **Haliplidae**

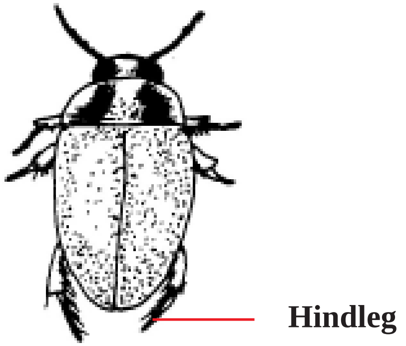


Hind coxae not expanded into plates but extend posteriorly to divide the first abdominal sternite…………………………………………………………………………….**15**

15a. Eyes do not protrude; body convex shaped in cross section; hind tarsus with a single claw, if two claws are present, the mesoscutellum (a triangular plate lying mid-dorsally on the mesothorax between the elytra) is large and exposed …………………………………………………………………………**Dytiscidae**



15b. Hind tarsus with two claws; mesoscutellum concealed; dorsal surface more strongly convex than the ventral surface………………………………**Noteridae**

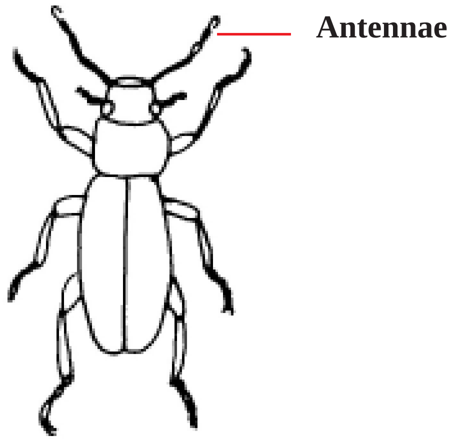


Not with above combination of characters……………………………………………**16**

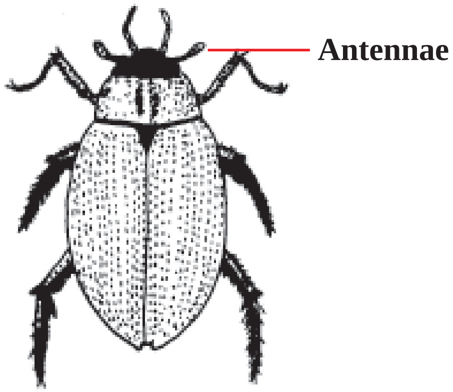
16. Tips of antennae an abrupt globular or elongate club……………………………**17**

Tips of antennae do not form a club…………………………………………………**18**

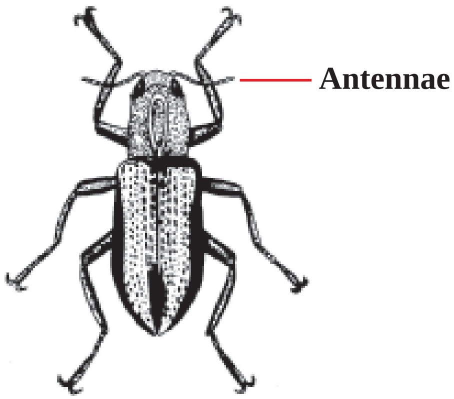
17a. Antennal club made up of five segments; abdomen with six or seven segments visible on the underside……………………………………………**Hydraenidae**



17b. Antennal club made up of three segments with five segments before the 'club'; abdomen with five segments visible on the underside; fore tarsi with five segments. Pronotum broadens posteriorly; eyes prominent or not……..…..**Hydrophilidae**

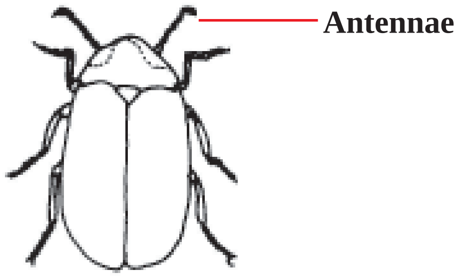


18. Abdomen with six or seven segments visible on the underside; antennae filiform and concealed within the prothroax and never longer than the combined length of head and prothorax; body heavily sclerotized……..**Elmidae**

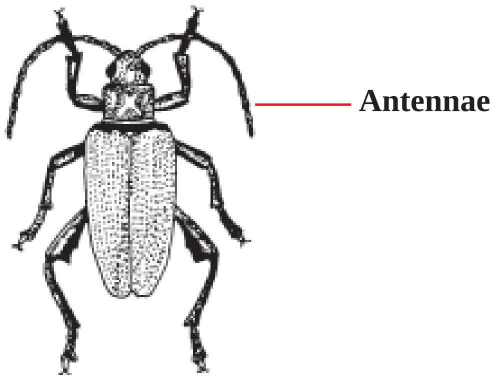


Antennae longer than the combined length of head and prothorax…..............**19**

19a. Antennae somewhat comb-like; broadly oval and somewhat flattened weakly-sclerotized beetles with less than 10 mm body length; antennae inserted between the eyes……...…..**Psephenidae**



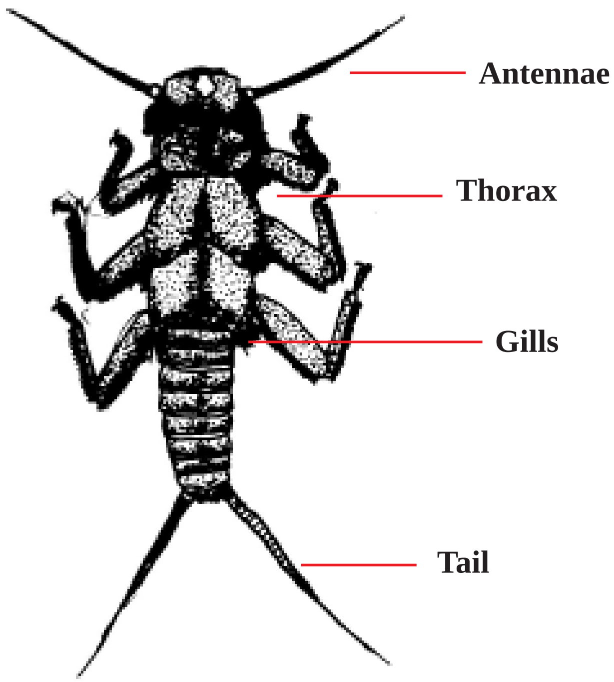
19b. Antennae slender and longer; mandibles inconspicuous, directed venterally; brightly coloured, metallic or iridescent beetles; semiaquatic and associated with aquatic plants…………...................................…..**Chrysomelidae**



Space for Field Notes on Aquatic Beetles (Coleoptera)

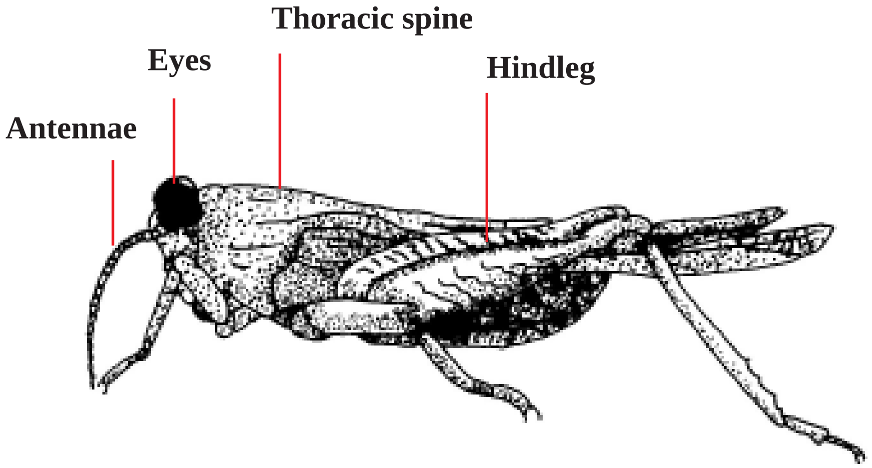
Key to Larval Stoneflies (Plecoptera)

1. Larvae generally brown with yellow markings; branched thoracic gills are present; abdomen terminates in two tails..............................**Perlidae**

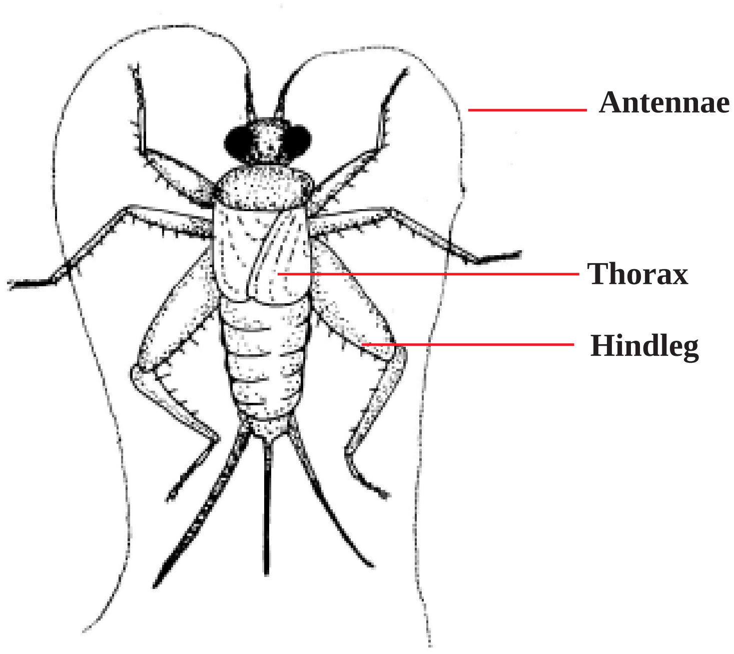


Key to Semi-aquatic Grasshoppers and Crickets (Orthoptera)

1. Hind femora enlarged and adapted for jumping; body laterally compressed; throax drawn into a long spine over the abdomen; eyes dorsally placed...**Tetrigidae**

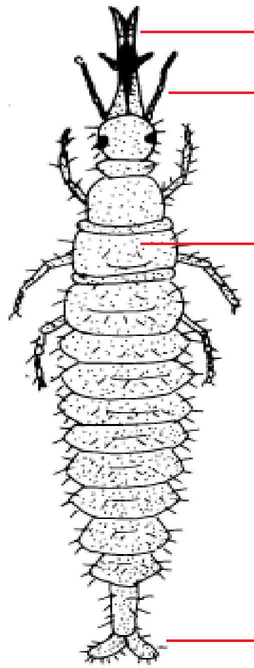


2. Body dorso ventrally compressed; antena longer than the body and thread like; wings absent or reduced..................**Gryllidae (Nemobinae)**



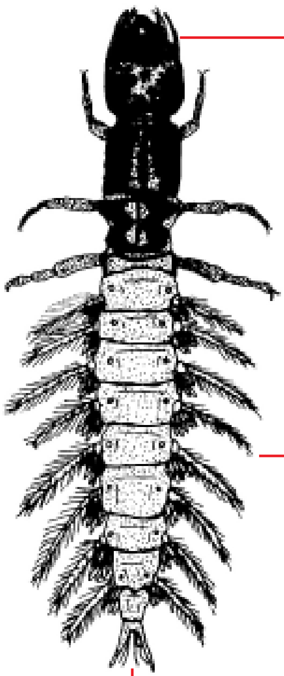
Key to Spongillaflies (Neuroptera)

1. Body covered with small bristles; antenna long; mouth parts needle like; wings pads and tails like structures are absent..................**Sisyridae**



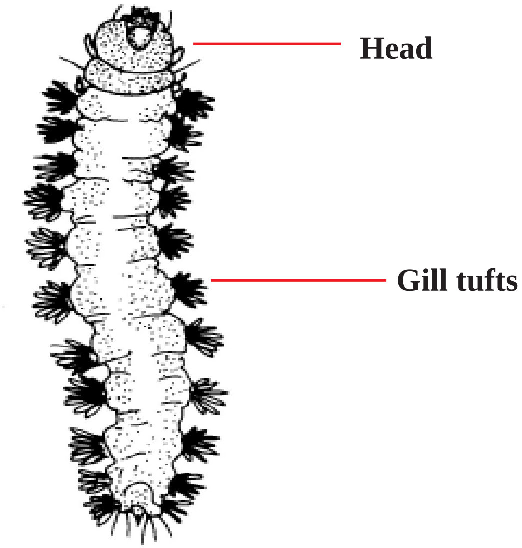
Key to Alderflies (Megaloptera)

1. Abdomen with eight pairs of lateral filament and hooked anal prolegs; mandibles large and conspicous..**Coridalidae**



Key to Aquatic Moths (Lepidoptera)

1. Abdomen with gill tufts and pseudo legs; associated with aquatic plants..**Pyralidae**



Space for Field Notes on other Aquatic Insects (Odonata, Plecoptera, Orthoptera etc.)