Technical Report Documentation Page

1. REPORT No.
CA/TL-82/01

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
A Simplified Taxonomic Key to the Families of California Aquatic Insects- 1st Revision

5. REPORT DATE
January 1982

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
G.R. Winters, G.R. Leidy and M. Forbes

8. PERFORMING ORGANIZATION REPORT No.
19107-641139

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Manual is used for water-quality investigations and with the aquatic-biology training course.

16. ABSTRACT

The revised manual includes changes in the taxonomy of aquatic insects in California since the publication in 1976 of the original manual.

This manual was compiled to facilitate the identification by transportation environmental personnel of the orders and families of selected aquatic insects found in California. The keys are simplistic with illustrations for use by personnel not trained in biology and unfamiliar with entomological terminology and techniques.

Field and laboratory procedures for processing of collected insect materials are discussed. Taxonomic keys to the orders and families of aquatic insects are presented. The keys will allow the identification of fairly well developed immature aquatic insects. There is a short synopsis of general information for each order. Additionally, there is a discussion of some ecological information for the families covered by this manual.

17. KEYWORDS
Taxonomic keys, aquatic insects, water quality

18. No. OF PAGES:
249

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1981-1988/82-01.pdf

20. FILE NAME
82-01.pdf

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

A SIMPLIFIED TAXONOMIC KEY TO THE FAMILIES OF CALIFORNIA AQUATIC INSECTS - 1st REVISION

Study Supervised by .... E. C. Shirley, P.E.

Principal Investigator .... G. R. Winters

Report Prepared by .... G. R. Winters
G. R. Leidy
M. Forbes

82-01

85-01

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO
CA/TL-82/01		

4. TITLE AND SUBTITLE	5. REPORT DATE
A SIMPLIFIED TAXONOMIC KEY TO THE FAMILIES OF CALIFORNIA AQUATIC INSECTS - 1st REVISION	January 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
G. R. Winters, G. R. Leidy and M. Forbes	19107-641139
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO
Office of Transportation Laboratory California Department of Transportation Sacramento, California 95819	11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT & PERIOD COVERED
California Department of Transportation Sacramento, California 95807	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Manual is used for water-quality investigations and with the aquatic-biology training course.

16. ABSTRACT

The revised manual includes changes in the taxonomy of aquatic insects in California since the publication in 1976 of the original manual.

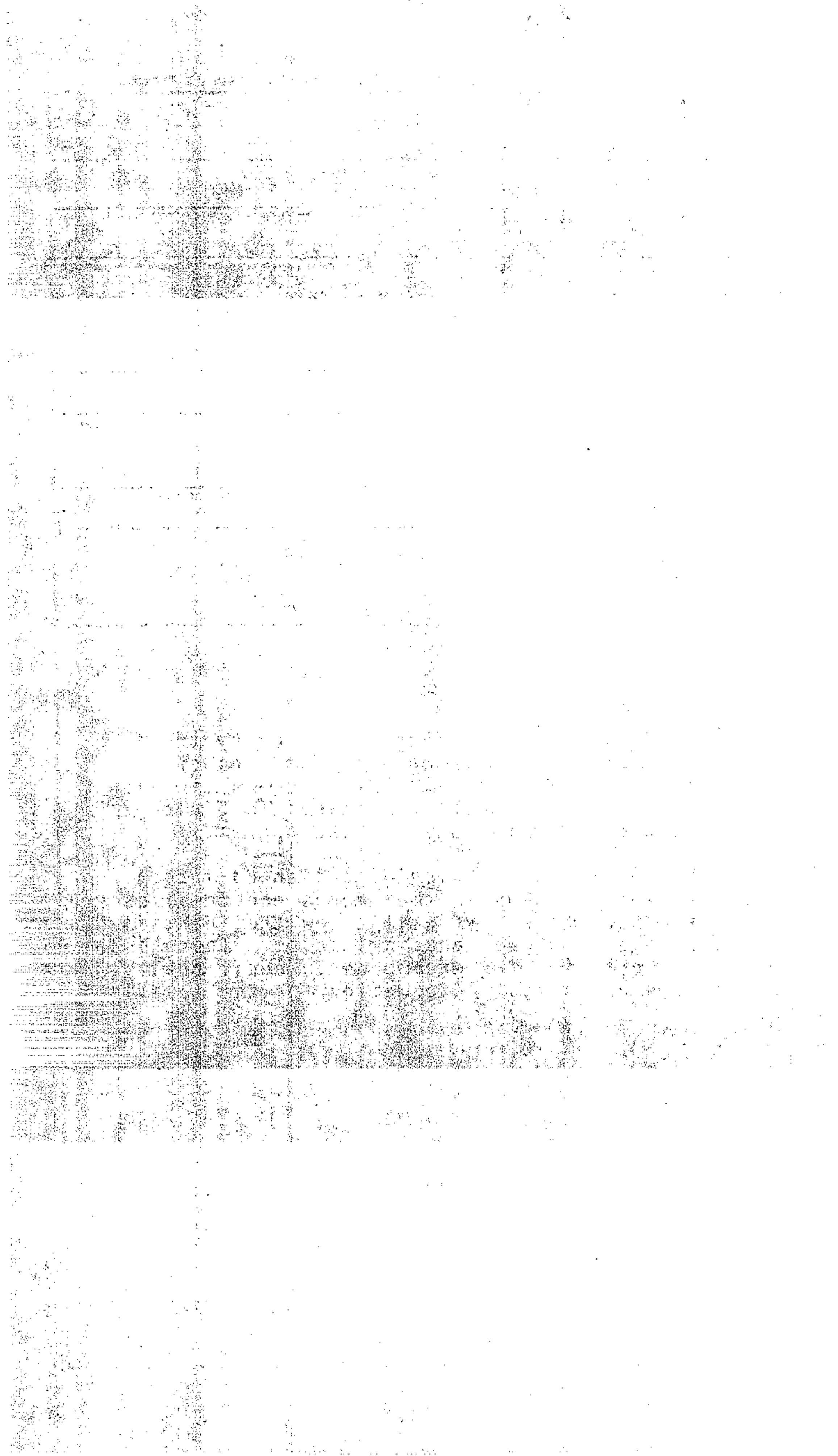
This manual was compiled to facilitate the identification by transportation environmental personnel of the orders and families of selected aquatic insects found in California. The keys are simplistic with illustrations for use by personnel not trained in biology and unfamiliar with entomological terminology and techniques.

Field and laboratory procedures for processing of collected insect materials are discussed. Taxonomic keys to the orders and families of aquatic insects are presented. The keys will allow the identification of fairly well developed immature aquatic insects. There is a short synopsis of general information for each order. Additionally, there is a discussion of some ecological information for the families covered by this manual.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Taxonomic keys, aquatic insects, water quality	

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	138	

DS-TL-1242 (Rev.6/76)



INTRODUCTION

During the course of environmental investigations, aquatic organisms may be studied to assess potential impacts from proposed projects and to evaluate the recovery of an ecosystem following construction. In order to effectively develop this information, it may be necessary to collect and identify the aquatic macroinvertebrates found during field investigations.

Macroinvertebrates are defined as animals that are large enough to be seen with the unaided eye, are retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595 millimeter [mm] openings) and live at least part of their life cycles within or upon available substrates in a body of water or water transport system (EPA, 1973). The major taxonomic groups included in freshwater are insects, annelids, molluscs, flatworms, roundworms, and crustaceans.

Normally, Caltrans studies the insect portion of the macroinvertebrate populations. The macroinvertebrate community, with its substantial insect segments, is very sensitive to environmental stress. Monitoring of this community is an effective method for detecting environmental change. An analysis of macroinvertebrate communities can yield water quality information not always available through physical and chemical measurements.

Macroinvertebrates are relatively large, have limited mobility and usually have a long life span. As a result, these organisms as aquatic communities are indicators of environmental conditions encountered during their development. This community can give investigators an indication of unfavorable or limiting conditions that have occurred prior to sampling.

When an organism is collected, the investigator will wonder "what is it?", usually meaning "what is its name?". The science of naming and classifying of all biological organisms is called Taxonomy. A different name is given to every known or discovered organism and the name acts as a reference point which must be known to find information about a particular organism. Currently there are over 1-1/2 million different animals described and each must be given a different name to ensure its uniqueness in the literature. Add to these names the large number of plants in the world which also must be given names and it is easy to understand the necessity for long names and the problems they can cause the newly interested worker.

The necessity of a different scientific name for each organism becomes apparent when using everyday common names for animals. For example, on the Pacific Coast one species of salmon is known as king, silver, spring, dog, blackmouth, tyee, chinook and quinnat salmon. Scientific names get around the difficulty of multiple common names. The scientific name of the king salmon is Oncorhynchus tshawytscha and this name will definitely identify this fish as a particular species of salmon. In addition, the scientific name is a classification system which is intended to show relationships as well as for identification.

While many of the larger and more common animals and plants have rather stable common names, at least for a particular geographic area, many of the smaller and less familiar organisms do not. As a result, many of the insects and other smaller animals and plants are referred to by their generic designation. For example, a small fly may not have a common name but is known as Chironomus, the name of its genus.

The system of biological nomenclature is used to name organisms and is based on a system of groups and super groups. The inherent peculiarities or characters of organisms are the basis of this classification. The species is the basic building block of this classification and is defined as a group of natural populations which are reproductively isolated having many characters in common and differing from all other forms in one or more ways.

In the classification scheme, similar species with common characteristics are grouped into genera (singular: genus). Similar genera with shared common characters are grouped into families while similar families are grouped into more encompassing orders. As before, orders with particular characters in common are grouped into classes and similar classes into phyla (singular: phylum). All of the animal phyla are brought together forming the Animal Kingdom, which is comparable with the Plant Kingdom.

An example of the classification hierarchy can be shown using the common Rainbow Trout for illustrative purposes:

Kingdom	Animal
Phylum	Chordata
Class	Osteichthyes
Order	Salmoniformes
Family	Salmonidae
Genus	Salmo
Species	gairdnerii
Scientific name	Salmo gardnerii

It should be emphasized that the species category is a naturally occurring assemblage of organisms in nature while all categories above the species level are essentially human concepts. As a result, there is often divergence of opinion in regards to how certain organisms should be grouped. The higher categories are always in a state of flux with changes resulting as knowledge accumulates and relationships between organisms becomes more understood.

This manual was compiled to facilitate identification of the orders and families of selected aquatic insects found in California. An attempt was made to keep the keys as simplistic as possible for use by personnel not familiar with entomological terminology and techniques. In cases where technical terms are necessary, the user will find them defined in the glossary and illustrated where applicable.

The list of references at the end of this manual consists of many works that will serve as aides in identification processes. Many of these references have been used as a source of illustrations and technical assistance. The authors would like to thank the various publishers for the use of illustrations and drawings found in this compilation.

The keys found in this manual are based on the "dichotomy" concept, that is, they are arranged in couplets with each couplet consisting of a set of opposing characters. Examination of the specimen in hand will determine which of the two opposing characters in each couplet best describes the specimen. Each part of the couplet ends with a number directing the investigator to a new couplet. The process continues until the organism is identified.

Most often each couplet will have an accompanying illustration, but be careful in using these aides. The illustrations were chosen to show general appearance of an order or family characteristic. The beginning worker should keep in mind the vast array of insect species (over 700,000 species of beetles alone), and the problem of variability. For example, some species of a family may have wings while others do not. Immature aquatic insects often do not look like later developmental stages or the adults. This key will allow the identification of fairly well developed immature aquatic insects.

It should be noted these keys do not follow a natural arrangement and the families are arranged in the manner in which they key out most easily. As a worker progresses in his identification ability, ordinal characters will become second nature and the worker will often dispense with ordinal keying and go directly to the family keys. Hopefully, most workers will progress to the point where families will be readily identified and the investigator will learn to key out the lower more numerous and difficult taxonomic categories.

There will be cases where specimens being worked will be unidentifiable for one of numerous reasons. For example, damaged, very small, newly hatched and terrestrial insects are unidentifiable in many cases. In some instances the key will not be adequate for the identification of some rarer insect groups. If you are unable to key a specimen, assistance can be obtained from the Biology Unit at the Transportation Laboratory (TransLab).

FIELD AND LABORATORY PROCEDURES

General

As in all environmental impact studies, the macroinvertebrate study must be carefully thought out and planned to be a success. Ideally, the design of these studies should be based on study objectives which may have to be tempered by available resources, time limitations and the type of area to be studied.

Information for designing a study, selecting sampling methods, equipment and data evaluation can be found in the Federal Highway Administration's Final Report, Water Quality Manual, VOL. V, "Chemical, Bacteriological, and Ecosystem Analysis of Water from Highway Sources for Environmental Impact Studies". Further information is very well presented in EPA's, "Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents" 1973, and the United States Geological Survey's, "Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples" (1973). The American Public Health Association's, "Standard Methods for the Examination of Water and Wastewater (15th ed.)" (1980), has additional information.

Field Procedures

When field samples are taken by one of the many sampling devices and methods available, they should be preserved immediately in the field. If subsequent sorting will be accomplished very shortly after sample acquisition, preservation can be deferred until that time. When selecting the collection container, the appropriate sized container is a must. Collection containers should be filled no more than one-half full of sample material (not including preservative). This will ensure an adequate preservative to sample ratio for complete preservation. The appropriate sized container will minimize sloshing and possible damage to collected organisms.

The aquatic stages of nearly all insects are usually best preserved in vials of 70 to 80 percent ethyl alcohol (ethanol). If ethyl alcohol is unavailable, 40 percent isopropyl alcohol (rubbing alcohol) will suffice until ethanol can be secured. If the specimens are not to be examined for a period of time, replacement of the original preserving fluid after two or three days with fresh ethanol is recommended. Formalin is not recommended as a preservative.

Labeling

Each sample must be labeled for proper identification in the laboratory. Labeling must be done at collection time. Sample labels of water-resistant paper should be placed inside the sample container. If the container is too small, the label should be secured to the outside of the container. All information should be written in soft lead pencil or some absolutely waterproof ink.

Minimum information required on the sample label is a sample identification (log) number. The log number identifies the sample in a field notebook where the name of the water body, station number, date, sampling device used, name of collectors, substrate characteristics, and other environmental information are placed. An example of an aquatic field notebook sheet, and a field sample label are in the appendix.

Sorting and Subsampling

Once a sample is taken, the organisms must be removed and separated from extraneous materials. Laboratory sorting of insects can be time consuming and tedious. The authors have found preliminary sorting in the field to be an effective method to reduce laboratory processing time. As a sample is taken, the sample or a small portion of the sample, is placed in a white enamel laboratory pan or tray filled 1/3 full or water and the organisms picked as they contrast themselves with the white background. Dispersion of the sample in the water will facilitate sorting procedures. Field picking or sorting is sometimes not possible due to time limitations and/or inclement weather.

Many samples, especially benthic samples, contain large numbers of organisms. Sorting time can be reduced considerably by subdividing the sample before laboratory analysis. Before sorting, the entire sample is evenly distributed on the bottom of a laboratory pan or tray. The pan is divided into equal quarters and opposite quarters sorted.

As organisms are picked from extraneous materials, they should be separated into similar groups. Very quickly the worker will be sorting out mayflies, beetles, etc., into aggregations. Once the major groups are sorted, the many different types of insects in each major group can be further broken down into similar subgroups (families). Each similar group or type of insect should be kept in separate alcohol filled vials and labeled (log number) for later identification. A laboratory taxonomic bench sheet is helpful in keeping records and identifications in coherent form. An example of a laboratory bench sheet can be found in the appendix.

Data

Recorded macroinvertebrate data should include:

1. Collection Method - Quantitative or qualitative?
2. Biomass (standing crop) - Weight of organisms per unit area.
3. Number of taxonomic categories (taxa) represented.
4. Percentage composition of each taxon.
5. Total number or organisms per taxon and total sample.
6. Number of sampling replicates.

Keying Instructions

The first section of this key is to the orders of aquatic insects. In using the key, couplets are given which give the worker a dichotomous choice. For example, beginning with the "Key to the Orders of Aquatic Insects" (page 1), the worker starts with couplet 1. Couplet 1a states "wings or developing wings present"; if so, proceed to couplet 2. If the insect has "no evidence of wings or wing development" (as in couplet 1b), proceed to couplet 26. If the specimen in question has wings of some type, couplet 2 will give you a choice of "wings developing as external flap-like appendages (wing pads); broad base of attachment to the thorax, wings nonfunctional" or "wings well developed and functional". If the specimen had wings which were well developed, you would proceed to couplet 3; if not, proceed to couplet 15. Continue using the key in this manner until the "order" of the aquatic insect is determined. The number in parenthesis following the couplet number shows which previous couplet led to the present one and will allow easy reference back if necessary.

The key to the "families" of aquatic insects begins on page 10 and the procedure for using these keys is the same as for the "order" determination. An example, for the identification of the order and family of an aquatic Stonefly (Plecoptera, Perlodidae) follows:

1a Wings or developing wings present.................. 2*
1b No evidence of wings or wing development...........26

2a(1) Wings well developed and functional.......... 3
2b Wings developing as external flap-like appendages (wing pads); broad base of attachment to the thorax; wings nonfunctional...................................15*

15a(3) Body mummy-like with appendages encased in sheath which may be free or fused to the body....................16
15b Body not mummy-like..................21*

21a(15) Hind femora greatly enlarged for jumping...ORTHOPTERA
21b Hind femora not greatly enlarged for jumping...22*

22a(21) Mouthparts form a piercing-sucking beak.................................HEMIPTERA
22b Mouthparts not forming a beak, developed for biting and chewing.................23*

23a(22) Labium (lower lip) forms a scoop-like, extensible, elbowed, grasping organ.....................ODONATA
23b Labium not as above............24*

24a(23) Tarsi with 1 claw; sides of abdomen usually with plate-like or leaf-like gills; 2 or 3 "tails" at the end of the abdomen...................EPHEMEROPTERA
24b Tarsi with 2 claws; sides of abdomen usually without plate-like or leaf-like gills; 2 "tails" at the end of the abdomen..........PLECOPTERA*

In the case of the Plecoptera determination above, its characteristics fit couplets 1a, 3b, 15b, 21b, 22b, 23b, and 24b. In the example the correct couplet portion is starred to make them readily discernable.

To determine the family of the example, turn to the section covering that family. As in all cases, a short discussion of the Plecoptera is followed by the "Key to the Families of California PLECOPTERA Nymphs". Using Perlodidae as an example, the keying sequence follows:

1a Glossae and paraglossae about equal in length...... 2
1b Glossae much shorter than paraglossae.............. 4*

4a(1) Profusely branched gills at the lower corner of the thorax..............................PERLIDAE
4b Branched gills absent from the thorax........ 5*

5a(4) Hind wing pads nearly parallel to the axis of the body; cerci not more than 3/4 the length of the abdomen..CHLOROPERLIDAE
5b Hind wing pads set at an angle to the axis of the body, cerci usually as long or longer than the abdomen.........PERLODIDAE*

THE BASIC STRUCTURE OF AQUATIC INSECTS

Before attempting to classify aquatic insects, a general description of an aquatic insect may be useful. Because the basic structure pattern of insects has changed in so many ways throughout the course of evolution, the following generalization will have many exceptions, especially for insects in their immature stages.

The body of an insect is divided into three regions: the head, thorax and abdomen (Fig. 1). The head consists of the sensory organs and the feeding apparatus. The thorax is usually divided into three somites (segments), each bearing a pair of legs and the last two bearing a pair of wings also. The abdomen usually consists of 11 or fewer somites with the end somites modified as the sexual organs.

HEAD

Normally, one compound eye is located on each side of the head. The three simple eyes or ocelli are located between the compound eyes and are arranged in the shape of a triangle. In some groups (e.g., Coleoptera), the compound eyes have been replaced by ocelli and in many groups the ocelli between the compound eyes are missing. The antennae are situated in front of the compound eyes (Fig. 1).

The foremost portion of the head is formed by the labrum or upper lip, which is connected at its base to the clypeus. The clypeus in turn is fused to the frons (Fig. 1). The borders of the clypeus and frons are connected by the anterior portion of the "Y" shaped epicraneal suture. In some families the epicraneal suture may not be externally visible. The labrum also forms the top of the mouth and the paired mandibles and maxillae form the mouth laterally; the lower lip is the labium (Fig. 2). Attached to the labium and the maxillae are palpi (singular palpus). Located in the front of the labium is the hypopharynx or tongue (Fig. 2). In some nymphal forms, the hypopharynx forms a small, hardly noticeable lobe, but is modified in other orders.

The top of the head is called the vertex and the sides are called genae (singular, gena). The occiput is the region directly behind the vertex. The cervix or neck connects the head to the thorax. The way the cervix joins the head and thorax determines what direction the mouth parts will be pointed. Mouthparts can be directed downward (hypognathous), forward (prognathous) or backward (opisthognathous).

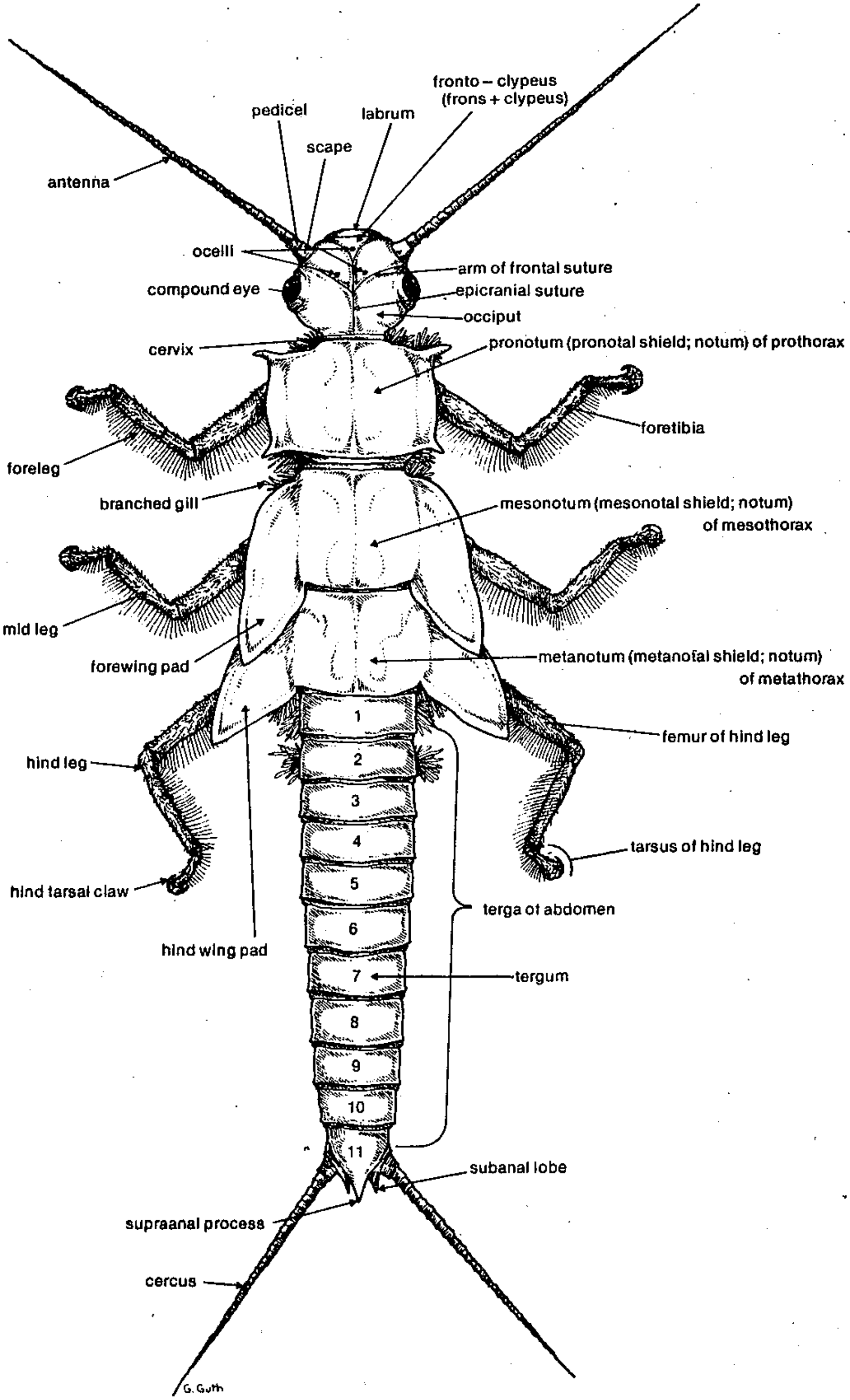
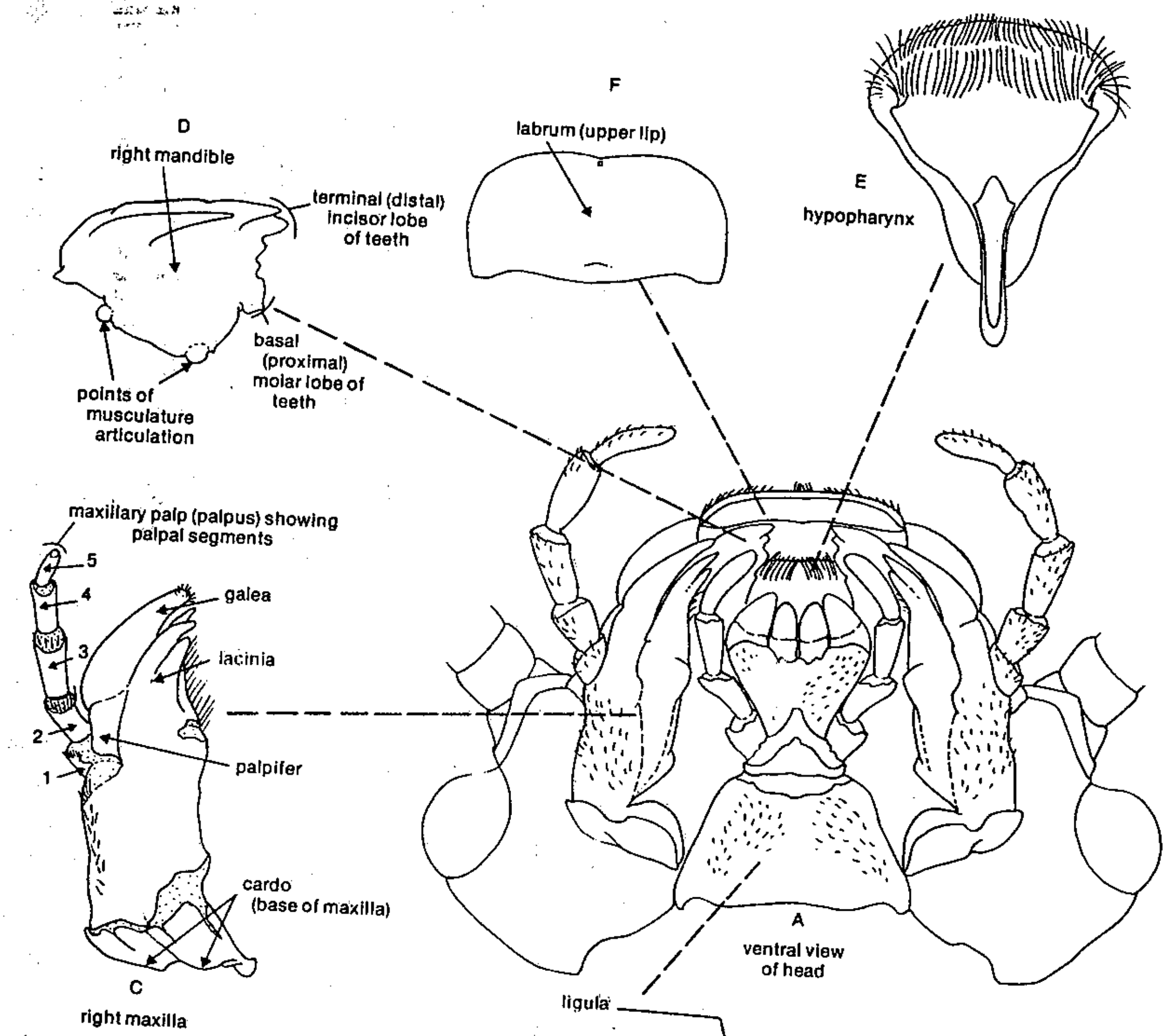


Fig. 1 Pteronarcidae. Dorsal view of nymph. (Merritt and Cummins, 1978).



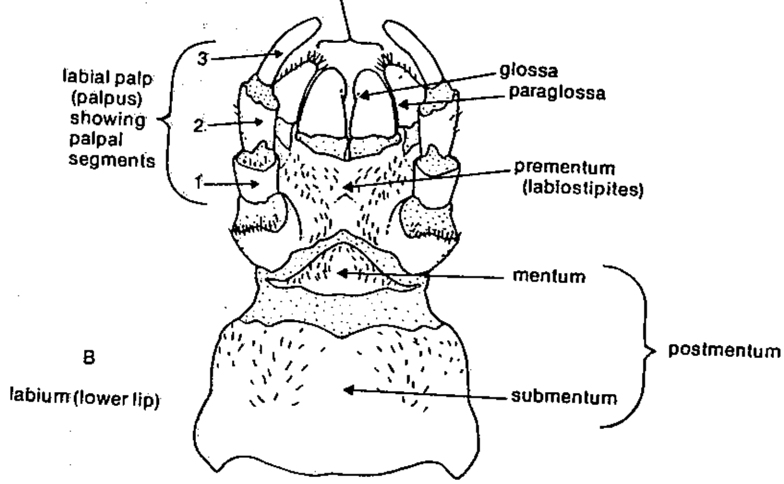


Fig. 2. Ventral view of head and mouthparts of Pteronarcidae (Plecoptera). (Merritt and Cummins, 1978).

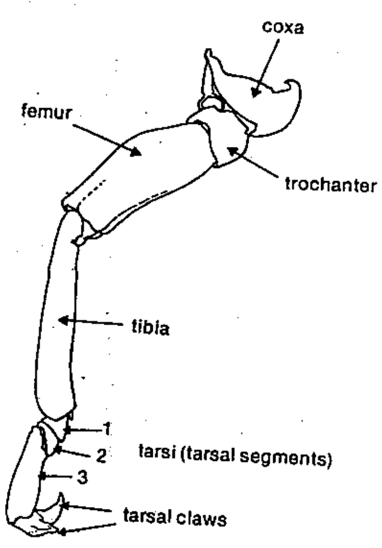


Fig. 3. Foreleg of Pteronarcidae (Plecoptera) showing segments. (Merritt and Cummins, 1978).

THORAX

The jointed legs and the wings are attached to the thorax (midsection of the body). The thorax is divided into three segments (Fig. 1). The three segments are: 1) the prothorax (front section), which bears the fore or prolegs, 2) the mesothorax (middle section) which bears the midlegs and fore wings and 3) the metathorax (end section), which bears the hind legs and hind wings.

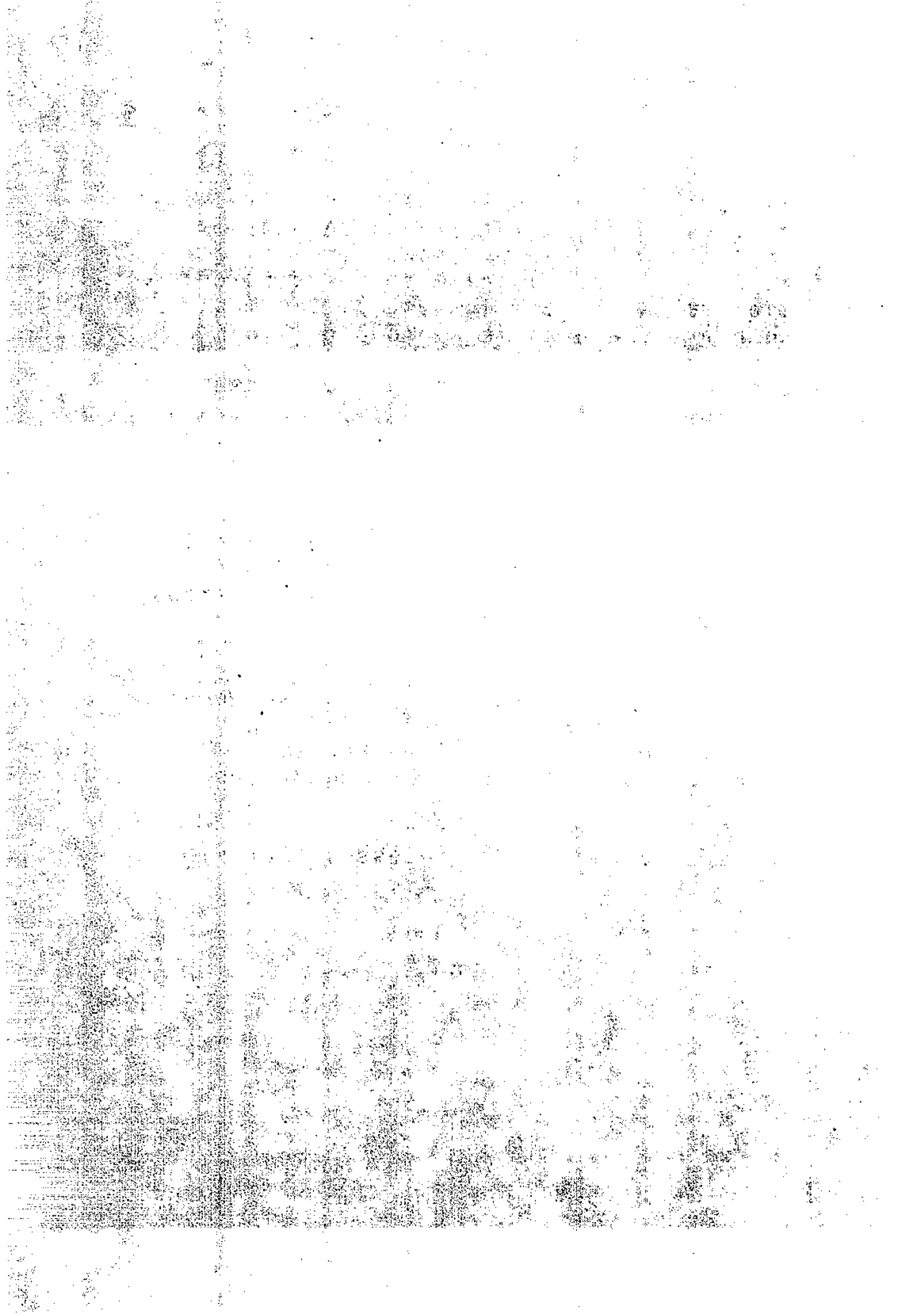
The legs consist of five segments: the coxa, trochanter, femur, tibia and the three to five segmented tarsi (Fig. 3). The tarsus may end in one or two tarsal claws. The legs of different orders will be modified for swimming or burrowing.

Most aquatic insects are equipped with two pairs of wings, but there are some exceptions. Some Diptera (true flies) and Mayflies have only one pair of wings, while Collembola, some females of Tricoptera and some Diptera have no wings (referred to as apterous).

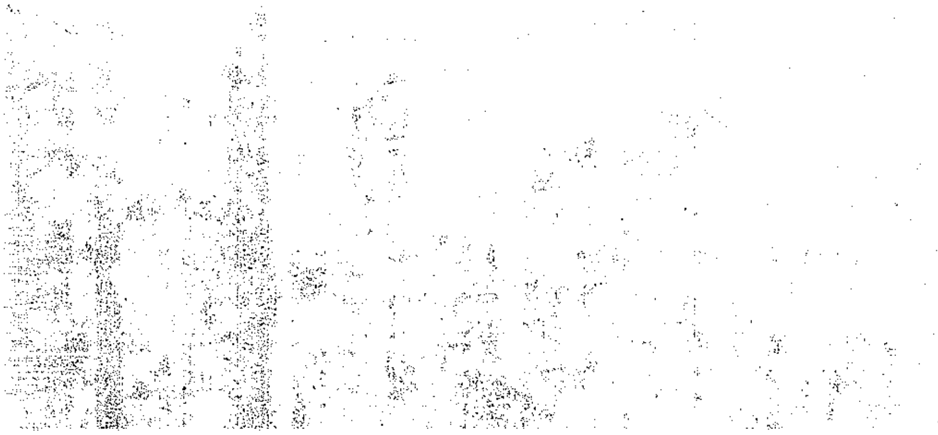
ABDOMEN

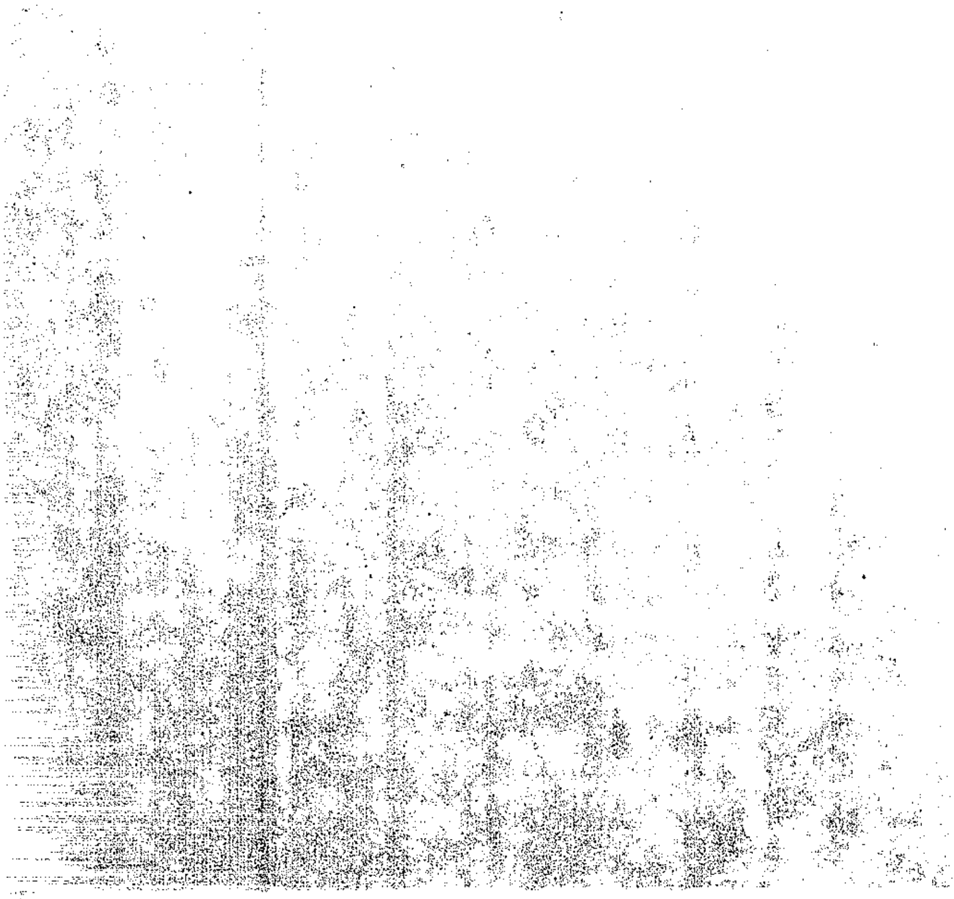
The abdomen may have 4 to 11 segments (tegra). The last segments are involved in the formation of the sexual organs. In some insects, spiracles will be found on the first eight or fewer segments, but others may have none at all. The abdomen varies greatly from order to order.

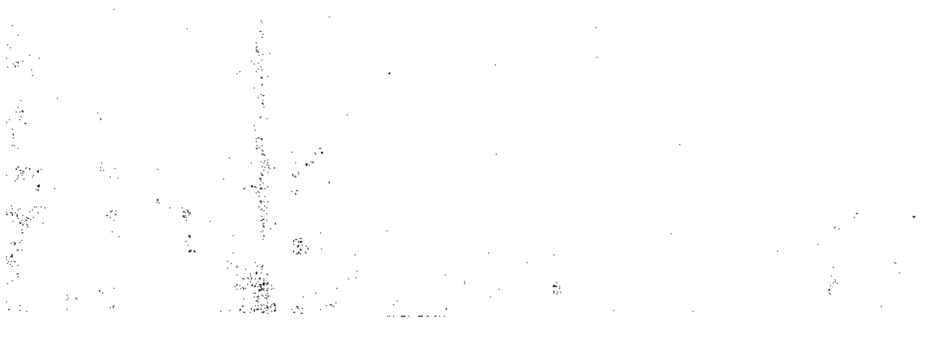
Many groups of aquatic insects also have anal processes (tails) borne on the last segment.



KEY TO THE ORDERS OF CALIFORNIA AQUATIC INSECTS







KEY TO THE ORDERS OF AQUATIC INSECTS

1a Wings or developing wings present (Figs. 4, 12, 48, 57, 108).. 2

1b No evidence of wings or wing development (Figs. 17, 71, 73, 75, 148)..............................25 (larvae)

2a(1) Wings well developed and functional (Figs. 4-11, 47, 102, 108).................................. 3 (adults)

2b Wings developing as external flap-like appendages (wing pads); broad base of attachment to the thorax; wings nonfunctional (Figs. 12, 13, 16, 18, 37, 48, 57)................................15 (nymphs & pupae)

3a(2) Fore wings horny or leathery, at least at the base (Figs. 47, 57, 108)............................ 4

3b Fore wings completely membranous (Figs. 4-11).. 6

4a(3) Hind femora greatly enlarged for jumping (Fig. 47) ....ORTHOPTERA (Pg.30)

4b Hind femora not greatly enlarged for jumping... 5

5a(4) Front wings without veination and forming a hard cover over the abdomen (Fig. 108)..COLEOPTERA (Pg.72)

5b Front wings membranous at the tip and leathery at the base; mouthparts form a piercing-sucking beak (Fig. 57) (except Corixidae which has a triangular beak)..................HEMIPTERA (Pg.41)

6a(3) One pair of wings............................ 7

6b Two pairs of wings............................ 8

7a(6) Two or three long "tails" at the end of the abdomen (as in Fig. 4) but with one pair or wings ..................................EPHEMEROPTERA (Pg.11)

7b No "tails" at the end of the abdomen (Fig. 5) ....DIPTERA (Pg.95)

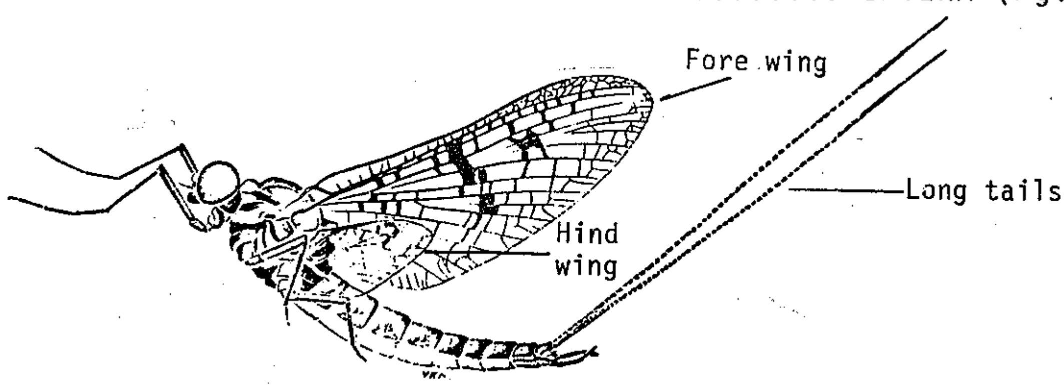


Fig. 4. Ephemeroptera. Adult in lateral view. (Usinger, 1956).

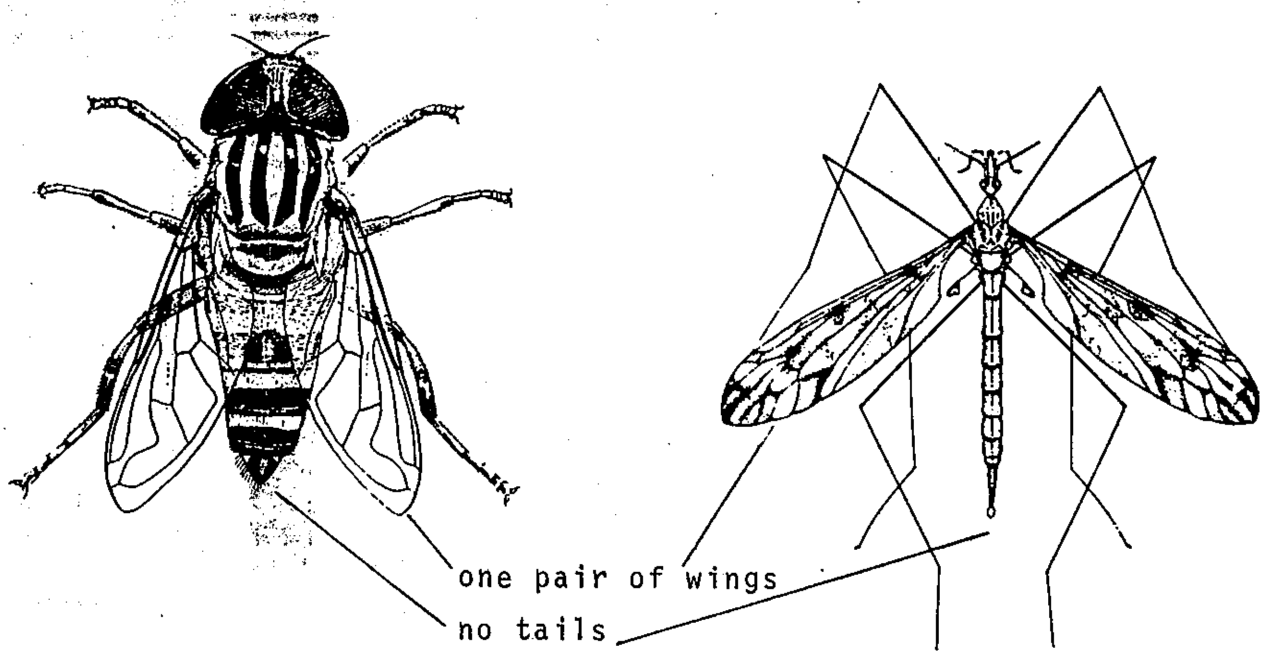


Fig. 5a,b. Diptera. Dorsal view of two species.*
(Williams, 1939, b. Alexander in Curran, 1934).

8a(6) Abdomen distinctly constricted at the base and narrowly joined to the thorax (Fig. 102) ....HYMENOPTERA (Pg.71)
8b Abdomen broadly joined to the thorax...........9

9a(8) Tarsi 3-segmented (Figs. 6, 7)................10
9b Tarsi 4 or 5 segmented (Figs. 8, 9, 10........11

10a(9) Two pairs of wings not equal in size; antennae long (Fig. 6)..........................PLECOPTERA (Pg.31)
10b Two pairs of wings equal in size; antennae short (Fig. 7)..................................ODONATA (Pg.24)

11a(9) Wings covered by scales or hairs (Figs. 8, 9).12
11b Wings with few scales or hairs (Figs. 10,11)..13

12a(11) Wings covered with scales (Fig. 8)....LEPIDOPTERA (Pg.70)
12b Wings covered with hairs (Fig. 9)......TRICOPTERA (Pg.55)

*Diptera possesses two pairs of wings but one pair is usually reduced to simple balancing organs called halters.

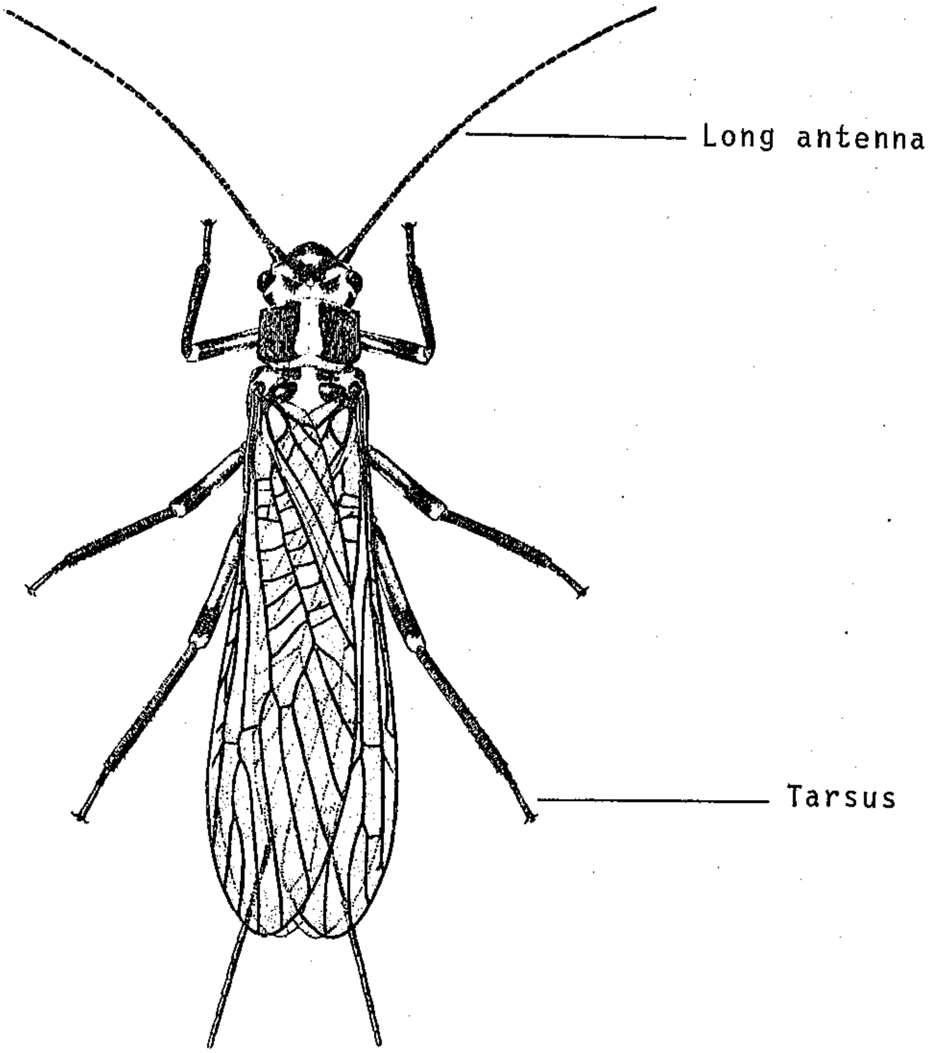


Fig. 6. Plecoptera. Dorsal view of an adult. The two pairs of wings are folded over the body in this illustration. (Pennak, 1978).

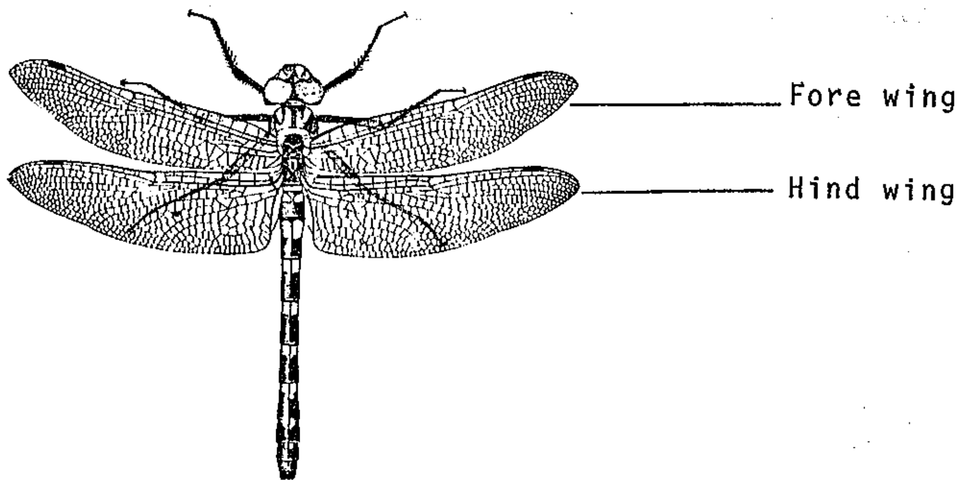


Fig. 7. Odonata. Adult in dorsal view. (Pennak, 1978).

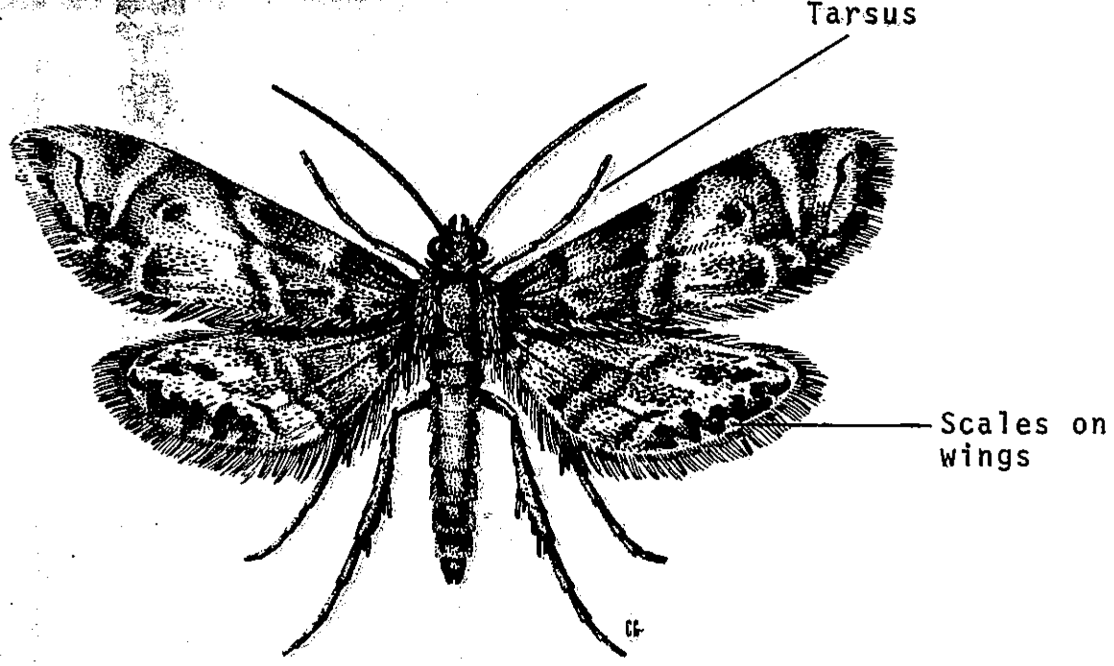
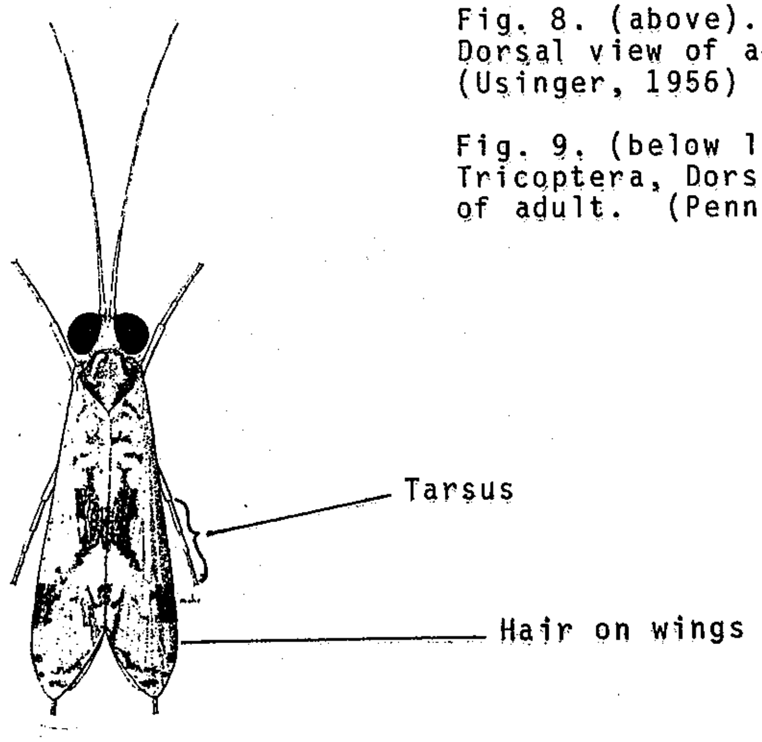


Fig. 8. (above). Lepidoptera Dorsal view of adult. (Usinger, 1956)

Fig. 9. (below left). Tricoptera, Dorsal view of adult. (Pennak, 1978)



13a(11) Two pairs of wings about equal in size (Figs. 10,11..14

13b Hind pair of wings much smaller than the front pair of wings; 2 or 3 long "tails" at the end of the abdomen (Fig. 4)..EPHEMEROPTERA (Pg.11)

14a(13) Pronotum small and inconspicuous; wings folded tent-like over the body (Fig. 10) ....NEUROPTERA (Pg.54)

14b Pronotum large and conspicuous; wings folded along the body (Fig. 11).......MEGALOPTERA (Pg.52)

15a(2) Body mummy-like with the appendages encased in sheaths which may be free or fused to the body (Figs. 12, 13, 15, 16)...................16 (pupae)

15b Body not mummy-like and the appendages not fused to the body (Fig. 18)...................21 (nymphs)

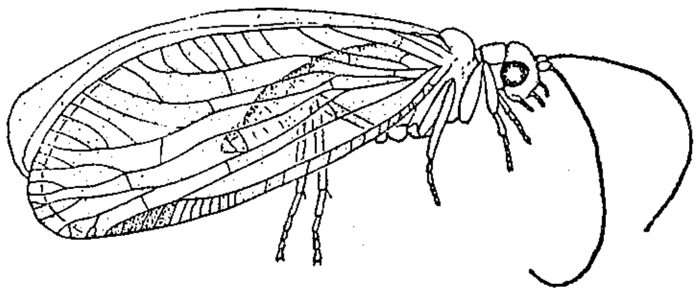


Fig. 10. Neuroptera
Side view of adult.
(Brown, 1952).

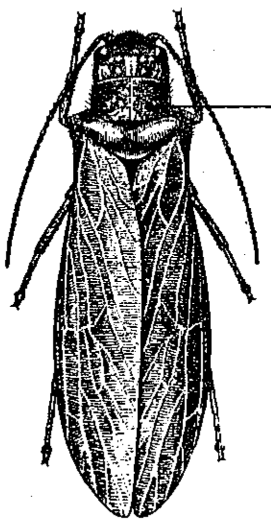


Fig. 11. Megaloptera
Dorsal view of an adult.
(Pennak, 1978)

16a(15) Body with 1 pair of wing pads (Fig. 12)...DIPTERA (Pg.95)
16b Body with 2 pairs of wing pads................17

17a(16) Appendages (wing pads, antennae, legs) appearing to be fused to the body (Fig. 13)..............................LEPIDOPTERA (Pg.70)
17b Characters not as above........................18

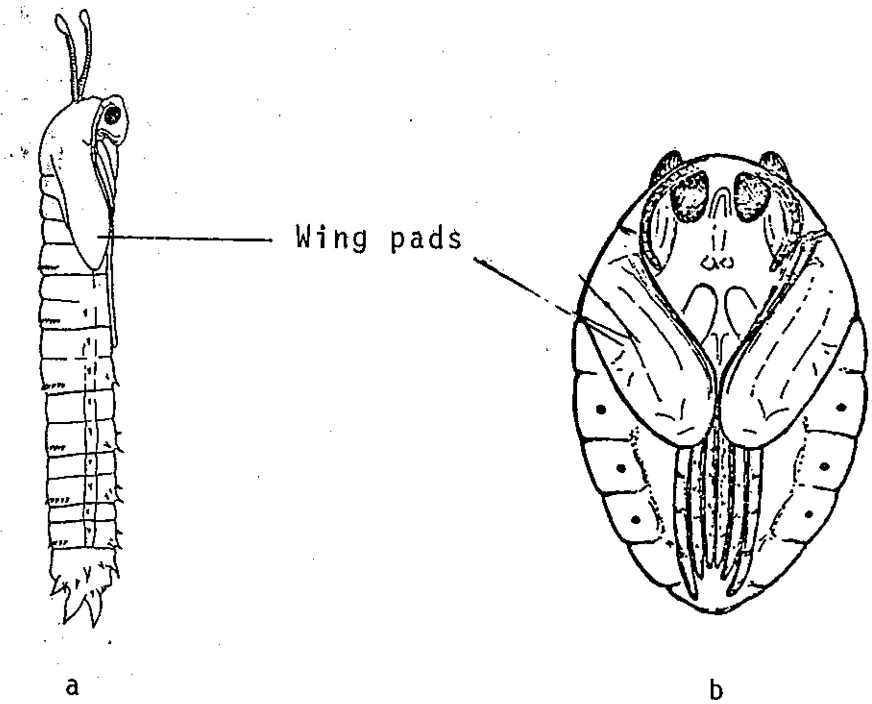


Fig. 12a,b. Diptera. Side (a) and front (b) views of two pupae. (Quate, 1955)

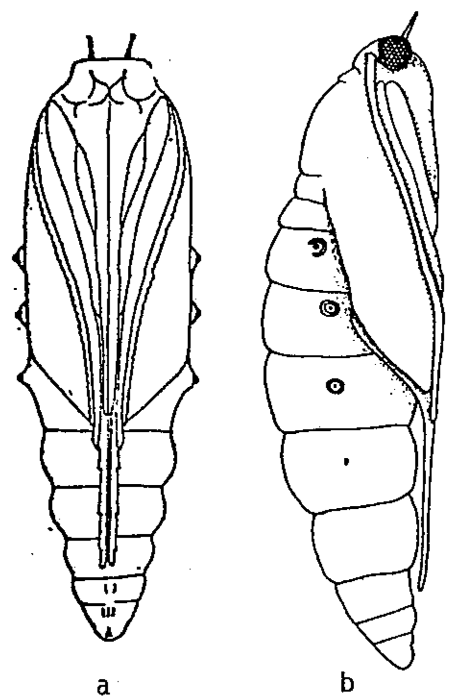


Fig. 13a,b. Lepidoptera. Front(a) and side (b) views of a pupae. (Welsh, 1916).

18a(17) Abdomen with a paired series of plates bearing hooks; mandibles curved, usually projecting forward and crossing each other (Figs. 14, 15).....TRICOPTERA (Pg.55)

18b Other abdominal characters; mandibles never overlapping or crossing each other...............19

Fig. 14. Tricoptera. Front view of the head of a pupae (Hickin, 1967).

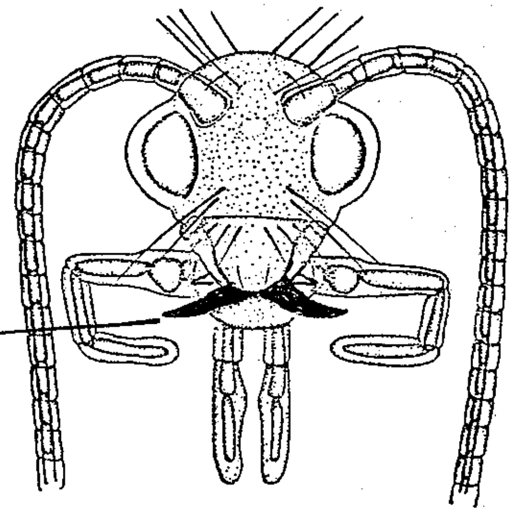
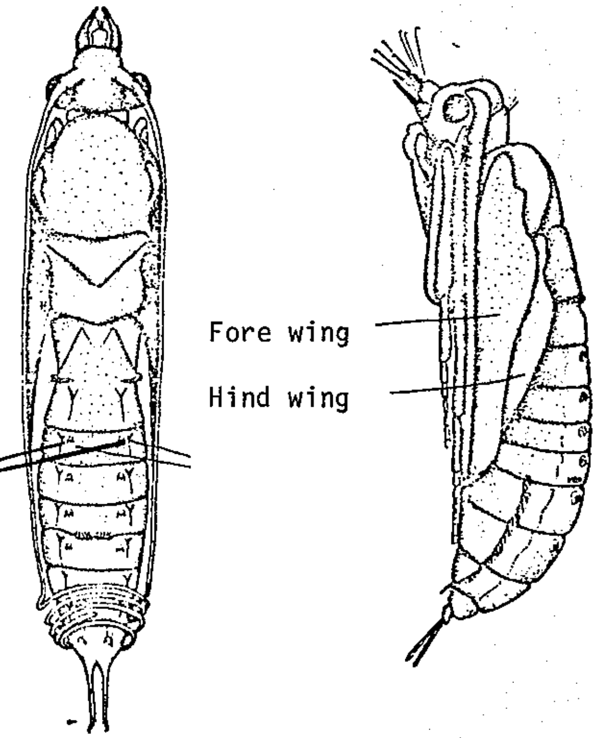


Fig. 15a,b. Tricoptera. Dorsal (a) and side (b) view of two different pupae. (Hickin, 1967).



19a(18) Pads of the fore wings thickened, leathery; antennae with less than 15 segments (Fig. 16)..............................COLEOPTERA (Pg.72)

19b Pads of the fore wings no thicker than the hind wing pads; antennae with more than 20 segments......................................20

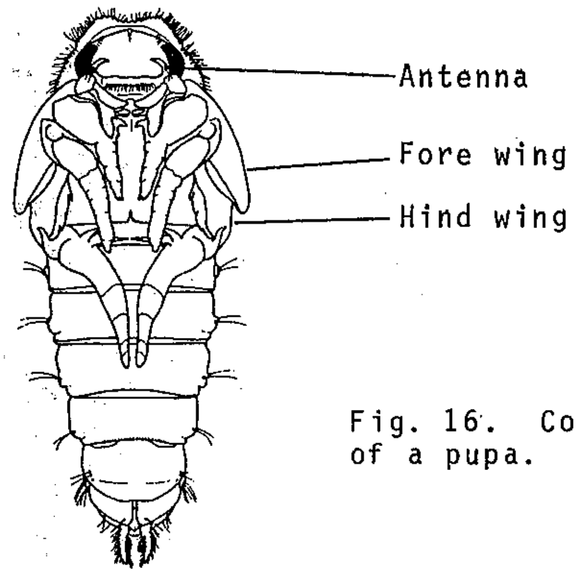


Fig. 16. Coleoptera. Front view of a pupa. (Wilson, 1923).

20a(19) Size small, 10 mm or less..............NEUROPTERA (Pg.54)

20b Size large, 12 mm or more.............MEGALOPTERA (Pg.52)

21a(15) Hind femora greatly enlarged for jumping (Fig. 47)..............................ORTHOPTERA (Pg.30)

21b Hind femora not greatly enlarged for jumping..22

22a(21) Mouthparts forming a piercing-sucking beak or short triangular beak (Figs. 57, 59)....HEMIPTERA (Pg.41)

22b Mouthparts not forming a beak, developed for biting and chewing............................23

23a(22) Labium (lower lip) forms a scoop-like extensible, elbowed, grasping organ (Figs. 37, 38)...........................ODONATA (Pg.24)

23b Labium not as above...........................24

24a(23) Tarsi with 1 claw; sides of abdomen usually with plate-like or leaf-like gills; 2 or 3 "tails" at the end of the abdomen (Figs. 18, 35).......................EPHEMEROPTERA (Pg.11)

24b Tarsi with 2 claws; sides of abdomen usually without plate-like or leaf-like gills; 2 "tails" at the end of the abdomen (Fig. 48)..............................PLECOPTERA (Pg.31)

25a(1) Thorax without jointed legs: prolegs may be present on the ventral side of the prothorax and abdomen (Figs. 143, 148, 157).........DIPTERA (Pg.95)

25b Thorax with jointed legs (Fig. 73)............26

26a(25) Abdomen with ventral "springing" apparatus; abdomen 6-segmented or less (Fig. 17)..COLLEMBOLA (Pg.10)

26b Abdomen without a "springing" apparatus; abdomen with 6 or more segments...............27

27a(26) Mouthparts forming a long, slender, sucking tube about 2/3 as long as the body (Fig. 73) ....NEUROPTERA (Pg.54)

27b Mouthparts not forming a long, slender, sucking tube.................................28

28a(27) Ventral side of the abdomen with at least 2 pairs of prolegs, each with a ringlet of small hooks around it (Fig. 101)............LEPIDOPTERA (Pg.70)

28b No prolegs on the abdomen.......................29

29a(28) End of the abdomen with terminal hook-bearing lobes (Figs. 72, 75, 139)......................30

29b End of the abdomen without terminal hook-bearing lobes.................................32

30a(29) End of the abdomen with 1 median lobe bearing 4 hooks (Fig. 139)......................COLEOPTERA (Pg.72)

30b End of the abdomen with 2 lateral lobes, each bearing 1 or 2 hooks..........................31

31a(30) Each lateral lobe with 2 claws (Fig. 72) ....MEGALOPTERA (Pg.52)

31b Each lateral lobe with 1 claw (Fig. 75) ....TRICOPTERA (Pg.55)

32a(29) Tarsi with 2 claws; end of the abdomen with a long, slender, median process like a "tail" (Fig. 71)............................MEGALOPTERA (Pg.52)

32b Tarsi with 1 or 2 claws; no slender, median process at the end of the abdomen (Figs. 123, 136)......................COLEOPTERA (Pg.72)

Order: COLLEMBOLA
Common Name: Springtails

Springtails are primitive wingless insects that do not undergo metamorphosis. The transition from young to adult involves a change in color and an increase in segmentation of the appendages. Springtails are small, rarely reaching 10 mm in length. They inhabit stagnant water and rain pools, with a few species occurring along the intertidal area of the coast. Some springtails are bright red in color while others are colorless. These insects have no gills and obtain their oxygen by diffusion through the skin. Even though members of this family live in water, they do not lay their eggs there. Their food consists of decaying plant and animal matter. The so-called "spring" from which the common name is derived is attached to the abdomen. It can be drawn under the body and suddenly released to propel these insects up to a few inches in the air. Springtails are worldwide in distribution.

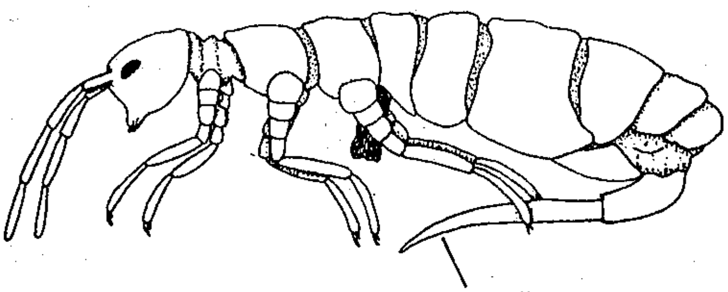
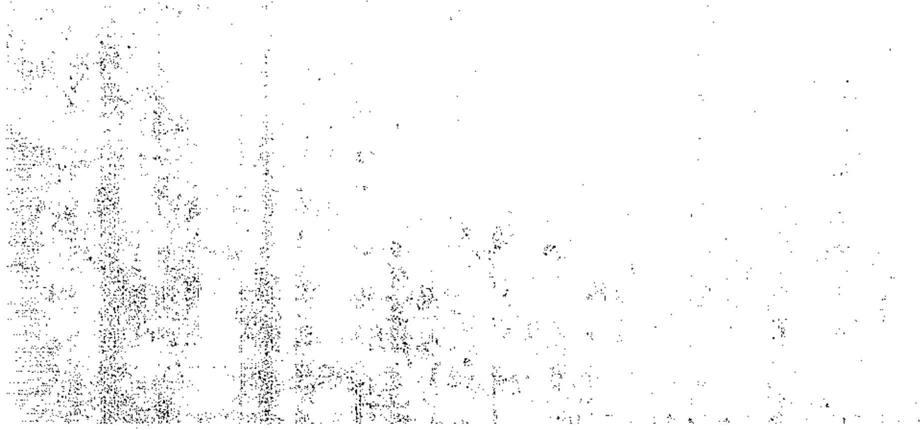
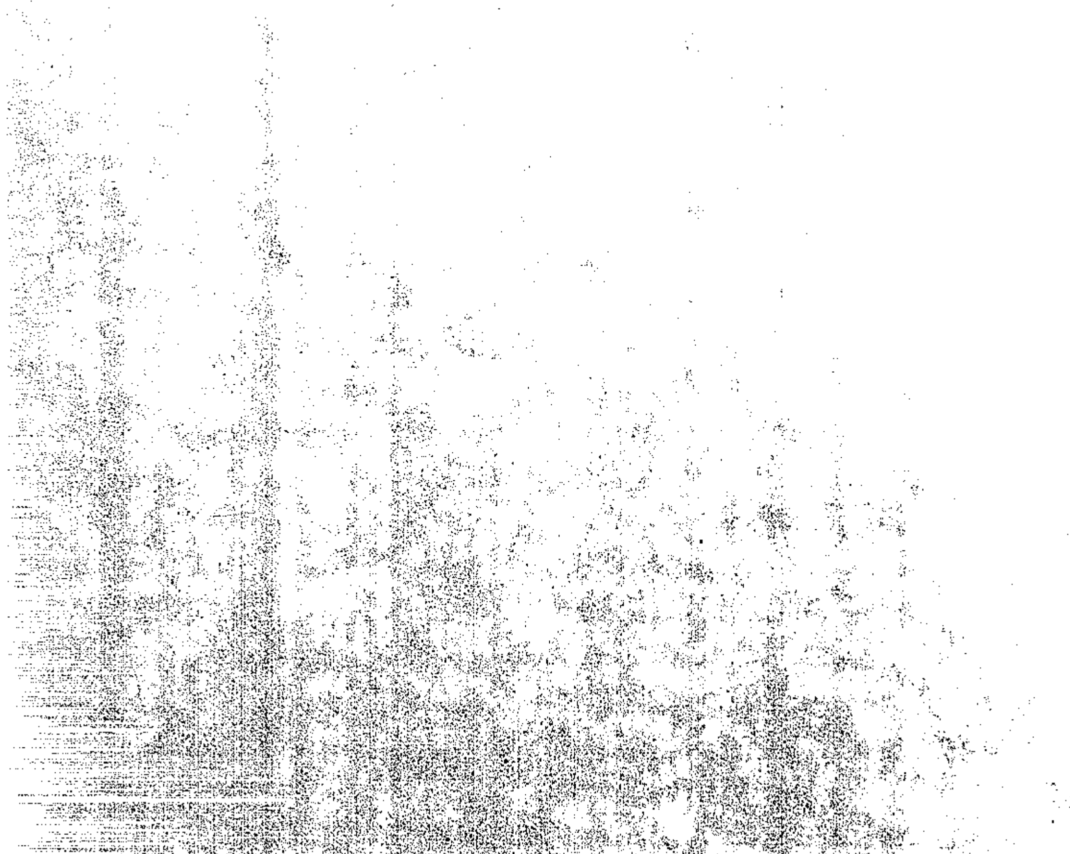


Fig. 17. Collembola.
Lateral view.
(Pennak, 1953).

KEY TO THE FAMILIES OF CALIFORNIA EPHEMEROPTERA (MAYFLIES)





Order: EPHEMEROPTERA (= briefly winged)
Common Name: Mayflies

Mayflies can be found all over the world. They dwell in or near freshwater lakes, ponds, streams, and rivers. Adult mayflies are easily recognized by their transparent, delicate wings held vertically over the body and by their two or three long, slender tails. Fly fishermen have tried imitations of mayflies for years, for it is well known that mayflies are a favorite food of many game fish. Mayfly nymphs are a very important element of the aquatic environment. These defenseless insects are preyed upon by almost every aquatic predator. The large population of mayfly nymphs makes up for their vulnerability. Adult mayflies serve as food for bats, birds, fish, dragonfiles and many others.

Mayfly nymphs can be distinguished from other aquatic insects by the presence of gills on the abdominal segments and a single claw at the end of each leg. The forms of the gills and from which abdominal segments they arise, vary greatly and are important in distinguishing different families. It is suggested that one count forward from the tenth abdominal segment to determine from which segments the gills arise when keying out a mayfly nymph. The last abdominal segment usually consists of three or sometimes two long, segmented and fringed tails. One or two pairs of wingpads can usually be seen, but they are sometimes hidden by the pronotum. The colors of mayfly nymphs vary greatly; some are dull brown, blackish or grey; others are pale, greenish, reddish and differently colored. Not including the tail, mature nymphs range from 3 to 28 mm in length.

The majority of mayfly nymphs live in the water for one year, but some species mature in two months, while others take up to two years. In California, nymphs emerge from the water from February through November. When a nymph is ready to emerge, it crawls out of the water and clings to vegetation or a rock. At this time, it undergoes a molt into a form, called the subimago, which closely resembles the adult. In most species this stage lasts for 24 hours, but in some species it may only last a few minutes or up to 48 hours. The nymphs then molt again into the reproductive adult called the imago. Mayflies are the only order of aquatic insects that have this double molt before adulthood.

Adult mayflies only live from two hours to, at most, a week. Adult mayflies, which have nonfunctional mouthparts, do not even eat. "The sole function of the adult is reproduction, and to this end they expend most of their energy" (Usinger, 1956). The male adult mayflies form swarms which the females fly into for mating purposes. Usinger (1956) states that swarms of many millions of mayflies can be seen in the Sacramento Valley, but such large flights are rather rare in other parts of California. "In the midwest, many species are attracted to lights at night, and sometimes mayflies may be present in such numbers as to form dense clouds around lights, and in the morning, their bodies may be found piled more than a foot deep on the ground below" (Pennak, 1978). Th females deposit their eggs on the water surface and the eggs sink to the bottom. In some species, the female is known to crawl underwater to attach the eggs to rocks.

Order: EPHEMEROPTERA

Synopsis of the California Families

Family: Ephemeridae

Members of this family are the most common mayflies in many areas of the United States. Only a single species, Hexagenia limbata, is known from California. Nymphs are found in lakes, rivers and streams where they may comprise an important food source for fish. Nymphs of this family usually burrow in the bottom.

Family: Tricorythidae

Only one species from this family, Tricorythodes fallax, is known from California. It is common in the north coastal region of the state. These small mayflies do not exceed 7 mm in length. The nymphs can be found in still water along stream margins.

Family: Caenidae

Nymphs in this family are small, from 2 to 4 mm in length. They inhabit silty bottoms of river eddies and stagnant pools. One genus, Caenis, is known from California.

Family: Isonychiidae

Members of this group have, until recently, been classified as a subfamily of the Siphlonuridae. The habits of adults and nymphs of this family are similar to the Siphlonurids. A single species, Isonychia velma, is known from Northern California.

Family: Ephemerellidae

Some of California's most common mayflies are found in this family. Twenty-two species are now recorded from the state. The somewhat flattened nymphs are found in rivers, fast-flowing streams and lakes, where they hide on the bottom among rocks and debris. Nymphs found in fast-flowing Sierran streams may crawl into crevices or under boulders to escape strong currents.

Family: Leptophlebiidae

Mayflies of this family inhabit ponds, as well as still to rapidly flowing water in streams. Nymphs often crawl around the bottom among the gravel and debris. Some species are strong swimmers while others are not. Many species from this group occur in California.

Family: Heptageniidae

Members of this family are found throughout California. The eyes of nymphs are dorsal and the body is flattened, and in many species the flattened body serves to act as a suction device to facilitate placement of the body in rapid currents. In collecting, some species are often difficult to remove from rocks. A few are found along stream margins where there is little current.

Family: Siphlonuridae

Nymphs are found in fast flowing rivers and streams, as well as standing pools detached from the streams. Nymphs of some species reach 20 mm in length. Most nymphs are excellent swimmers. Some members of this family, unlike most mayflies, are predaceous. This mayfly is widely distributed in California.

Family: Baetidae

This family is widespread in California and commonly collected. Nymphs inhabit shallow water ranging from the standing waters of lakes and ponds to very rapid streams. The nymphs in this family are capable of swimming for short distances against very rapid currents. Male and female nymphs are often difficult to identify because they often are very different in appearance.

Famile: Ametropidae

This family, represented by a single genus, has not been found in California. However, an undescribed species from Washington and Oregon may be found in northern California. The nymphs dwell in large rivers with fairly strong currents and they bury themselves in the firm, slightly silty sand at the bottom. These nymphs are excellent swimmers and range from 14 to 18 mm in length.

Family: Oligoneuridae

Oligoneuridae is another family that is very rare to California, probably limited to the eastern Sierra if they occur at all. The habits of the nymphs in this family vary and only two genera are found in North America. One genus, Homoeneurea, lives in moderately rapid to rapid streams with shifting bottoms. They quickly burrow into the sandy bottom and live one to two inches below the surface. The nymphs in this genera are awkward swimmers and range from 9 to 12 mm. Nymphs of the other genus, Lachlania, can be found clinging to small twigs lodged between rocks. They move slow and cling to twigs and rocks very strongly. These nymphs range from 8 to 10 mm in length.

Key to the Families of California EPHEMEROPTERA Nymphs

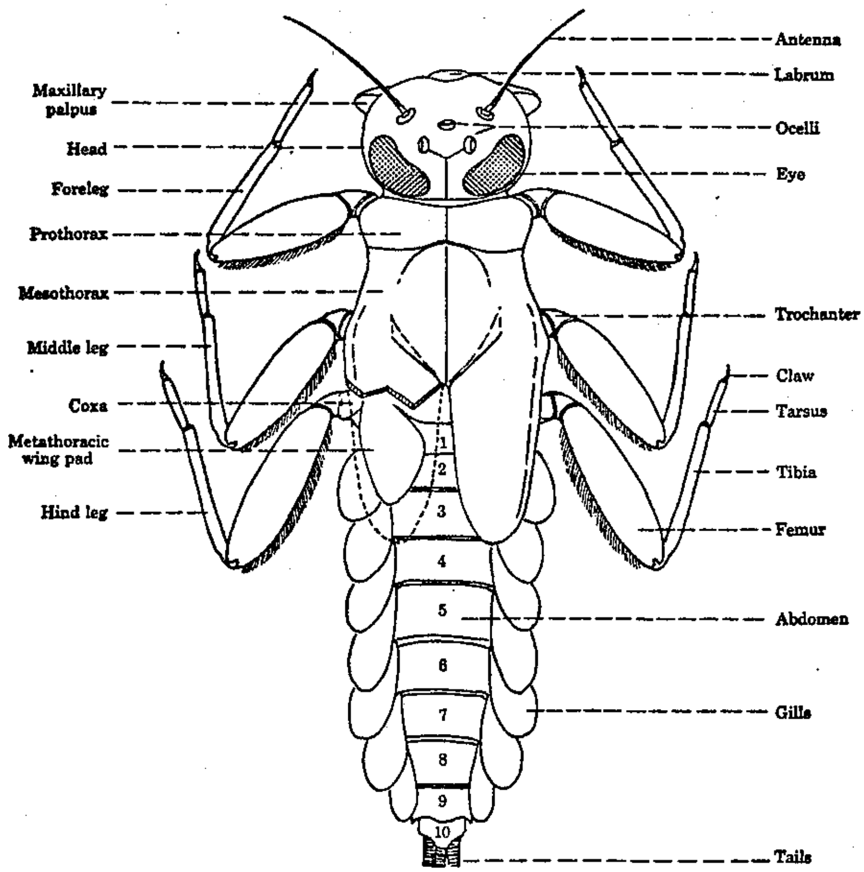


Fig. 18. Dorsal view of a mayfly nymph. (Burks, 1953)

1a Mandible with tusk projecting forward and visible from above the head (Fig. 19) 2

1b Mandible not as above 3

2a(1) Gills on abdominal segments forked (Fig. 27b) without fringe on margins .......................LEPTOPHLEBIIDAE

2b Gills not as above. Tusks curved upward at the tips when viewed from the side (Fig. 19)........EPHEMERIDAE

3a(1) Gills on abdominal segment 2 large and covering the succeeding pairs (Figs. 20, 24)...................... 4

3b Gills on abdominal segment 2 either absent or similar to those on the following segments (Figs. 25, 30).... 5

with single flotation tire static wheel loadings of 14 kips (0.040 inch) and 8 kips (0.017 inch) - see Figure 35, page 73.

2.2.2 Effect of Load Positions on Slotted Drain Deflections

Of the various load positions, the centerline parallel position of the loading plate caused the greatest vertical deflections with both bearing bars (grate side plates) deflecting the same amount. The eccentric parallel position of the loading plate caused the greatest grate rotation.

2.2.3 Effect of Different Types of Backfill on Stress Distributions and Vertical Deflections of the Slotted Drain

Slotted drains tested had greater deflections in soil backfill than in the soil cement backfill. Also, the soil backfill allowed the pipe to distort more under load, and transferred more load to the slotted drain than did the soil cement backfill. The magnitudes of bending stresses were greater in the slotted pipe drains which were backfilled with soil material than slotted drain with soil cement backfill. There seemed to be little difference in the strength of slotted drains backfilled with site-mixed soil cement and ready-mixed lean concrete of the same cement factor according to the vertical deflection data. However, the ready-mixed lean concrete had significantly higher 28-day compressive strength (1800 pounds per square inch) than did the site-mixed soil cement (720 pounds per square inch).

4a(3) Large gills on abdominal segment 2, triangular or oval with a fringed margin, large gills widely separated (Figs. 20, 21a); gills on the following abdominal segments without fringed margins (Fig. 21b)....................................TRICORYTHIDAE

4b Large gills on abdominal segment 2, large gills touching or almost touching (Figs. 23a, 24); gills on the following abdominal segments with fringed margins (Fig. 23b)..................................CAENIDAE

5a(3) Forelegs with a dense row of long setae on the inner surface (Fig. 22a)............................. 6

5b Forelegs with setae not as above........................ 7

6a(5) Gills on abdominal segment 1 on ventral side of abdomen (Fib. 22b)...........................OLIGONEURIDAE

6b Gills on abdominal segment 1 on dorsal side of abdomen.......................................ISONYCHIIDAE

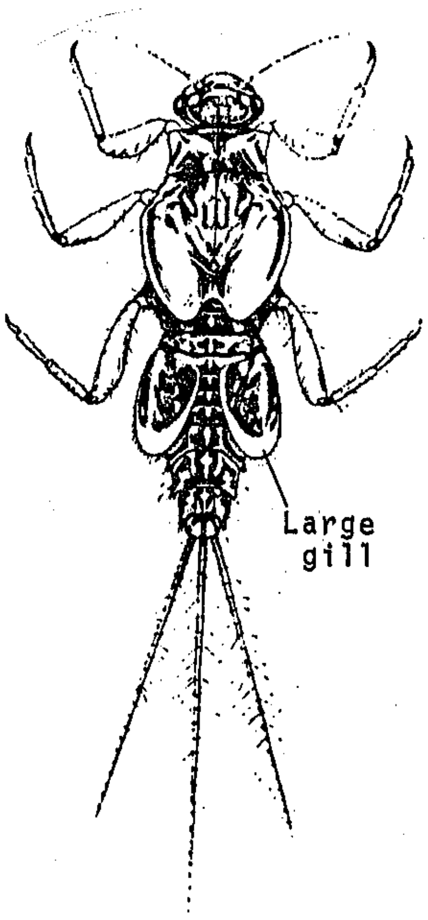


Fig. 20. Tricorythidae. Dorsal view of a nymph. (Burks, 1953).

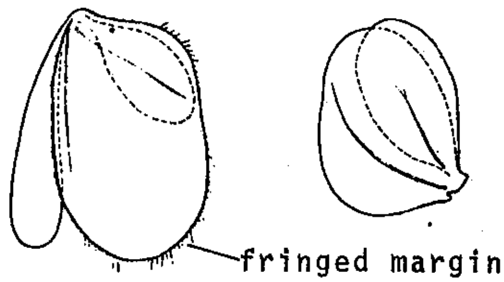


Fig. 21a,b. Tricorythidae
a. Large fringed gill of segment 2.
b. Unfringed abdominal gill (Burks, 1953).

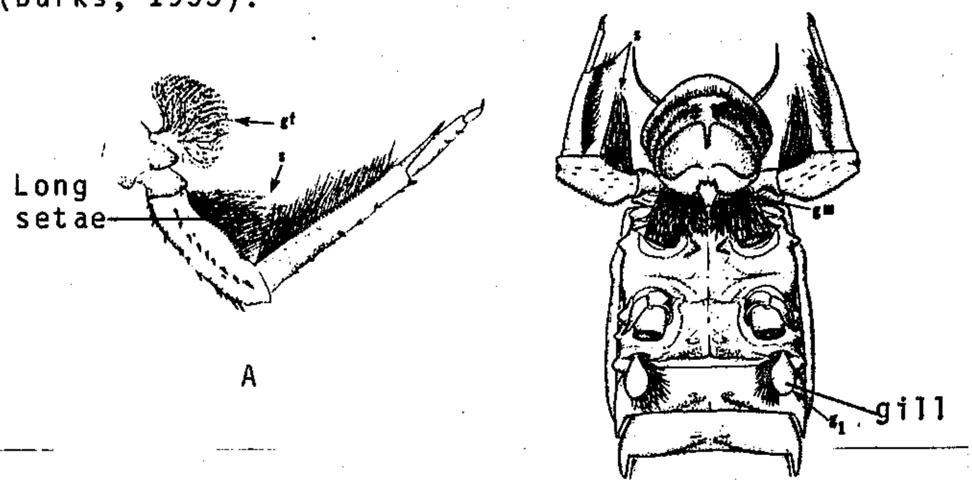


Fig. 22a,b.
a. Isonychiidae. Foreleg of a nymph.
b. Oligoneuridae. Abdominal gills on segment 1. (Edmunds,Jr.,et al., 1953).

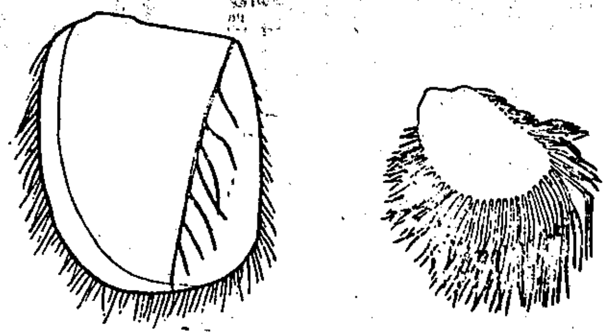
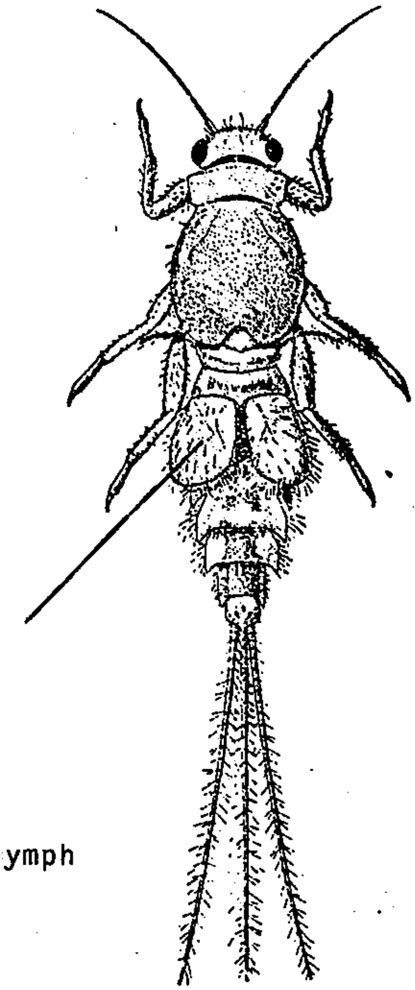
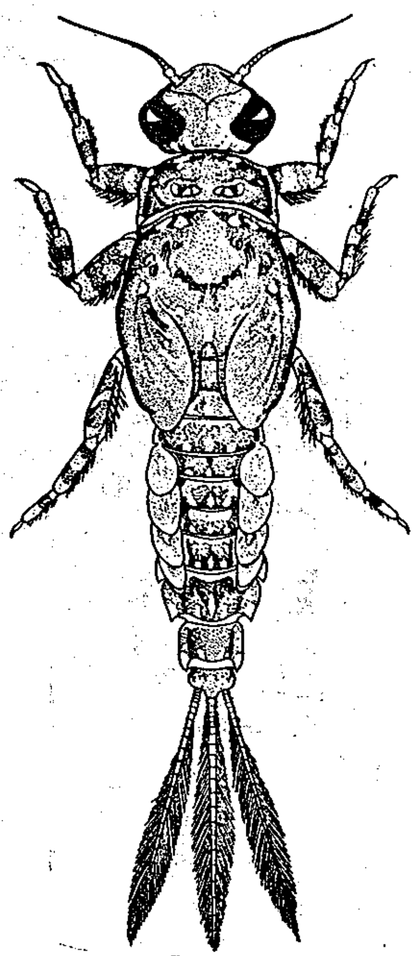


Fig. 23a,b. Caenidae.
a. Fringed gill of abdominal segment 2.
b. Fringed gills of other abdominal segments.
(Burks, 1953).



Large gill

Fig. 24. Caenidae
Dorsal view of a nymph
(Burks, 1953).



No gills on segment 2

Fig. 25. Ephemerellidae.
Dorsal view of a nymph.
(Pennak, 1978).

7a(5) Gills on abdominal segments 1-5, 1-7, or 2-7......... 8
7b Gills lacking on abdominal segment 2, gills may or may not be present on abdominal segments 1 and 3; gills present on abdominal segments 4 to 7 (Fig. 25) ....EPHEMERELLIDAE
8a(7) Gills of many type; may be forked. In clusters of filaments, fringed, divided at the apex, but never plate-like (Figs. 27, 28, 29).....LEPTOPHLEBIIDAE (in part)
8b Gills plate-like may have a filament-like tuft at or near the base (Fig. 26).......................... 9

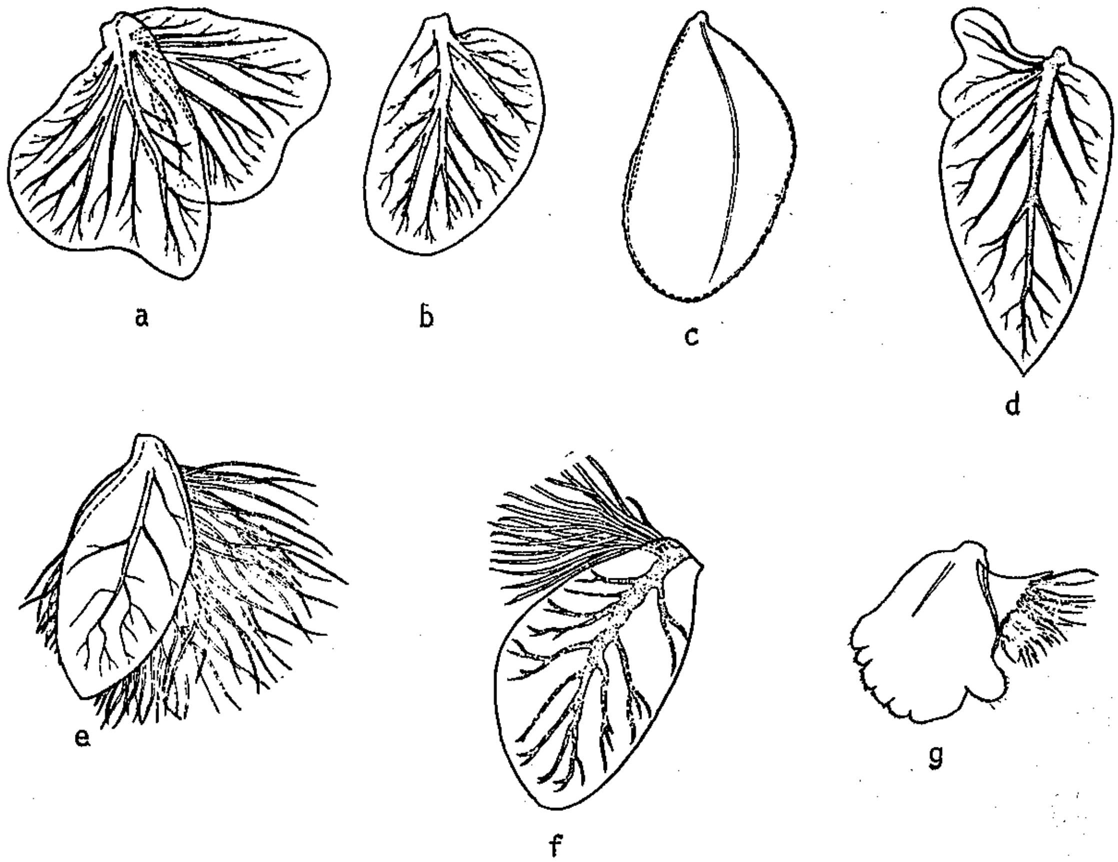


Fig. 26a-g. Appearance of gill fitting couplet 8b. (Burks, 1953).

Fig. 27a-d. Leptophlebiidae. Types of nymphal gills. (Burks, 1953).

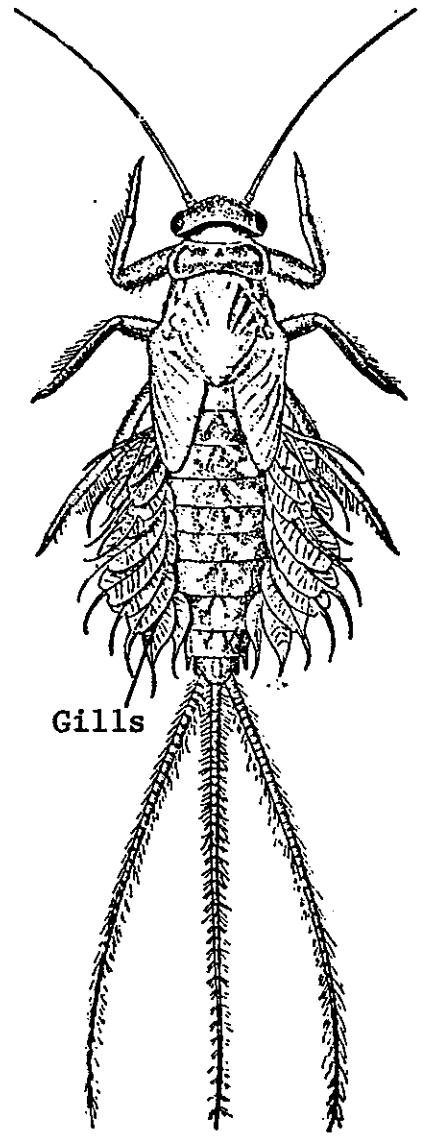


Fig. 28. Leptophlebiidae. Dorsal view of a nymph. (Burks, 1953).

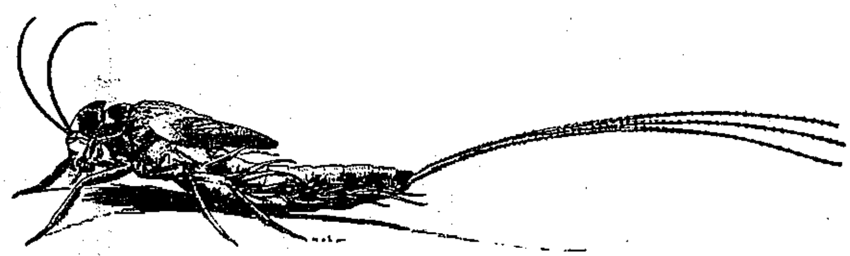


Fig. 29. Leptophlebiidae. Side view of a nymph. (Burks, 1953).

9a(8) Nymphs strongly flattened with eyes and antennae on the dorsal surface of the head (Fig. 30)....HEPTAGENIIDAE

9b Nymphs not flattened; eyes and/or antennae toward the lateral margin of the head....................10

10a(9) Claws on forelegs differ from those on middle and hind legs (Fig. 36)..........................AMETROPODIDAE

10b Claws on all legs similar...............................11

11a(10) Antenna short; length less than twice the width of the head, posterolateral angles of abdominal segments 8 and 9 prolonged into distinct, flattened, lateral spines (Fig. 31b); spines may be short, but then note the comb-like mouthparts (Fig. 33); front margin of labrum with a broad shallow emargination (Fig. 32a) ....SIPHLONURIDAE

11b Antenna long, length more than three times the width of the head; posterolateral angles of abdominal segments 8 and 9 without distinct, flattened, lateral spines (Figs. 31a, 34, 35); front margin of labrum with a distinct notch (Fig. 32b).................BAETIDAE

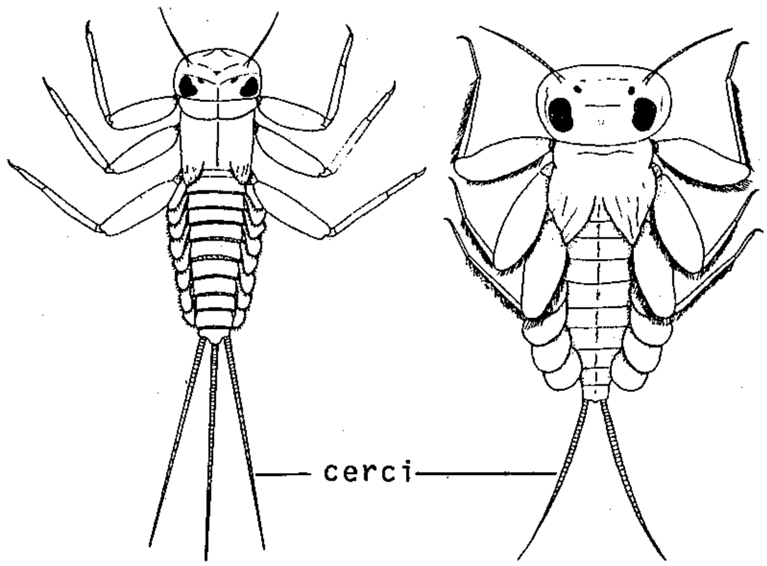


Fig. 30a,b. Heptaganiidae. Dorsal view of two nymph species. (Pennak, 1978)

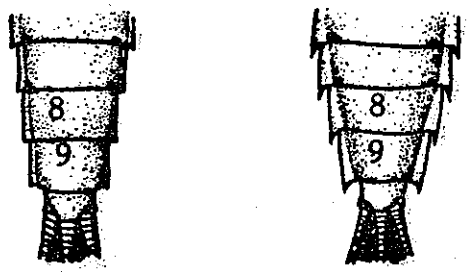


Fig. 31a,b. Posterior abdominal segments of two nymphs. a. Baetidae b. Siphlonuridae. (Burks, 1953).

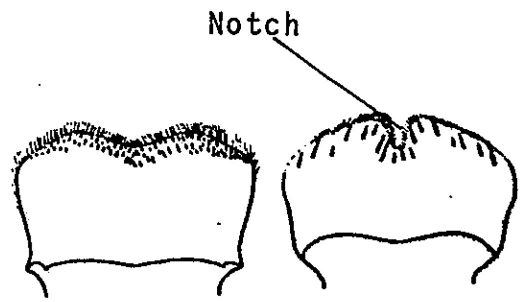
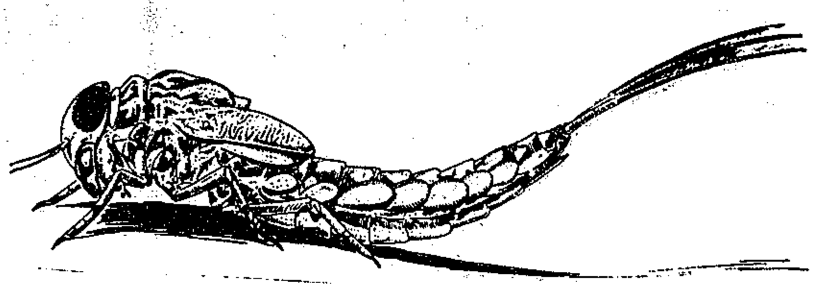


Fig. 32a,b. Labrums of two nymphs. a. Siphlonuridae b. Baetidae. (Burks, 1953).



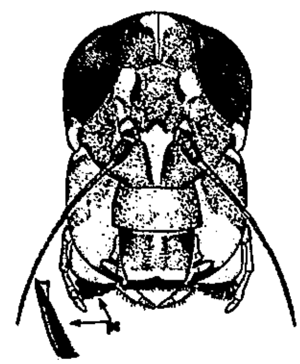


Fig. 33a,b. Siphlonuridae.
a. Side view of a nymph. (Burks, 1953).
b. Comb-like mouthparts. (Edmunds, Jr., et al, 1976).

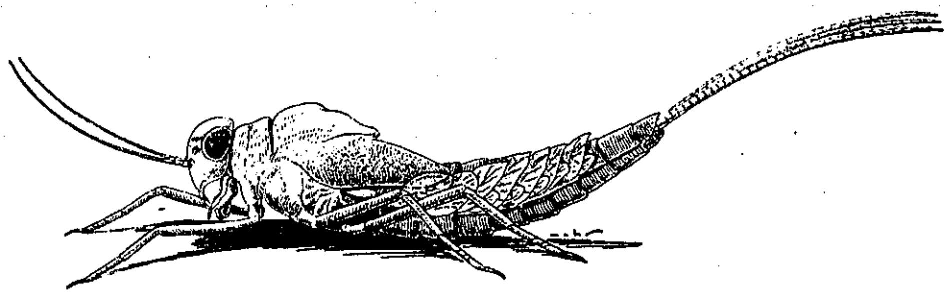


Fig. 34. Baetidae. Side view of nymph. (Burks, 1953).

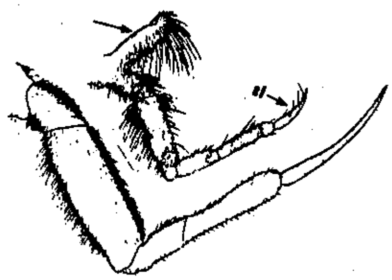


Fig. 36. Ametropodidae. Different claw structure on foreleg. (Edmunds, Jr., et al, 1976).

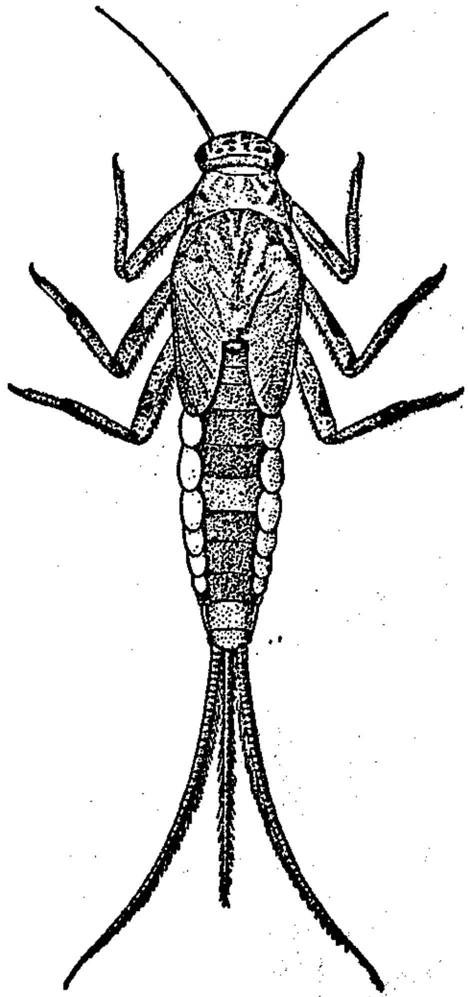
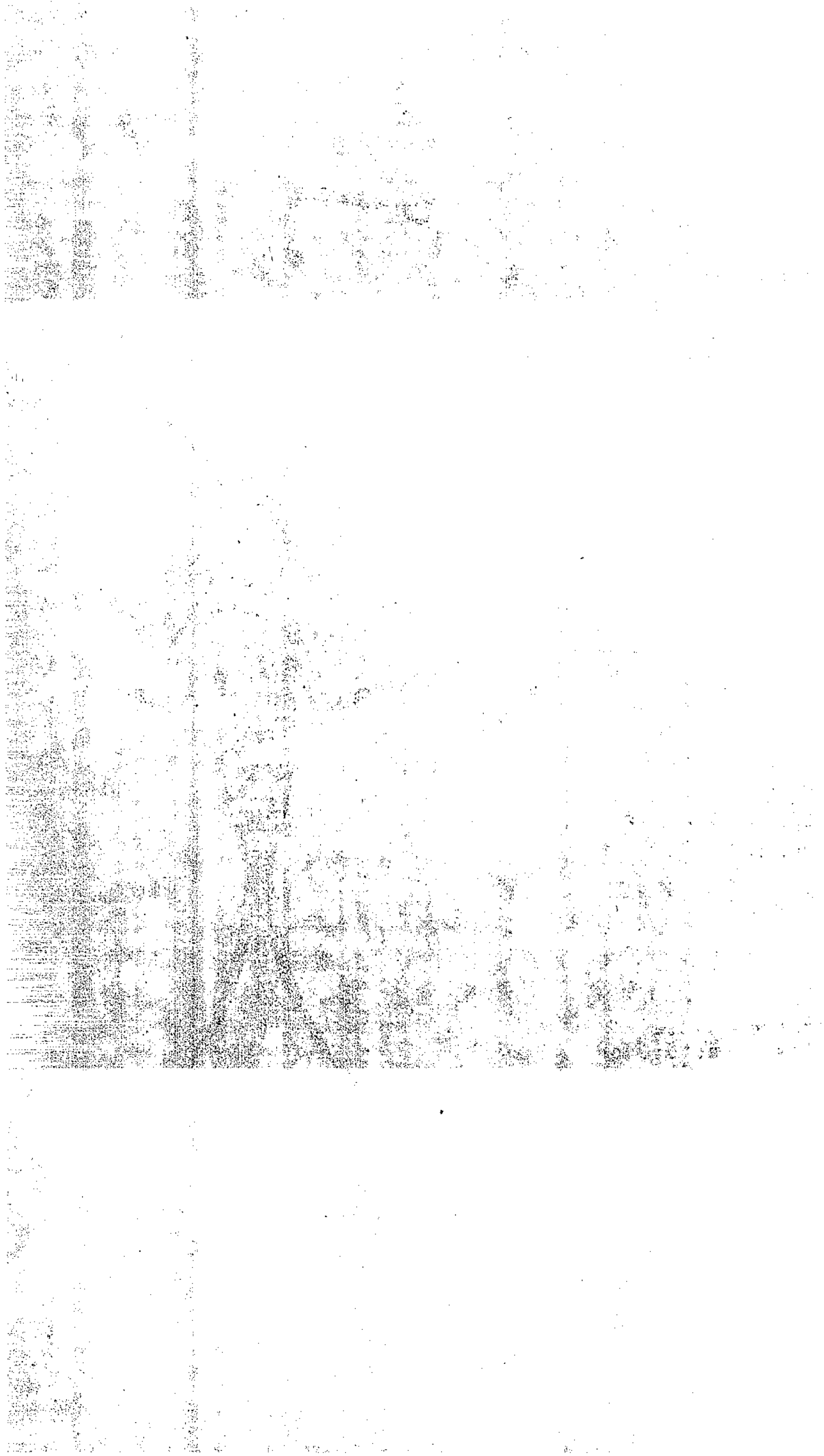
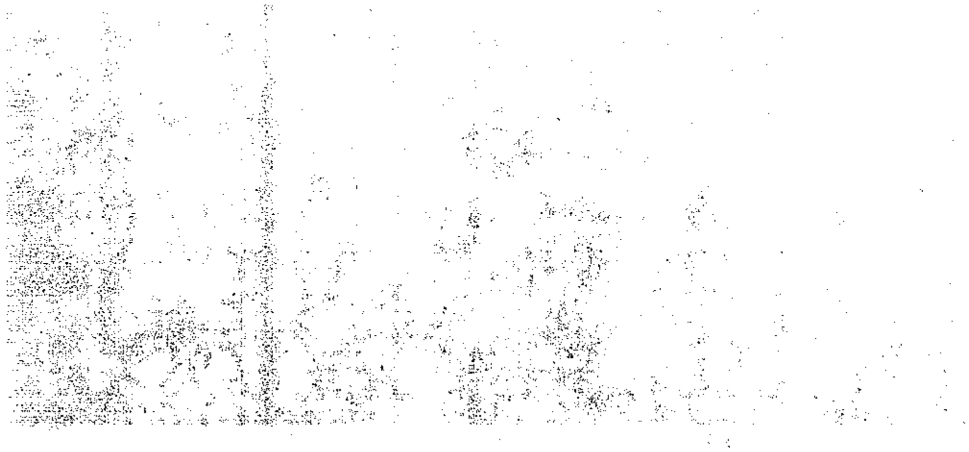
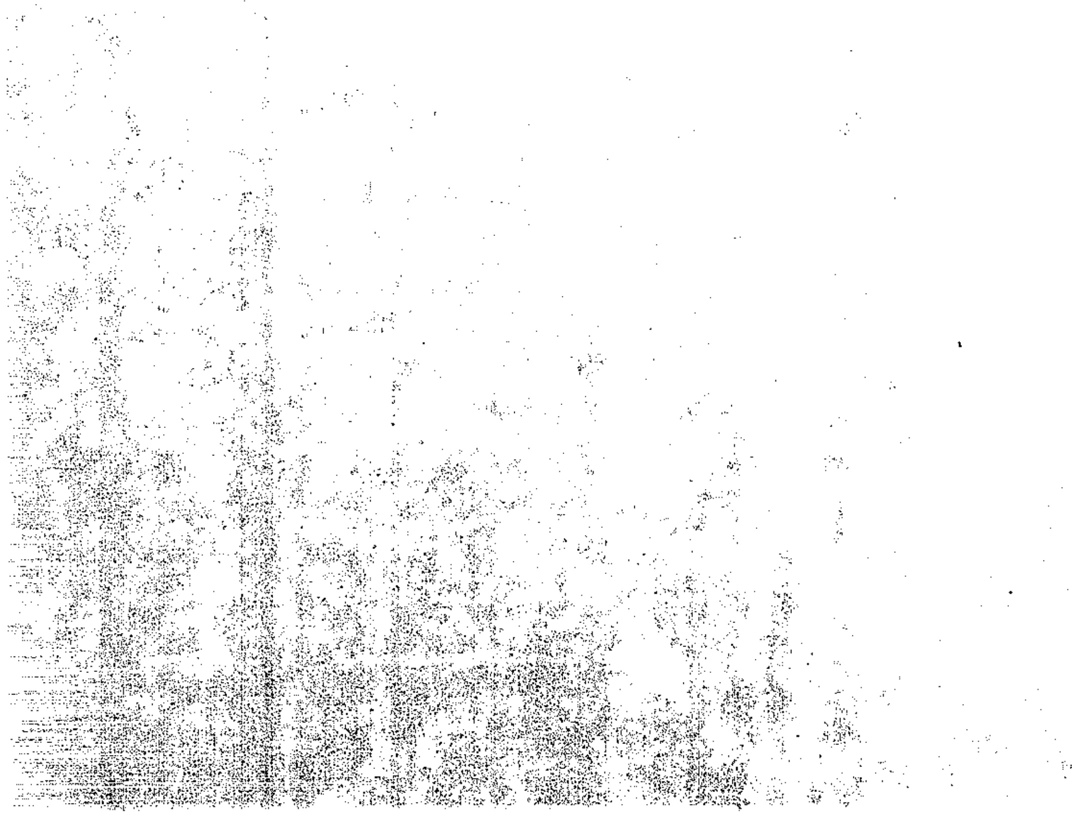


Fig. 35. Baetidae. Dorsal view of a nymph. (Burks, 1953).



KEY TO THE FAMILIES OF CALIFORNIA ODONATA (DRAGONFLIES)





Order: ODONATA (= toothed)
Common Name: Dragonflies and Damselflies

Dragonflies and damselflies are, perhaps, the best known of aquatic insects. They can be seen flying and darting erratically above the waters and shores of lakes, ponds, streams, and rivers. They are large and brightly colored in reds, blues and greens. There are many differences between dragonflies (suborder Anisoptera) and damselflies (suborder Zygoptera). "Damselflies are smaller, slender and more delicate. They are also slower and more uncertain in flight. In the dragonflies, the hind wings are broader at the base than the fore wings, whereas the two pairs of wings are similar in the damselflies" (Pennak, 1978). While at rest, the adult dragonflies usually hold their wings in a horizontal position, while the damselflies hold their wings in a vertical position or folded along the body. Because of their size, dragonflies and damselflies have been given many superstitous names such as mosquito hawk, devil's darning needle, snake doctor and horse stinger.

The immature forms or naiads of this order are all predacious. Some forms actively stalk their prey while others lie in ambush in the bottom debris. Naiads detect their prey by sight and may attack any organism small enough to handle. They have a very interesting method of capturing their prey. The labium, which is a modified food-gathering device, is very long (sometimes 1/4 of the body length) and usually lies folded back underneath the head and thorax with the middle hinge resting beneath the base of the legs. The distal end is enlarged and usually equipped with stout teeth and setae. They catch their prey by extending the labium and "grabbing" the organism. Naiads serve as an important food source for fish and are eaten to a lesser extent by frogs, birds, and other aquatic organisms.

Adult dragonflies and damselflies eat a variety of flying insects and have been known to eat trout fry. While in flight, they catch the insects and hold them with their legs. The adults are food for birds, frogs, lizards, spiders, and even other Odonata.

The eggs of this group are either deposited on objects in the water or simply dropped into the water. Usually the eggs hatch in 12 to 15 days. Depending on the species, the naiads may take from one to five years to develop.

Order: ODONATA

Synopsis of the California Families

Family: Calopterygidae (broad-winged damselflies)

Some species within this family are among the largest damselflies. Adults have wings that are colored from black to red and bodies that may be metallic green to brown. The naiads are camouflaged and remain clinging to the roots and stems of submerged aquatic plants. Members of this group are found along streams.

Family: Lestidae (spread-winged damselflies)

This family contains the largest damselfly species in North America. Members in this group are found along ponds, lakes, marshes, bogs, and slow flowing streams where there is abundant emergent aquatic vegetation. Adults are slow flying and have colorless wings. The adults can often be seen resting on vegetation near the water margin.

Family: Coenagrionidae (narrow-winged damselflies)

The small, clear-winged adults of this family have bodies of many colors including red, orange, black, blue, yellow, brown, and green. The naiads are usually green or brown. These damselflies can be found in a variety of habitats from ponds, lakes, and streams, to desert alkaline pools and brackish water. Some species prefer thick vegetation along streams while others are commonly found in open areas. Members of this group are common throughout North America.

Family: Gomphidae (clubtails)

This family derives its common name from the enlarged caudal end of the adult males. Adults are brown, yellow or black in color with clear wings. Adults and naiads are found in streams, ponds and lakes. The naiads are burrowers in the soft mud bottoms. This group ranges widely over North America.

Family: Petaluridae (graybacks)

This rare family of dragonflies has only two species in the United States. The only western species is found along small streams or boggy areas in mountain forests. The adults are gray or black in color. Naiads live in the bottom mud. The western species, Tanypteryx hageni, has been found in Northern California.

Family: Aeshnidae (darners)

The largest North American dragonfly, Anas walsinghami, is found in this family. This large species has a wing length to 125 mm and a body 250 mm long. It is found in California. Other adults in this family are large, strong fliers. Darners are usually found along ponds and lakes that have abundant aquatic vegetation. The naiads live among the aquatic plants and may take as long as three years to develop. The predaceous naiads have been known to stalk their prey and attack almost anything they come across including small fish and other naiads.

Family: Cordulegastridae (biddies)

This small, uncommon family of dragonflies usually occurs along small wooded streams. Adults are large, brown to black in coloration and covered with scattered yellow markings. The naiads lie buried in the mud of the stream bottom and have a thick hairy covering that is usually covered with silt and so makes them difficult to see. Naiads may take four years to develop.

Family: Macromiidae (belted skimmers, river skimmers)

These brown to black dragonflies are found along large rivers, lakes and boggy pond shores. The naiads live on the bottom and are well camouflaged. The adults are large, strong fliers. Some adults have bright green eyes.

Family: Libellulidae (common skimmers)

These common dragonflies are the ones most commonly seen around ponds and lakes. The adults are brightly colored and the naiads are usually camouflaged. The naiads are found in a variety of habitats from mud bottoms to thick growths of aquatic plants. Some species occur in brackish waters. Adults vary in size from about 2.5 cm to 10 cm long. This family of dragonflies is worldwide in distribution and common in California.

1a Three flat external gills at the end of the abdomen; head width greater than width of the thorax and abdomen (Fig. 37)...........ZYGOPTERA (Damselflies).. 2

1b No flat external gill at the end of the abdomen; head width about the same width as the thorax and abdomen (Fig. 38)..................ANISOPTERA (Dragonflies).. 4

2a(1) First antennal segment as long as or longer than the 6 following segments combined (Fig. 39)......CALOPTERYGIDAE

2b First antennal segment much shorter than the 6 following segments combined (Fig. 37)................ 3

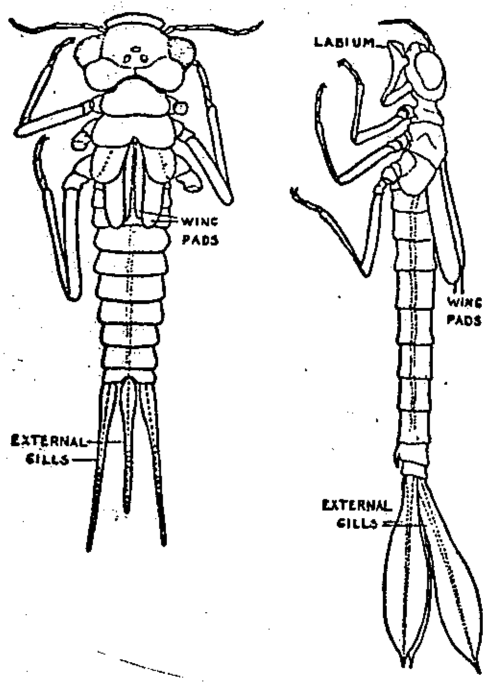


Fig. 37a,b. Zygoptera. Coenagrionidae. a. Dorsal view of naiad. b. Side view of a naiad. (Wright and Peterson,1944).

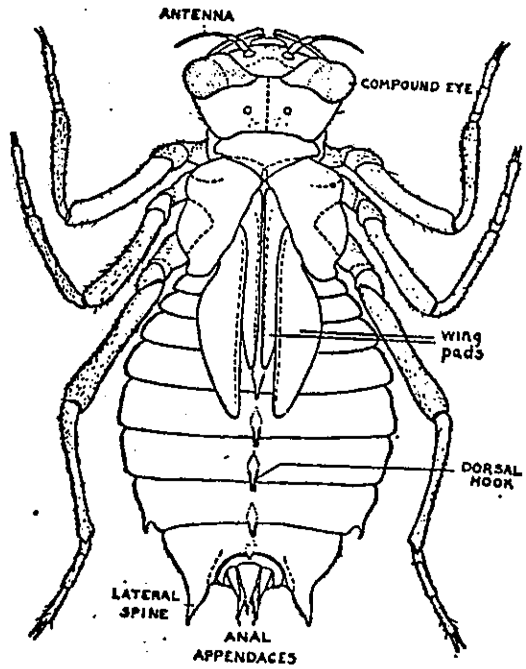


Fig. 38. Anisoptera. Libellulidae. Dorsal view of a naiad. (Wright and Peterson,1944).

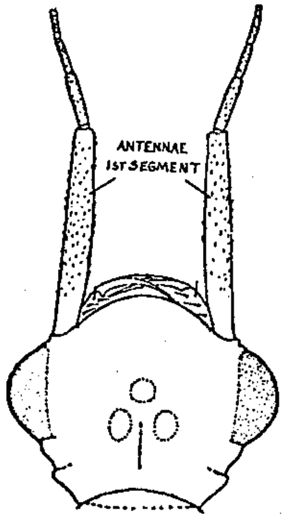


Fig. 39. Calopterygidae.
Dorsal view of naiad head.
(Wright and Peterson,1944).

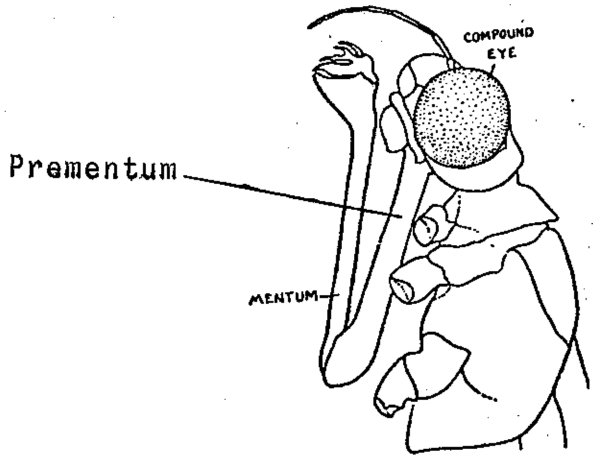


Fig. 40. Lestidae.
Side view of the head
and thorax of a naiad.
(Wright and Peterson,1944).

3a(2) Prementum when folded along the thorax reaches to the base of the second pair of legs or beyond (Fig. 40) ....LESTIDAE

3b Prementum when folded along the thorax reaches just beyond the first pair of legs but not to the second pair (Fib. 37b)..............................COENAGRIONIDAE

4a(1) Labium flat or nearly so (Fig. 41).................... 5

4b Labium spoon-shaped and covering the face to the base of the antennae (Fig. 42)................ 7

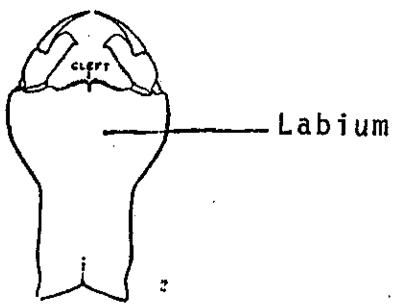


Fig. 41. Aeshnidae.
Dorsal view of labium.
(Wright and Peterson,1944).

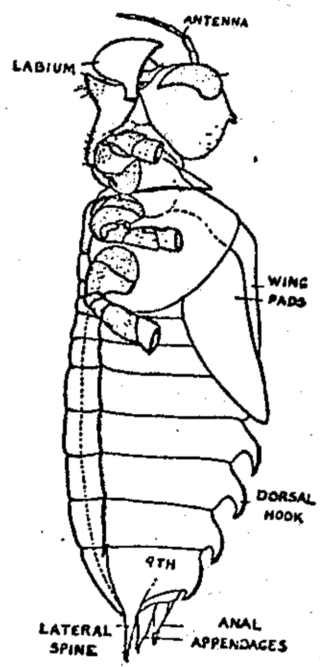


Fig. 42. Libellulidae.
Side view of a naiad.
(Wright and Peterson,
1944).

5a(4) Antennae with 6 or 7 segments (Fig. 44).............. 6
5b Antennae with 4 segments (Fig. 43)................GOMPHIDAE

6a(5) Antennae with a thick covering of setae (Fig. 44b) ....PETALURIDAE
6b Antennae without a thick covering of setae (Fig. 44a) ....AESHNIDAE

7a(4) Labium with large, irregular, deeply incised teeth on lateral lobes (Fig. 45)..................CORDULEGASTRIDAE
7b Labium with lateral lobe smooth or with small even teeth (Fig. 46)..............................LIBELLULIDAE

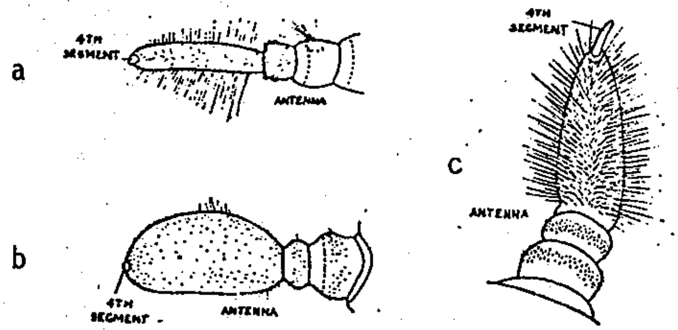


Fig. 43a-c. Gomphidae. 4-segmented antennae. (Wright and Peterson,1944).

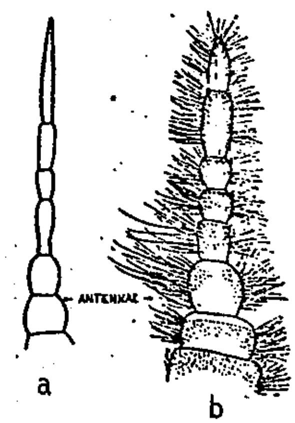


Fig. 44a,b. 6 and 7-segmented antennal types.
a. Aeshnidae
b. Petaluridae
(Wright and Peterson,1944).

Fig. 45. Cordulegastridae. Lateral lobe of a naiad. (Wright and Peterson,1944).

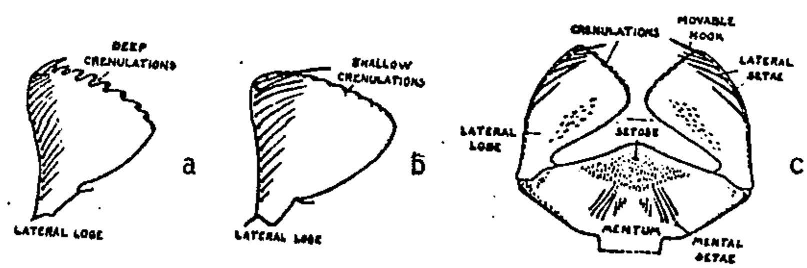


Fig. 46a-c. Libellulidae. Lateral lobe types. (Wright and Peterson,1944).

Order: ORTHOPTERA (= straight-winged)
Common Name: Grasshoppers and Crickets

Family: Tridactylidae (pigmy molecrickets)

Members of this family are semiaquatic in habit. Very little is known about these rather rare crickets. They are known from California. Molecrickets seldom exceed 10 mm in length. They inhabit the margins of streams and lakes where they burrow in the moist sand. The femora are greatly enlarged and the front tibia is expanded for digging. The hind tibia has special plates that are modifications for swimming. One author mentions that they can jump about on the water surface. This is the only aquatic family in the order.

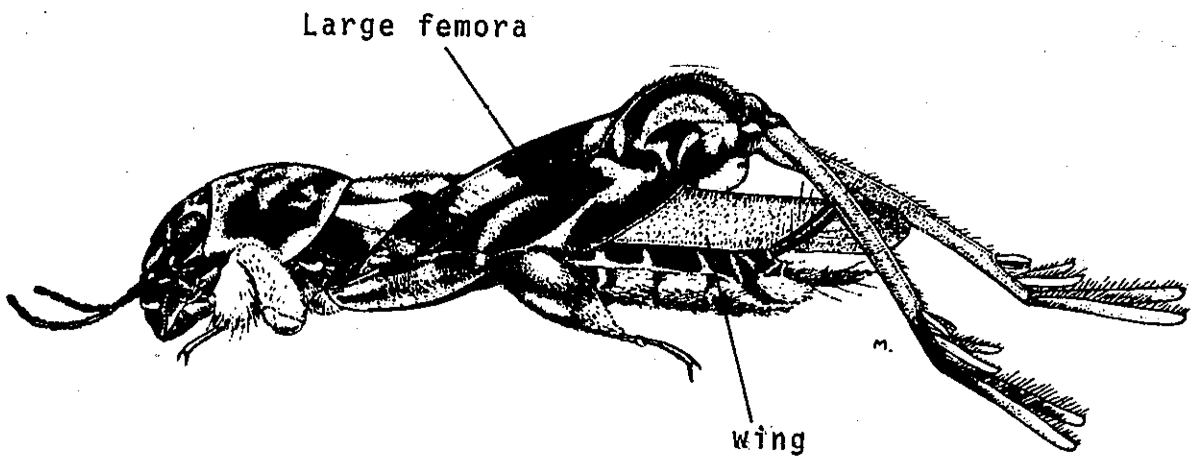
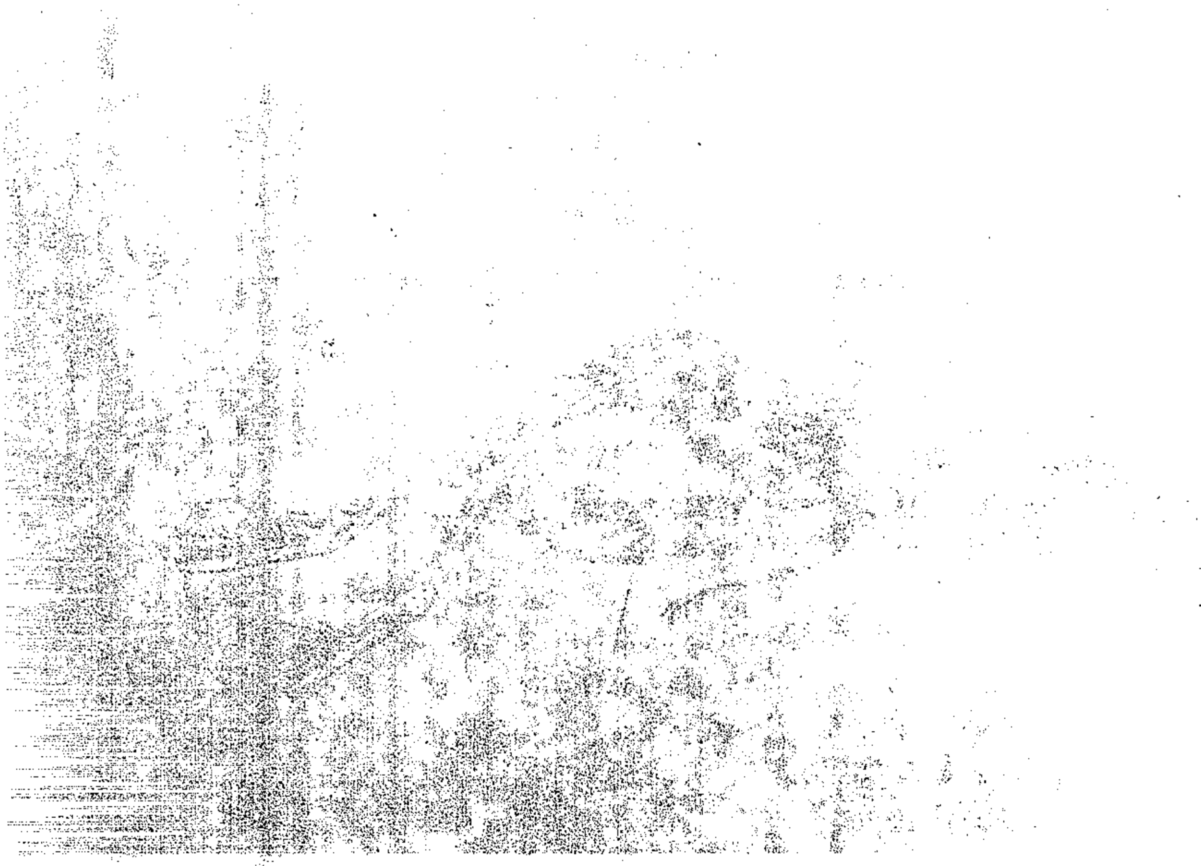
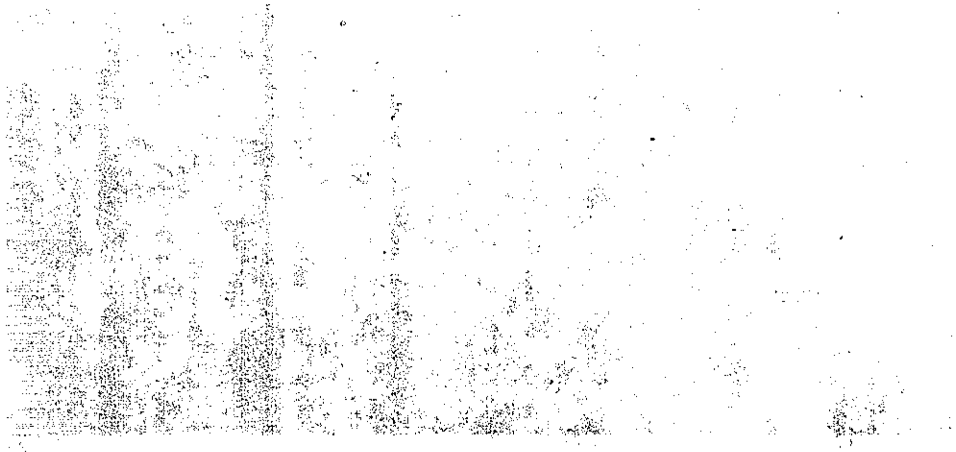
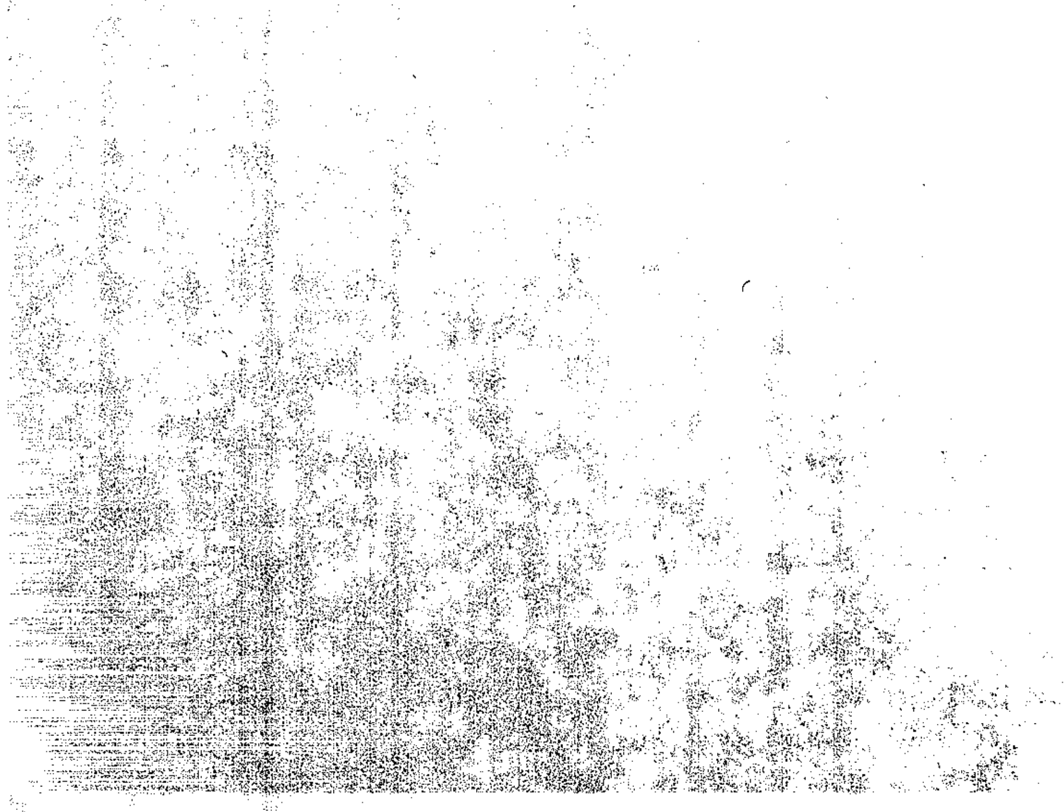


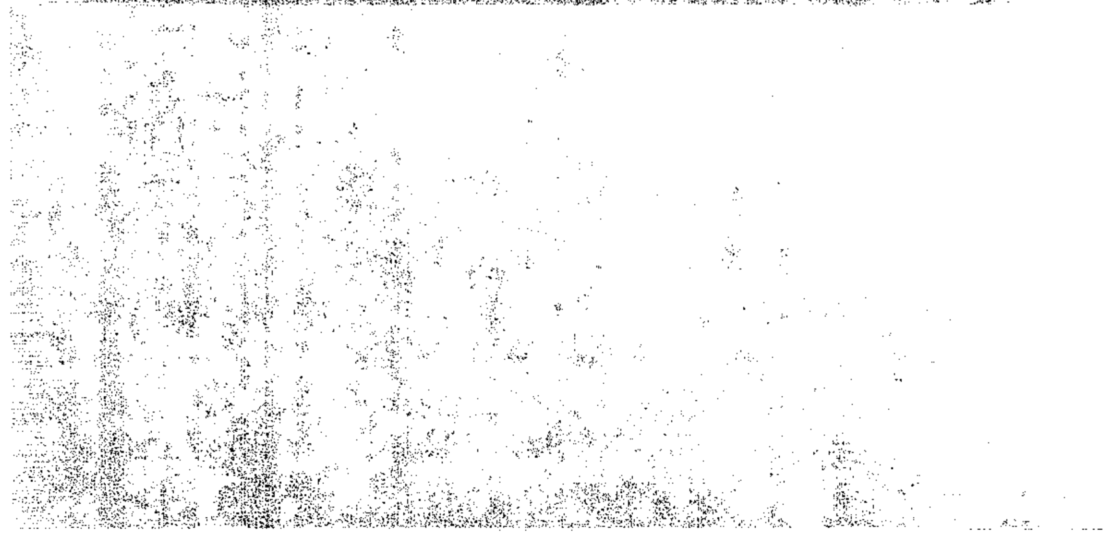
Fig. 47. Tridactylidae.
Lateral view of a molecricket
(Merritt and cummins, 1978).



KEY TO THE FAMILIES OF CALIFORNIA PLECOPTERA (STONEFLIES)







Order: PLECOPTERA
Common Name: Stoneflies

Stoneflies are worldwide in distribution. The majority of species occur in well-oxygenated streams and rivers, a few occur along the margins of cool, wave-washed oxygen enriched lakes. There is one unique species that spends its entire lifetime in depths greater than 50 meters in Lake Tahoe. Stonefly nymphs can be found under rocks, gravel and among detritus on stream bottoms. Adult stoneflies are poor fliers and can usually be found resting on objects near the shores of streams or lakes.

Two distinct groups of stoneflies are recognized. The vegetarian and omnivorous stoneflies (suborder Filipalpia) feed on algae and detritus and are usually diurnal in activity. The carnivorous stoneflies (suborder Setipalpia) feed on aquatic organisms such as mayfly numphs and Diptera larvae and are usually nocturnal in activity. Stoneflies are a major food source for fish, especially trout.

Adult stoneflies, when at rest, have their long wings folded over their backs. Some species have reduced or rudimentary wings. The body is elongated, fairly flattened, medium to large, and primitively structured. Stoneflies are usually yellow, tan, blackish or brown. There are 10 abdominal segments, but the last segment may be reduced or hidden. The abdomen ends in two segmented cerci. The broad head has long, slender antennae.

Eggs are deposited in several ways. They may be dropped into the water while in flight or deposited on the water surface. In some cases, the female may actually crawl underwater to deposit them. The females of some species may lay over 1000 eggs.

Stonefly nymphs take from one to three years to develop, but the normal period is one year. In temperate climates, nymphs emerge from November to August. Newly emerged adults from the family Nemouridae can be found, in California, crawling over the snow near streams in the winter.

Order: PLECOPTERA

Synopsis of the California Families

Family: Pteronarcidae (giant stoneflies)
Stoneflies in this family may reach 65 mm in length. Members in this group can be found in rivers where the nymphs feed on plant material. The adults can be found during the spring and summer months. This family is restricted to North America, Siberia and China.

Family: Peltoperlidae
Little is known about this uncommon family. Members in this group are known to occur in North America and eastern Asia. The nymphs are roachlike in appearance.

Family: Nemouridae (spring, winter, and rolled-winged stoneflies)
Members of this family occur throughout the world and are found in streams and rivers. The nymphs of all species are herbivorous as are the adults. Some adults feed on flowers and others on algae. Adults can be found from November through June depending on the species. Adults range up to 15 mm in length.

Family: Perlidae (common stoneflies)
Some species in this family reach 40 mm in length and are the most common of the stoneflies. Nymphs in this family are usually carnivorous. This family is the largest in the order and members are found worldwide.

Family: Chloroperlidae
Adults are yellow to green in color and 6 to 24 mm in length. The adults can be found during the spring months. Nymphs occur in small streams.

Family: Perlodidae
Some species in this family are common. Nymphs are found in streams of various types and adults can often be seen scurrying over vegetation at the water's margin. The adults range up to 25 mm in length.

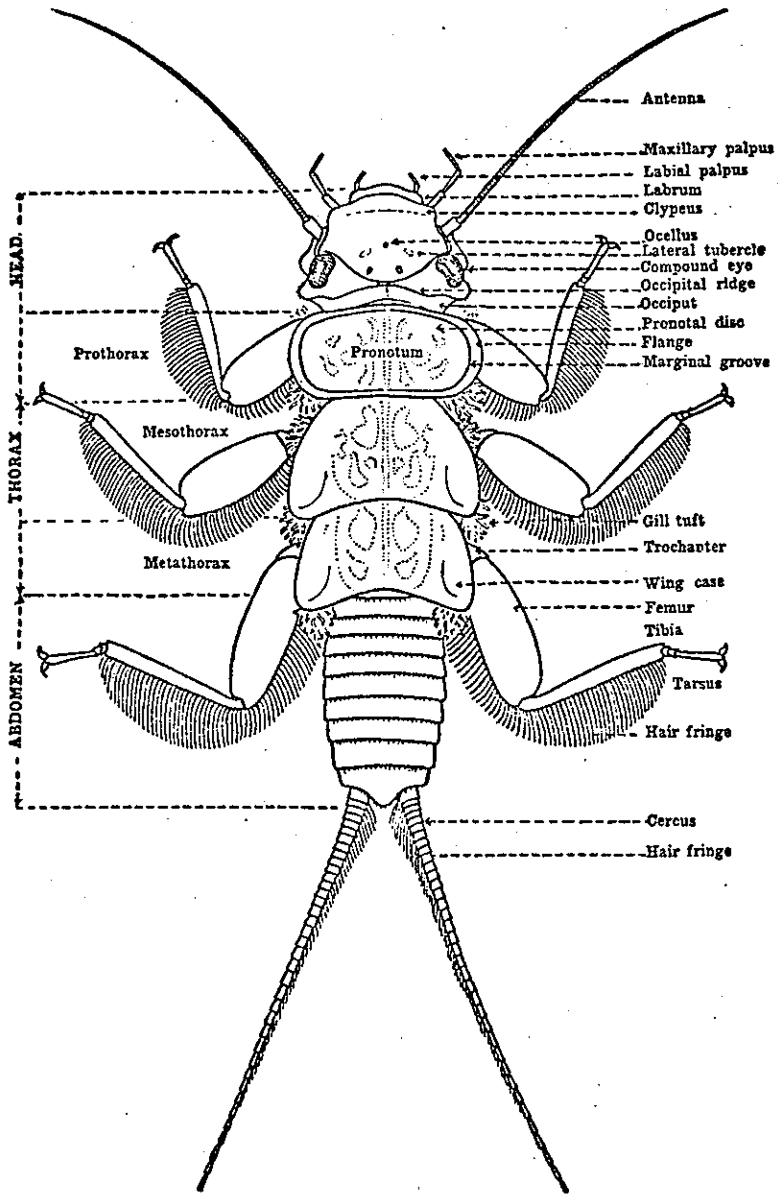


Fig. 48. Dorsal view of a stonefly nymph showing the structures used in classification. (Claassen, 1931).

1a Glossae and paraglossae about equal length (Fig. 49)... 2
1b Glossae much shorter than paraglossae in length (Fig. 50).. 4

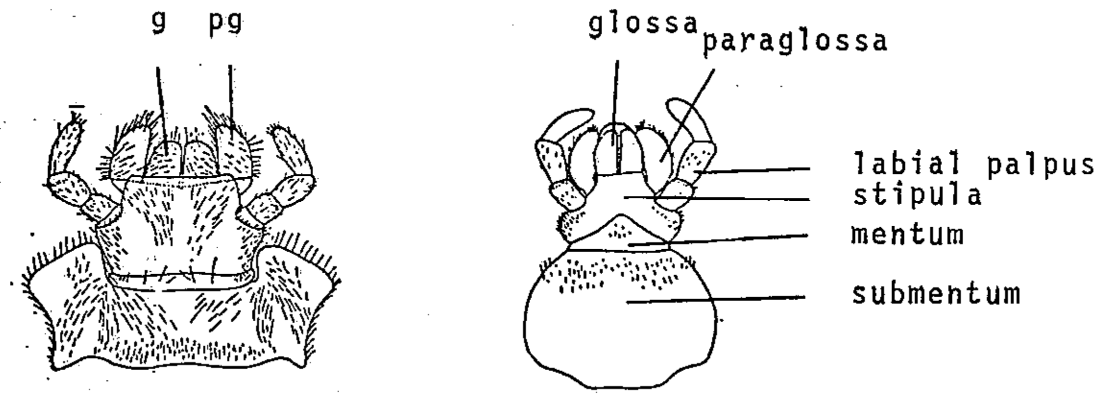


Fig. 49a,b. Appearance of the labium with the glossae and paraglossae of equal length. (Claassen, 1931).

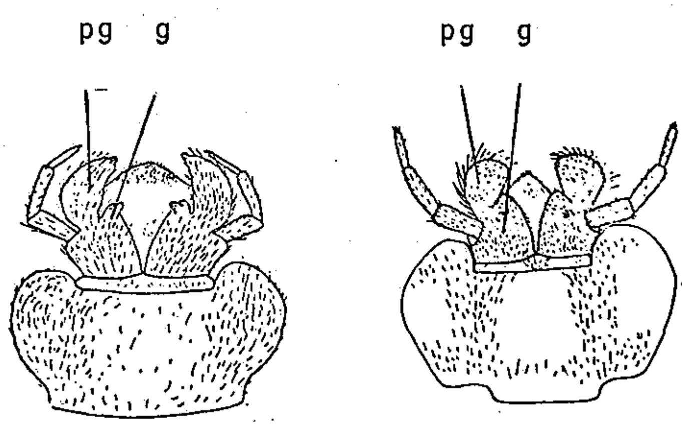


Fig. 50a,b. Appearance of the labium with the glossae shorter than the paraglossae. (Claassen, 1931).

2a(1) Branched gills present on the ventral side of abdominal segments 1 and 2, sometimes 3 (Fig. 51) ....PTERNOARCIDAE

2b Branched gills absent from the ventral side of the abdomen...................................... 3

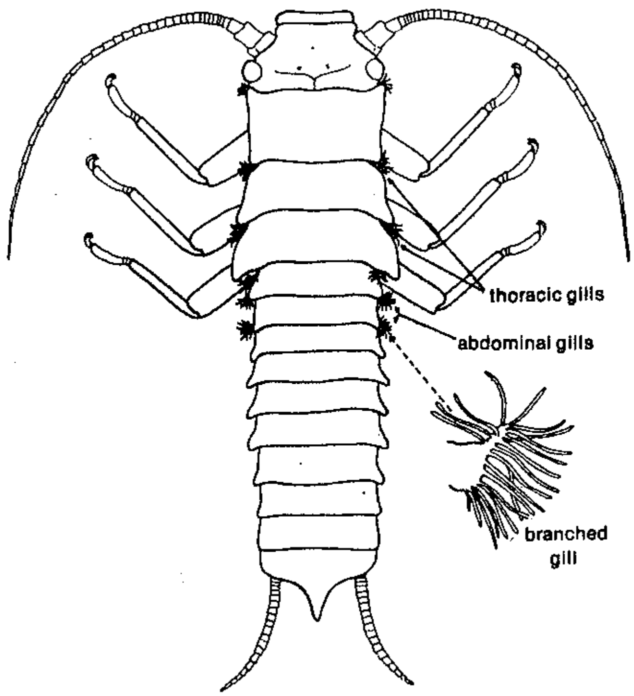


Fig. 51. Pteronarcidae. Dorsal view of a nymph. (Merritt and Cummins, 1978).

3a(2) Two ocelli; thoracic sterna produced posteriorly to overlap the segment behind (Fig. 52).......PELTOPERLIDAE

3b Three ocelli; thoracic sterna not produced posteriorly (Fig. 53)..........................NEMOURIDAE

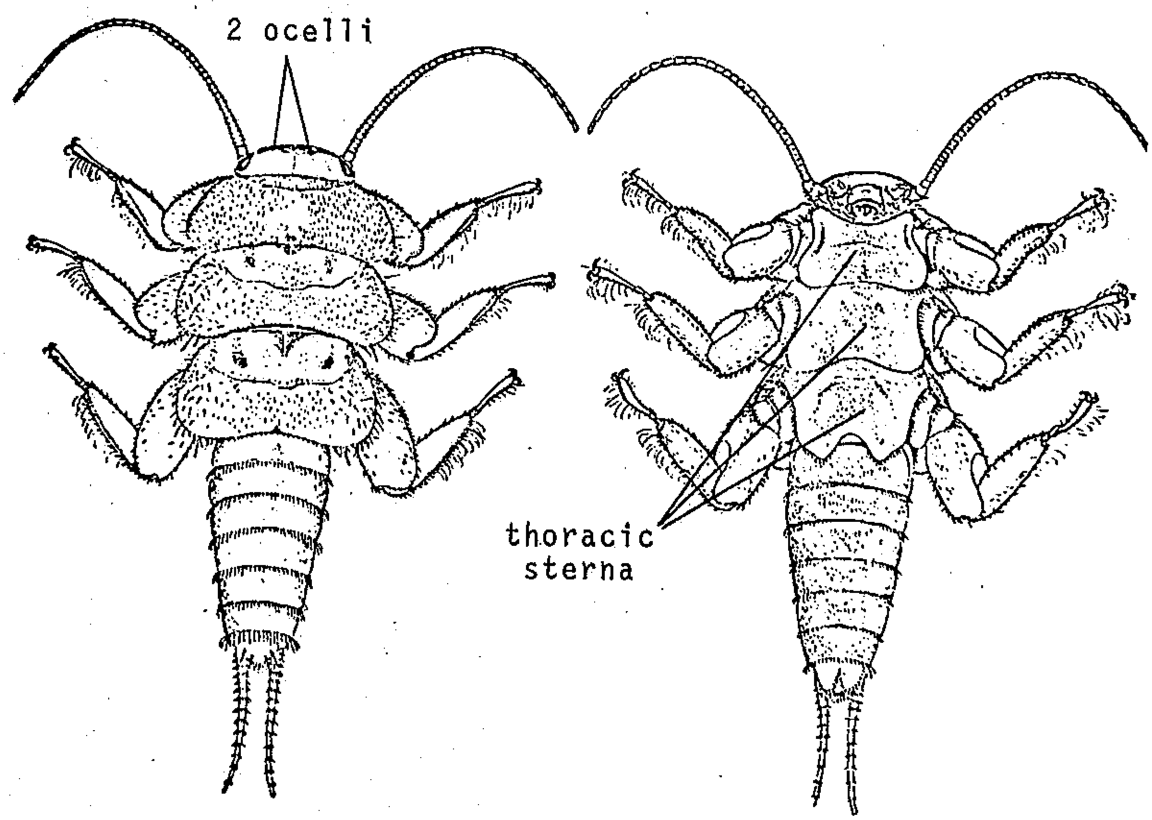


Fig. 52a,b. Peltoperlidae. Dorsal (a) and ventral (b) view of a nymph. (Claassen, 1931).

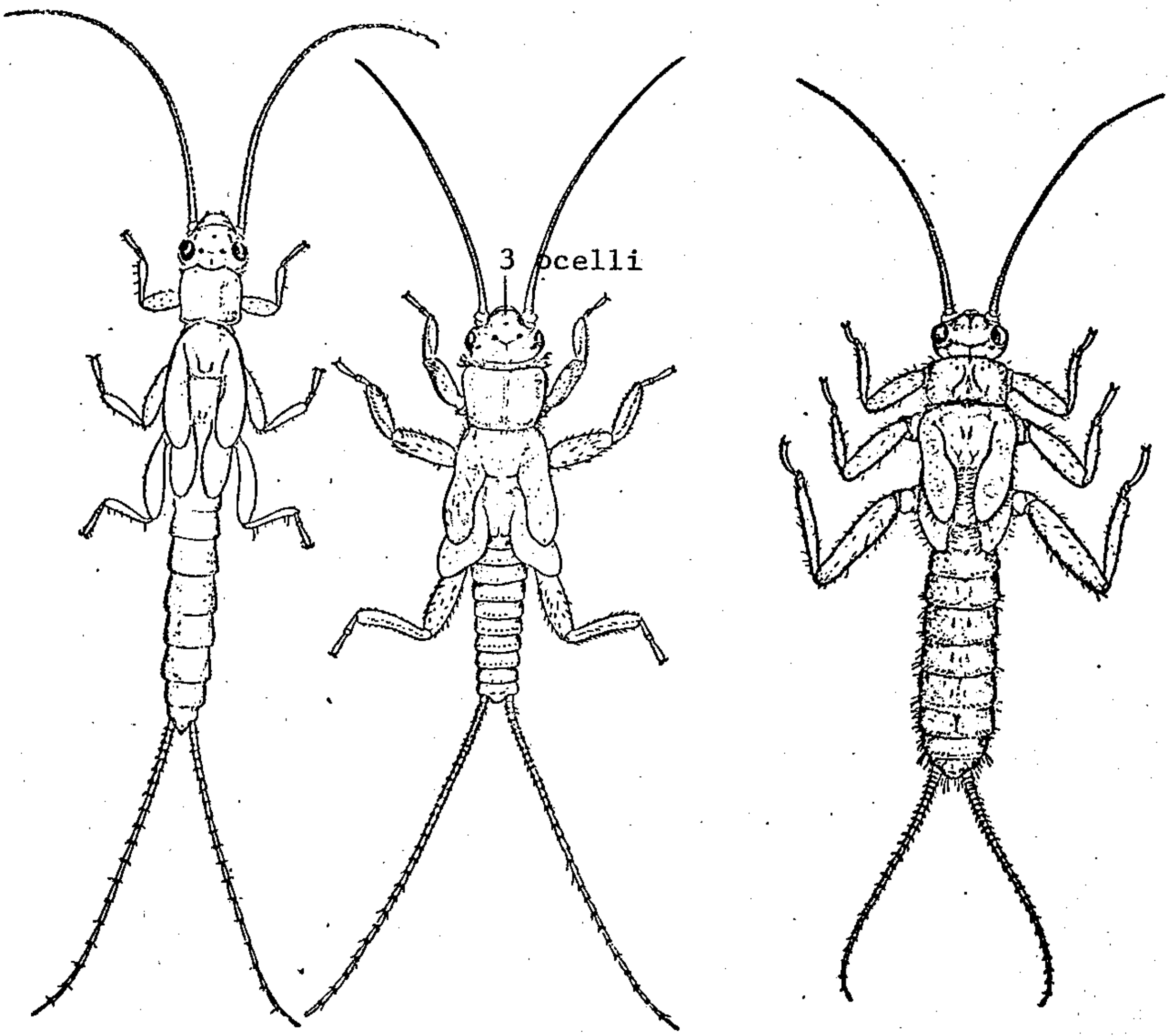


Fig. 53a-c. Nemouridae. Dorsal views of three different species of nemourid nymphs. (Claassen, 1931).

4a(1) Profusely branched gills at the lower corner of the thorax (Fig. 54)...............................PERLIDAE

4b Branched gills absent from the thorax................ 5

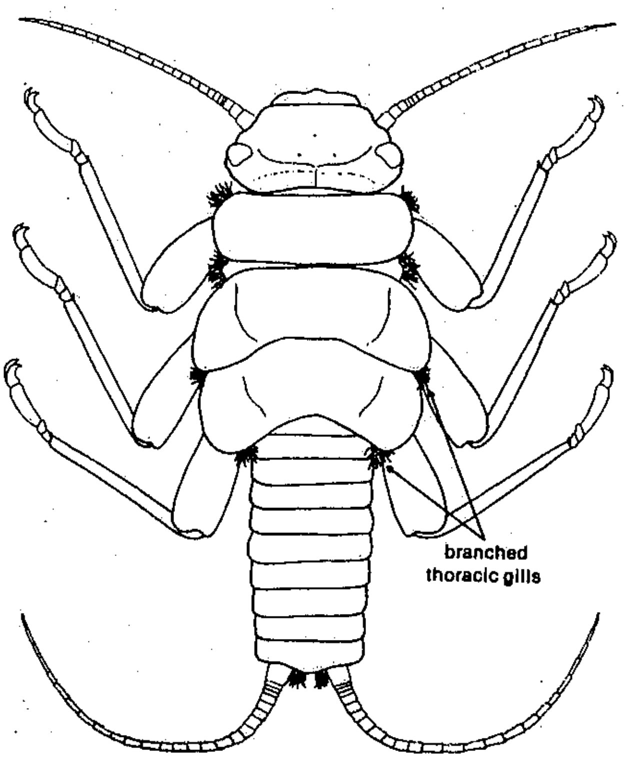


Fig. 54. Perlidae. Dorsal view of a nymph. (Merritt and Cummins, 1978).

5a(4) Hind wing pads set nearly parallel to the axis of the body; cerci not more than 3/4 the length of the abdomen (Fig. 55).........................CHLOROPERLIDAE

5b Hind wing pads set at an angle to the axis of the body; cerci usually as long or longer than the abdomen (Fig. 56)............................PERLODIDAE

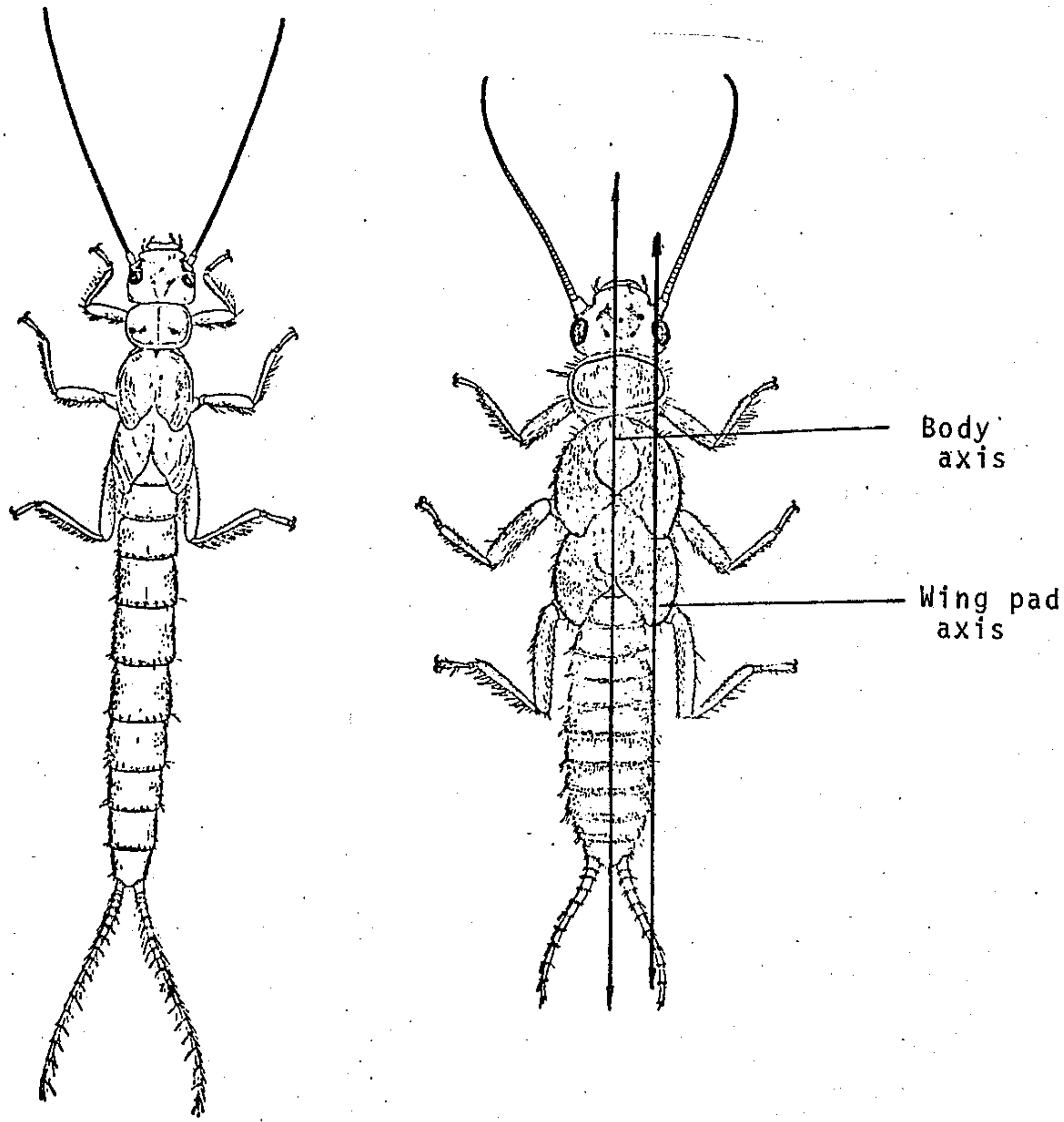


Fig. 55a,b. Chloroperlidae. Dorsal view of two chloroperlid species of nymphs. (Claassen, 1931).

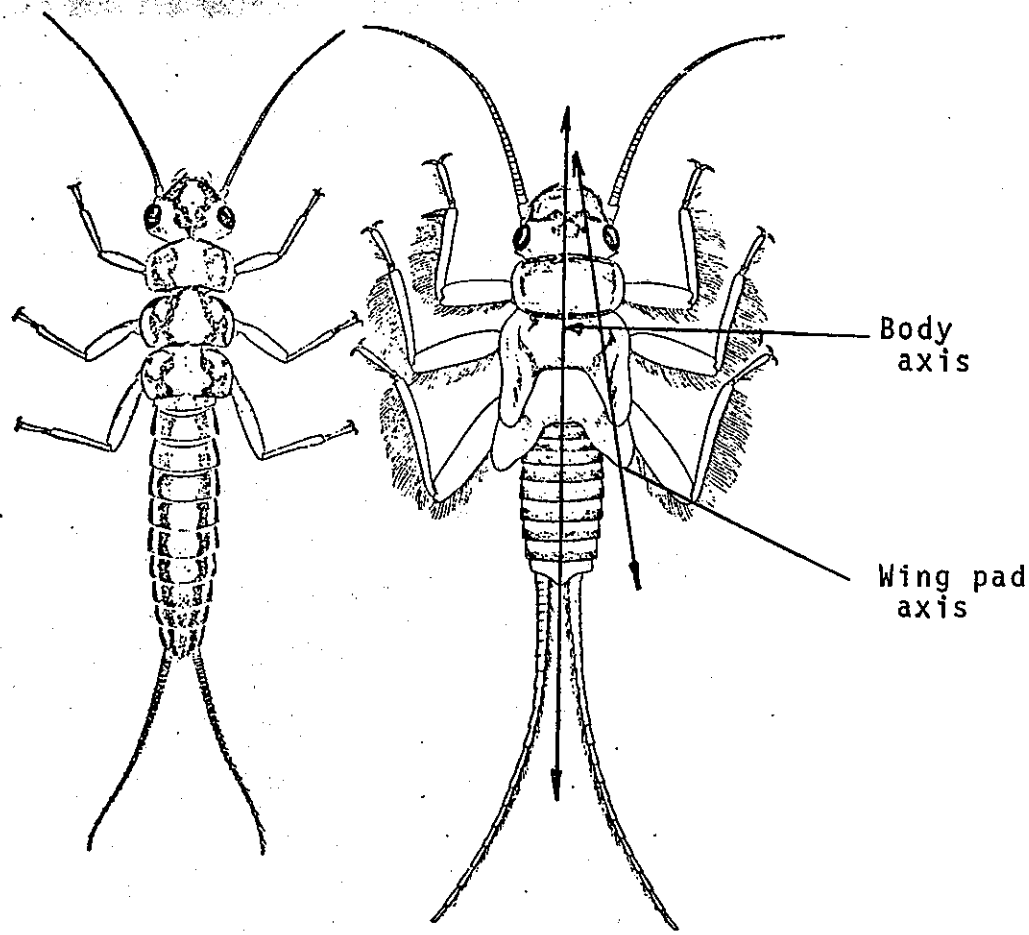
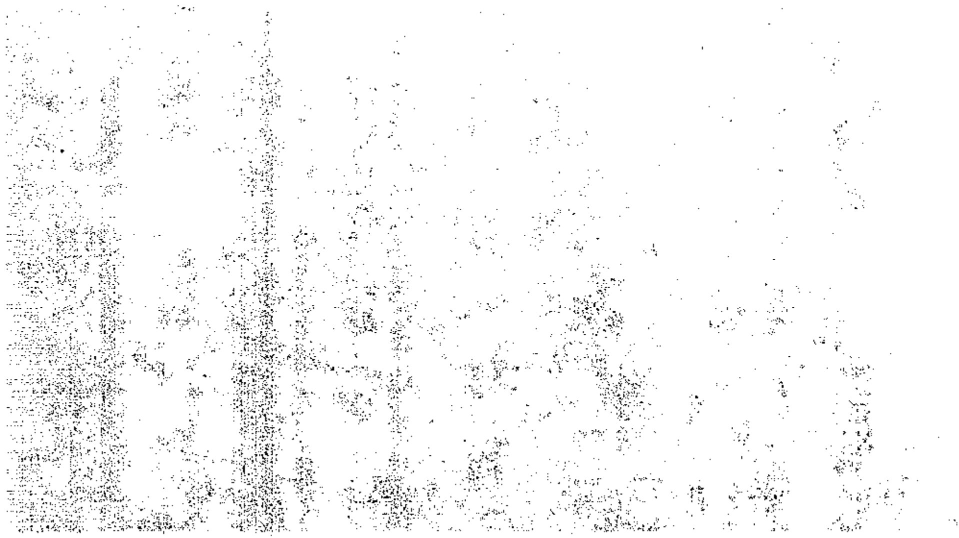
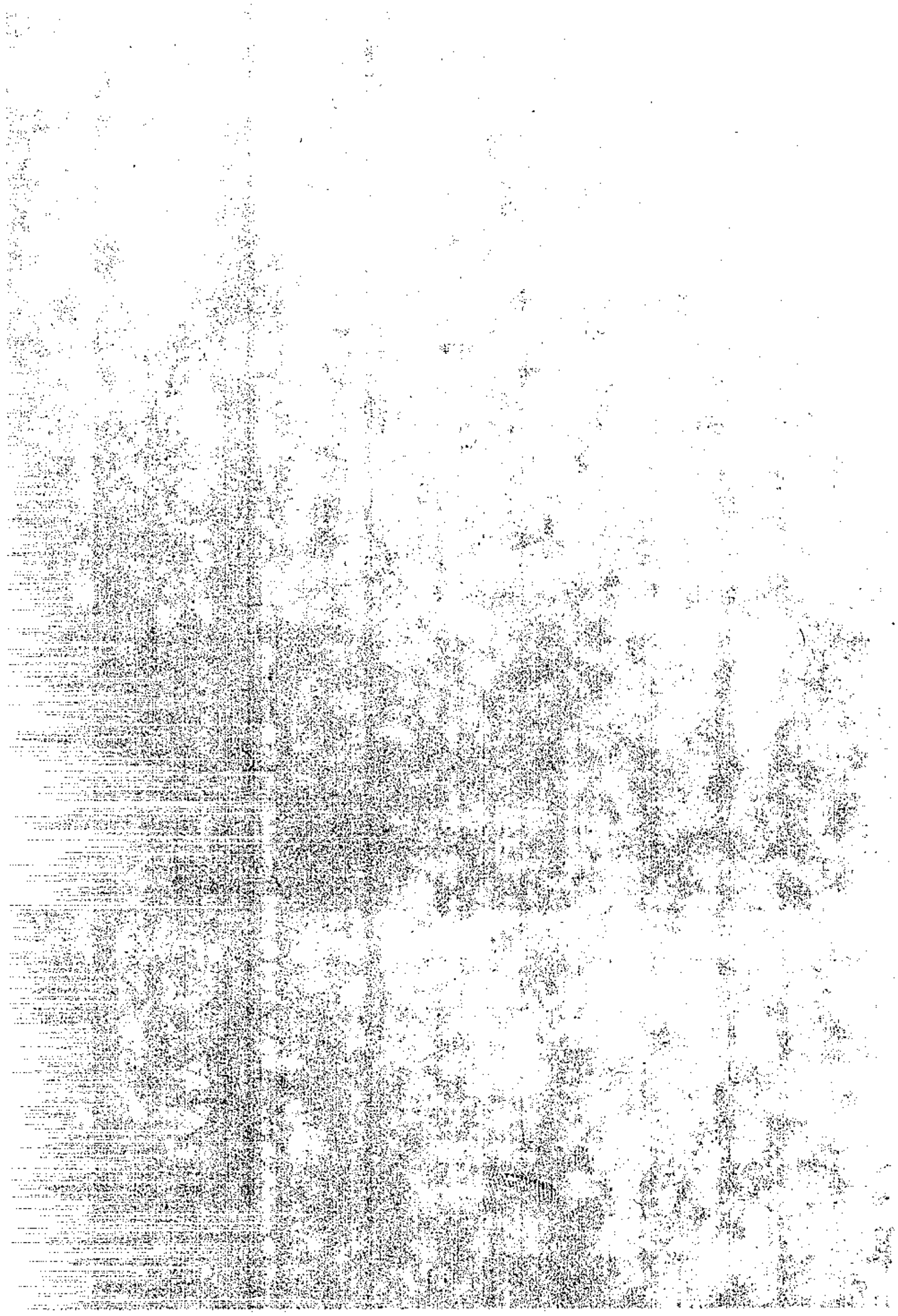


Fig. 56a,b. Perlodidae. Dorsal view of two perlodid species of nymphs. (Claassen, 1931).

KEY TO THE FAMILIES OF CALIFORNIA HEMIPTERA (TRUE BUGS)





Order: HEMIPTERA (= half-winged)
Common Name: True bugs

The Hemiptera are found in a variety of habitats all over the world. Water bugs are known from desert hot springs, saline lakes, the open ocean, freshwater streams, rivers, ponds, and lakes. Most Hemipterans have in common sucking mouthparts in the form of a three to four segmented beak, which they use for piercing the body of their prey and sucking the body fluid. All water bugs are predacious to some extent. They feed primarily on aquatic and terrestrial insects, but also on other aquatic organisms.

Water bugs usually overwinter as adults and lay their eggs in the spring. The female attaches the eggs to objects underwater, and in some species to the backs of the males. Some members of the family Corixidae deposit eggs on crayfish, snails and dragonfly nymphs.

Hemipterans range in size from very small to very large and vary in shape from oval to long and cylindrical. Some are also flattened.

Most Hemipterans can fly but some have lost their wings, and other species have members with or without wings. Sound production is also known for a few species.

Not all Hemipterans have become fully adapted to aquatic habitats. Some species live on the shore, running, jumping and taking short flights but usually landing in the water only by accident. Others run around on the damp shores, floating vegetation close to shore, or on the surface of the water. Another group can be found further out in the water on algae and plant rafts. The six truly aquatic families are found below the surface.

Some families are considered economically important, while others are great nuisances. A family that is a relished food item in Mexico (under the name of Auhutle) is also used as food for fish and turtles. Another family is considered a delicacy in Asia. Biting forms of some families are attracted to lights and are pests in swimming pools. Another family can be a nuisance in fish hatcheries.

Water bugs obtain their air for respiration from the surface. They cannot remain underwater for long periods of time without returning to the surface to secure a new air supply. One hundred seventeen species of Hemipterans are known from California.

Order: HEMIPTERA

Synopsis of the California Families

Family: Gelastocoridae (toad bugs)
Members of this family are worldwide in distribution and can be found along the sandy or muddy margins of streams and ponds. The family derives its common name from the hopping motion of some of its members. Toad bugs are predaceous on other insects.

Family: Corixidae (water boatmen)
Water boatmen comprise a large, common family found throughout the world. These bugs occur in a variety of habitats including the ocean, brackish waters, inland saline lakes, freshwater ponds, lakes, and slow flowing streams. Water boatmen have been recorded from below sea level to near 15,000 feet. Bugs in this family are primarily omnivorous, feeding on algae, protozoans and aquatic insects. Corixids often are an important food item in the diets of fish, and in some areas of the world they are eaten by man.

Family: Notonectidae (backswimmers)
Backswimmers, as the common name implies, swim and float on their backs with their heads pointed down into the water. These bugs can be found in slow flowing streams, lakes, ponds and stagnant pools. Backswimmers are predaceous and feed on anything they can handle including other aquatic insects, crustacea and small fish. If not handled carefully, they can give a sharp bite similar to a bee sting. Some members of this family make chirping sounds. These insects are found worldwide.

Family: Nepidae (water scorpions)
Water scorpions resemble the terrestrial "walking sticks". These rather uncommon water bugs are voracious predators and feed on crustacea, aquatic insects and even small fish. Water scorpions are usually found in a tangle of aquatic vegetation in ponds where they lie in ambush for their prey. They can inflict painful bites. The eggs of these bugs are inserted into plant tissues for development.

Family: Belostomatidae (giant water bugs, toe biters)
Large species in this family reach 50 mm in length. The term toe biter refers to the painful bite they can inflict to the unwary individual. Giant water bugs inhabit ponds and occasionally the back eddies of slow flowing streams where they hide among the vegetation. As predators they feed on aquatic insects, crustacea, arthropods, and fish. Females of some genera lay their eggs on the backs of males, who in turn carry them around until they hatch. Some species when removed from the water become rigid and feign death. In Asia, giant water bugs are used for food by man.

Family: Naucoridae (creeping water bugs)
These bugs are found in streams, rivers, ponds, lakes, hot springs, and desert saline waters. Creeping water bugs are predators that feed on a variety of aquatic invertebrates. These bugs can give a painful bite. The eggs are deposited on stones in the shallows of lakes and streams.

Family: Ochteridae
These rather rare shore bugs occur along the margins of ponds and slow flowing streams. The adults are predaceous. The eggs of one eastern species are deposited on plants or debris along the water margin. The immature stages are reported to camouflage themselves by carrying sand grains on their bodies.

Family: Hydrometridae (marsh treaders)
These delicate water bugs occur in or near the aquatic vegetation of ponds. Marsh treaders often walk across the surface of the water. They feed on aquatic insects and other aquatic invertebrates. The eggs of these bugs are attached to objects just above the water surface. Marsh treaders are found over most of the United States.

Family: Gerridae (water striders)
Water striders are the commonly seen bugs skimming over the water surface of ponds, lakes, streams, and rivers. One genus is found in the open ocean and around reefs of tropical islands. These bugs are predaceous and feed upon aquatic organisms as well as terrestrial animals that fall into the water. Water striders are also cannibalistic. Some of the species in this group lack wings while others have wings fully or only partially developed.

Family: Veliidae (small water striders, riffle bugs)
Adults of this family seldom exceed 5 mm in length. They are found in a variety of habitats including ponds, streams and mangrove swamps. These water striders skim over the water surface as do members of the family Gerridae. Their food consists of aquatic and terrestrial invertebrates.

Family: Herbridae (velvet water bugs)

Little is known about the North American members of this small, rather rare family of water insects. Adults are less than 3 mm in length and can be found in debris along the margins of streams and ponds or on floating aquatic vegetation. Their food is primarily small insects. Velvet water bugs have soft hairy coverings over the body, hence the common name of this family. This particular family is cosmopolitan in nature.

Family: Mesoveliidae (water treaders)

The standing waters of ponds and lakes that have abundant aquatic vegetation are the preferred habitat of these small water bugs. Water treaders usually feed on small insects that they capture on the water surface. Their eggs are deposited within plants that grow near the water margin. Members in this family are distributed from Canada to Brazil, including the West Indies.

Family: Macroveliidae

Macrovelia is the sole genus in this family. Taxonomists often combine this family with Veliidae. The species Macrovelia hornii occurs throughout California and usually inhabits streams where it is found in moss along the water's margin. This species does not have the ability to walk on water as do the related water striders.

Family: Dipsocoridae

These rare ground bugs usually are found in debris and under rocks and rotten logs. A few species are semiaquatic and occur along the margins of streams. A soft hairy covering over the body prevents them from getting wet. Little is known about the life history of the North American species. Members of this group have been found along the margins of hot springs in California.

Family: Saldidae (shore bugs)

Bugs in this family are not truly aquatic but are often associated with water. In California, shore bugs have been found along the margins of freshwater lakes, ponds and streams as well as hot springs, salt marshes, and ocean beaches. These bugs are predaceous on small insects. Many are brightly colored in black and yellow. Shore bugs are widely distributed in North America and have been collected as far north as Alaska.

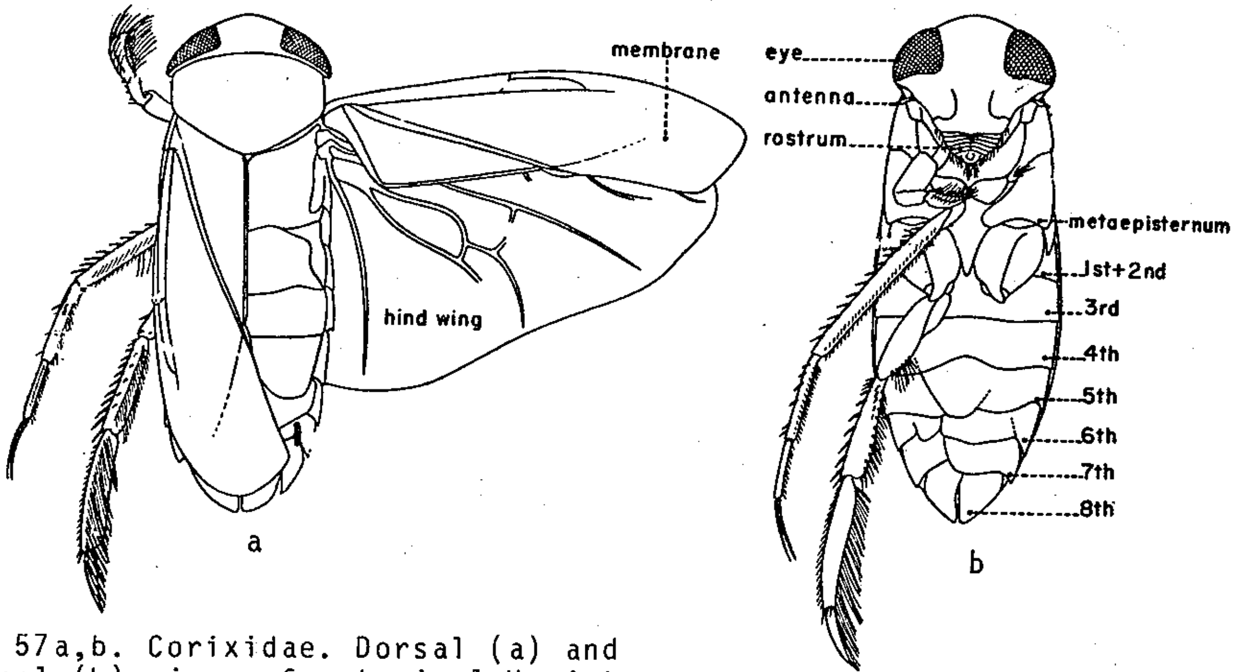


Fig. 57a,b. Corixidae. Dorsal (a) and ventral (b) views of a typical Hemipteran to show the structures used in classification. (Usinger, 1956).

1a Antennae not visible from above the head (as in Fig. 57a) 2
1b Antennae visible from above the head (as in Fig. 67) 7

2a(1) Ocelli present (Fig. 58) .... GELASTOCORIDAE
2b Ocelli absent 3

3a(2) Tarsi of rear leg with two distinct claws (Figs. 60, 61, 62) 5
3b Tarsi of rear leg without distinct claws (Figs. 57a, 59a) 4

4a(3) Base of the head overlapping the front margin of the pronotum; beak not distinctly segmented (Fig. 57a,b) .... CORIXIDAE
4b Base of the head not overlapping the front margin of the pronotum; beak distinctly segmented (Fig. 59a,b) .... NOTONECTIDAE

5a(3) Abdomen with a pair of posterior appendages (Figs. 61, 62) 6
5b Abdomen without a pair of posterior appendages; front femora greatly enlarged (Fig. 60) .... NAUCORIDAE

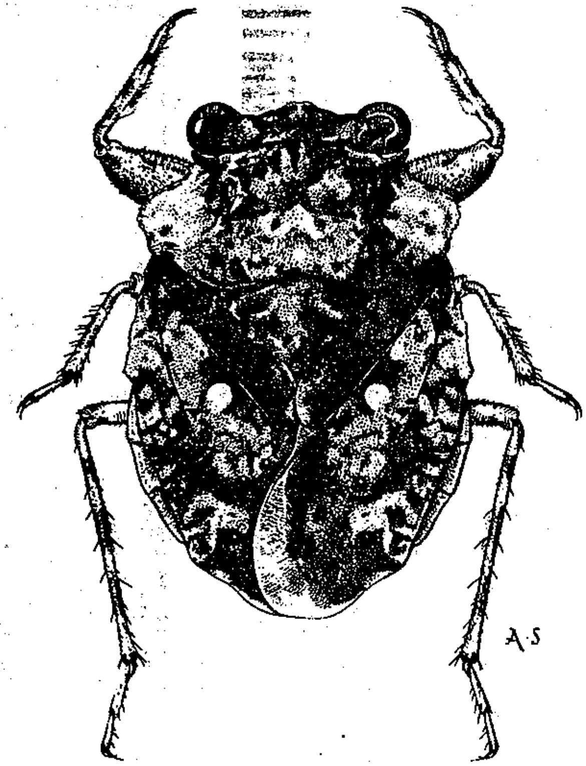
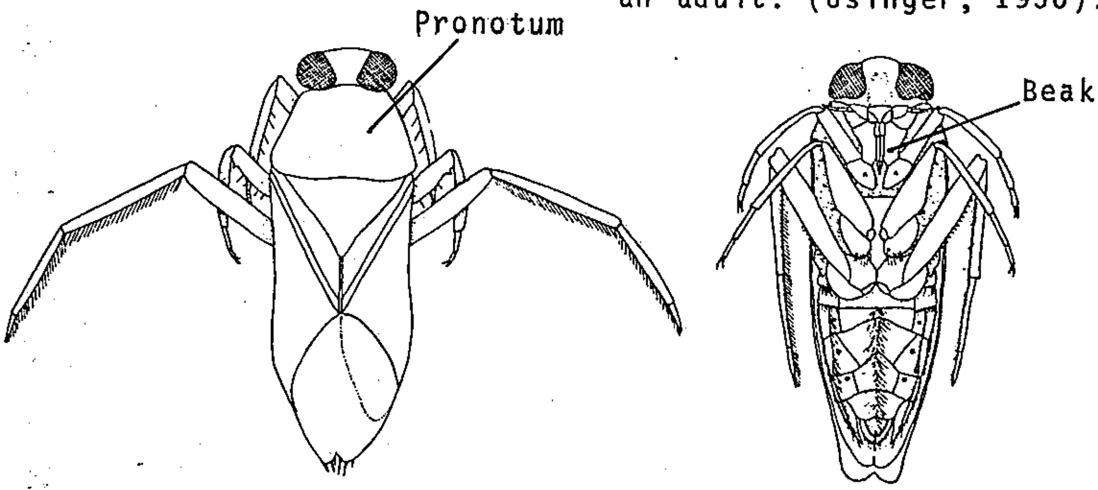


Fig. 58. Gelastocoridae. Dorsal view of an adult. (Usinger, 1956).

Fig. 59a,b. (below). Notonectidae. Dorsal (a) and ventral (b) view of an adult. (Usinger, 1956).



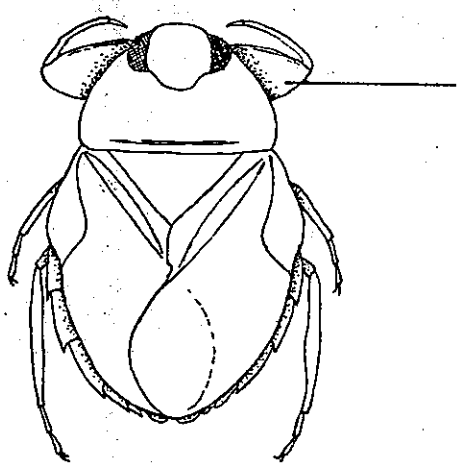


Fig. 60. Naucoridae. Dorsal view of an adult. (Usinger, 1956).

6a(5) Posterior appendages of abdomen long and slender (Fig. 61)..NEPIDAE
6b Posterior appendages of abdomen short and flat (Fig. 62)...............................BELOSTOMATIDAE

7a(1) Antennae shorter than the width of the head (Fig. 63)..OCHTERIDAE
7b Antennae longer than the width of the head (Figs. 64, 65, 66)................................ 8

8a(7) Body long and cylindrical with the head nearly 3 times as long as the width across the eyes (Fig. 64)...............................HYDROMETRIDAE
8b Head short and broad................................ 9

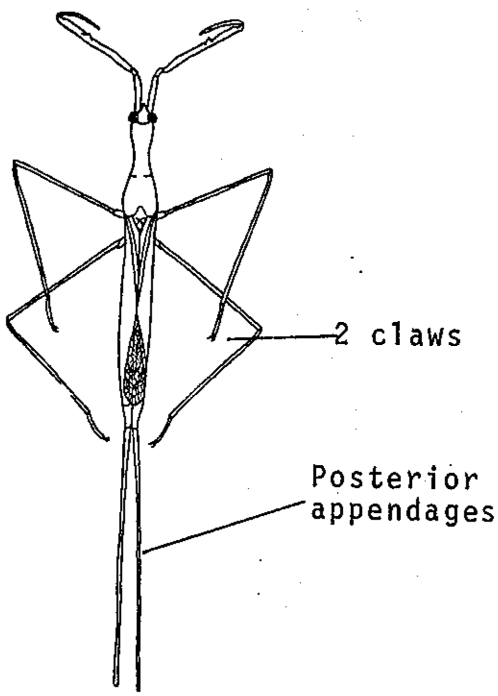


Fig. 61. Nepidae.
Dorsal view of an adult.
(Usinger, 1956).

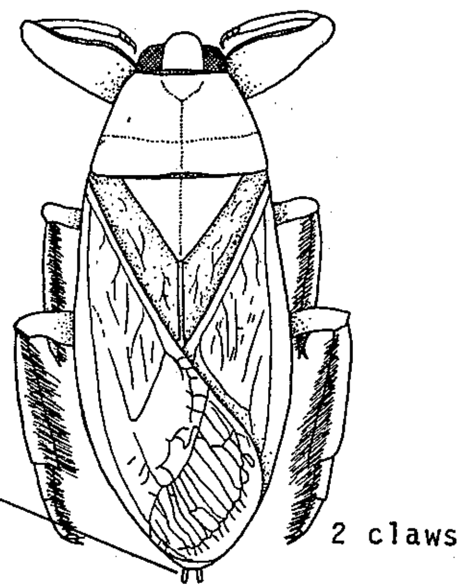


Fig. 62. Belostomatidae.
Dorsal view of an adult.
(Pennak, 1953).

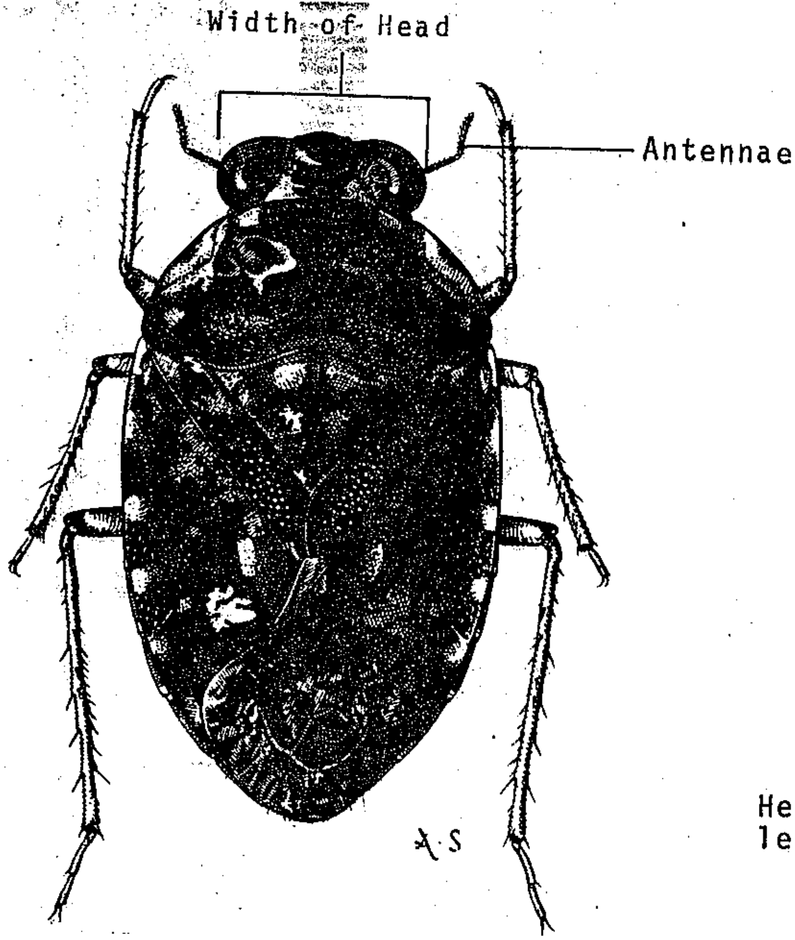


Fig. 63. Ochteridae.
Dorsal view of an adult.
(Usinger, 1956).

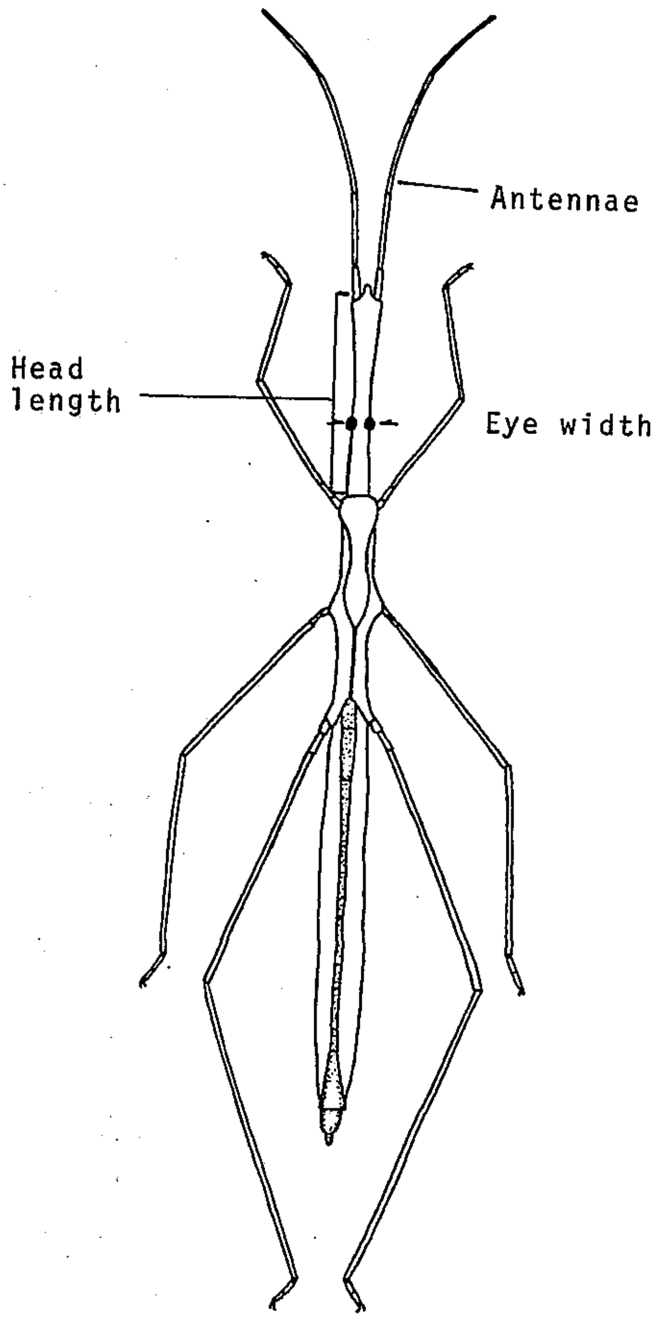


Fig. 64. Hydrometridae.
Dorsal view of an adult.
(Pennak, 1953).

9a(8) Claws of front tarsi inserted before the apex (Fig. 65) 10
9b Claws of front tarsi inserted at the apex (Figs. 67-70) 11

10a(9) Hind femora very long, extending beyond the end of the abdomen (Fig. 65a) .... GERRIDAE
10b Hind femora not long and scarcely, if at all, extending beyond the end of the abdomen (Fig. 65b) .... VELIIDAE

11a(9) Adults with 2-segmented tarsi; the underside of the head with a deep groove (Fig. 67) .... HEBRIDAE
11b Adult with 3-segmented tarsi; the underside of the head without a groove 12

12a(11) Coxae of the hind leg short and freely movable 13
12b Coxae of the hind leg long and broadly joined to the sides of the thorax (thoracic pleura) 14

13a(12) Scattered stiff, black bristles on the legs (Fig. 68) .... MESOVELIIDAE
13b No scattered stiff, black bristles on the legs (Fig. 69) .... MACROVELIIDAE

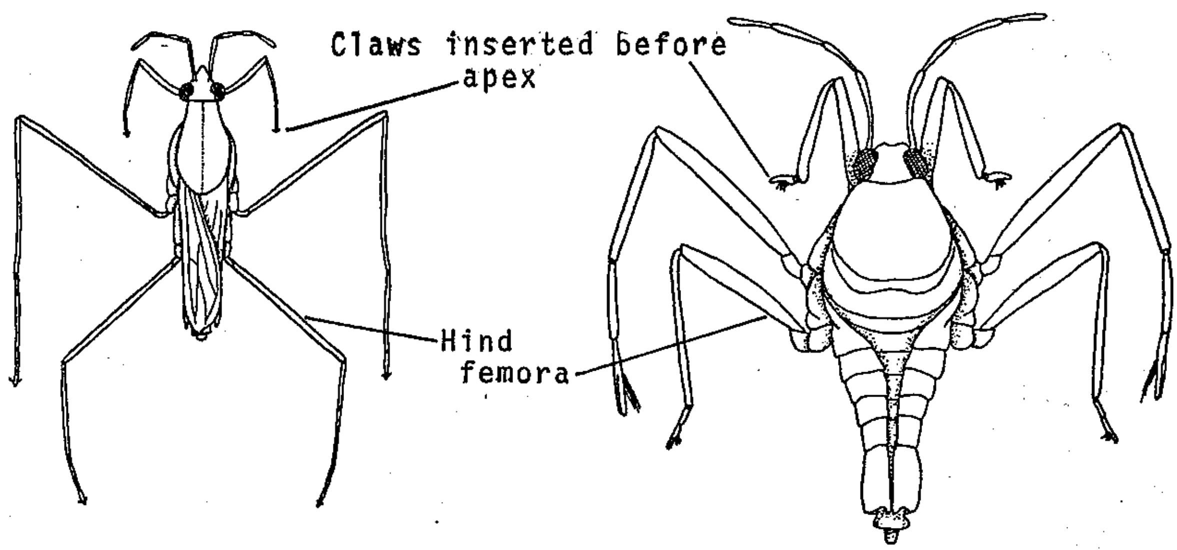


Fig. 65a. Gerridae. Dorsal view of an adult. (Pennak, 1953).

Fig. 65b. Veliidae. Dorsal view of a wingless adult. (Pennak, 1953).

14a(12) Ocelli nearer to eyes than to each other (not illustrated)............................DIPSOCORIDAE

14b Ocelli nearer to each other than to the eyes (Fig. 66)..SALDIDAE

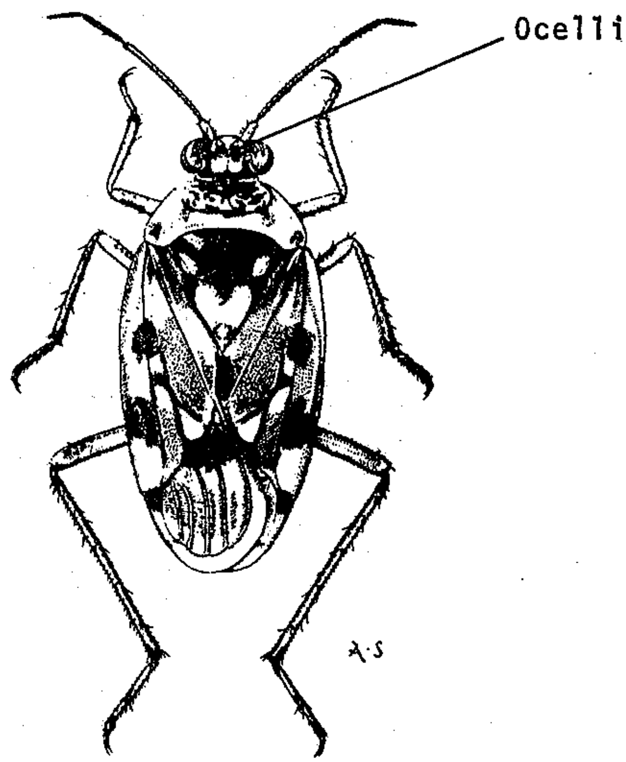


Fig. 66. Saldidae.
Dorsal view of an adult.
(Usinger, 1956).

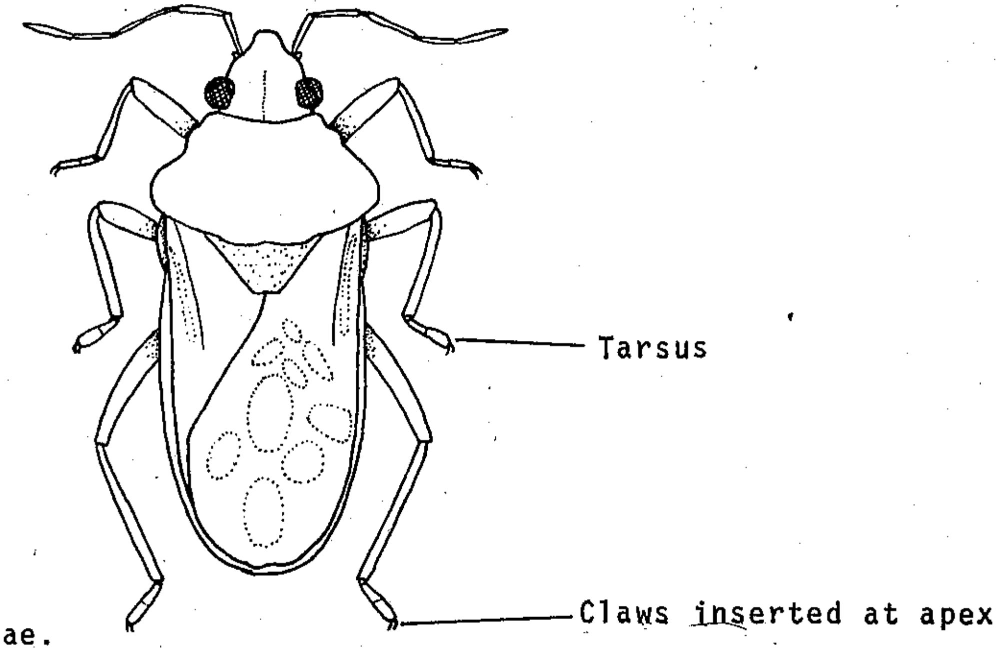


Fig. 67. Hebridae.
Dorsal view of an adult.
(Redrawn from Hungford, 1919).

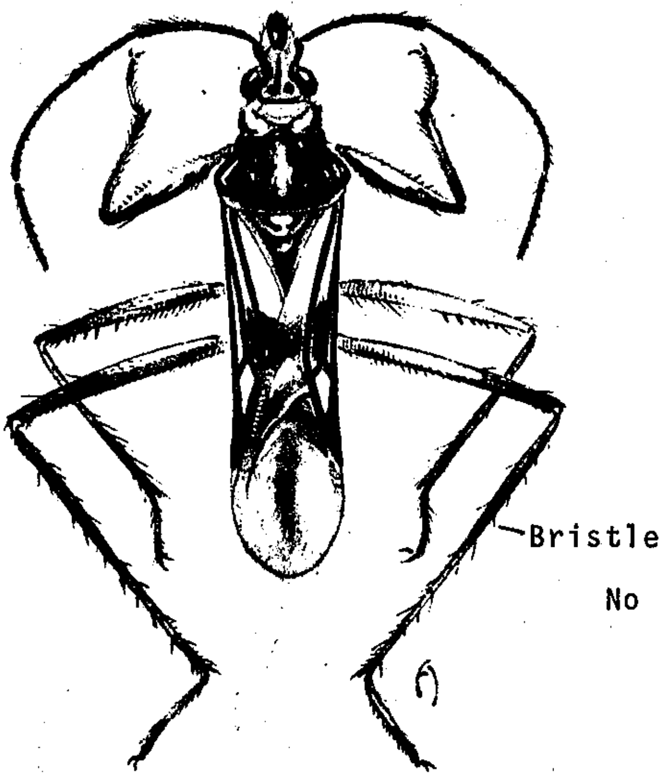


Fig. 68. Mesoveliidae.
Dorsal view of an adult.
(Usinger, 1956).

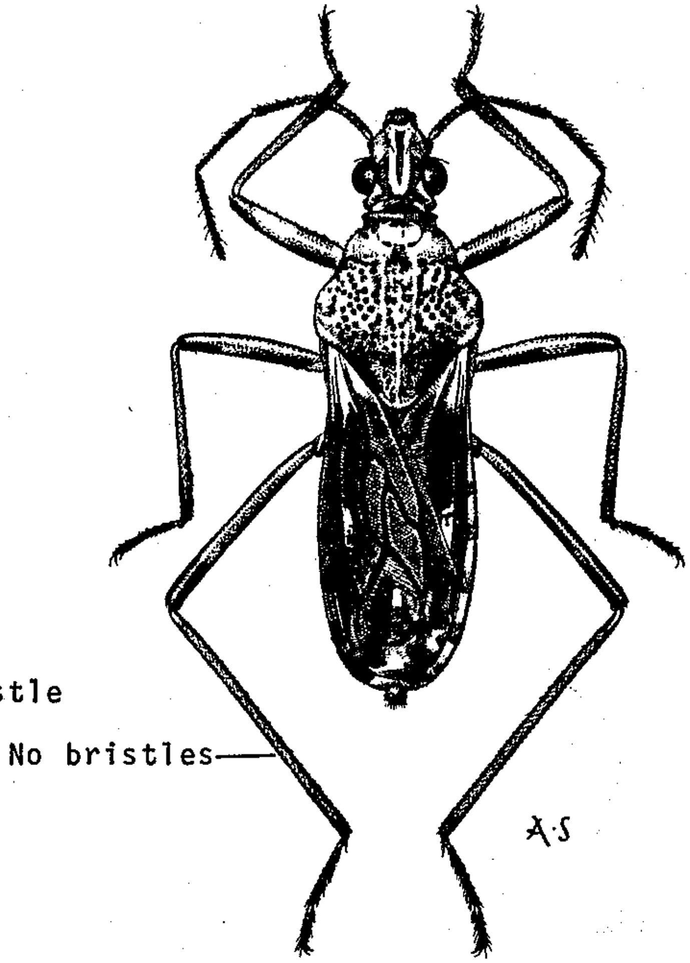
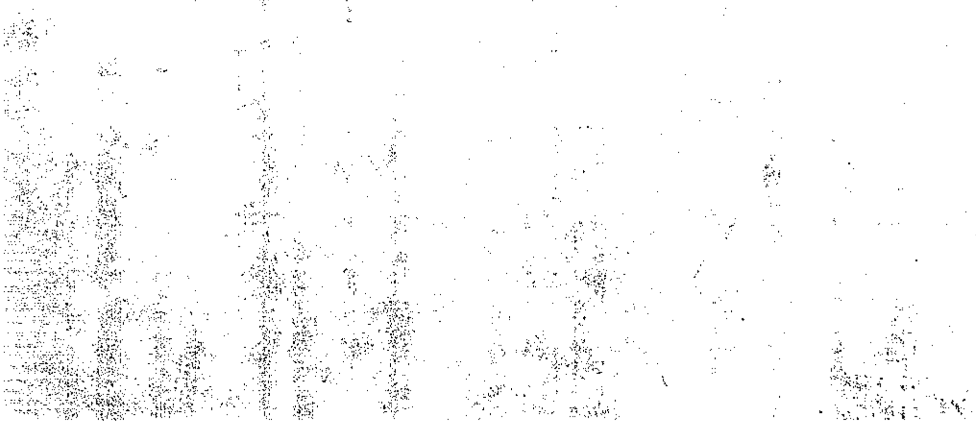
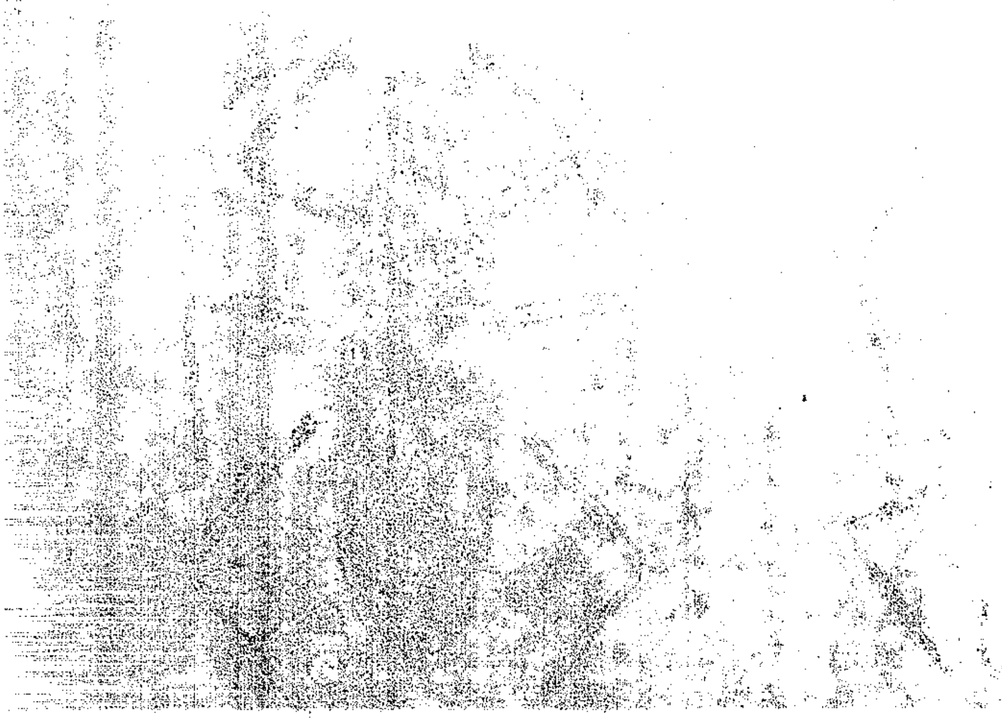


Fig. 69. Macroveliidae.
Dorsal view of an adult.
(Usinger, 1956).





KEY TO THE FAMILIES OF CALIFORNIA MEGALOPTERA

Order: MEGALOPTERA
Common Name: Dobsonflies, Alderflies, Fishflies

Megalopterans are distributed worldwide but there are relatively few species. Adults in North America range from 10-17 mm in length. The adults are poor fliers and when at rest their wings are held rooflike along the body. The adults are found in the spring and early summer near streams, ponds and lakes. They live only a few days. Eggs are laid in rows of several thousand on plants or other objects that overhang the water. When the eggs hatch, the larvae drop into the water for development. The larvae are predaceous and develop for two to three years. The larvae leave the water to pupate. They crawl as far as 50 meters from the water to build a pupation chamber under a rock.

There is some disagreement about whether the families of this order should be under the order of Megaloptera or Neuroptera. Some believe that Megaloptera belongs to the order of Neuroptera. The status changes often and one will find references to these families under both order titles.

Synopsis of the California Families of MEGALOPTERA

Family: Sialidae (alderflies)
Adult alderflies are gray to black and less than 20 mm long. The larvae are found in running water and back eddies of streams. The larvae are predaceous but the adults appear to feed little. The larvae leave the water to pupate in the ground. Alderflies are weak fliers and will often run along the ground rather than fly when disturbed.

Family: Corydalidae (dobsonflies, fishflies)
The larval stage of these insects are called hellgrammites and are commonly used as fishing bait. The larvae are predaceous and will eat any aquatic organism they can handle. The adult males of some species have large mandibles that overlap when closed. The largest dobsonflies have a wing span of over 150 mm. Dobsonflies and fishflies prefer rivers and streams with coarse, rocky bottoms, although a few species are found on mud bottoms and in stagnant water. This family is found throughout the world.

Key to the California Families of MEGALOPTERA Larvae

1a Last abdominal segment with a long median filament (Fig. 71)...SIALIDAE

1b Last abdominal segment without a long median filament; anal prolegs at the end of the abdomen with 2 hooks on each (Fig. 72)....................CORYDALIDAE

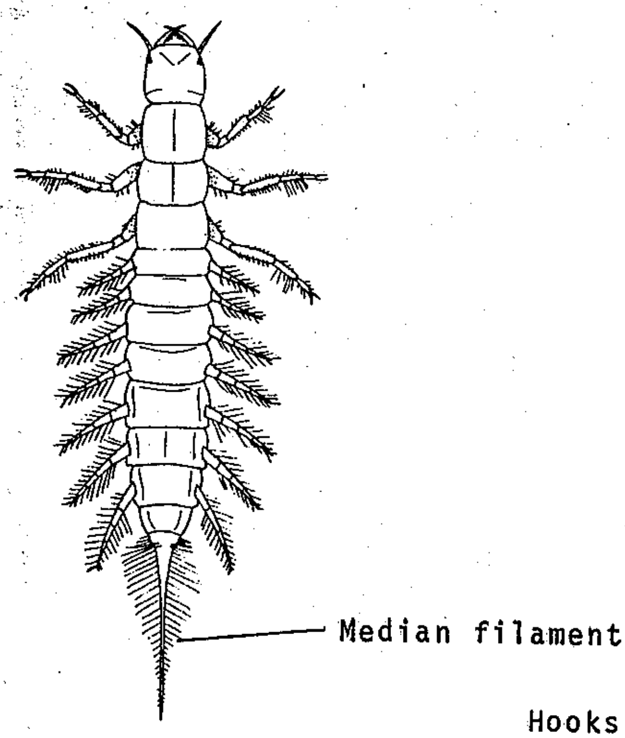


Fig. 71. Sialidae.
Dorsal view of a larvae.
(Ross, 1937).

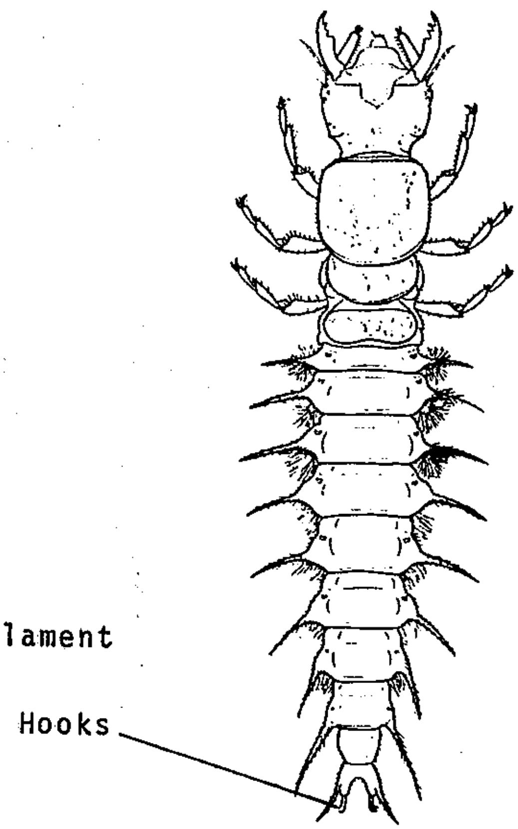


Fig. 72. Corydalidae.
Dorsal view of a larva.
(Hellgrammite).
(Edmondson, 1959).

Order: NEUROPTERA (= nerve-winged)
Common Name: Spongilla-flies

These interesting insects are parasites on freshwater sponges. The larvae crawl into host sponges and pierce the tissue with their mouthparts. By means of two drinking siphons they suck in juices from the living sponge tissues. The larvae which match their color to that of their host sponge, may be green to light brown in color. The adults resemble small, delicate lacewings and lay their eggs on objects which overhang the water. A single family, Sisyridae, is found in California.

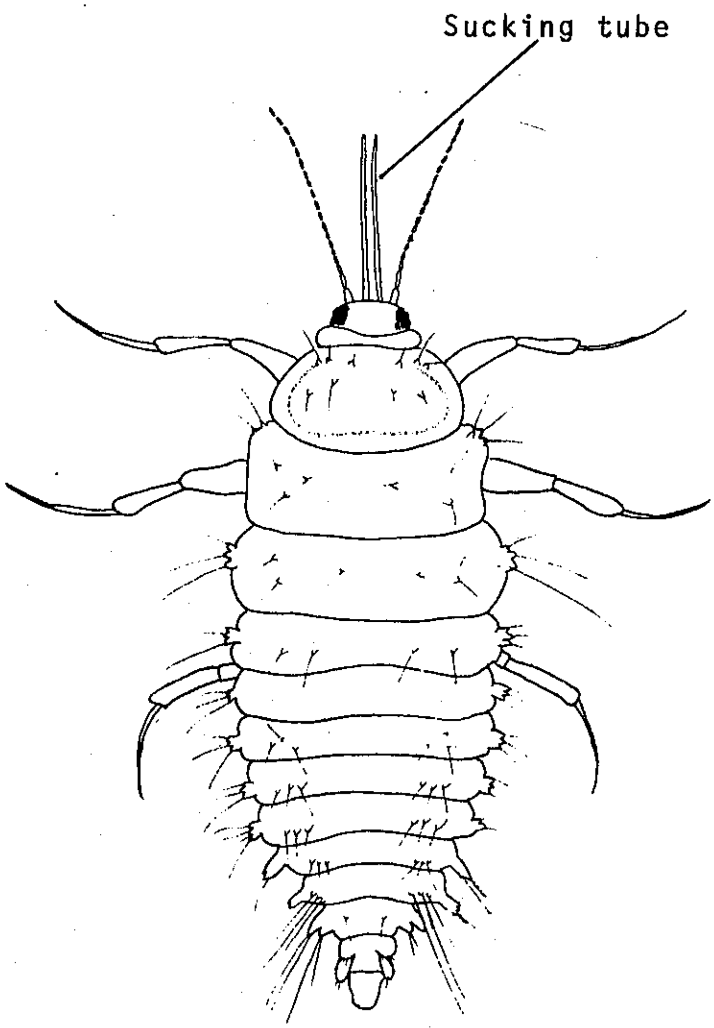


Fig. 73. Sisyridae. Dorsal view of a larva. (Brown, 1952).

KEY TO THE FAMILIES OF CALIFORNIA TRICOPTERA (CADDISFLIES)

Order: TRICOPTERA (= hairy-winged)
Common Name: Caddisflies

The caddisflies appear to be related to the butterflies and moths (order Lepidoptera). Adult caddisflies have wings with hair-like setae and some species have wings with a few scales as in lepidopterans. Adults are secretive in habit. Eggs are deposited in strings or masses in or near the water.

Usinger (1956) states that only about 15% of the larvae have been associated with the adults. This makes specific, and often generic identification of the larvae very difficult. The larvae are aquatic and build some type of case or they may be free living without a case. The free-living species are carnivorous, while the case builders are herbivorous. A description of the larval types by Ross (1944) include:

Free-Living Forms. The larvae of the genus Rhyacophila are completely free living having no case or shelter; they lay a thread trail and have many modifications for free life in flowing water, including widely spaced, strong anal hooks. For pupation they form a stone case or cocoon. Many Hydroptilidae instars are free living.

Net-Spinning Forms. Larvae of Hydropsychidae, Philopotamidae, and Psychomyiidae spin a fixed home which is fastened to plants or other supports in the water; sometimes in still water but more frequently in running waters. The three common types of these structures are found, all of them spun from silk and forming some sort of net; when taken out of water they collapse into shapeless string. There is always an escape exit at the end of the tube.

1. Finger nets. These are long, narrow pockets of fine mesh, with the front end anchored upstream, the remainder trailing behind with the current. They are built by the Philopotamidae.

2. Trumpet nets. In this type, the opening of the net is funnel-shaped, and is fastened in such a way that the water movement distends the net into a trumpet-shaped structure. This type net is used extensively by the Psychomyiidae.

3. Hydropsychid net. Peculiar to the family Hydropsychidae is the habit of erecting a net directly in front of a tubelike retreat concealed in a crevice or camouflaged by bits of wood, leaves, or similar material. These nets may be erected between two supports in the open, as in the case of Potamyia, or the net may be constructed as one side of an antechamber, as in the case of many species of Hydropsyche.

Tube-Making Forms. Some psychomyiid larvae, notably of the genus Phylocentropus, burrow into sand at the bottom of streams, cementing the walls of the burrow into fairly rigid structure which may be dug out intact. The mechanics of food gathering in this group are not well understood.

Saddle-Case Makers. Larvae of the family Glossosomatidae make a portable case which consists of an oval top made of stones and a ventral strap made of the same material. The larvae proceeds with its head and legs projecting down in front of the strap and the anal hooks projecting down at the back of the strap. For pupation, the strap is cut away and the oval dome is cemented to a support, the pupa being formed in the stone cell produced.

Purse-Case Makers. Following the designs of the above group are many cases of the family Hydroptilidae. In general, they resemble a purse. The larva occupies the case with the head and legs projecting out of a slit in the front margin while the anal hooks project out of a slit in the posterior margin. For pupation, the case is cemented along one side to support and the slits are cemented shut to form the pupal chamber. Not all Hydroptilidae have cases of this type, some of them have true cases.

Case-Makers. All caddisfly larvae except those listed above make portable cases which the larvae drag with them in their daily movement. The cases are usually made of pieces of leaves, bits of twigs, sand grains or stones which are cemented or tied together with silk. Rarely, the case is made entirely of silk. Case construction varies a great deal from one group to another, from one species to another within the same genus, and frequently within the same species. In general, cases subject to the greatest stream currents are the most solidly constructed, whereas those in small ponds where there is little current often are quite loosely constructed. In pupation, the case is anchored to a support and a top is added to the case; the pupa is formed inside this shelter and no additional cocoon is made.

Order: TRICOPTERA

Synopsis of the California Families

Family: Hydropsychidae, including Arctopsychidae (net-spinning caddisflies)

Members of this group build a cup-shaped net in streams. The net is open on the upstream end and serves to strain food from the water. The larvae live in a chamber at the edge of the water. The adults are usually found along streams and their margins. These families are widely distributed and are fairly common.

Family: Philopotamidae (finger-net caddisflies)

The larvae of this family build long, silken nets of finger-like design in rapidly flowing streams. The adults are about 6 to 9 mm in length and black in color. When the larvae pupate, they build cases of small stones and debris that are attached to the underside of larger rocks. This family has only a few members but is worldwide in distribution.

Family: Psychomyiidae, including Polycentropidae (trumpet-net and tube-net caddisflies).

These families contain many species and are found worldwide. The larvae, which occur along lake shores and rivers, make nets that are either trumpet-shaped or tube-shaped. The tube-nets are constructed in burrows in the bottoms of rivers and the sides are cemented with sand grains. Adults range up to 11 mm in length.

Family: Hydroptilidae (microcaddisflies)

Microcaddisflies are usually under 6 mm in length. Larvae do not build cases until their last stage in development. Larval cases are purse-shaped and have both ends open. These caddisflies are found along ponds, lakes and streams where they are often very common. This family is widespread in North America.

Family: Rhyacophilidae

Larvae of the caddisflies in this family do not build cases but rather live free as predators on other aquatic organisms. Larvae and adults can be found in and along cold, rapidly flowing streams. Mature larvae build cases of small pebbles for pupation. This family is large and widely distributed.

Family: Glossosomatidae

Members of this family are found in cold, rapid streams. the larvae construct dome-shaped cases of small stones. During pupation, the case is cemented to a stone. Adults seldom reach 7 mm in length and are brown to black in color.

Family: Leptoceridae (long-horned caddisflies)
Some adults of this family have antennae much longer than the body, hence the common name. These caddisflies can be found in lakes, ponds or streams, and the larvae build cases out of a variety of materials. Cases may be constructed of sand grains or pieces of plants and they vary in design. Adults are under 18 mm in length.

Family: Phryganeidae
Adults in this family are fairly large in size, ranging from 12 to 25 mm in length. The adults and larvae inhabit lakes, marshes and slow flowing streams where submerged plants are found. The larvae build spiral cases from bits of vegetation.

Family: Helicopsychidae
Larvae of this family build their cases out of sand grains in the form of a snail shell. Larvae live in springs and clear streams over much of North America. Adults are only 5 to 7 mm in length.

Family: Brachycentridae
Caddisflies of this family inhabit clear, cool streams and rivers in mountain areas. The larvae build conical cases of sand grains or squarish cases of plant material. Some species build one-half of their case of one type, and the other another. Adults are 6 to 12 mm in length.

Family: Limnephilidae
Species in this family can be found in a variety of habitats including springs, ponds, lakes and streams. The larvae build cases of many different designs and out of a variety of materials. This family contains many species and is well represented in California.

Family: Lepidostomatidae
This family is widely distributed in North America. Its members are found in streams, rivers, springs and ponds. Larval cases are of various types including conical cases of sand grains and rectangular cases of plant material.

Family: Calamoceratidae
Members of this family are uncommon. Adults and larvae inhabit springs and fast flowing streams. The larval cases are composed of plant materials and sometimes are triangular in cross section. Hollowed out twigs have also been used as cases.

Family: Odontoceridae
Little is known about this rare family of caddisflies. The larvae build cylindrical tapering cases of small sand grains. Members in this family are found in riffle areas of cold, fast flowing streams.

Family: Sericostomatidae

This small family contains less than a dozen species in North America. Adults and larvae are found in lakes and streams. Larvae build cylindrical cases of sand grains.

Key to the California Families of TRICOPTERA Larvae

1a Pro-, meso-, and metanota each with a single sclerotized shield covering the entire notum (Figs. 74a,b, 75)................................... 2

1b Either meso-, or metanotum or both without a complete sclerotized shield (may be subdivided into separated sclerites) (Figs. 83, 96)............. 4

2a(1) Abdomen with conspicuous branched ventral gills; anal gills present. Larvae construct retreats (Fig. 75).. 3

2b Abdomen without ventral gills; no anal gills; larvae with the abdomen swollen and usually much wider than the thorax; larvae not larger than 5 mm;(Fig. 74a,b) .......................HYDROPTILIDAE

3a(2) Fore trochantin forked or if simple then the gula is triangular or rectangular and of even width (Figs. 75, 76a,b, 77a,b)..............HYDROPSYCHIDAE

3b Fore trochantin simple and the gula rectangular but it narrows posteriorly (Figs. 76c, 77b)...........................ARCTOPSYCHIDAE*

4a(1) Anal legs projecting beyond the membranous 10th abdominal segment. Larvae free living or in silken retreats - usually no case Figs. 79, 83).. 5

4b Anal legs embedded in the side of the 10th abdominal segment and only part of the claws projecting beyond the segment (Figs. 90, 96)......... 9

*Many authors include the Arctopsyhidae in the Family Hydropsychidae.

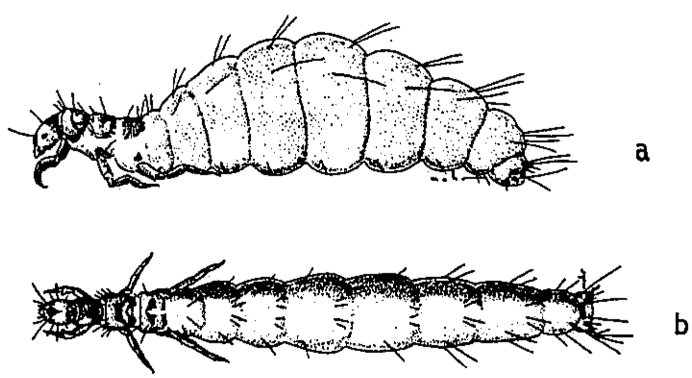


Fig. 74a,b. Hydroptilidae. Lateral (a) and dorsal (b) view of a larva. (Pennak, 1978).

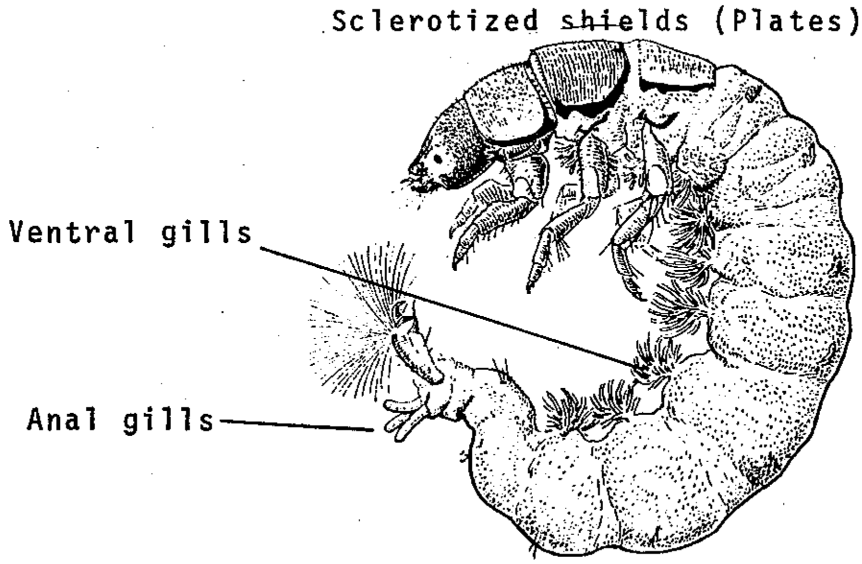


Fig. 75. Hydropsychidae.
Lateral view of a larva.
(Edmondson, 1959).

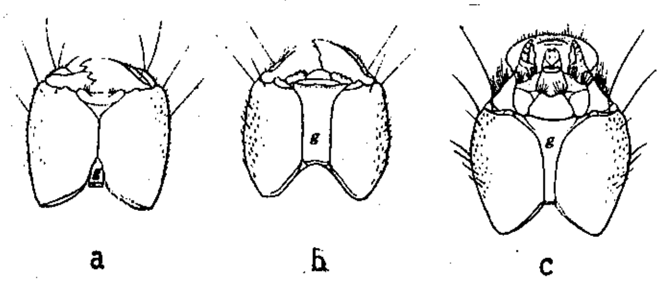


Fig. 76a-c. Ventral views of the head showing the gula(g).
a. Hydropsychidae with triangular gula(g)
b. Hydropsychidae with rectangular gula(g)
c. Arctopsychidae with rectangular gula that narrows posteriorly.
(Edmondson, 1959).

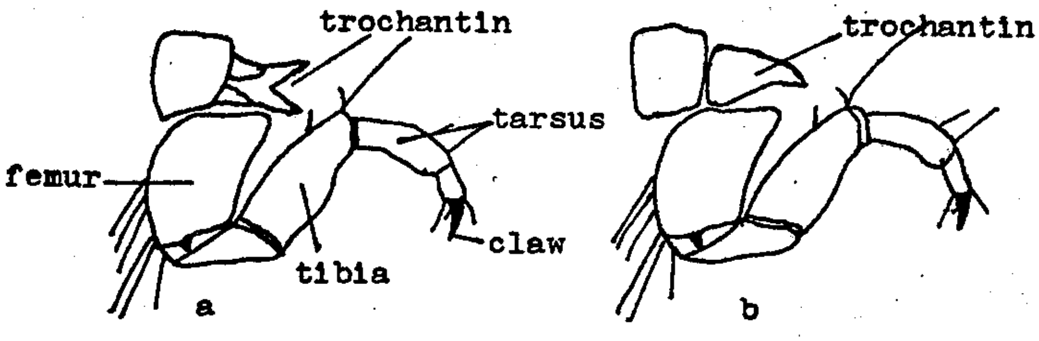


Fig. 77a,b. Foreleg and fore trochantin of two larvae showing the different types of trochantin.
a. Trochantin forked.
b. Trochantin simple(single point).

5a(4) Sclerotized shield on the dorsum of the 9th abdominal segment (Figs. 79, 81) 6

5b No sclerotized shield on the dorsum of the 9th abdominal segment, the segment completely membranous (Figs. 82, 83, 85) 7

6a(5) Anal claw large and nearly as long as the sclerite on the anal leg. Larvae free-living (Figs. 78, 79) .... RHYACOPHILIDAE

6b Anal claw very small and much shorter than the sclerite on the anal leg. Larvae with a case (Figs. 80, 81) .... GLOSSOSOMATIDAE

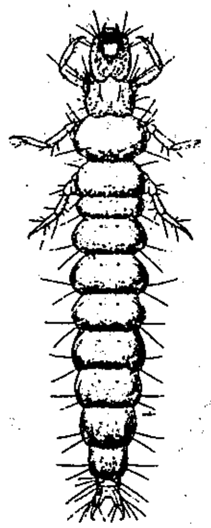


Fig. 79. Rhyacophilidae. Dorsal view of a larva. (Pennak, 1978).

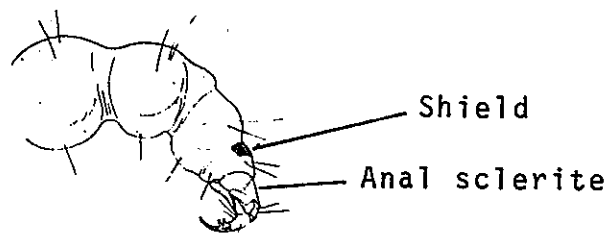


Fig. 78. Rhyacophilidae. Lateral view of the last 6 segments of the abdomen of a larva. (Edmondson, 1959).

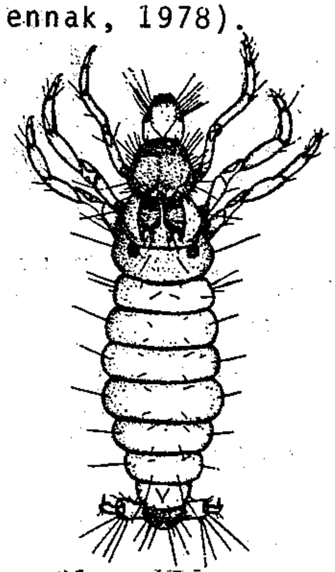


Fig. 81. Glossosomatidae. Dorsal view of a larva. (Pennak, 1978).

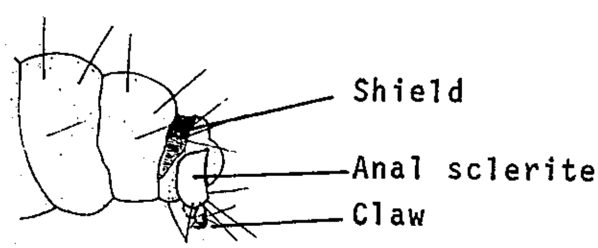


Fig. 80. Glossosomatidae. Lateral view of the last 7 segments of the abdomen of a larva.

7a(5) Labrum membranous and expanded distally. Larvae live in silken tubes under rocks (Figs. 82a,83)....................PHILOPOTAMIDAE

7b Labrum not expanded distally. Larvae live in retreats under rocks (Fig. 82b).................. 8

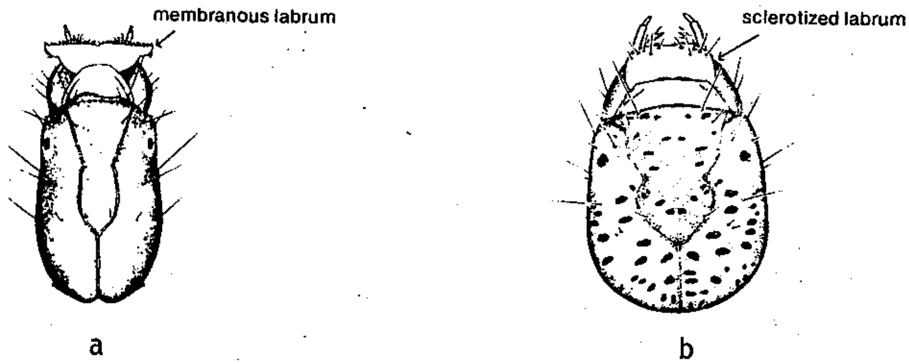


Fig. 82a,b. Two types of larval labrums.
a. Philopotamidae.
b. Psychomyiidae and Polycentropidae.
(Edmondson, 1959).

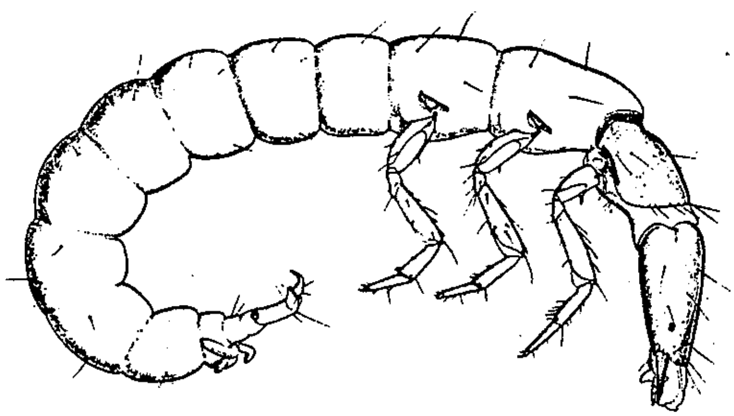


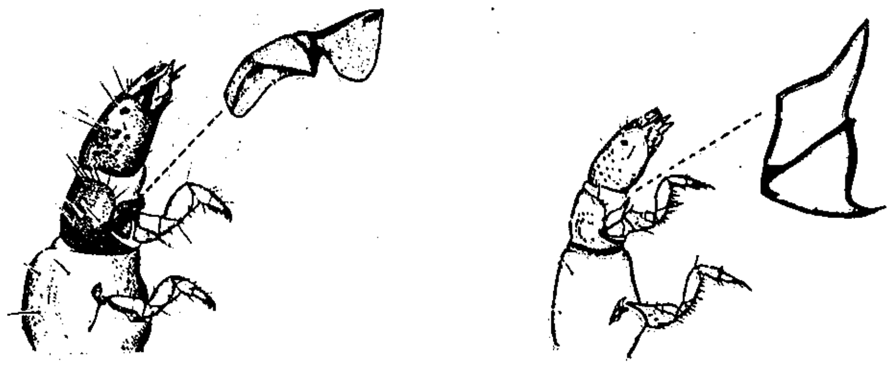
Fig. 83. Philopotamidae.
Lateral view of a larva.

8a(7) Fore trochantin squarish, set off from the pleuron by a ridge visible externally as a black line (Figs. 84a,85)....................PSYCHOMYIIDAE

8b Fore trochantin pointed and fused to the pleuron; no black line visible (Figs. 84b,86)............................POLYCENTROPIDAE

9a(4) Antennae at least 8 times longer than wide and originating at the base of the mandibles (Fig. 87)...........................LEPTOCERIDAE (in part)

9b Antennae not more than 3 or 4 times longer than wide and originating at various points and often difficult to see (Figs. 95, 97)............10



a b

Fig. 84. Lateral view of the forelegs of two larvae showing the appearance of the fore trochanters.

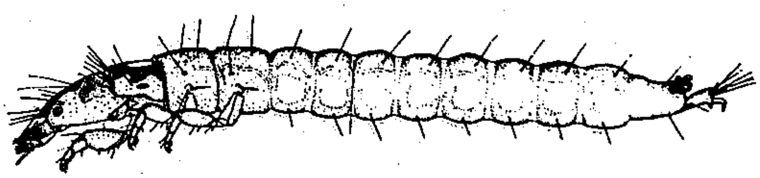


Fig. 85. Psychomyiidae. Lateral view of a larva. (Hickin, 1967).

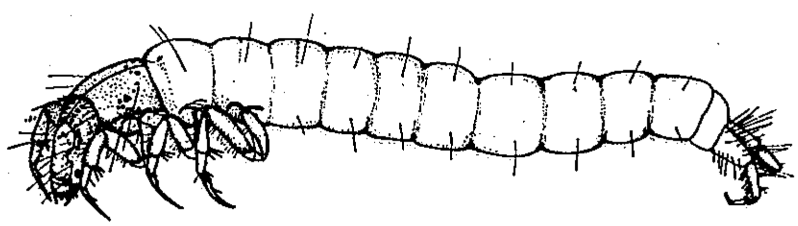


Fig. 86. Polycentropidae. Lateral view of a larva. (Hickin, 1967)

10a(9) Mesonotum membranous except for a pair of parentheses-like sclerotized bars (Fig. 88)..........................LEPTOCERIDAE (in part)

10b Mesonotum without parentheses-like bars............11

11a(10) Meso-, and metanota without membranous sclerites (Fig. 89) or mesonota with small sclerites covering no more than 1/2 the nota, but note cluster of hairs at anterior-lateral margin of nota...........PHRYGANEIDAE

11b Mesonotum and/or metanotum with some distinct sclerotized plates (Figs. 94, 96, 99a-d)...........12

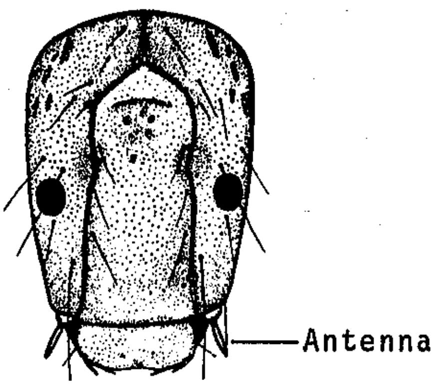
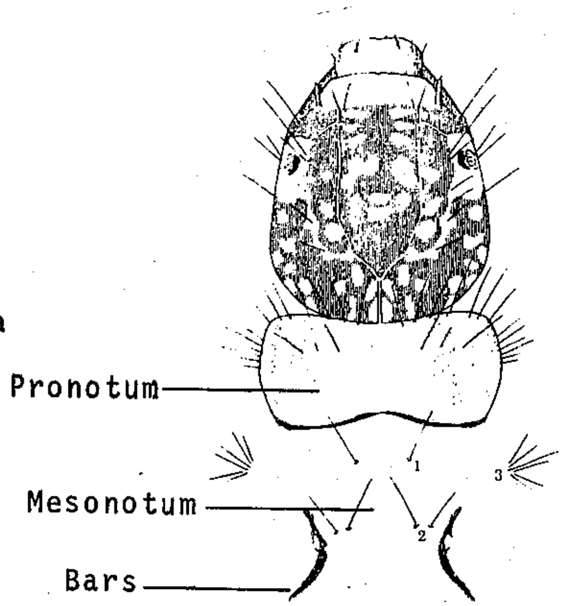


Fig. 87. Leptoceridae. Frontal view of the head of a larva. (Hickin, 1967).



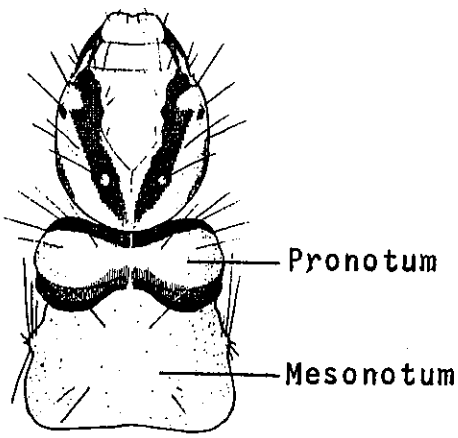


Fig. 88 (above) Leptoceridae. Dorsal view of the head and thorax of a larva.

Fig. 89. (left) Phryganeidae. Dorsal view of the head and thorax of a larva. (Edmondson, 1959).

12a(11) Teeth of the anal claw are comblike in appearance (Fig. 87); the larval case looks like a snail shell (Fig. 88)................................HELICOPSYCHIDAE

12b Teeth of the anal claw are not comblike in appearance.......................................13

13a(12) Pronotum in side view with a furrow running in front of a ridge along the posterior margin of the pronotum (Fig. 89a)...14

13b Pronotum without the furrow (Fig. 89b,c)...........16

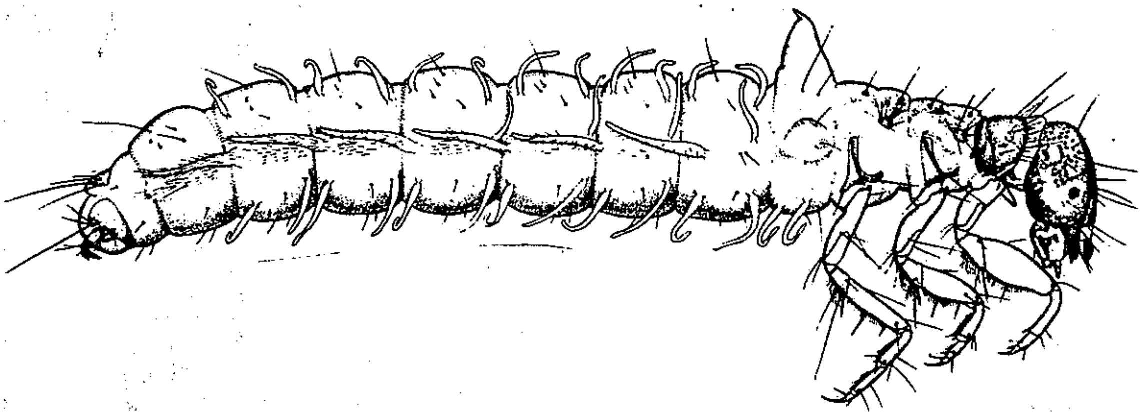


Fig. 90. Phryganeidae. Lateral view of a larva. (Hickin, 1967).

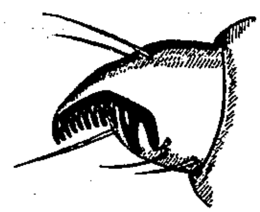


Fig. 91. Helicopsychidae. Anal claw of the larvae.

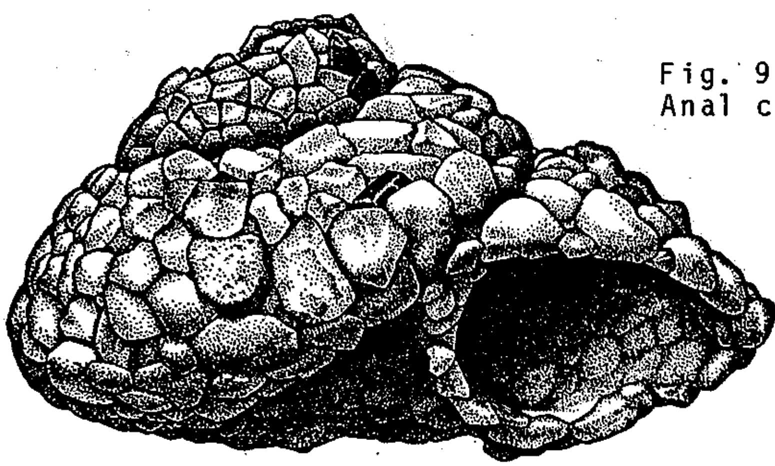


Fig. 92. Helicopsychidae. Larval case. (Ross, 1944).

14a(13) Pronotum with a distinct, sharp furrow crossing it near the middle (Fig. 94)..............BRACHYCENTRIDAE
14b Pronotum without a furrow or at most with a shallow furrow......................................15

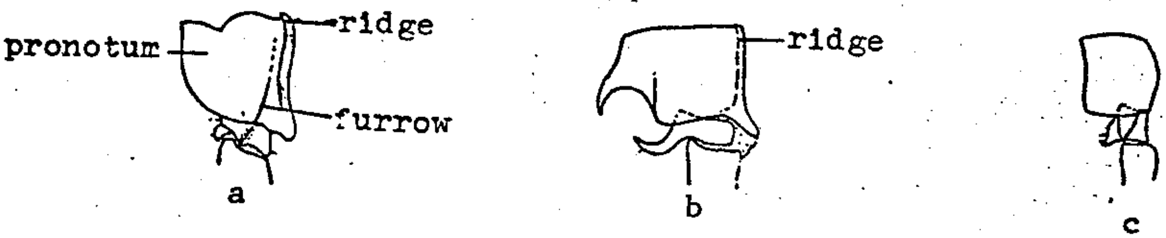


Fig. 93a-c. Lateral views of the pronota of three different larvae.
a. Pronotum with furrow in front of ridge.
b. Pronotum with a ridge but no furrow.
c. Pronotum without a ridge or a furrow.

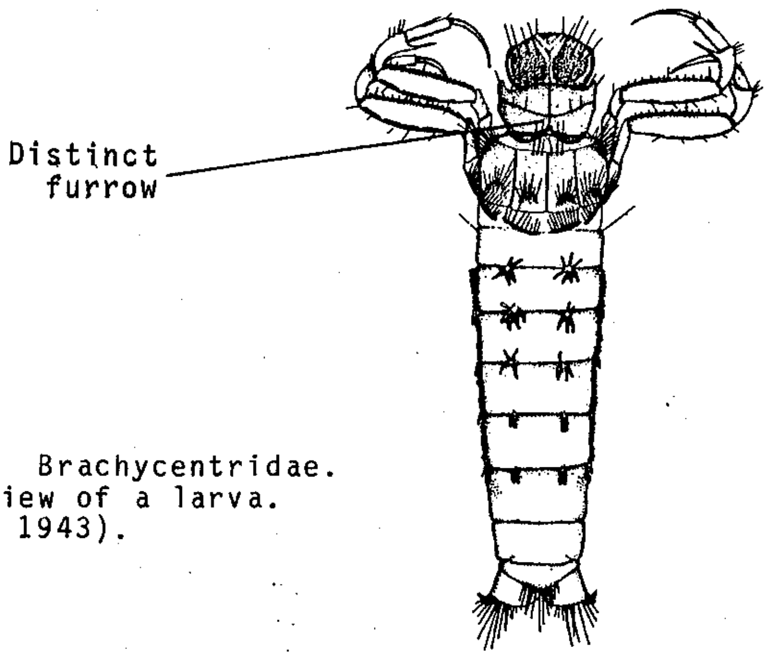


Fig. 94. Brachycentridae. Dorsal view of a larva. (Hickin, 1943).

15a(14) A dorsal tubercle on abdominal segment 1 (Fig. 96); antennae arising midway between the eyes and the mandibles or closer to the mandibles than to the eyes (Fig. 95)..............................LIMNEPHILIDAE

15b No dorsal tubercle on abdominal segment 1 (Fig. 98); antennae arising very close to the eyes (Fig. 97) ....LEPIDOSTOMATIDAE

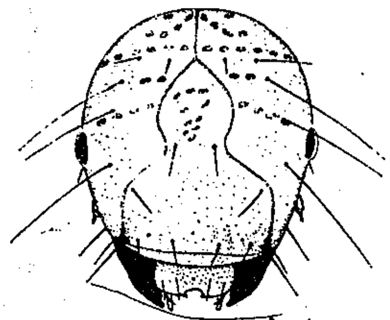


Fig. 95. Limnephilidae. Frontal view of the head of a larva. (Hickin, 1967).

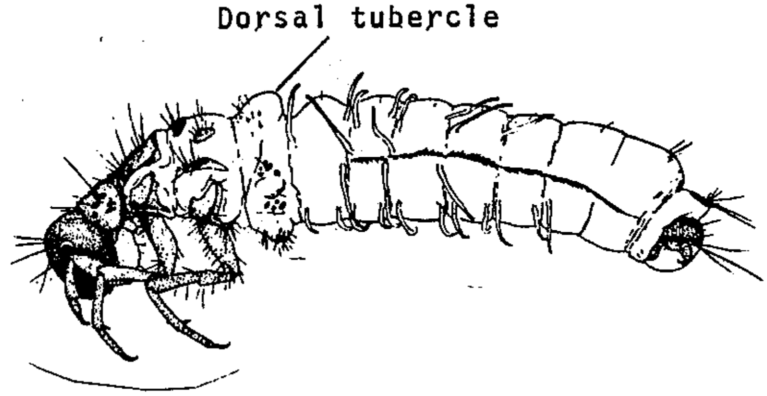


Fig. 96. Limnephilidae. Lateral view of a larva. (Hickin, 1967).

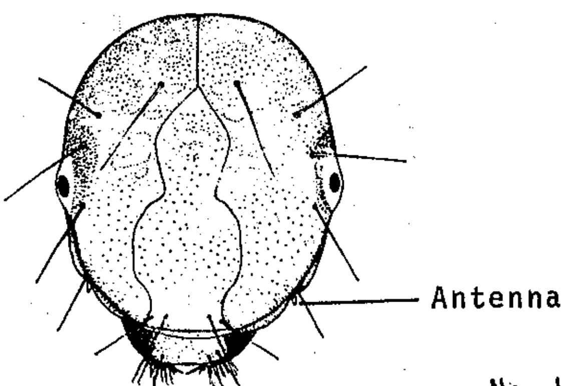


Fig. 97. Lepidostomatidae. Frontal view of the head of a larva. (Hickin, 1967).

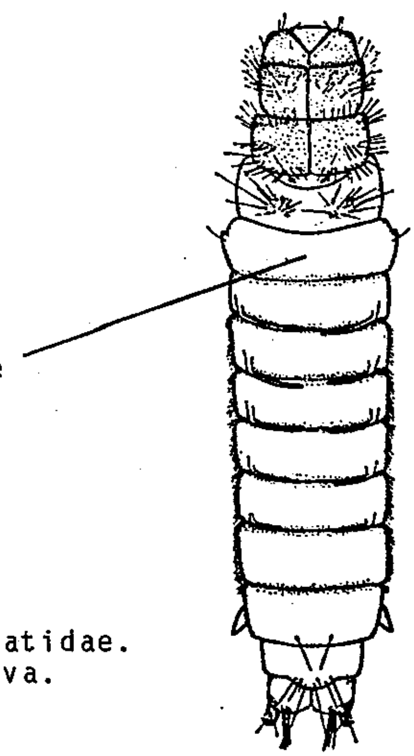


Fig. 98. Lepidostomatidae. Dorsal view of a larva. (Hickin, 1967).

16a(13) Metanotum with sa 1*a single hair (Fig. 99a); larvae living in hollowed out twigs.......CALAMOCERATIDAE

16b Metanotum with sa 1*bearing a row of hairs which may be difficult to see because of their light color Fig. 99b-d).....................................17

17a(16) Gills in tufts of fine threads; sa 2*a row of hairs on a thin, faint linear plate (Fig. 99b,c) ....ODONTOCERIDAE

17b Gills slender and single (Fig. 100); metanotum with sa 2*a single setae on a small plate (Fig. 99d)................................SERICOSTOMATIDAE

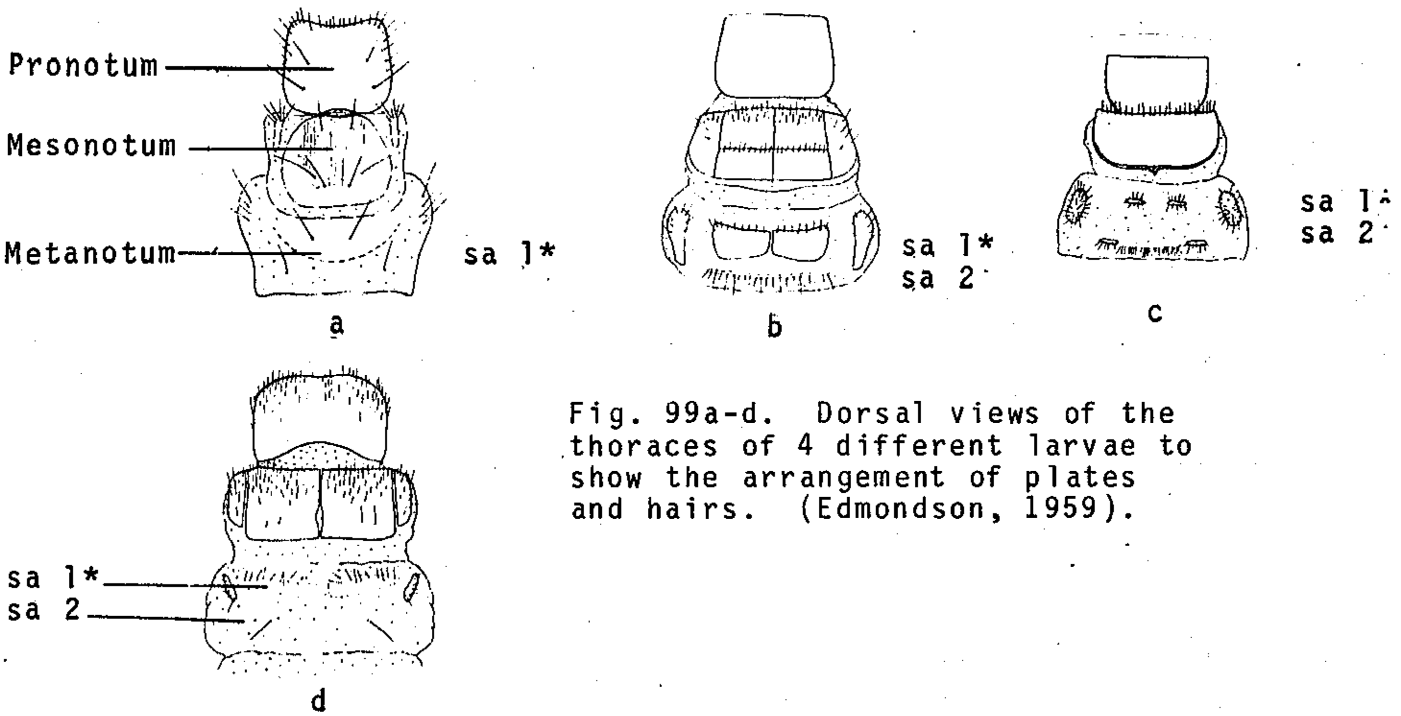


Fig. 99a-d. Dorsal views of the thoraces of 4 different larvae to show the arrangement of plates and hairs. (Edmondson, 1959).

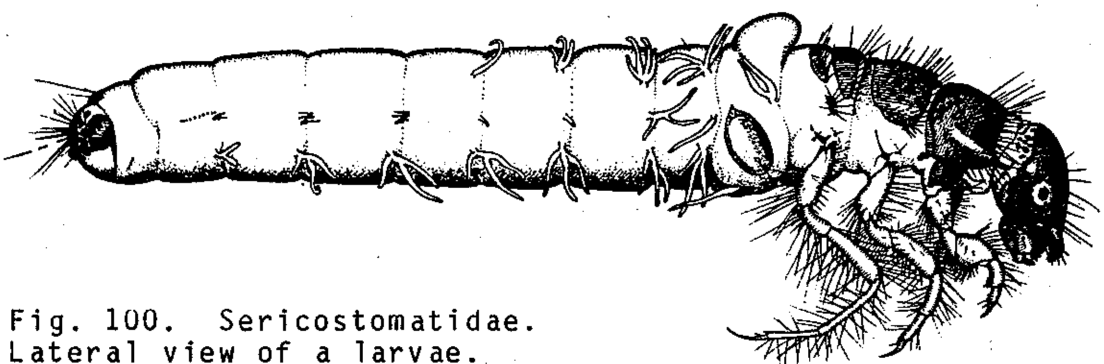


Fig. 100. Sericostomatidae. Lateral view of a larvae. (Wiggins, 1977).

Order: LEPIDOPTERA (= scale-winged)
Common Name: Butterflies and Moths

Family: Pyralidae (aquatic moths)

The only aquatic moths of the order are in this family. The aquatic members of this family feed on aquatic macrophytes, algae and diatoms. Some species make cases out of the leaves of plants on which they feed. Eggs are usually laid on the underside of floating aquatic plants. The species that feed on diatoms and algae are often found on rocks in swift streams. The adult females of these species swim underwater using their hind legs like oars and lay their eggs on rocks. Some species of wasps parasitize the pupae of these aquatic moths.

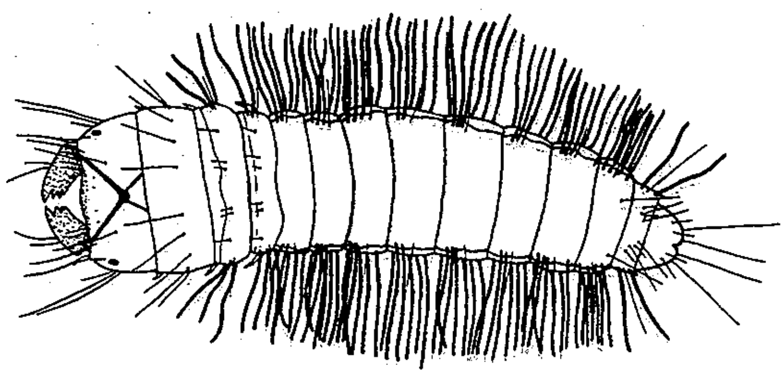


Fig. 101. Pyralidae. Dorsal view of a larva.

Order: HYMENOPTERA (= membrane-winged)
Common Name: Wasps

Some species within this order are semiaquatic in habit. The adults of only a few species enter the water to lay their eggs on or in a host organism. The immature stages of the wasps develop in the host's body eventually killing it. The aquatic wasps of this order are known to parasitize caddisflies, water bugs, aquatic moths, aquatic beetles, damselflies, shore flies, and semiaquatic spiders. Observations have shown that some species use their wings and legs to swim underwater, while other species use only their legs. Adults of many aquatic insects are parasitized by wasps when they are out of the water. Knowledge about these interesting semiaquatic wasps in California is limited.

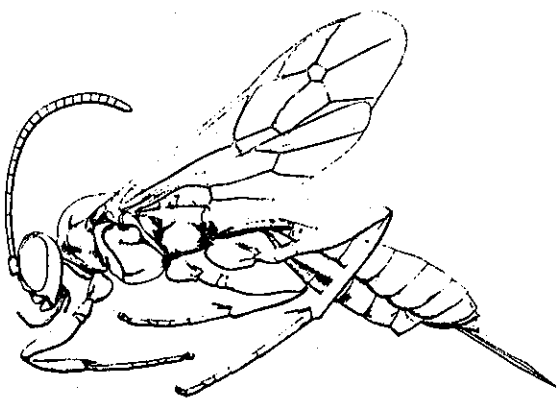
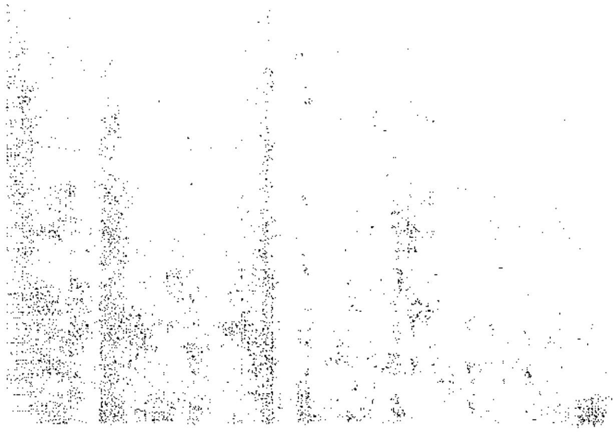
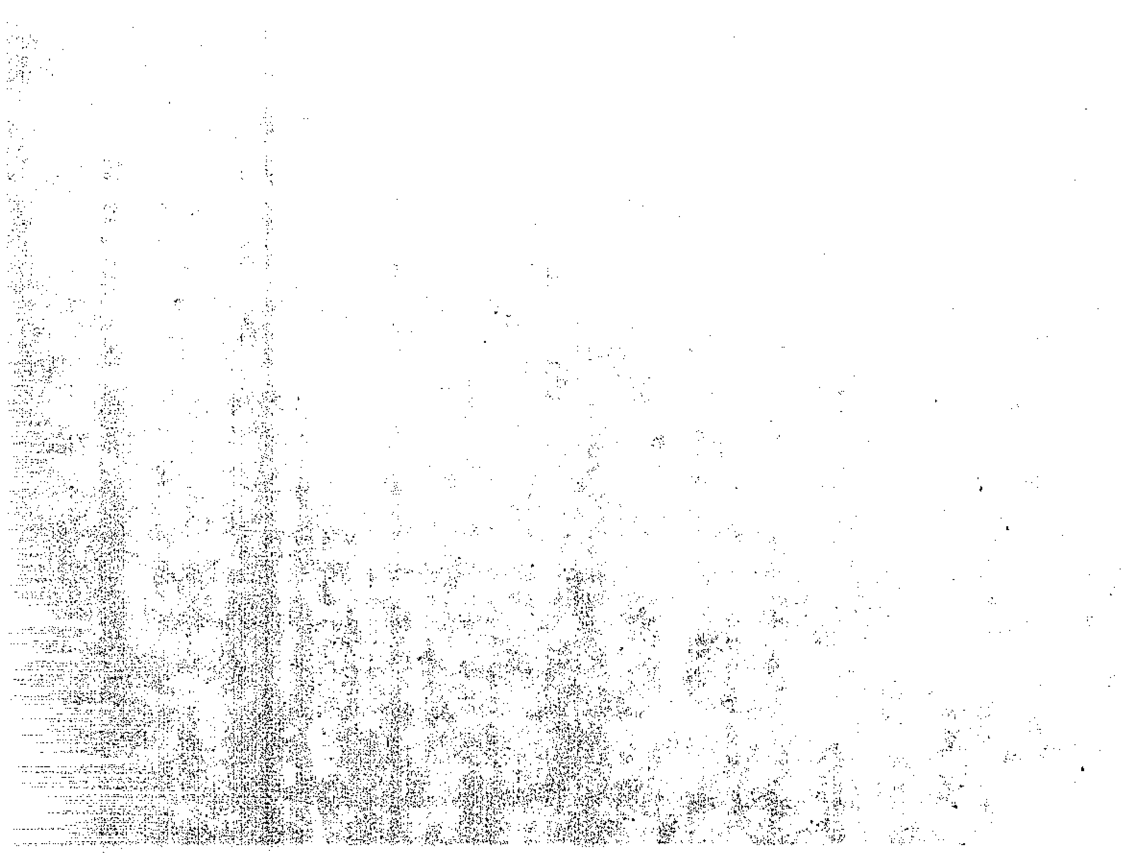
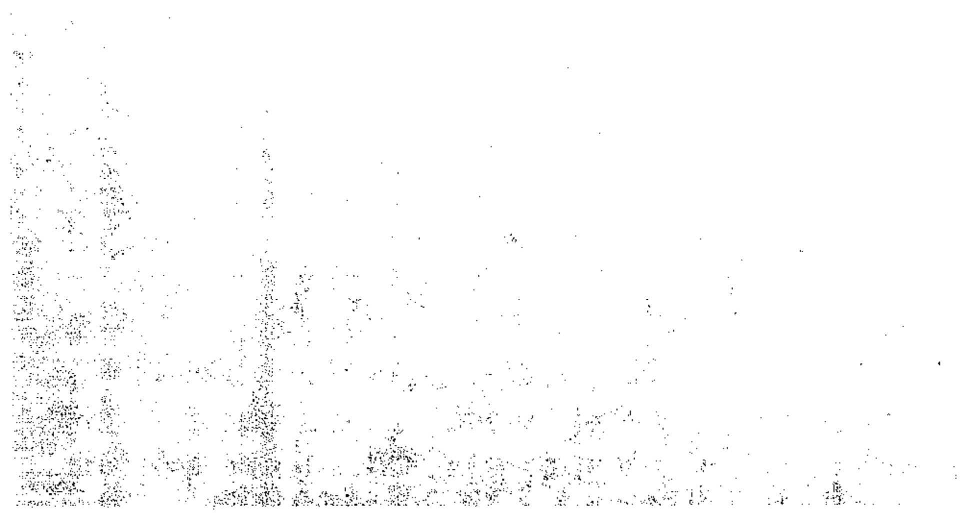


Fig. 102. Hymenoptera.
Lateral view of an adult.

KEY TO THE FAMILIES OF CALIFORNIA COLEOPTERA ADULTS (BEETLES)







Order: COLEOPTERA (= sheathed-winged)
Common Name: Beetle

Coleoptera is the largest order of insects with over 300,000 species already discovered and about 1000 new species being described each year. Within this order, about 5000 species can be described as aquatic at some stage of their life cycle. Aquatic beetles can be found in many habitats including freshwater ponds, lakes, streams, rivers, inland saline lakes and ocean beaches.

Many families are completely aquatic with both the larval and adult stages occurring in the water. Other families may have only the larval state in the water, and still others may only be semiaquatic with the larvae and adult living along the water's edge.

Many species of aquatic beetles fly and migrate nightly from one body of water to another. The fore wings are horny or leathery and cover the abdomen, meeting to form a straight, median, dorsal suture. The hind wings, if present, are membranous and folded under the fore wings.

Most beetle larvae leave the water to pupate on the land. They usually construct a pupal chamber within five meters of the water. Sometimes the pupae build hollow chambers several inches below the surface of the land. Others may build one of mud pellets or bits of vegetation. They may also dig chambers in stones, logs or other objects. Pupae are usually pale, grooved and covered with a thin soft cuticle.

Adult aquatic beetles depend on atmospheric oxygen for respiration, and they obtain it in two ways. Members of the families Amphizoidae, Haliplidae, Dytiscidae, Noteridae, and Gyrinidae carry an oxygen supply under the elytra (fore wings). When they return to the surface to renew their air supply, they break the surface with the ends of the elytra and abdomen. Members of the other aquatic beetle families, in addition to carrying air under the elytra, hold a film of air on the ventral side of the abdomen by means of short, dense hairs. This film of air is what gives beetles a silvery appearance when they are underwater. When the beetles of this group return to the surface, they break the surface with their antennae.

Adult beetles are either carnivorous or omnivorous and have mouthparts that have been adapted for chewing and biting.

Eggs of aquatic beetles are deposited underwater on plants or other objects. Development usually takes from three to six months, with one generation per year.

Both adults and larvae can be harmful to certain crops, such as rice, but most are beneficial to man. In Asia, some of the larger beetles are eaten by man for food and medicine. Beetles comprise an important segment in the diet of frogs, toads, salamanders, aquatic birds, and fish.

This key does not include beetle families that are found only along the water margins, or those in the intertidal habitat. If the key characteristics do not fit the specimen, do not attempt to key that particular organism.

Order: COLEOPTERA

Synopsis of the California Families

Family: Gyrinidae (whirligig beetles)

These shiny, black beetles are found on lakes, ponds, and the slow-flowing backwater of streams. They are often seen on the water surface circling around or just floating quietly. Each eye is divided into two halves, the upper half, when the beetle is on the surface is in the air and the lower half is below the water. When disturbed, the adults often dive quickly to the bottom or gyrate rapidly in circles. The adults and larvae are scavengers or predators. This group has been known to feed on worms, dragonfly naiads, other insects, small fish, and dead plant and animal matter. Adult beetles hibernate in the pond or stream bottoms during the winter.

Family: Haliplidae (crawling water beetles)

The crawling water beetles are small, being less than 5 mm in length. This widespread group is found in shallow water areas of ponds, lakes and streams. The adults are herbivorous and carnivorous while the larvae are strictly herbivorous. Some species of adult beetles hibernate during the winter while others remain active even under an ice cover. The eggs of these beetles are laid in and on aquatic vegetation.

Family: Amphizoidae

The adults and larvae of this family inhabit clear streams and rivers. Both adult and larvae crawl rather than swim and are usually found under rocks or in debris at the margins of the water. Their food is thought to be only stonefly nymphs. The eggs are laid in the cracks of floating logs or other debris. All known members of this family are from the western United States and Canada except for a single species described from Tibet.

Family: Noteridae (borrowing water beetles)

The adults of this family are worldwide in distribution and are active swimmers. Larvae and adults are found in ponds and lakes having abundant aquatic vegetation. The adults are predaceous while the larvae are thought to be omnivorous. The larvae have legs adapted for rapid burrowing in mud, giving rise to his family's common name. The adults also burrow in bottom debris while the eggs are laid in mud or on the roots of aquatic plants.

Family: Dytiscidae (predaceous water beetles)

Members of this family occupy a wide variety of habitats from streams, rivers, ponds and lakes, to salt marshes and bogs. Adults of some species are powerful swimmers and propel themselves by using their hind legs like oars. Some species can fly over considerable distance while others are flightless. Both adults and larvae are carnivorous and have been known to feed on other aquatic insects, microorganisms, small fish and tadpoles. Some species produce sounds by rubbing the legs against the abdomen. Eggs are usually deposited on or in aquatic plants under the water. This family is worldwide in distribution and even occurs on some oceanic islands.

Family: Hydroscaphidae

These very small beetles are no more than 1 mm in length. They have been found along the margins of streams and hot springs where they feed on filamentous algae. Eggs are developed one at a time and are deposited on algae.

Family: Hydraenidae

These small beetles are worldwide in distribution and can be found in a variety of habitats. They have been reported from ponds, lakes, swift-flowing streams and rivers, saline waters and hot springs, and the intertidal zone of the ocean. The adults of most species are aquatic but they are not well adapted for swimming. The larvae are littoral and occur in moist areas along shore margins. The adults are usually herbivorous while the larvae are carnivorous.

Family: Hydrophilidae (water scavenger beetles)

Beetles in this large family usually occur along the margins of slow-flowing streams or in weedy ponds and lakes. The adults are omnivorous while the larvae are carnivorous. These beetles are an important item in the diet of other animals such as frogs, toads, fish, birds and ducks. Nearly 200 species are known from the United States and many species are found in California.

Family: Curculionidae (weevils, snout beetles)

The weevils are a large family with most of the members being terrestrial. The aquatic species are associated with aquatic plants on which they feed. One species is a serious pest to rice crops. Most adults and larvae are not truly aquatic, but they do bore into the stems of plants below the water to feed and lay eggs. Air filled chambers within the plants protect them from the water.

Family: Chrysomelidae (longhorn leaf beetles)

These beetles are intimately associated with aquatic plants on which they feed. The larvae are aquatic and the adults are known to briefly crawl underwater. Mating occurs out of the water and the eggs are deposited on the emergent parts of the plants or within the plant tissues. Larvae obtain oxygen by directly absorbing it from the water through the skin or by piercing plant tissues and using cellular air.

Family: Helodidae

This family of small beetles is worldwide in distribution. The adults are all terrestrial but the larvae are aquatic. Larvae can be found in ponds, streams and cavities of trees. The larvae are herbivorous. The mature larvae of most species leave the water to pupate in wet soil.

Family: Ptilodactylidae

Beetles of this small family are found only in North America. The adults can be found along the margins of streams and springs. The larvae are herbivorous.

Family: Limnichidae

These small, uncommon beetles are known only from North America. The adults can be found along the margins of streams under debris. Aquatic larvae occur on stones and debris in clear streams. The adults are covered with a dense mat of short hairs and the body may have a metallic luster to it.

Family: Psephenidae (water pennies)

Water pennies occur in swift water areas of streams, usually on rocks. The adults are littoral in habit and enter the water to deposit eggs. The larvae are oval and flat, like a limpet, which is an adaptation to their swift water habitat. Water pennies are a small family found only in North America. This type of beetles are one of the few aquatic beetle families adapted to fast-flowing water.

Family: Dryopidae

None of the aquatic or semiaquatic beetles in this family can swim, rather they hold tight to plants and debris or crawl slowly over the bottom. Both the adults and larvae are herbivorous. Adults readily enter the water to feed. These beetles have been found in fast-flowing streams and rivers as well as water storage tanks. The family is worldwide in distribution.

Family: Elmidae (riffle beetles)

Adult elmids are small beetles only 2 or 3 mm in length. Most are found in streams but a few occur in ponds and lakes. Adults usually hide under rocks and logs at the water margin. Larvae cannot swim but rather crawl slowly over the bottom or hold on to vegetation. Both the adult and the larvae are herbivorous. This group is worldwide in distribution.

Key to the California Families of Coleoptera Adults

1a First visible abdominal sternite completely divided by the hind coxal cavities (Fig. 103)................ 2
1b First visible abdominal sternite extending for its entire length behind the hind coxal cavities (Fig. 104)....................................... 6

2a(1) Eyes divided by the sides of the head and appearing as four (4) (Fig. 105)...........................GYRINIDAE
2b Eyes 2, not divided by the sides of the head......... 3

3a(2) Hind coxae expanded into large plates which cover the first 2 or 3 abdominal sternites (Fig. 106)..HALIPLIDAE
3b Hind coxae not expanded into large plates and not covering more than the first abdominal sternite...... 4

4a(3) Metasternum with a transverse, triangular, antecoxal sclerite separated by a distinct suture; hind tarsi not flattened or fringed with hairs (Fig. 107)..AMPHIZOIDAE
4b Metasternum without a transverse, antecoxal sclerite separated by a suture; hind tarsi flattened and usually fringed with long hairs...................... 5

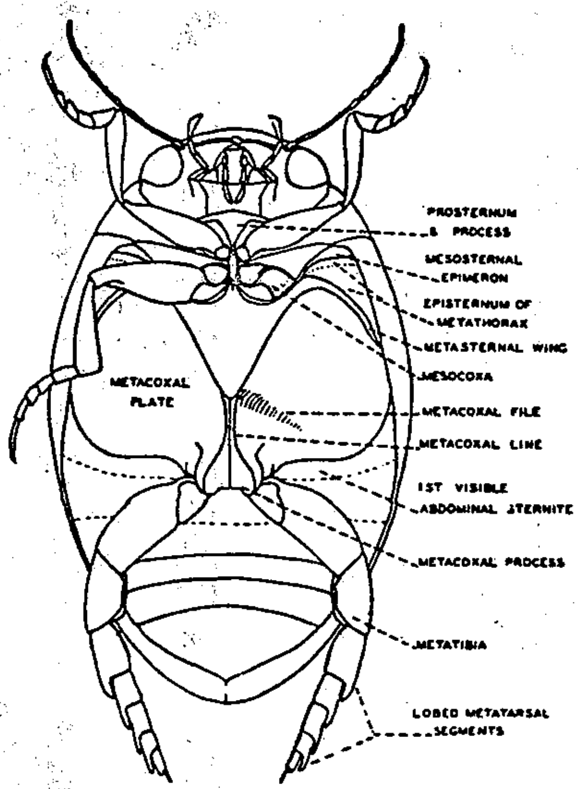


Fig. 103. Dytiscidae. Ventral view of an adult. (Leech, 1948).

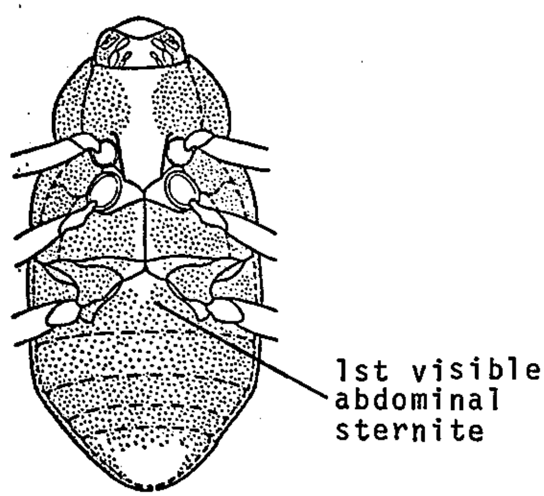


Fig. 104. Dryopidae. Ventral view of an adult.

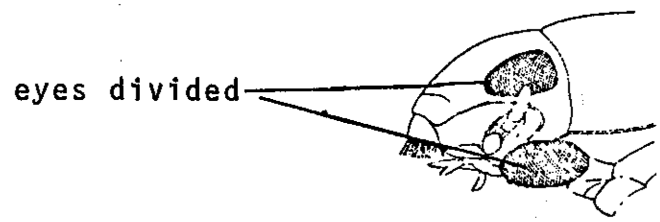


Fig. 105. Gyrinidae.
Lateral view of the head
of an adult. (Edmondson, 1959).

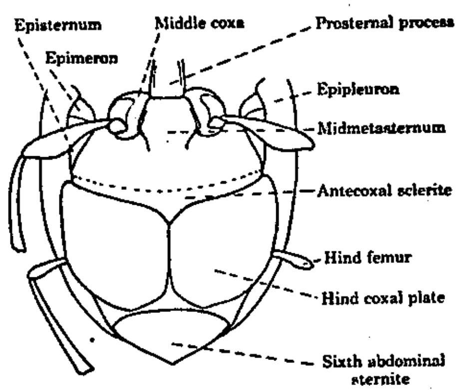


Fig. 106. Haliplidae.
Ventral view of the abdomen
of an adult. (Edmondson, 1959).

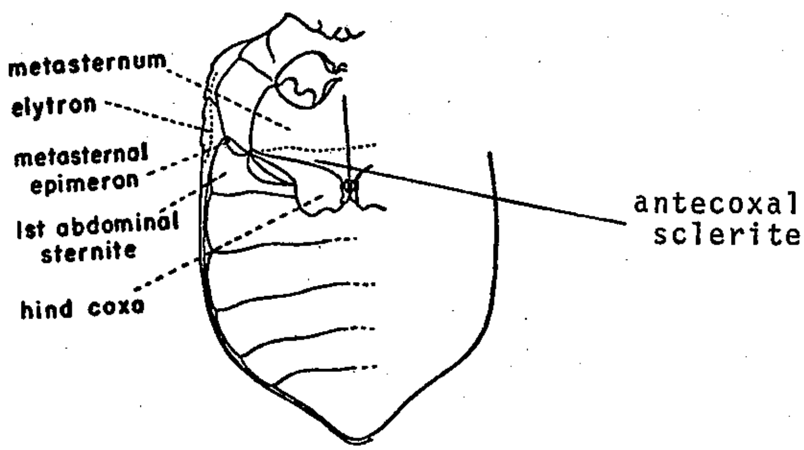


Fig. 107. Amphizoidae.
Ventral view of the abdomen
of an adult.

5a(4) Scutellum covered by the bases of the elytra and the hind margin of the pronotum; hind tarsi with two curved claws (Fig. 108)......................NOTERIDAE

5b Scutellum visible, or if concealed, the hind margin of the hind tarsal segments produced into lobes, and the anterior tibiae without recurved spines or spurs (Figs. 103, 109)..............................DYTISCIDAE

6a(1) Hind tarsi 3-segmented; hind coxae widely separated (Fig. 110)........................HYDROSCAPHIDAE

6b Hind tarsi with more than 3 segments................ 7

7a(6) Antennae short with segment 6 cup-shaped; segments 7 to 11 forming a pubescent club (there may only be 9 segments((Figs. 111, 112)......................... 8

7b Antennae not as above (Figs. 115, 118)............... 9

8a(7) Antennal club beyond cup-shaped segment 6, five segmented (Fig. 111)...........................HYDRAENIDAE

8b Antennal club beyond cup-shaped segment 6, three segmented (Fig. 112)..........................HYDROPHILIDAE

9a(7) Head in front of the eyes forming a distinct beak (Fig. 113)...................................CURCULIONIDAE

9b Head formation not as above..........................10

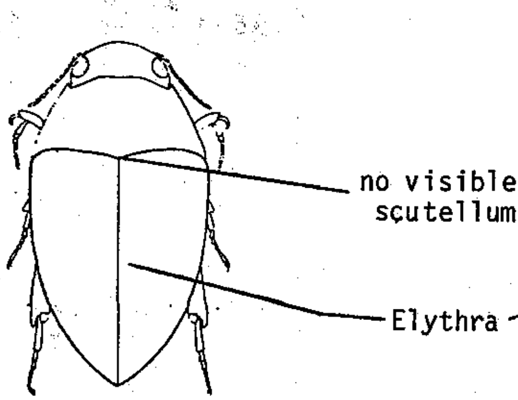


Fig. 108. Noteridae. Dorsal view of an adult. (Edmondson, 1959)

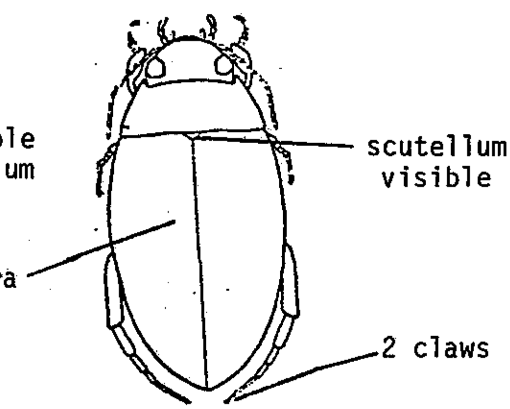


Fig. 109. Dytiscidae. Dorsal view of an adult. (Edmondson, 1959)

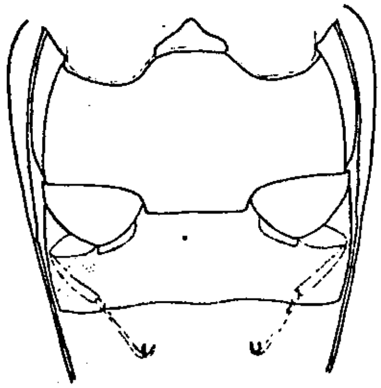


Fig. 110. Hydroscaphidae.
Ventral view of the abdomen of an adult. (Edmondson, 1959).

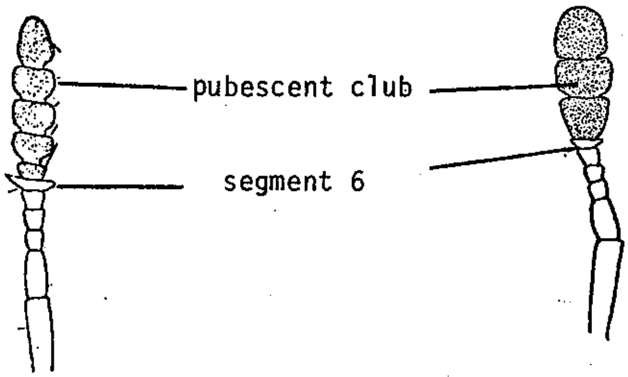


Fig. 111 Hydraenidae.
Antennal configuration.

Fig. 112. Hydrophilidae.
Antennal configuration.

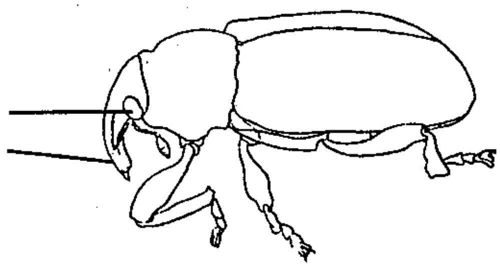


Fig. 113. Curculionidae.
Lateral view of an adult.
(Edmondson, 1959).

10a(9) Tarsi with 5 segments, the 4th segment is very small and nearly hidden within the lobes of segment 3; first 3 segments expanded with hairy pads beneath (Fig. 114)....................CHRYSOMELIDAE
10b Tarsi with 5 or fewer segments, but not as above...11

11a(10) Front coxae more or less conically projecting; hind margin of prothorax never crenulate (Fig. 115)....................................HELODIDAE
11b Front coxae variously formed and if they are projecting, then the hind margin of the prothorax is crenulate (Figs. 116, 118, 122)..........12

12a(11) Antennae long with segments 4 to 10 bearing long basal processes; scutellum heart-shaped, notched anteriorly (Fig. 116).............PTILODACTYLIDAE
12b Antennae not as above..............................13

13a(12) Middle coxae widely separated and the hind coxae touching or nearly touching (Fig. 117)........LIMNICHIDAE
13b Middle and hind coxae not as above.................14

14a(13) Six or 7 abdominal sternites (Fig. 118).......PSEPHENIDAE
14b Five abdominal sternites...........................15

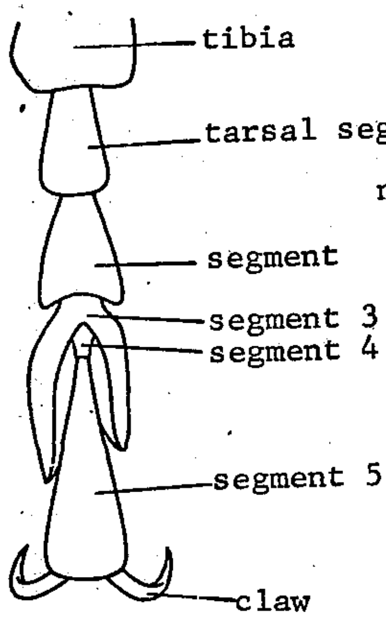


Fig. 114. Chrysomelidae. Tarsus of an adult. (Leech, 1948).

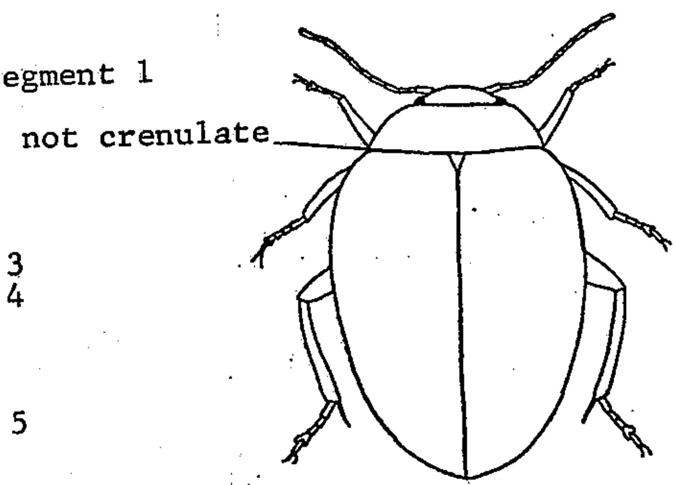


Fig. 115. Helodidae. Dorsal view of an adult. (Leech, 1948).

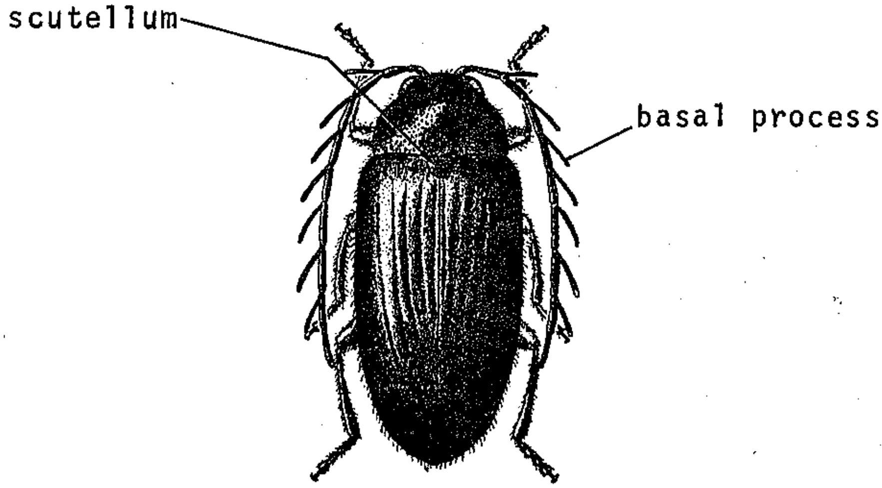


Fig. 116. Ptilodactylidae.
Dorsal view of an adult.

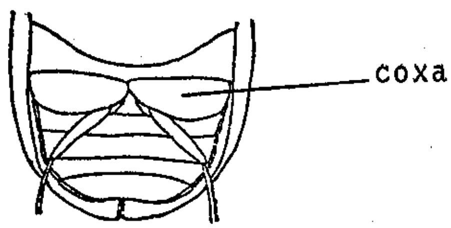


Fig. 117. Clambidae. Similar to members of the family Limnichidae. Ventral view of the abdomen of an adult. (Edmondson, 1959).

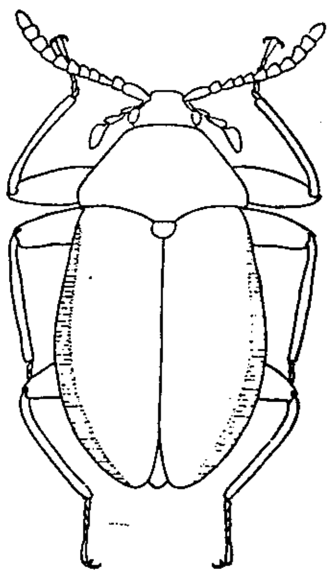


Fig. 118. Psephenidae. Dorsal view of an adult. (Edmondson, 1959).

15a(14) Antennae very short in length with apical segments serrate (Figs. 119, 120)...............DRYOPIDAE

15b Antennae short to moderate in length and clubbed or threadlike, never with apical segments serrate (Figs. 121a-c, 122)..............ELMIDAE

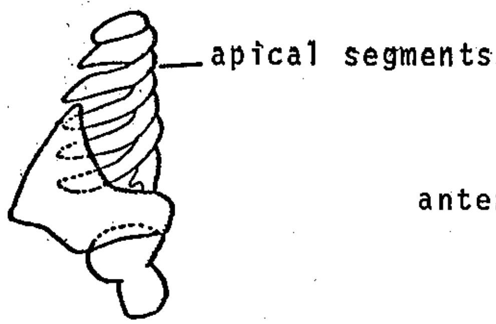


Fig. 119. Dryopidae. Antennae. (Hinton,1939).

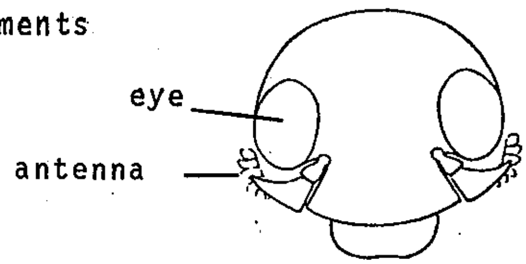


Fig. 120. Dryopidae. Frontal view of the head of an adult. (Edmondson,1959).

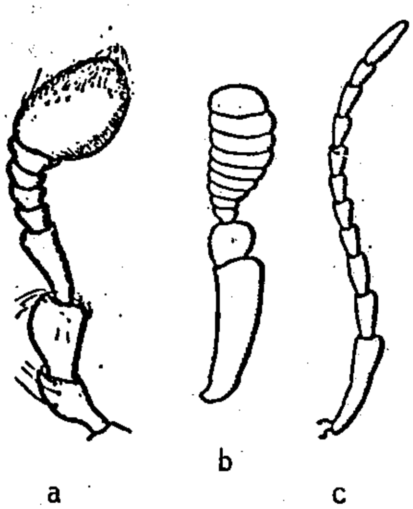


Fig. 121a-c. Elmidae. Types of antennae. (Hinton,1939).

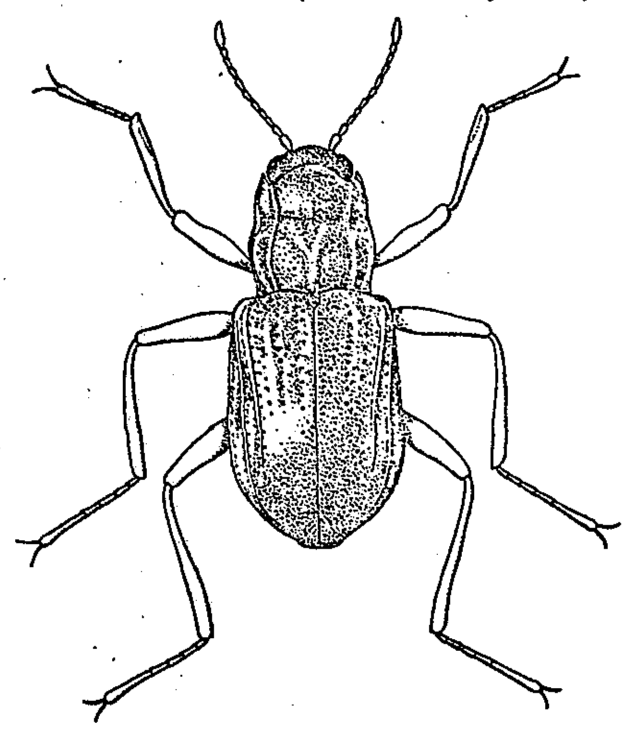


Fig. 122. Elmidae. Dorsal view of an adult. (Hinton,1940).

KEY TO THE FAMILIES OF CALIFORNIA COLEOPTERA LARVAE (BEETLES)

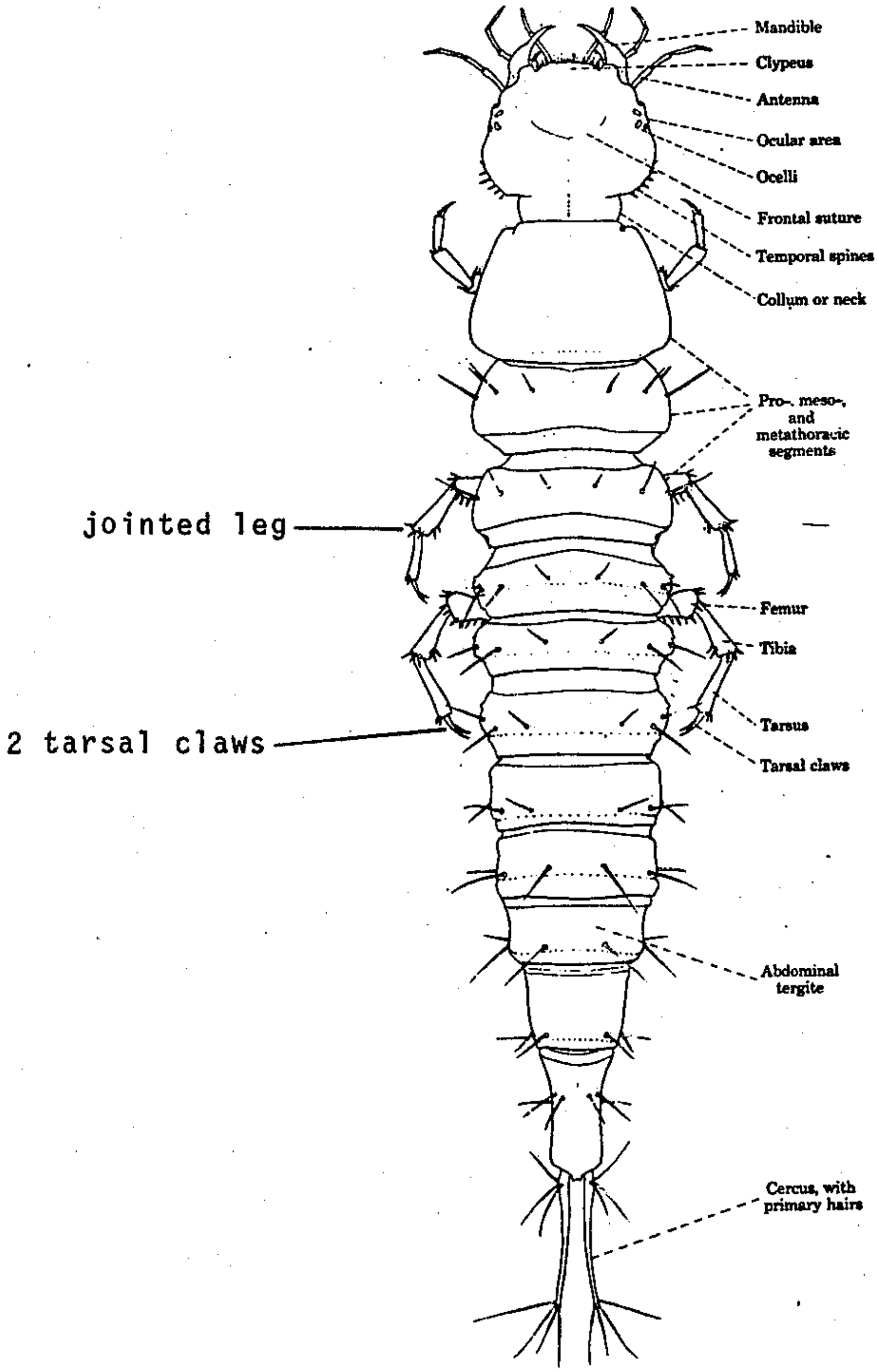


Fig. 123. Dytiscidae. Dorsal view of a larva to show general features. (Edmondson,1959).

1a With legs.. 2
1b Without legs (Fig. 124).......................CURCULIONIDAE

2a(1) Tarsi with 1 claw (Fig. 126)......................... 3
2b Tarsi with 2 claws (Fig. 123).........................13

3a(2) Legs 4 segmented (Fig. 126).......................... 4
3b Legs 5 segmented (Figs. 125, 127a,b).............HALIPLIDAE

4a(3) Cerci segmented and usually movable, often retracted into a breathing pocket on the 8th abdominal segment (Figs. 123, 136a-k, 137a,b, 138a,b, 139-141).........11
4b Cerci solidly fused at the base or absent (Figs. 128, 129, 131a-c, 132, 134, 135).............. 5

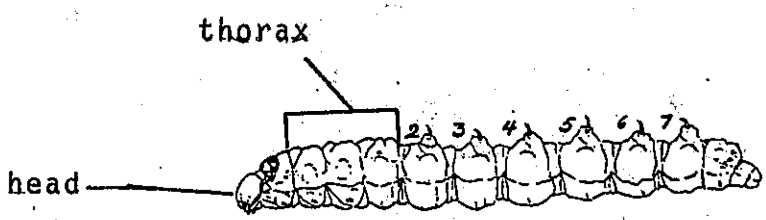


Fig. 124. Curculionidae.
Lateral view of a larva.
(Boving and Craighead,1930).

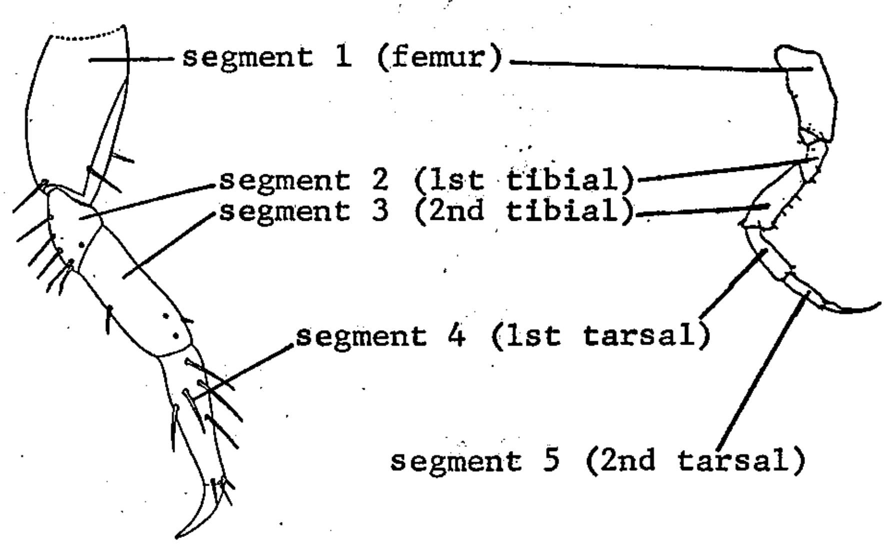


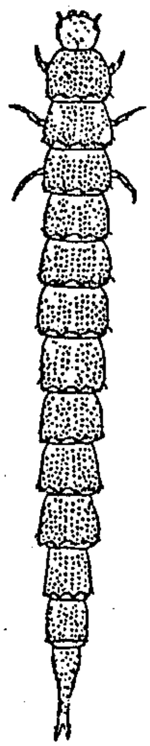
Fig. 126. General appearance of a 4-segmented leg.

Fig. 125. Haliplidae. Leg.

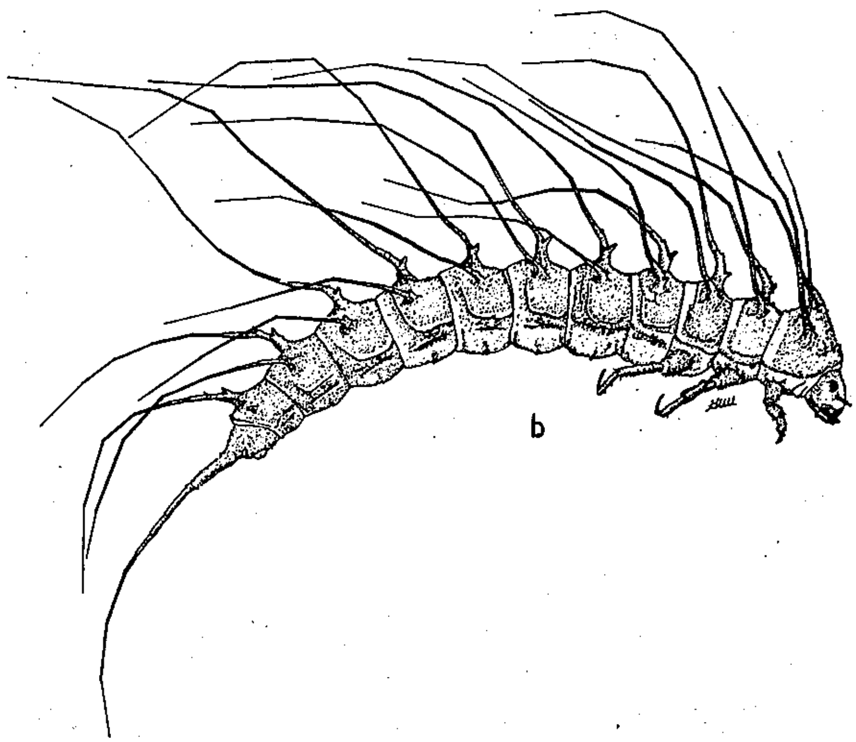
5a(4) Body rounded or oval and greatly depressed with the lateral margins of the body segments expanded to cover the head (Fig. 128a,b)....................PSEPHENIDAE
5b Body slender and round or triangular in form, the head exposed from above................................. 6

6a(5) Ninth abdominal segment with a ventral, movable operculum closing a caudal chamber (Figs. 129, 131a-c)... 7
6b Ninth abdominal segment without ventral operculum.... 9

7a(6) Abdominal sternites 1 to 5 or 8 with a median fold (Fig. 129)..DRYOPIDAE
7b Abdominal sternites without a median fold............ 8



a



b

Fig. 127. Haliplidae. Dorsal (a) and lateral (b) views of two different larvae.

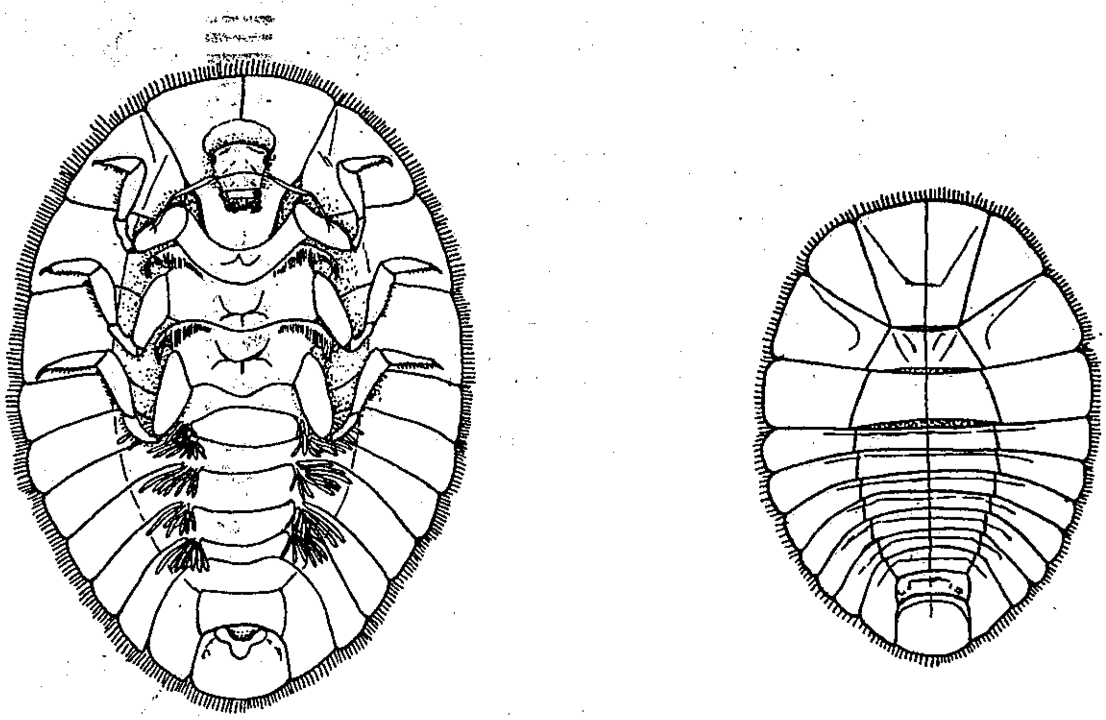


Fig. 128a,b. Psephenidae.
Ventral (a) and dorsal (b) views
of larva. (Pennak,1978).

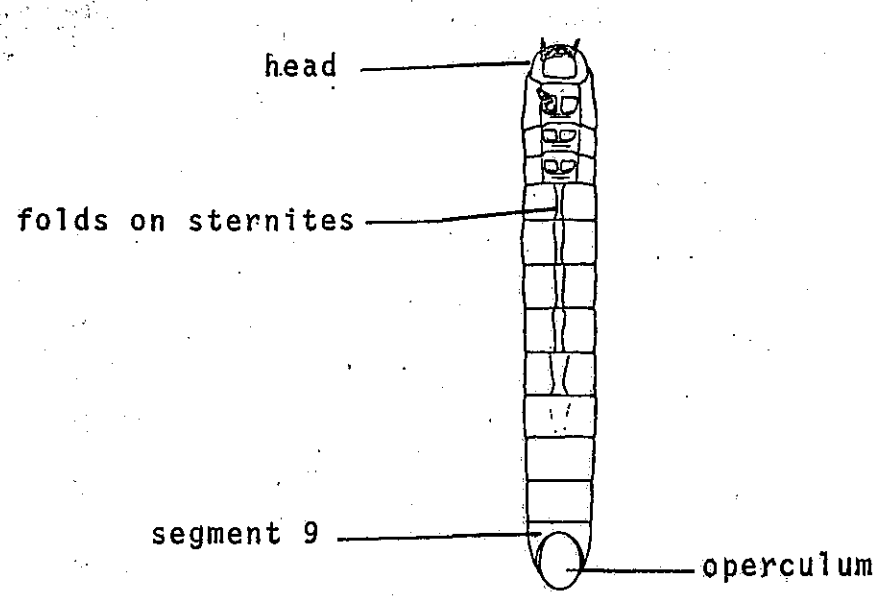


Fig. 129. Dryopidae.
Ventral view of a larva.
(Edmondson,1959).

8a(7) End of the last abdominal segment evenly rounded (Fig. 130)....................................LIMNICHIDAE

8b End of the last abdominal segment emarginate (Fig. 131a)....................................ELMIDAE

9a(6) Four or more of the first 7 abdominal segments with 2 ventral tufts of filamentous gills (Fig. 132); if gills are absent from the abdomen, then there are 5 to 21 mamillaeform gills in a caudal chamber on the 9th abdominal segment (Fig. 133a,b).........PTILODACTYLIDAE

9b Abdominal segments without gills as above; gills may be present in a caudal chamber on the 8th abdominal segment....................................10

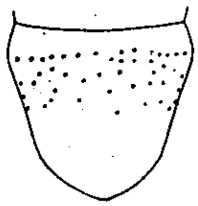


Fig. 130. Limnichidae.
Dorsal view of the last abdominal segment of a larva. (Edmondson,1959).

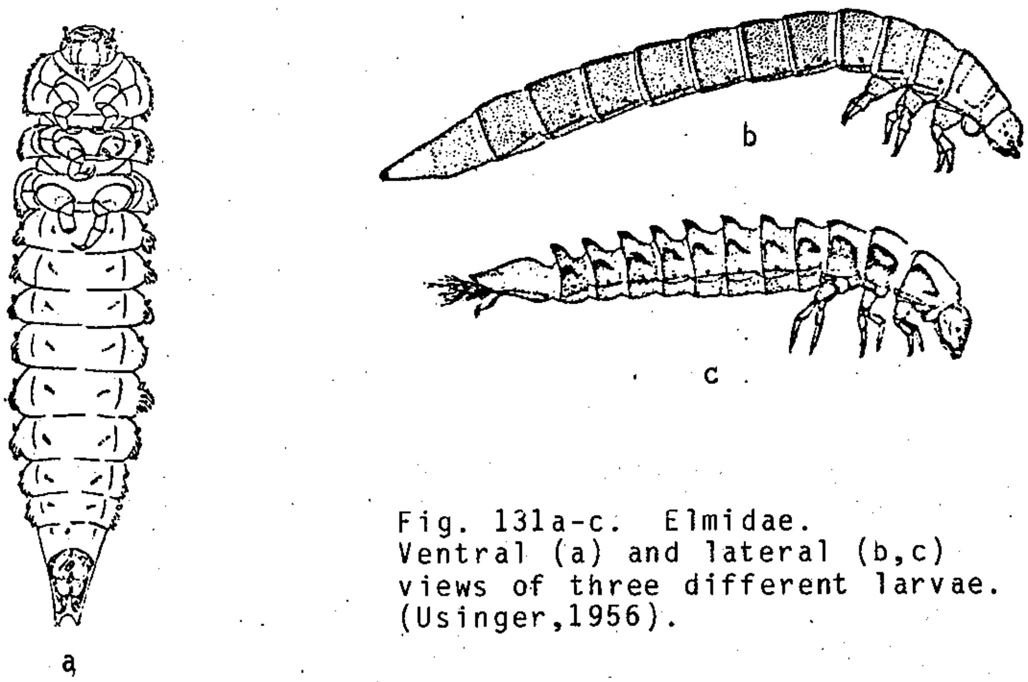


Fig. 131a-c. Elmidae.
Ventral (a) and lateral (b,c) views of three different larvae. (Usinger,1956).

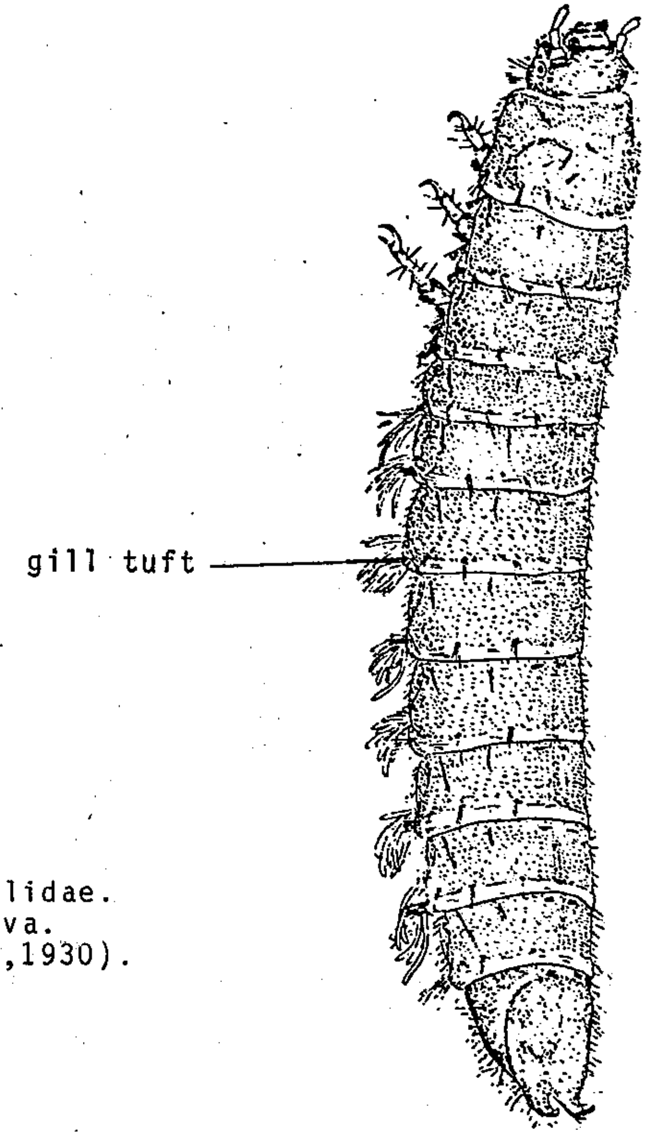


Fig. 132. Ptilodactylidae.
Lateral view of a larva.
(Boving and Craighead,1930).

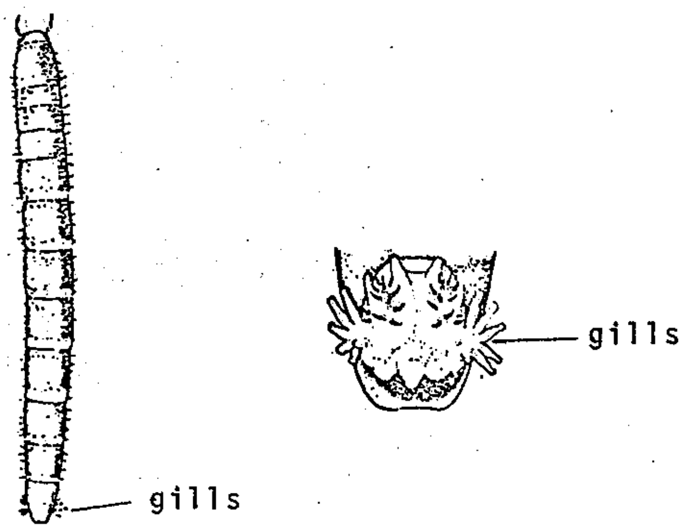


Fig. 133. Ptilodactylidae.
Dorsal view of a larva with mamillaeform gills(a) and a ventral view of the gills in the caudal chamber(b). (Boving and Craighead,1930).

10a(9) No conspicuous gills on the abdomen; legs poorly developed; abdominal segments mostly membranous; antennae very short (Fig. 134a,b)............CHRYSOMELIDAE
10b Gills in a caudal chamber on the 8th abdominal segment; antennae long and tapering (Fig. 135)...HELODIDAE

11a(4) Ocelli in groups of 5 (Fig. 137a)..................12
11b Ocelli usually in groups of 6 (Fig. 136a-k)..HYDROPHILIDAE

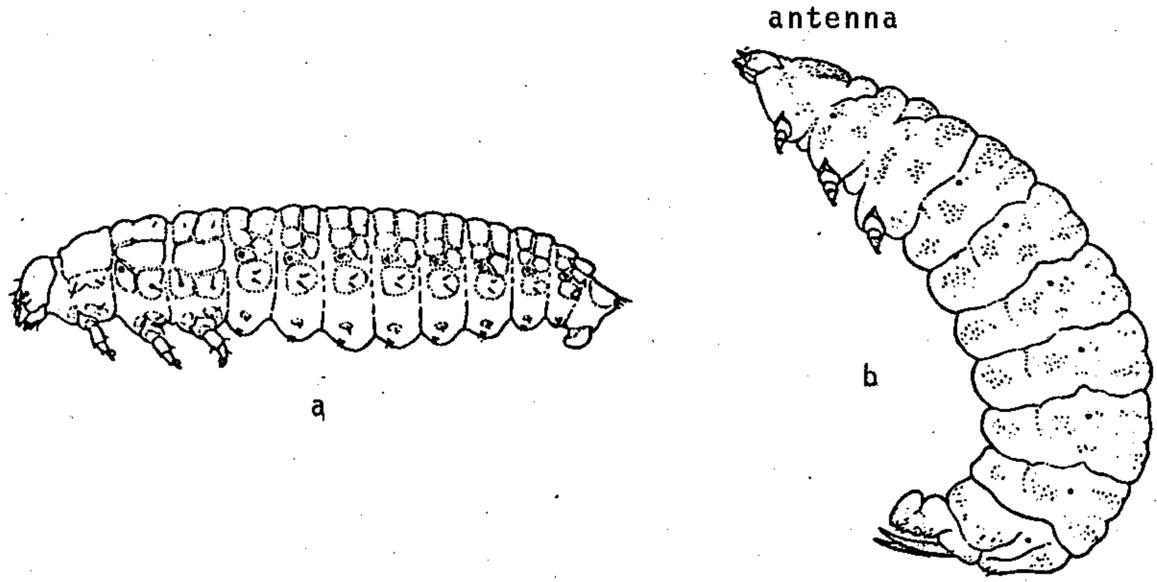


Fig. 134a,b. Chrysomelidae.
Lateral views of two different larvae. (Pennak,1953).

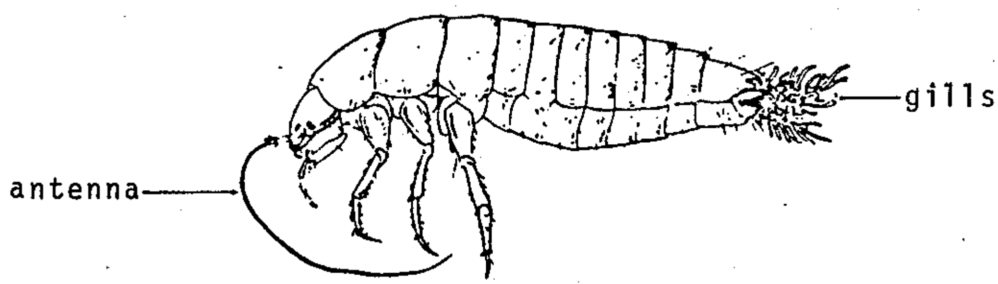


Fig. 135. Helodidae.
Lateral view of a larva.
(Boving and Craighead,1930).

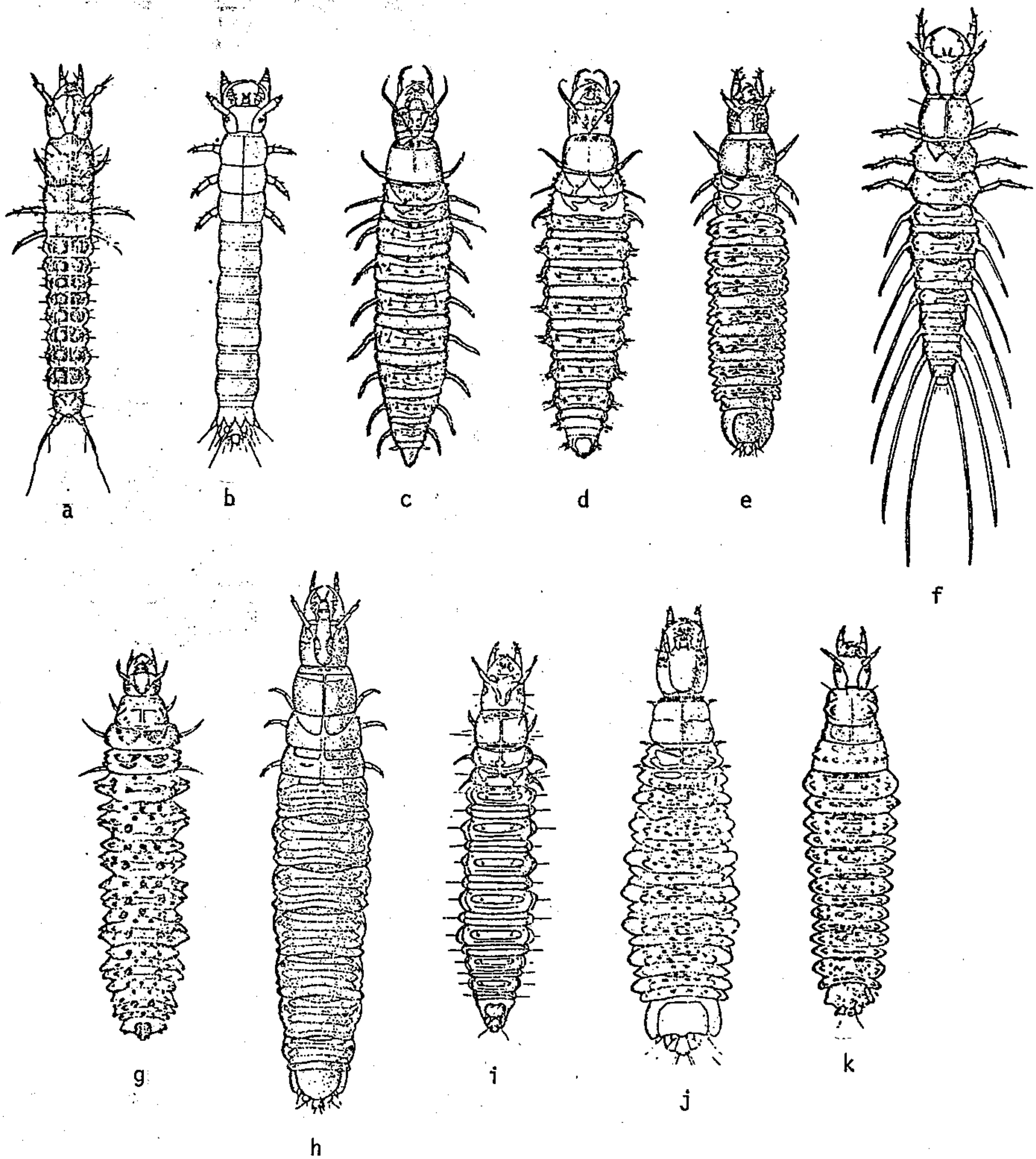


Fig. 136a-k. Hydrophilidae. Dorsal view of 11 different types of larvae. (Richmond,1920).

12a(11) Tenth abdominal segment with a pair of curved hooks; no balloon-like structures on the prothorax or abdomen (Fig. 137a,b)........................HYDRAENIDAE

12b Tenth abdominal segment without a pair of curved hooks; balloon-like structures on the prothorax and abdominal segments 1 and 8 (Fig. 138a,b) ....HYDROSCAPHIDAE

13a(2) Tenth abdominal segment with 4 hooks; lateral gills present on all the abdominal segments (Fig. 139) ....GYRINIDAE

13b Tenth abdominal segment without hooks; lateral gills may or may not be present..........................14

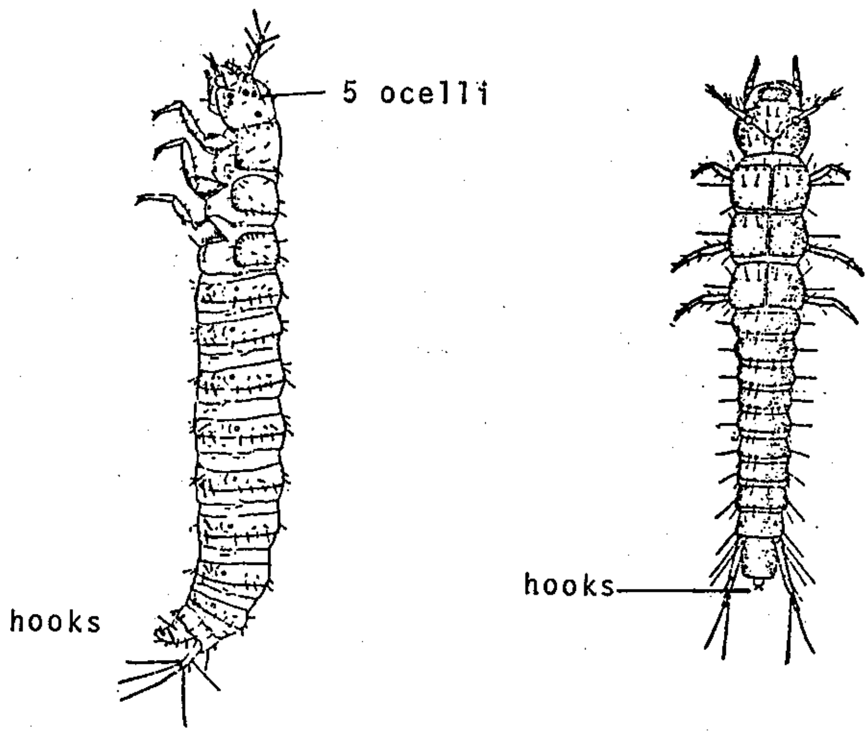


Fig. 137a,b. Hydraenidae. Lateral (a) and dorsal (b) views of two different larvae.

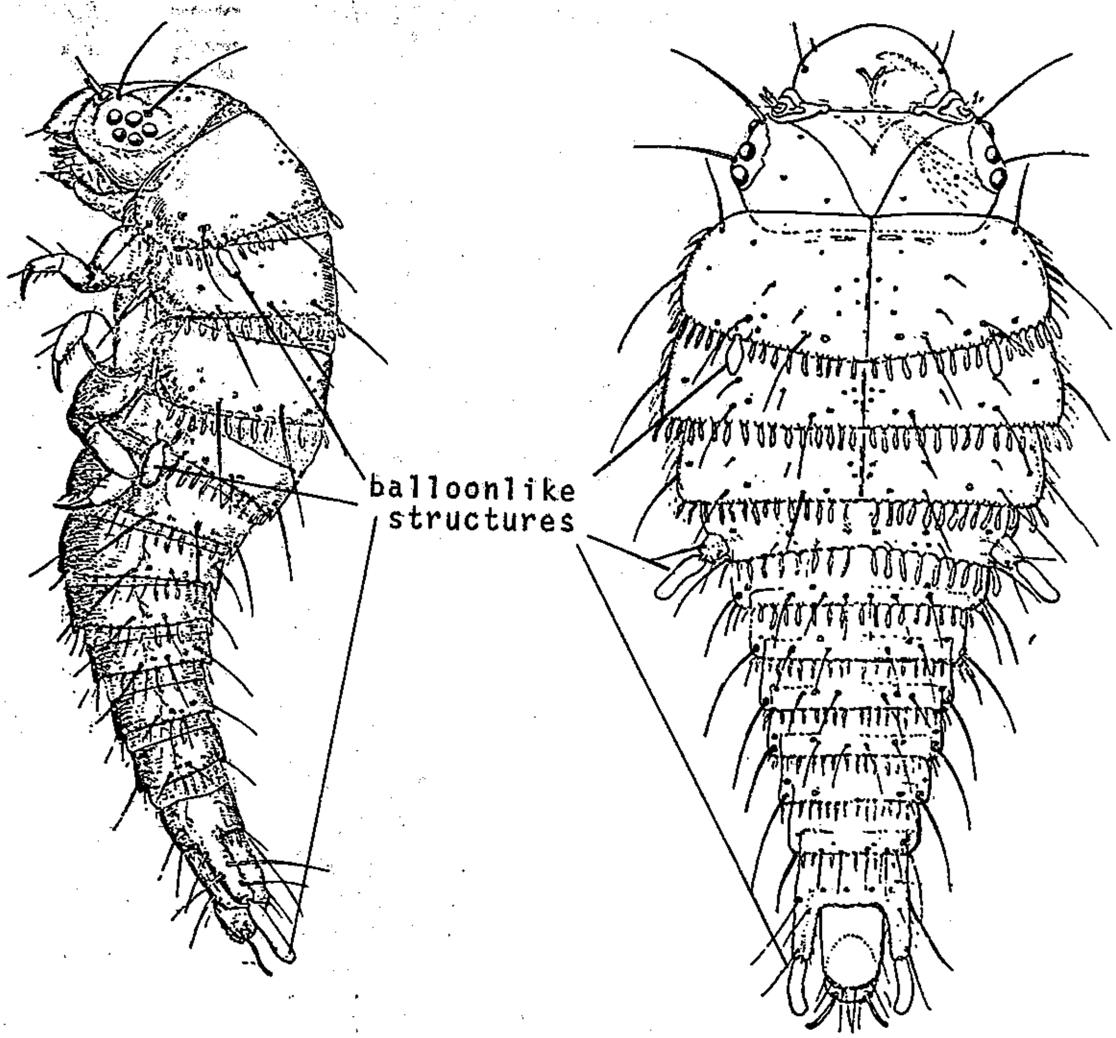


Fig. 138a,b. Hydroscaphidae.
Lateral (a) and dorsal (b)
views of a larva.
(Boving and Craighead,1930).

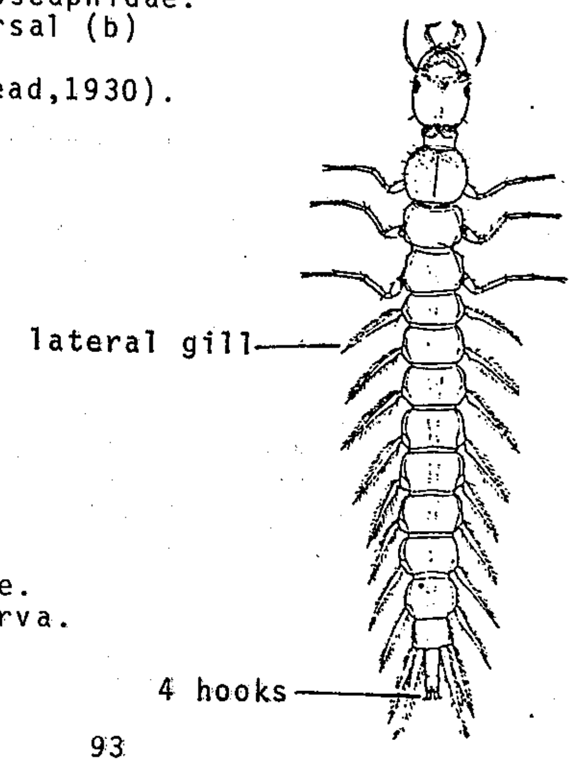


Fig. 139. Gyrinidae.
Dorsal view of a larva.

14a(13) Legs stout, adapted for burrowing and body form like a wireworm (Fig. 140)..........................NOTERIDAE

14b Legs adapted for walking or swimming and body form not like a wireworm..................................15

15a(14) Larvae flattened with the sides of the thorax and abdomen expanded into thin lateral plates (Fig. 141)....................................AMPHIZOIDAE

15b Larvae without the above (Fig. 123)............DYTISCIDAE

Fig. 140. Noteridae. Dorsal view of a larva. (Usinger,1956).

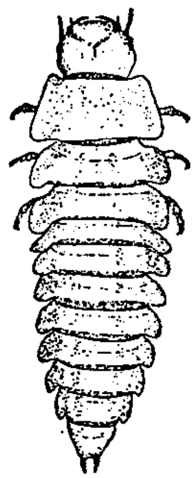
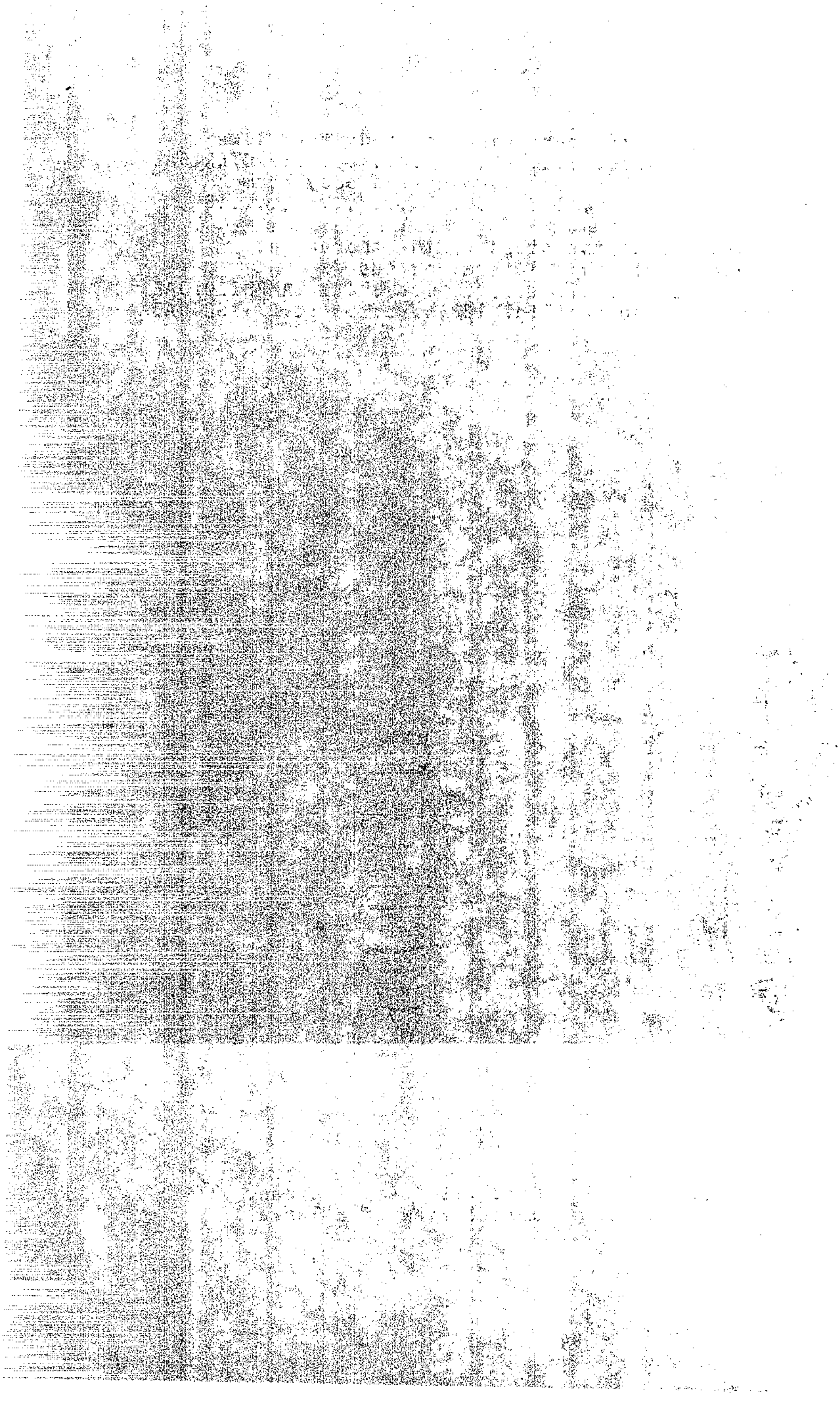
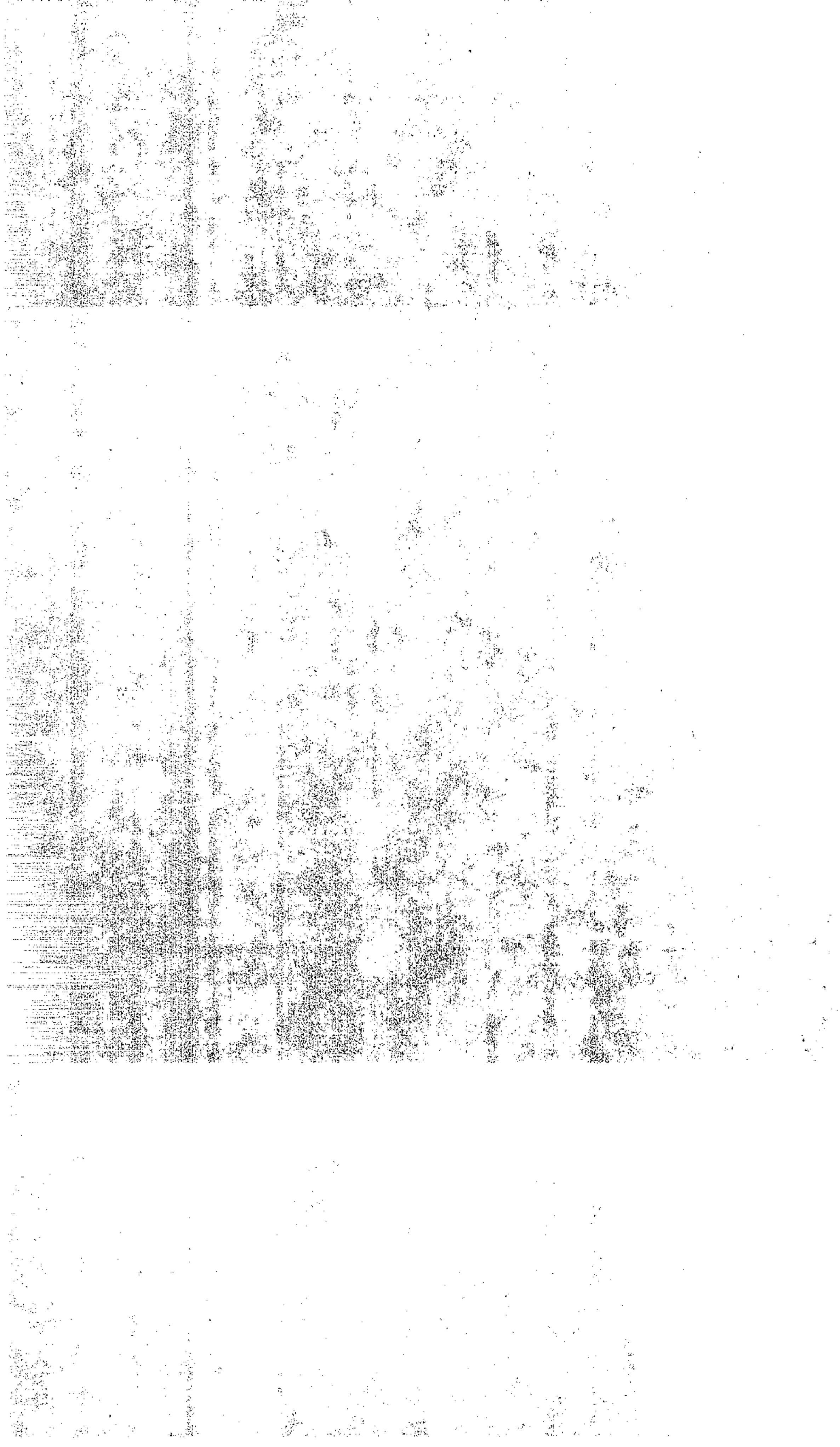


Fig. 141. Amphizoidae. Dorsal view of a larva.



KEY TO THE FAMILIES OF CALIFORNIA DIPTERA (FLIES)



Order: DIPTERA
Common Name: Flies, Mosquitos, Gnats, Midges

The Diptera are a diverse group of insects. About 50% of the species in the order live in water during the immature stages of development, but the adults are not aquatic. Many Diptera are known to carry such diseases as malaria, filariasis, yellow fever and encephalitis. Beneficially, Diptera provide an important food source for many organisms, including game birds and fish. Members of this order are found in an amazing variety of habitats including the intertidal zone of the coast, brine pools, hot springs and geysers, natural seeps of crude petroleum, and the usual freshwater ponds, lakes, rivers and streams. Diptera fulfill the roles of scavengers, carnivores and herbivores.

The adult body form of these flies is diverse. However, the members of Diptera only have one pair of wings; the usual second pair has been reduced to balancing organs called halters. The mouthparts are variable within the order and are formed for lapping or piercing and sucking.

Diptera larvae body forms also vary but can be distinguished from other aquatic insects by the long, worm-like shape and the absence of true legs and eyes. "The body is usually soft and flexible, and the most common colors are white, green, yellow, reddish, brown and black" (Pennak, 1978). The body textures of different families also vary. They may be smooth or covered with scales, bristles, spines or tubercles. Another characteristic of Diptera larvae is that they rarely have prominent antennae.

The adults may deposit their eggs in masses or strings on objects above, below or on the surface of the water. The larval stage lasts from two weeks to two years, and the pupae stage from less than two weeks to several months.

Order: DIPTERA

Synopsis of the California Families

Family: Tipulidae (crane flies)
Adult crane flies are often mistaken for very large mosquitoes. They do not bite and the family is composed of nearly 1500 species in North America alone. Larvae live in water or at the margins of streams and ponds in moist soils, moss and algae. Larvae usually feed on decaying plant material, however, some are carnivorous. Adults are common near water in vegetation.

Family: Blephariceridae (net-winged midges)
This family is worldwide in distribution with 16 species being known from California. The larvae are found attached to rocks in swift flowing mountain streams. The larvae feed on algae while the adults, which may be found on rocks or vetegation near streams, are carnivorous.

Family: Deuterophlebiidae (mountain midges)
These uncommon flies are found in cold mountain streams of western North America, Japan and Asia. Larvae feed on algae which they scrape from the rocks as they slowly move over the bottom of swift riffle areas.

Family: Tanyderidae (primitive crane flies)
Adults of this very rare family occur in thick vegetation near streams while the larvae can be found in wet sand along stream margins. Only 2 species are known from California although 33 species are known worldwide.

Family: Chironomidae (nonbiting midges)
This large family of nearly 3000 known species is worldwide in distribution. Adults are small, delicate flies often seen in swarms near ponds and lakes. Larvae are usually found in shallow water areas where aquatic plants are abundant. Adults and larvae are important food items of larger insects, birds and fish. Larvae of some species build tubes of debris. The immature stages are herbivorous.

Family: Thaumaleidae (solitary midges)
Adults of this uncommon family occur along the margins of clear water streams in vegetation. Larvae occur in the rocks in the stream with a thin film of water flowing over them. Larvae feed on detritus and algae.

Family: Ceratopogonidae (biting midges)

Adults of some species are bloodsuckers while others are predaceous on other small insects. They are also called punkies and no-see-ums, and some species do prey on man. The larval stages are predominately aquatic and range in habitat from fresh to salt water. The larvae are predators or herbivores. Some species breed in water contained in tree holes or the cups of pitcher plants.

Family: Simuliidae (black flies, buffalo gnats)

Female black flies do bite man and can be very irritating. Adults are found swarming along the margins of streams and larvae are found attached to rocks and debris in the swiftest portions of streams. Larvae are attached by a posterior sucking disc and the head trails downstream. The larvae have two large mouth brushes which strain the water for food particles. The biting nature of the female flies often is a serious problem to livestock, wild mammals and birds.

Family: Ptychopteridae (phantom crane flies)

Nine species are known from California with about 60 species worldwide. The immature stages are found in wet soil among decaying plants at the margins of ponds or swampy areas. The decomposing vegetation serves as the food for the larvae. The long breathing tubes of the larvae are pushed through the decaying material to the surface where oxygen is obtained.

Family: Dixidae

The larvae of these midges are found in streams and ponds attached to the downstream margins of rocks and debris. Food for the larvae consists of detritus and microorganisms filtered from the water. The adult midges are nonbiting and are usually found in small swarms near ponds or streams at dusk.

Family: Culicidae including Chaoboridae (mosquitoes and phantom midges)

This large group of worldwide distribution has gained fame for its transmission of disease and its biting members. Only the females of certain species have the biting habit. Larval forms in this family feed on algae, protozoa, organic detritus, crustaceans, and other small insect larvae. They, in turn, are an important component in the diets of fish, birds and larger insects. Some larvae lie near the surface of the water and when disturbed, swim downward in a wriggling fashion.

Family: Psychodidae (moth flies)

Larvae live in decaying materials in moist places near water, often on mats of floating moss and algae in slow-flowing streams. A few species occur in drains and sewers. Some tropical species bite and transmit diseases. Food of the larvae consists of decaying vegetation and algae. The adult flies have bodies covered with hairs and the wings are hairy or scaly. The family is found worldwide.

Family: Stratiomyidae (soldier flies)

Adults of these brightly colored flies are often found on flowers. Eggs are layed on aquatic plants and other materials in ponds and streams. The larvae feed on algae, microorganisms, and organic debris.

Family: Tabanidae (horseflies and deerflies)

This large family is worldwide in distribution with over 300 species being known from North America. The adult females of some species do bite man as well as other large mammals. The males are often found feeding on flowers. The eggs are laid above water over streams and ponds. When they hatch, the larvae drop into the water to develop. Larvae feed on organic debris or are predators on other aquatic organisms.

Family: Rhagionidae (snipe flies)

Adults are found in vegetation along streams. Only one species is known to be aquatic in the United States. Adult females lay their eggs on vegetation over water and upon hatching the larvae drop into the water. The females die but remain attached to the egg mass, and other females deposit eggs on the same mass. The cycle is repeated so that often a large mass of eggs and dead females may develop.

Family: Dolichopodidae (long-legged flies)

These common, small flies are often seen in wet meadows and marsh areas. The adults perform a mating "dance" with specific movements and orientations. The larvae are predaceous, as are the adults, and can be found in a variety of habitats including mud, beach sands and tree cavities.

Family: Empididae (dance flies)

This family gets its common name from the interesting mating "dance" of the adults. As in the Dolichopodidae, the dance involves specific movements and orientations and is performed in mating swarms. In some species, the males offer food to the females or build shiny balloons to attract the females. The adults are predators or flower feeders but the larvae are predaceous.

Family: Syrphidae (flower flies)

The brightly colored adults of this family are important pollinators of flowers. The immature form of the aquatic members of this family are often called rattailed maggots due to their resemblance to maggots and the long air tube developed from the body. The aquatic larvae are usually associated with highly polluted waters. Some of the nonaquatic adults in this family mimic bees and wasps but they are not harmful to humans.

Family: Sciomyzidae (marsh flies)

The brightly colored adults of this family are found near ponds, streams and marshy areas. The aquatic larvae are thought to be strictly predaceous on aquatic snails. Some forms undergoing pupation have been shown to be adapted to fit the form of the snail shell.

Family: Ephydridae (shore and brine flies)

The small, dull adults of this group are found near freshwater ponds and streams, the ocean, inland saline and alkaline lakes and mineral springs. One unique member of this family breeds in pools of crude petroleum in California (Los Angeles County) and Cuba. The adults feed on algae and the larvae are also herbivorous, with some species boring in the stems and leaves of aquatic plants.

Family: Scopeumatidae (dung flies)

Most dung flies are found breeding in excrement or decaying vegetation. The only semiaquatic species are borers in the stems of aquatic plants such as water lilies and bullrushes. The larvae undergo pupation in the stem of these plants and the adults float to the surface and fly off.

Family: Muscidae (house flies, stable flies)

These common flies are often vectors of human diseases. The adults are found in a variety of habitats, the aquatic species occurring near the margins of streams and ponds on vegetation. The aquatic species are predaceous as adults and the larvae are herbivorous or scavengers on decaying plant and animal material. Over 500 aquatic species are known from the United States.

Key to the California Families of Diptera Larvae

1a Mandibles and other mouthparts opposed to each other and moving in a horizontal plane; head capsule complete or nearly so (Figs. 142, 143, 152, 171).............. 2
1b Mandibles absent or, if present, parallel to each other and moving in a vertical plane; head capsule incomplete (Figs. 156, 157, 164a, 165a, 170b)........14

2a(1) Head capsule almost complete and not hardened posteriorly; head with lobes or rods extending backward from posterior end; head can be pulled back within the thorax (Figs. 142, 143a-c)....................TIPULIDAE
2b Head capsule almost complete and without lobes or rods extending from the posterior end; head cannot be pulled back within the thorax (Fig. 144, 148, 152)......... 3

3a(2) Thorax fused with the head and the first abdominal segment; first 6 abdominal segments with a median row of suckers (Fig. 144)..................BLEPHARICERIDAE
3b Thorax distinct from the head and the first abdominal segment...................................... 4

4a(3) Body flattened and the abdomen with 7 pairs of lateral prominences, each with several rows of small hairs (Fig. 145).....................DEUTEROPHLEBIIDAE
4b Body not flattened and lacking lateral prominences... 5

5a(4) Prolegs present (Fig. 148)........................... 6
5b Prolegs absent (Fig. 155)............................12

6a(5) Prolegs present on the anal segment (may also be on the prothorax), not on the intermediate segments (Figs. 146, 148, 149, 151b)......................... 7
6b Prolegs present on the intermediate body segments or only on the prothorax (Figs. 152, 153b, 154a,b)...10

7a(6) Prolegs in pairs (Figs. 146, 148).................... 8
7b Prolegs not in pairs (Figs. 149, 151b)............... 9

8a(7) Posterior end of the body with 6 long filaments and 2 prolegs; no prolegs on the prothorax (Figs. 146, 147)...............................TANYDERIDAE
8b Posterior end of the body without any long filaments; prolegs on the prothorax (Fig. 148).....CHIRONOMIDAE

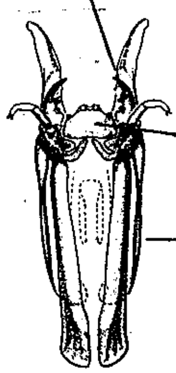


Fig. 142. Tipulidae.
Dorsal view of the head capsule of a larva.

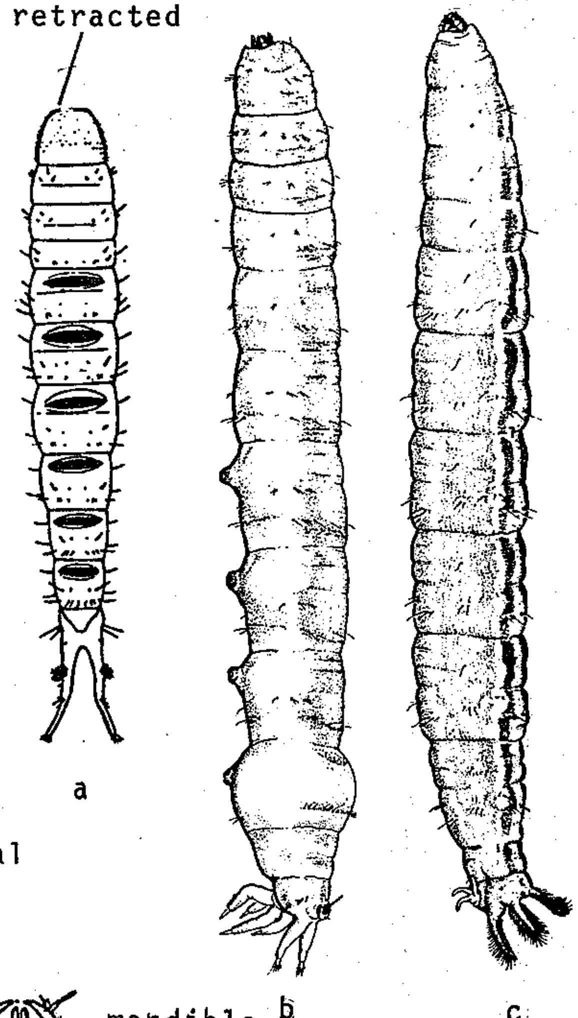


Fig. 143a-c. Tipulidae.
General appearance of larval types.

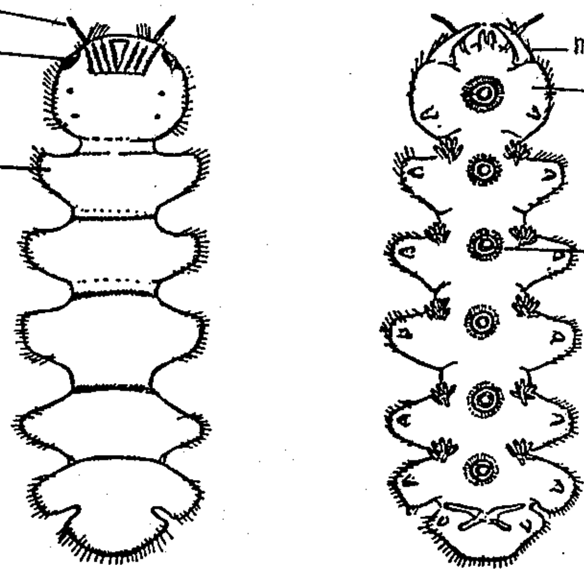


Fig. 144. Blephariceridae.
Dorsal (a) and ventral (b) view of a larva.

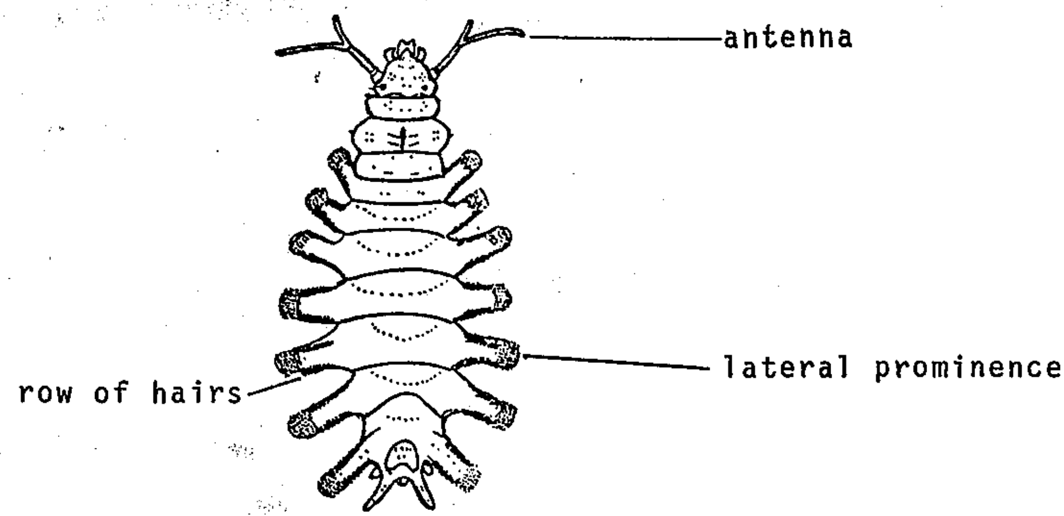


Fig. 145. Deuterophlebiidae. Dorsal view of a larva. (Alexander,1930).

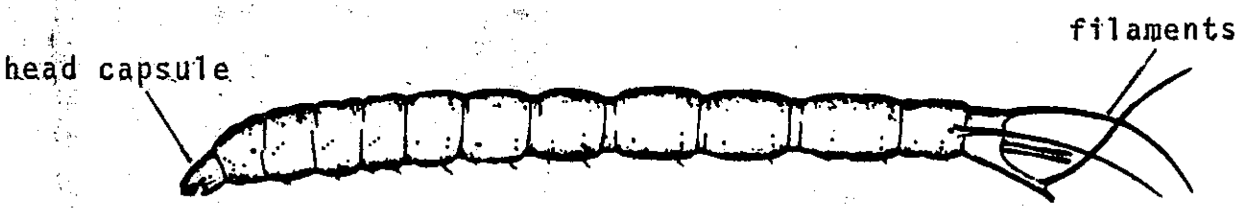


Fig. 146. Tanyderidae. Lateral view of a larva. (Alexander,1930).

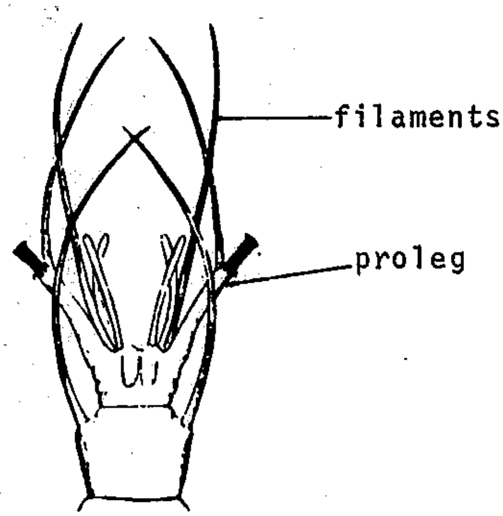


Fig. 147. Tanyderidae. Ventral view of the posterior end of a larva. (Alexander,1930).

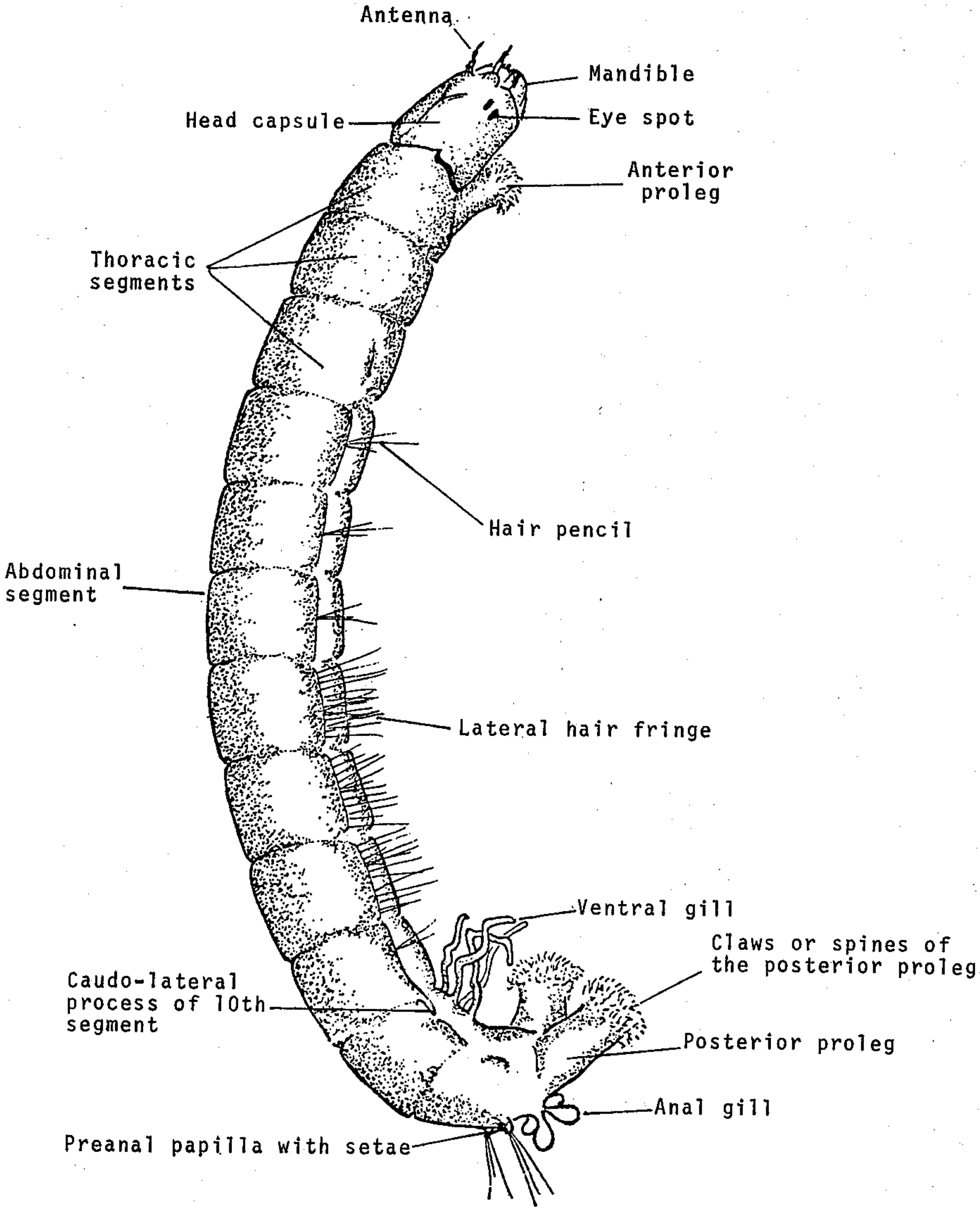


Fig. 148. Chironomidae.
Lateral view of a larva.

9a(7) Posterior end of the body with a spiracle between 2 short processes; prothorax with a pair of respiratory tubes (Fig. 149).......................THAUMALEIDAE

9b No posterior spiracle and no respiratory tubes on the prothorax (Fig. 151a,b)......CERATOPOGONIDAE (in part)

10a(6) Prolegs present only on the prothorax; adhesive disc at the end of the abdomen (Fig. 152)............SIMULIIDAE

10b Prolegs present on the intermediate body segments; no adhesive disc at the end of the abdomen (Figs. 153b, 154a)..................................11

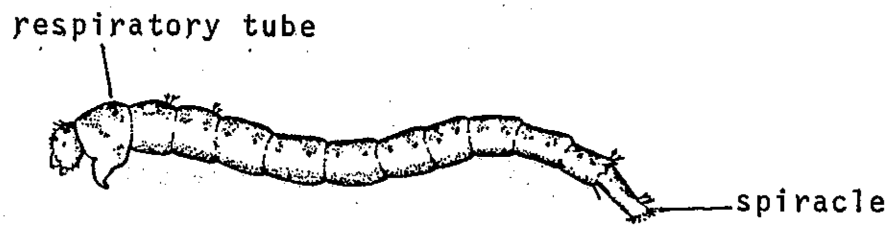


Fig. 149. Thaumaleidae.
Lateral view of a larva.
(Johannsen,1934).

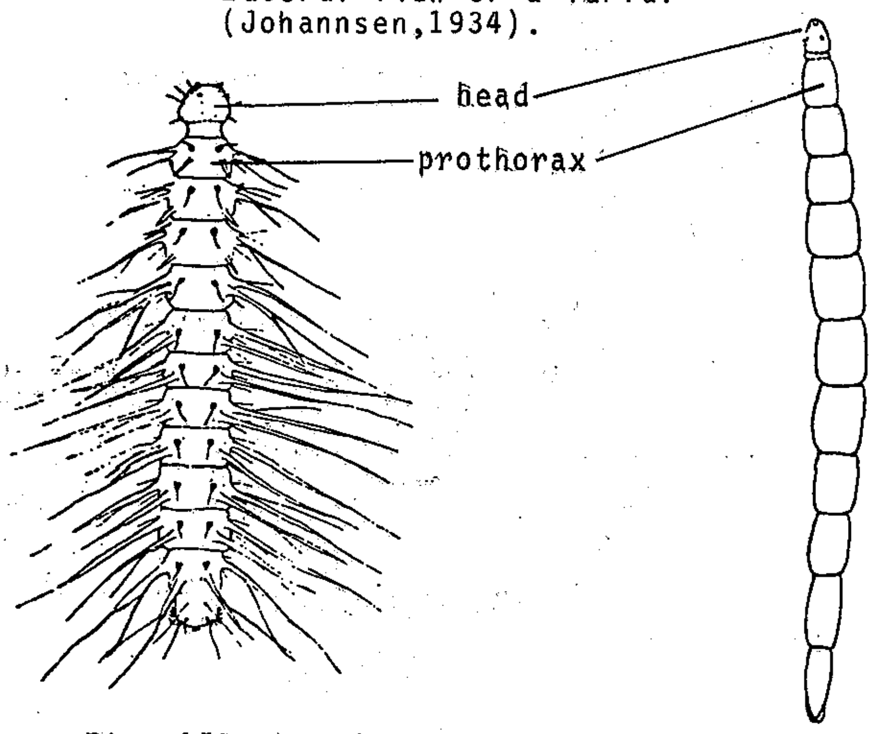


Fig. 150a,b. Ceratopogonidae.
Dorsal views of two different larvae.
(a.Thomsen,1937; b.Edmondson,1959).

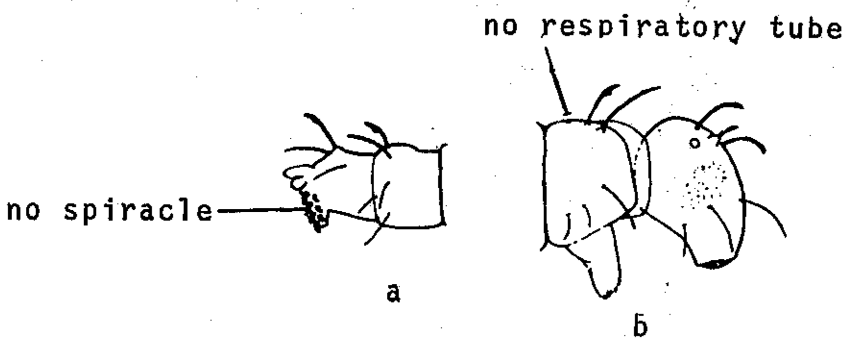


Fig. 151a,b. Ceratopogonidae.
a. Posterior end of a larva in lateral view.
b. Head and prothorax of a larva in lateral view.

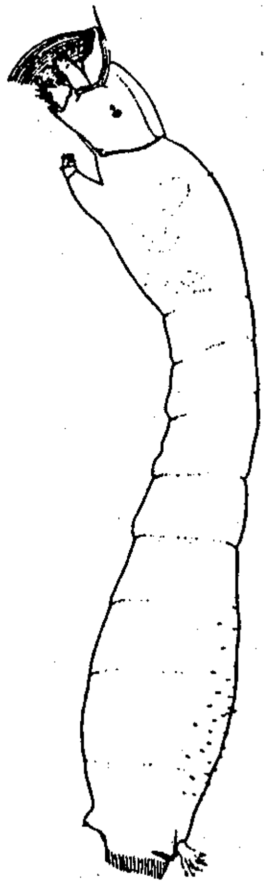


Fig. 152. Simuliidae.
Lateral view of a larva.
(Usinger,1956).

11a(10) A pair of prolegs on abdominal segments 1 to 3: abdomen ending in long, segmented tube (Fig. 153a,b)............................PTYCHOPTERIDAE

11b A pair of prolegs on abdominal segment 1 only, or on segments 1 and 2 only; end of abdomen without a long tube (Fig. 154a,b).................DIXIDAE

12a(5) Thoracic segments combined into an enlarged section that is much broader than the abdomen (Figs. 171, 172)..................................23

12b Thoracic segments distinct from one another and about as broad as the abdomen......................13

13a(12) Segments of the thorax and abdomen with secondary segmentation more or less; the posterior abdominal segments with conspicuous hardened dorsal plates (Fig. 155)....................................PSYCHODIDAE

13b Segments of the thorax and abdomen without dorsal plates (Fig. 150a,b)...........CERATOPOGONIDAE (in part)

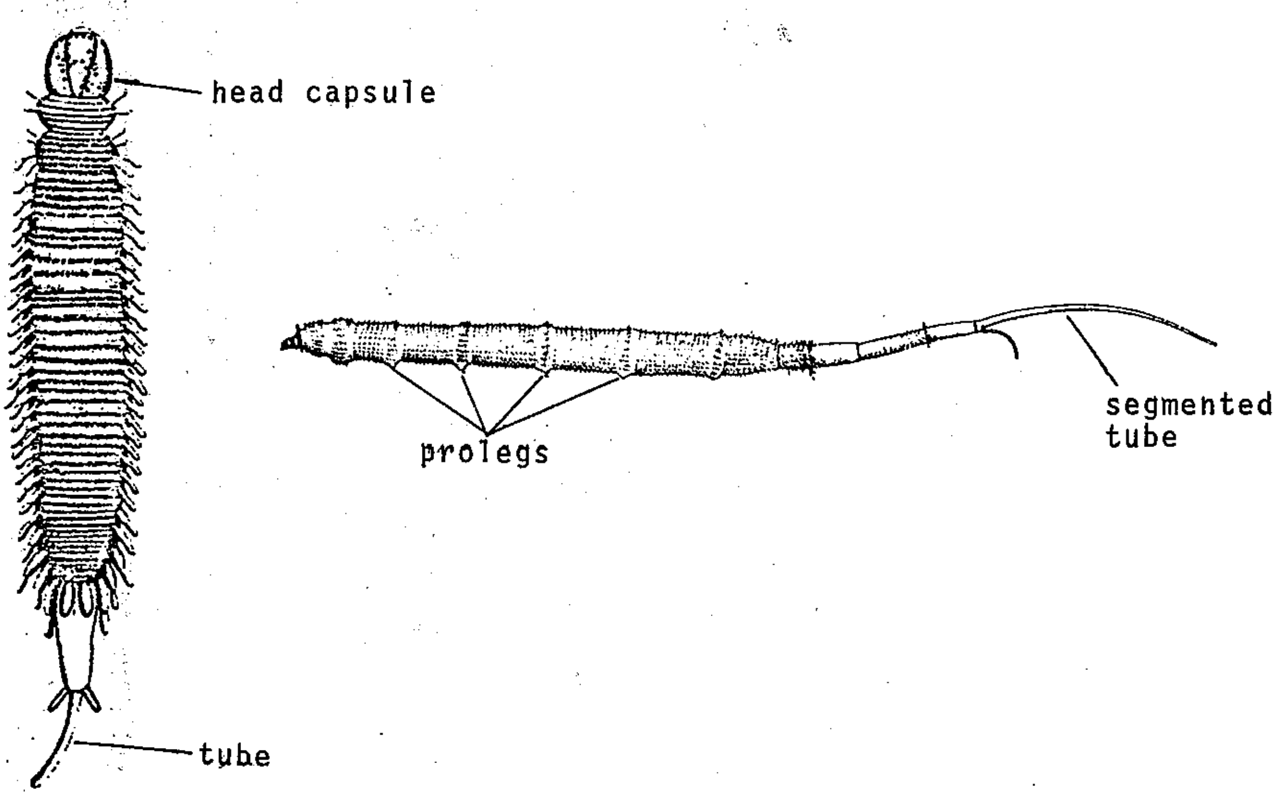


Fig. 153a,b. Ptychopteridae. Dorsal (a) and lateral (b) views of two different larvae.

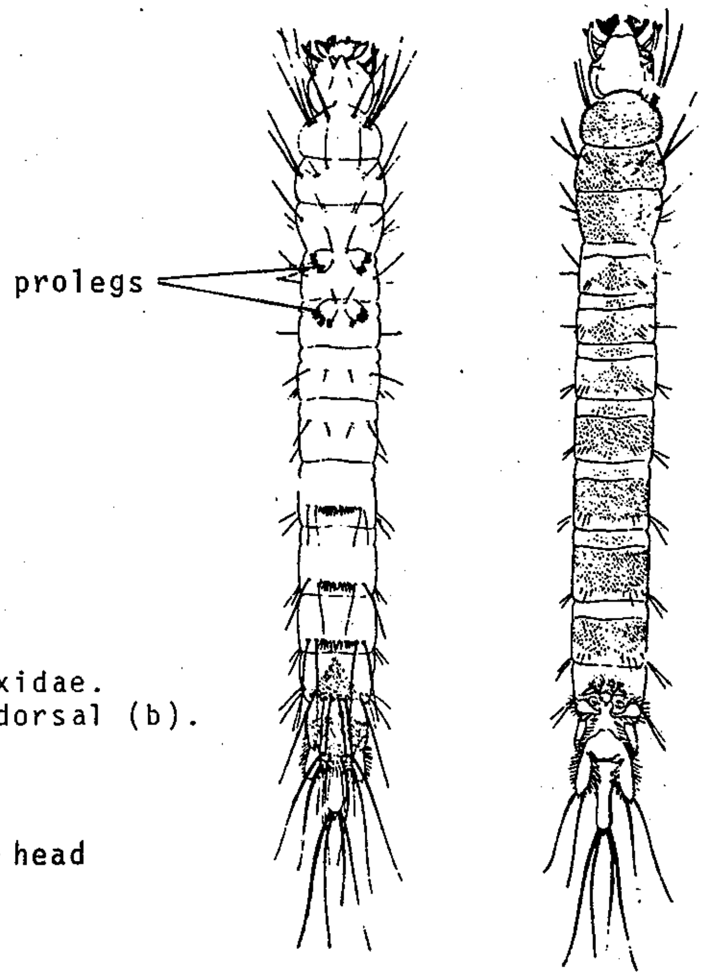


Fig. 154a,b. Dixidae.
Ventral (a) and dorsal (b).
(Nowell,1951).

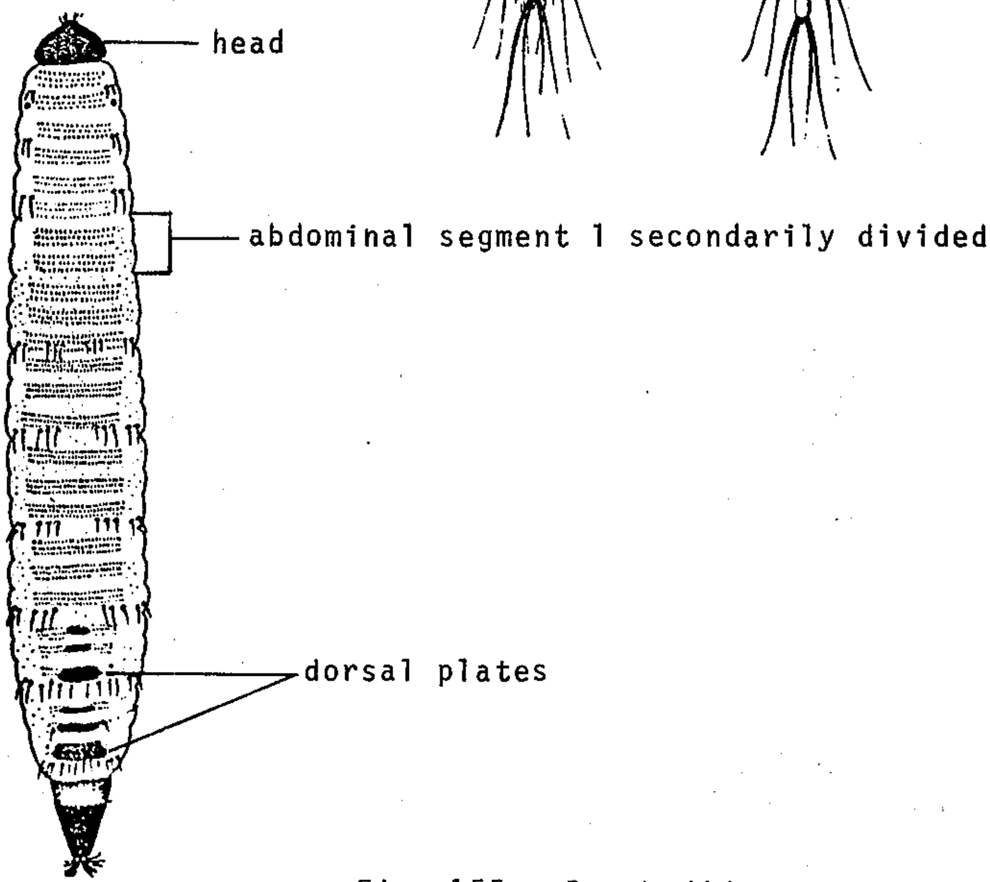


Fig. 155. Psychodidae.
Dorsal view of a larva.
(Quate,1955).

14a(1) Head capsule usually hardened dorsally and may be pulled back into the prothorax; slender rods produced for posterior from the head capsule; mandibles sickle-shaped (Figs. 156a,b, 157, 158, 159a, 160a, 161)..15

14b Head not hardened, no real head capsule; head permanently pulled within the prothorax; mandibles usually short and hook-like (Figs. 162, 163a, 165c, 166, 167, 168, 170a,b)............................19

15a(14) Body more or less depressed; no prolegs (Figs. 156a,b)............................STRATIOMYIDAE

15b Prolegs present, or if absent, the body is cylindrical..16

16a(15) Body cylindrical in form; a girdle of prolegs around each abdominal segment which may bear hooks; posterior respiratory organs in a vertical cleft (Fig. 157)...............................TABANIDAE

16b Body variable; each abdominal segment with never more than 1 pair of prolegs; posterior respiratory organs not in a vertical cleft.........17

17a(16) End of the abdomen with a pair of caudal processes longer than the prolegs; each abdominal segment with a pair of ventral prolegs (Figs. 158a,b)...............................RHAGIONIDAE

17b End of the abdomen without caudal processes, or if present, then they are shorter than the prolegs, or the prolegs are absent................18

18a(17) Caudal end of the abdomen ending in a spiracular pit surrounded by several pointed lobes (Fig. 160a,b)............................DOLICHOPODIDAE

18b Caudal end of the abdomen not ending in several pointed lobes, but sometimes ending with 2 pairs of distinct raised processes (Figs. 159,a,b, 161)..EMPIDIDAE

19a(14) Mandibles absent or minute; spiracles at the end of a long tube which, when extended, is 1/2 the length of the body or more (Fig. 162)...........SYRPHIDAE

19b Mandibles present; spiracles in well separated discs close to the abdomen or at the end of a tube.20

20a(19) Spiracular disc distinctly lobed (Fig.163a,b).SCIOMYZIDAE

20b Spiracular disc without lobes.......................21

21a(20) Mandibles serrate, palmate or finger-like; if the mandibles are simple (curved without teeth) then the posterior spiracular disc end in needle-like spines (Figs. 164a,b, 165a-c, 166, 167)........EPHYDRIDAE

21b Mandibles simple...................................22

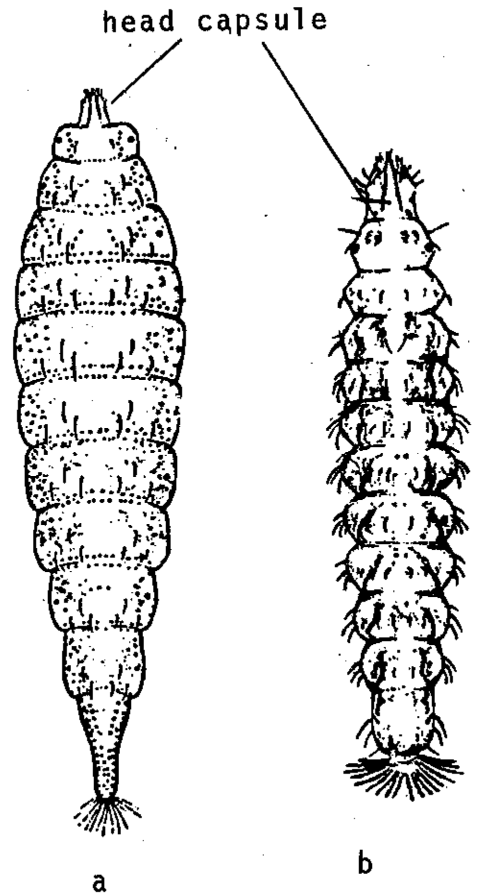


Fig. 156a,b. Stratiomyidae.
Dorsal view of two larvae.
(Johannsen,1935).

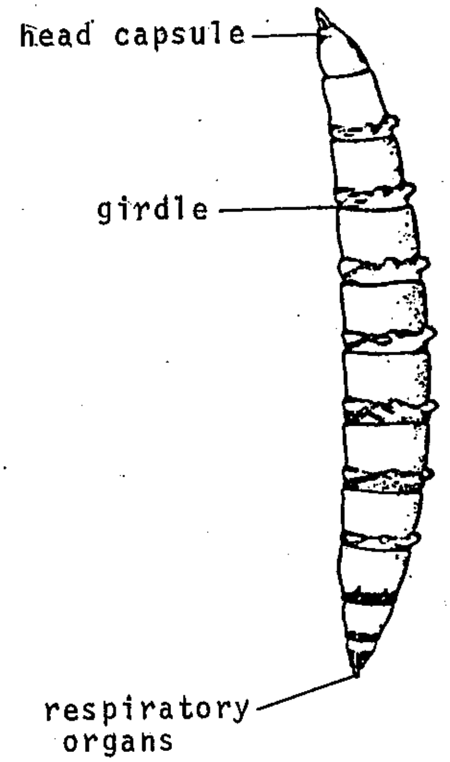


Fig. 157. Tabanidae.
Lateral view of a larva.
(Cameron,1926).

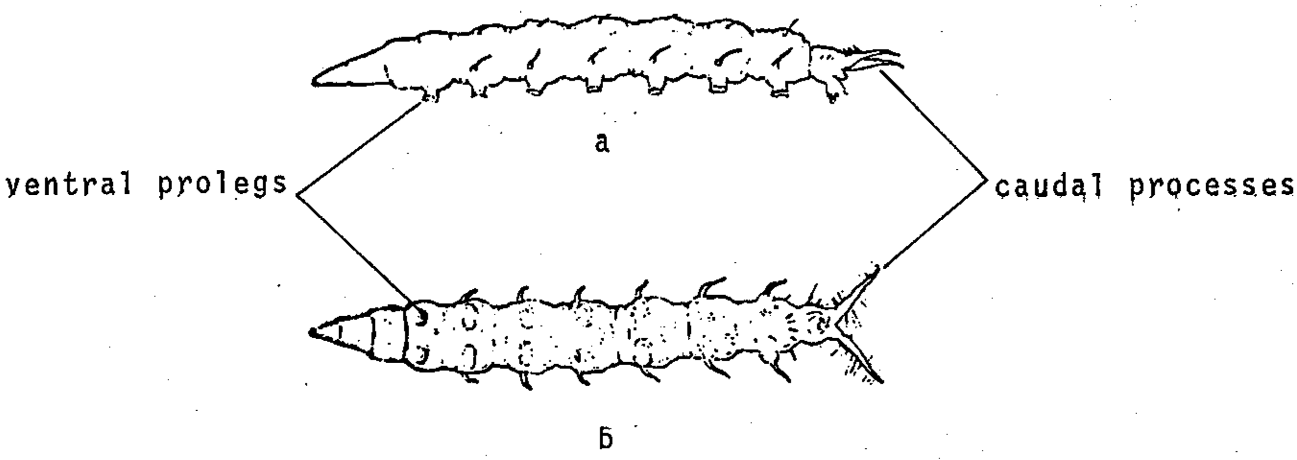
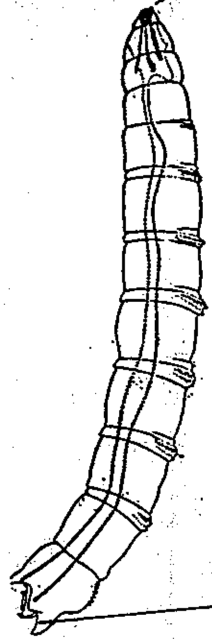
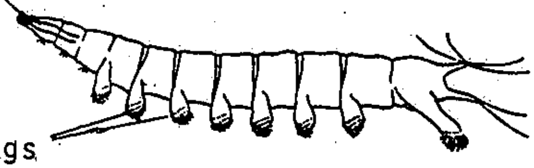


Fig. 158a,b. Rhagionidae.
Lateral (a) and ventral (b)
views of a larva.
(Johannsen,1935).





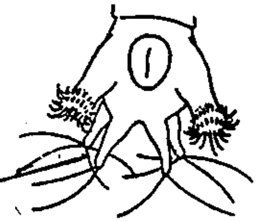


Fig. 159a,b (above). Empididae.
a. Lateral view of a larva.
b. Ventral view of the posterior end of a larva. (Usinger,1956).

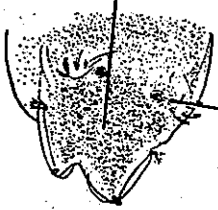


Fig. 160a,b. Dolichopodidae.
a. Lateral view of a larva.
b. View of the spiracular pit.

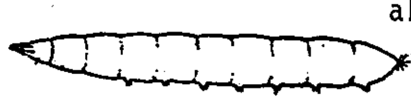


Fig. 161. Empididae.
Lateral view of a larva.
(Johannsen,1935).

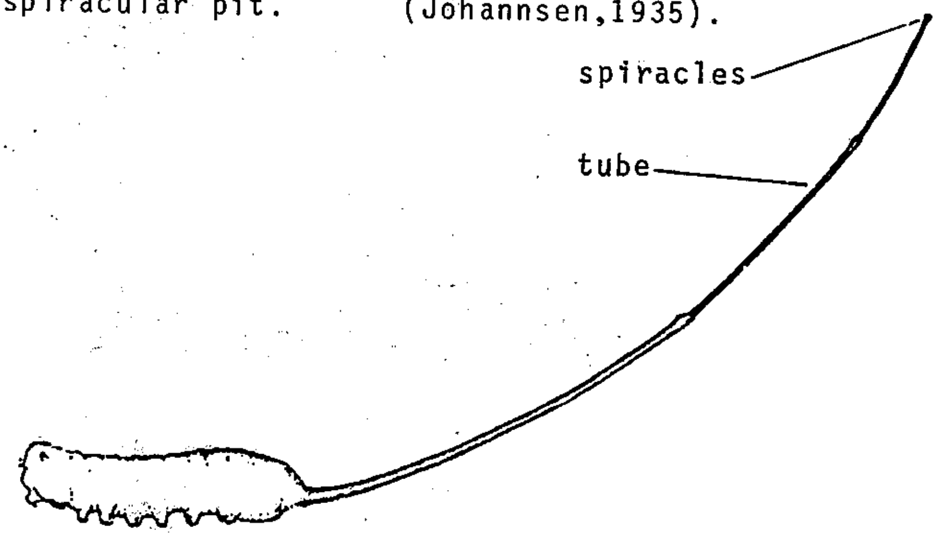


Fig. 162. Syrphidae.
Lateral view of a larva.
(Johannsen,1935).

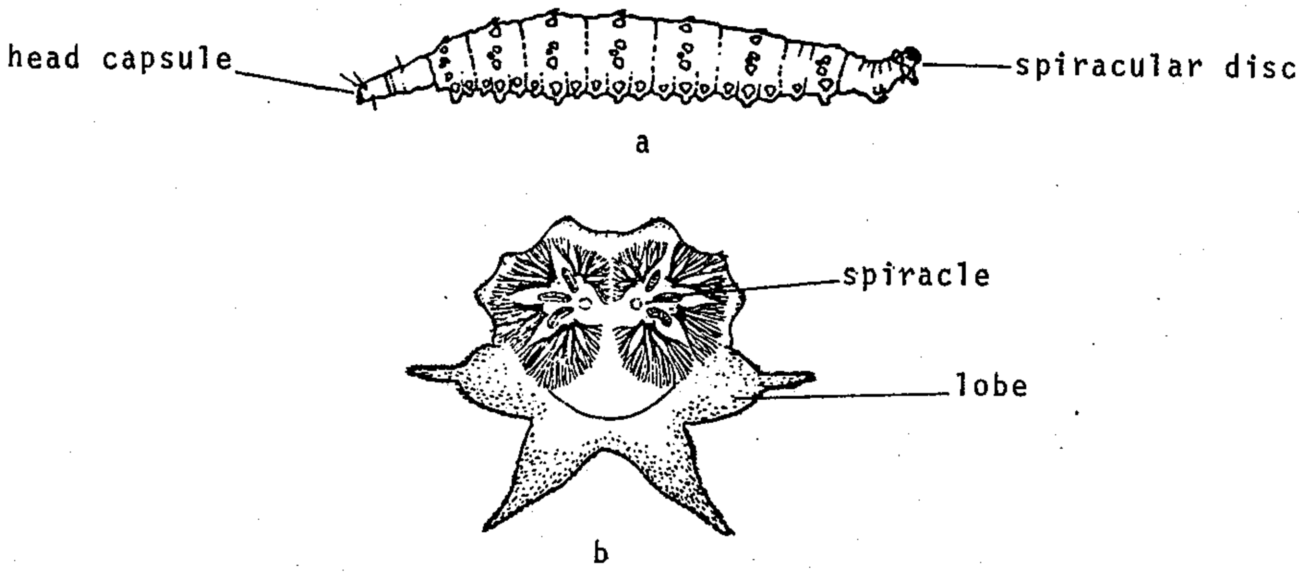


Fig. 163a,b. Sciomyzidae.
a. Lateral view of a larva.
b. End view of the spiracular disc of a larva. (Peterson,1951).

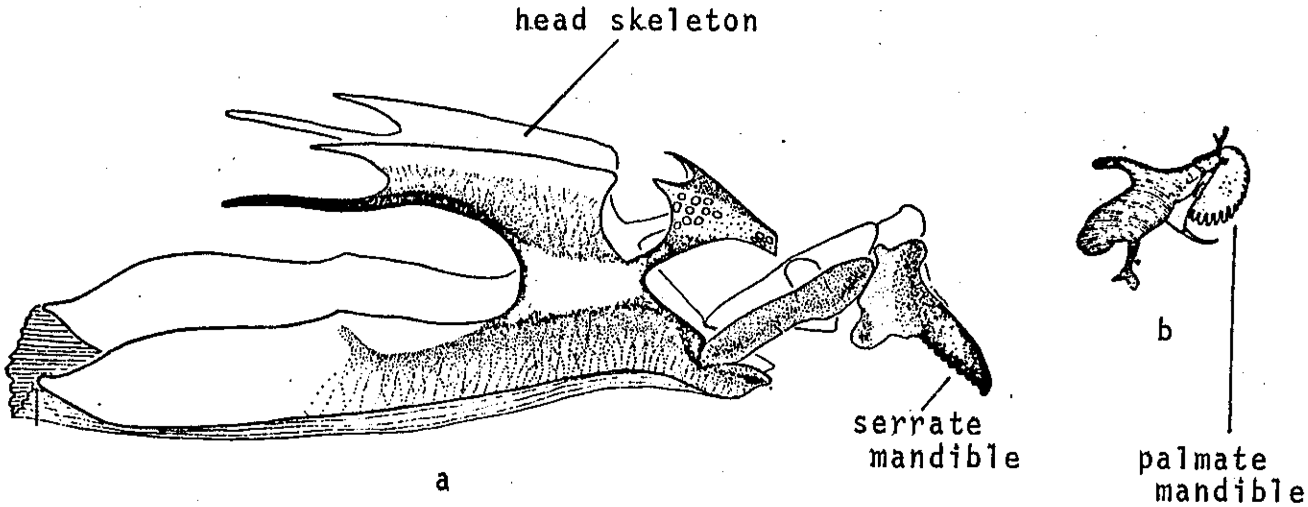


Fig. 164a,b. Ephydridae.
Types of larval mandibles.
(Berg,1950).

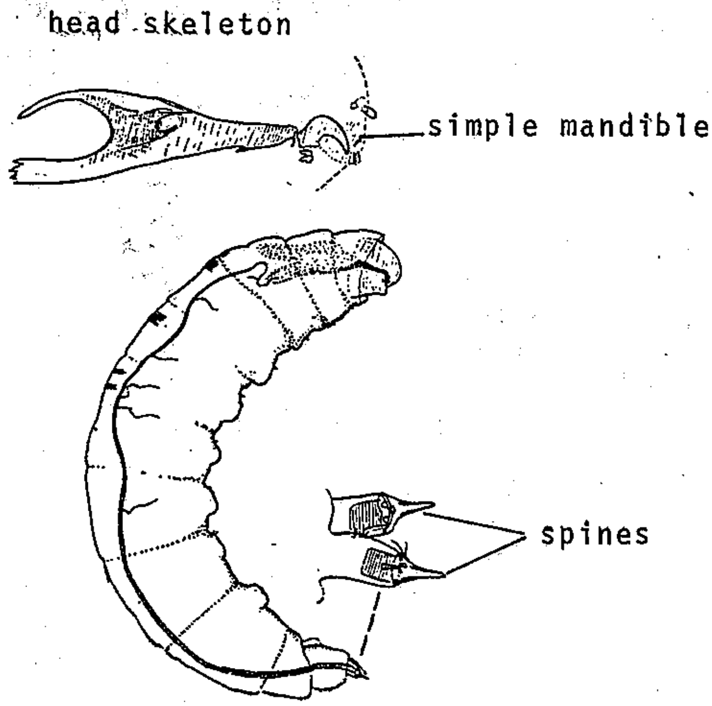


Fig. 165a-c. Ephydridae.
a. Lateral view of larval head structures.
b. Lateral view of a larva.
c. Spiracular disc ending in spines.
(Williams,1939).

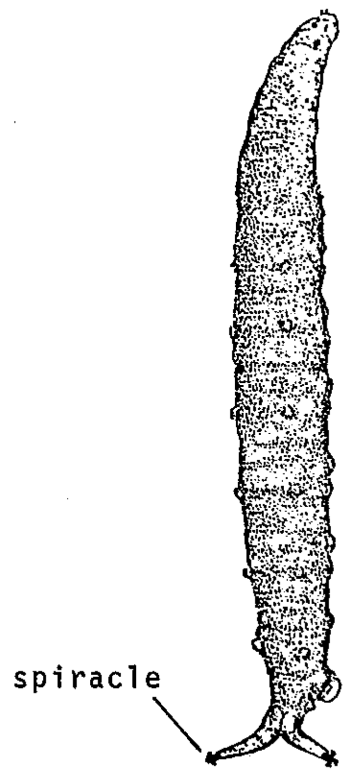


Fig. 166. Ephydridae.
Dorsal view of a larva.
(Williams,1939).

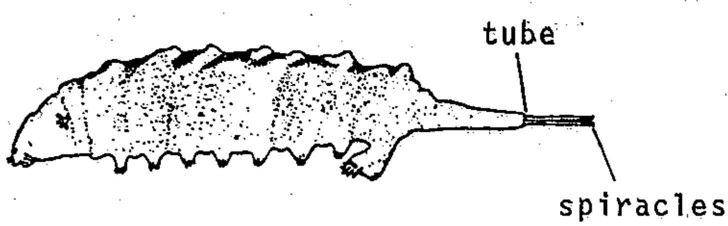


Fig. 167. Ephydridae.
Lateral view of a larva.
(Johannsen,1935).

22a(21) Posterior spiracle with a spine-like slit-bearing process (Figs. 168, 169)............SCOPEUMATIDAE
22b Posterior spiracle not as above (Figs. 170a,b)...MUSCIDAE

23a(12) Antennae prehensile, with long and strong apical spines (Fig. 172)......................CHAOBORIDAE
23b Antennae not prehensile and lacking the strong apical spines (Fig. 171)........................CULICIDAE

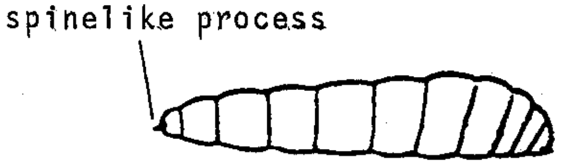


Fig. 168. Scopeumatidae. Lateral view of a larva. (Needham,1907).

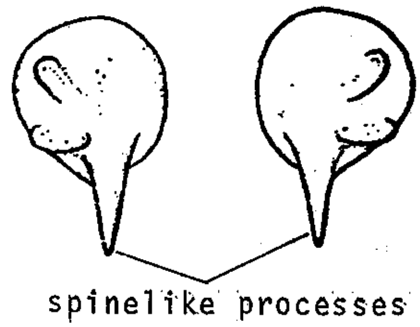


Fig. 169. Scopeumatidae. End view of the spiracular plates. (Johannsen,1935).

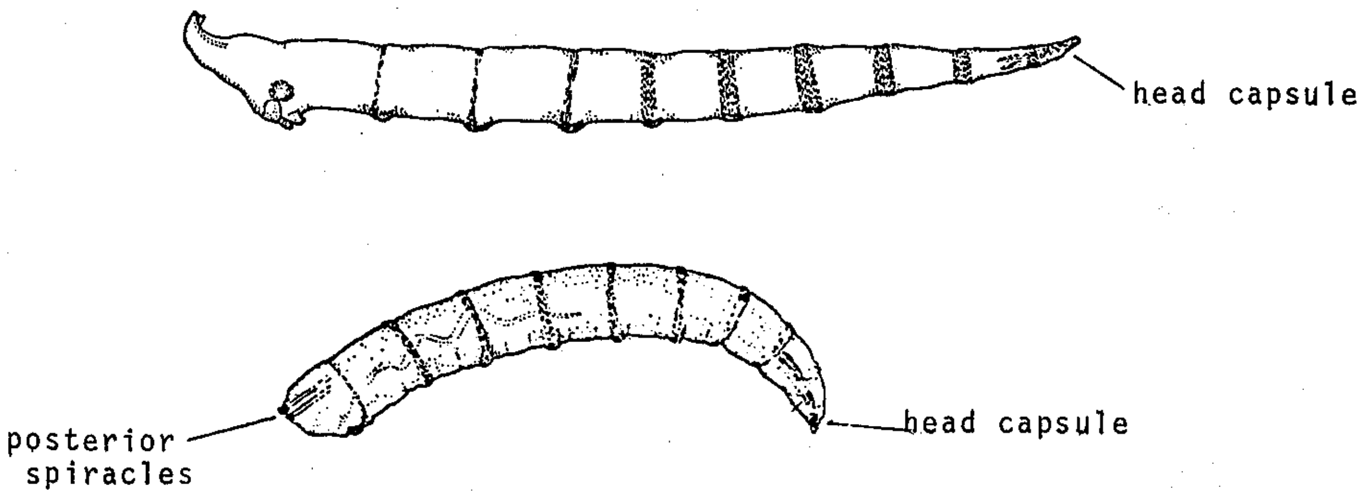


Fig. 170a,b. Muscidae. Two different larvae in lateral view. (Williams,1939).

GLOSSARY

Abdomen - The third division of the insect body, normally consisting of 9 or 10 segments (Fig. 1).

Abdominal - Belonging to or pertaining to the abdomen.

Adult - The full-grown, sexually mature insect.

Anal - In the direction of, pertaining or attached to the anus or to the last segment of the abdomen (Fig. 1).

Antecoxal sclerite - An inner sclerite between the trochantin and the episternum (Fig. 107).

Antenna - The paired segmented sensory organs, found one on each side of the head, often near the eyes (Figs. 1, 111, 121).

Antennal club - The enlarged terminal segments of an antenna (Figs. 111, 112).

Anterior - In front.

Apex - The part of any joint or segment opposite the base where it is attached.

Apical - At, near or pertaining to the apex of any structure.

Appendage - Any part, piece or organ attached by a joint to the body or to any other body structure.

Beak - The jointed structure covering the maxillae of the mouth in the order Hemiptera, and usually long and pointed (Fig. 59b).

Bristles - Stiff hairs, usually short and blunt.

Carnivorous - Subsisting or feeding on animal tissues.

Caudal - Situated in or directed toward the hind part of the body.

Cercus (pl., cerci) - An appendage (usually paired) of the tenth abdominal segment, usually slender, filamentous and segmented (Figs. 1, 30).

Claw - A hollow, sharp organ at the end of an insect leg (Figs. 3, 61, 62, 114).

Conically projecting - Projecting in the general form of a cone.

Coxa (pl., coxae) - The basal (bottom) segment of the leg, which attaches to the body (Figs. 3, 110).

Coxal cavity - The opening or space in which the coxa articulates.

Crenulate - With small scallops, evenly rounded and rather deeply curved (Figs. 46a-c).

Depressed - Having the central part lower than the margin.

Distal - Far from the point of attachment or origin.

Diurnal - Recurring every day; relating to, or occurring in the daylight.

Divergent - Spreading out from a common base.

Dorsal - Belonging to the upper surface.

Elytra - The anterior leathery wings of beetles, serving as coverings to the hind wings (Fig. 108).

Emarginate - Having the margin notched or deprived of a margin.

Encased - Enclosed.

Episternum - The anterior and larger lateral thoracic sclerite between the matathorax (Figs. 103, 106).

Extensible - Capable of being extended; outstretched.

Family - The taxonomic category below order consisting of genera (see Taxonomy).

Femur (pl., femora) - The thigh; usually the stoutest segment of the leg, articulated to the body through the trochanter and coxa and bearing the tibia at its distal end (Figs. 3, 48, 60, 65).

Filamentous - A single thread or a thin flexible threadlike object process, or appendage.

Fringe - An edging of hair, scales or other processes extending well beyond the margin.

Frontal - Referring to the front of the head or to the anterior aspect of any part.

Fused - Run together; combined.

Genus - The taxonomic category below the family, consisting of species; the first part of an organism's scientific name.

Gill - A special, variously formed respiratory organ in the aquatic immature stages of many insects, by means of which they get dissolved oxygen from the water (Figs. 1, 18, 20, 26).

Glossa (pl, glossae) - The two inner lobes of the labium; loosely used as a synonym for the tongue (Figs.49a,b;50a,b).

Gula - The throat (Figs. 76-a.c).

Hair - A slender flexible filament of equal diameter throughout.

Head - The first region of the insects body, connected at its base to the thorax, bearing the mouth structures and antennae (Figs. 1, 48).

Head capsule - The welded together sclerites of the head which form a hard compact case (Figs. 153, 157).

Instar - A stage in the life of an arthropod (as in insects) between two successive molts.

Labium - The lower lip; a compound structure which forms the floor of the mouth (Figs. 2, 37b, 41, 42).

Labrum - The upper lip which forms the roof of the mouth (Figs. 2, 18, 32a,b).

Larva - The immature form of an insect that undergoes metamorphosis.

Lateral - Relating, pertaining, or attached to the side.

Lobe - Any prominent rounded process on a margin or structure.

Macroinvertebrate - Animals that are large enough to be seen with the unaided eye and can be retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595 mm openings), and live at least part of their life cycle within or upon available substrates in water transport systems.

Mandibles - The first pair of jaws in insects, stout and tooth-like in chewing insects, needle or sword-shaped in piercing-mouthed sucking insects (Figs. 2, 14).

Maxillae - One of the first or second pair of mouthparts posterior to the mandibles in insects (Fig. 2).

Median - In or at the middle.

Membranous - Thin and semitransparent; of a thin pliable texture.

Mentum - The anterior sclerite of the insect labrum bearing the movable parts (Figs. 2, 40).

Mesothorax - The second or middle segment of the thorax which bears the middle legs and the anterior wings (Figs. 1, 48).

Metamorphosis - A marked and more or less abrupt change in the form or structure of an animal (as in insects or amphibians), occurring subsequent to birth or hatching.

Metasternum - The upper surface of the third or posterior thoracic segment (Fig. 88).

Metathorax - The posterior segment of the thorax of an insect (Fig. 1).

Mouth - The anterior opening into the alimentary canal, where the feeding structures are situated and in which the food is readied for digestion.

Mouthparts - A collective name including labrum, mandibles, maxillae, labrium and appendages (Fig. 2).

Naiad - An aquatic nymph, usually referring to the immature stages of dragonflies and damselflies (Odonata).

Notched - Indented, cut or nicked.

Nymph - A young insect which hatches from the egg in an advanced stage of development, differing from the adult in having wings and reproductive organs incompletely developed; an immature aquatic insect.

Occiput - The back part of the head (Figs. 1, 48).

Ocellus (pl., ocelli) - The simple eye in adult insects, occurring singly or in small groups (Figs. 1, 70, 123, 137).

Omnivorous - Feeding on both animal and plant substances.

Order - The taxonomic category below class consisting of families (see Taxonomy).

Palpus - A segmented usually tactile or gustatory process on the insect mouth (Figs. 2, 49b).

Paraglossae - The lateral terminal lobes of the labium (Figs. 2, 49a,b).

Plate - Any broad, flattened piece of the body, often hardened and darker in color than the surrounding skin.

Posterior - Hindmost; opposed to anterior.

Predaceous - Adapted to predation.

Prementum - The part of the insect labium lying in front of the mentum and bearing a part of the lobes (Figs. 2,40).

Proleg - Any unjointed appendage that serves the purpose of a leg, found on the thorax and/or abdomen of some immature aquatic insects (Figs. 147, 148, 152, 153, 154).

Pronotum - the upper or dorsal surface of the prothorax (Figs. 1, 88).

Prosternum - The fore-breast; the sclerite between the first pair of legs.

Prothorax - The first segment of the thorax bearing the front pair of legs but no wings (Figs. 1, 48).

Pubescent - Downy; clothed with soft, short, fine, closely set hair.

Pupa (pl., pupae) - The intermediate resting stage of some insects between the larva and adult.

Quadrangular - Four angled; square or nearly so (Figs. 23a, 24).

Quadrate - Something more or less resembling a square (Figs. 23a, 24).

Rectangular - In the form of a rectangle.

Retractile - Capable of being extended and pulled back or retracted.

Ringlet - A small circle.

Scale - A flat plate-like structure of the body wall of insects.

Sclerite - Any piece of the insect body wall bounded by sutures (Figs. 106, 107).

Sclerotized plate - A hardened area of the insect skin forming a yellow or black plate (Fig. 75).

Scutellum - In Coleoptera, the triangular piece between the elytra (Figs. 108, 109, 116).

Segment - A ring or subdivision of the body or of an appendage between areas of flexibility.

Serrate - Saw-like; with notched edges like the teeth of a saw.

Setae (sing., seta) - Commonly known as hairs; slender hair-like appendages (Fig. 46).

Sheath - A structure enclosing others.

Simple - Unmodified by any condition; not complex.

Species - The basic unit of the taxonomic classification of organisms; the taxonomic category below genus and the latter portion of the scientific name of an organism. The current biological concept of a species is defined as, "a group of actually or potentially interbreeding organisms reproductively isolated from other such groups of interbreeding organisms.

Spine - A thorn-like process or outgrowth of the skin not separated from it by a joint.

Spiracle - A breathing pore through which air enters the body (Fig. 160).

Spiracular disc - An oval to round cup-shaped area at the posterior end of some insect larvae that contain one or more spiracles (Fig. 163b).

Spur - A spine-like appendage, usually on the tibia.

Sternite - The ventral (underside) piece of a segment.

Sternum (pl., sterna) - The underside of an insect thorax between the leg articulations.

Sucking tube - A long, slender tube that is used to siphon juices from plants in the order Neuroptera (Fig. 73).

Suture - A seam or impressed line indicating the division of the distinct parts of the body wall.

Tail - An elongate segment at the end of the abdomen (Fig. 1.).

Tarsal claw - The claw or claws at the end of the tarsus (foot) (Figs. 3, 67).

Tarsus (pl., tarsi) - The foot; the last section of an insect leg attached to the tibia consisting of from one to five segments or joints (Figs. 3, 67).

Taxon (pl., taxa) - Any classification category such as phylum, class, order, family, genus or species.

Taxonomy - The curriculum within biology which deals with the classification and naming of organisms. The classification of organisms follows a hierarchial scheme built on the basic species unit.

Terminal - Situated at the tip.

Thoracic - Belonging or attached to the thorax.

Thorax - The second or midregion of the insect body bearing the true legs and wings and made up of three smaller sections called the pro-, meso-, and metathorax. When the thoracic sections are all combined as in Coleoptera, Orthoptera and Hemiptera, the term thorax is used (Figs. 1, 48).

Tibia (pl., tibiae) - The fourth division of an insect leg between the femur and the tarsi (Figs. 3, 114, 126).

Transverse - Running across; cutting the longitudinal axis at right angles.

Trochanter - The second segment counting from the base of the leg of an insect (Figs. 3, 18).

Trochantin - In Coleoptera, a structure often present on the outer side of the coxa and sometimes movable on this structure; also the small sclerite connecting the coxa with the sternum in Dytiscidae (Figs. 3, 77a,b).

Tubercle - Rounded lobes or raised bump on the dorsal and/or lateral margins of some aquatic insect larvae (Fig. 96).

Veins - The rod-like structures supporting and stiffening the wings in insects.

Venation - The complete system of veins of a wing.

Ventral - Pertaining to the under surface of the abdomen.

Ventral cleft - A vertical split in a structure.

Wings, wing - The paired membranous organs of flight in insects.

Fore wings - The first pair (front pair) of wings attached to the mesothorax (Figs. 7, 16).

Hind wings - The second pair (hind pair) of wings attached to the metathorax (Figs. 7, 16).

Wing buds - The undeveloped wings of some aquatic insect larvae from which the wings develop.

Wing pads - The undeveloped wings of the nymphs of some aquatic insects which show behind the thorax as two lateral flat structures (Figs. 1, 12a,b).

Wing sheaths - Wing pads.

REFERENCES

General

American Public Health Association and Others. 1975. Standard Methods for the Examination of Water and Wastewater (14th ed.). American Public Health Assoc., New York, 1193 pp.

Edmondson, W.T., Ed. 1959. Ward and Whipple's Freshwater Biology. John Wiley and Sons, Inc. New York, 1248 pp.

Environmental Protection Agency. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. EPA-670/4-73-001. EPA, Cincinnati, Ohio.

Gaufin, A.R. and C.M. Tarzwell. 1952. Aquatic Invertebrates as Indicators of Stream Pollution. In Public Health Reports. Vol. 67, No. 1, pp. 57-64.

Gaufin, A.R. and C.M. Tarzwell. 1956. Aquatic Macro-invertebrate Communities as Indicators of Organic Pollution in Lytle Creek. In Sewage and Industrial Wastes. Vol. 28, No. 7, pp 906-924.

Hynes, H.B.N. 1972. The Ecology of Running Waters. University of Toronto Press. 555 pp.

Hynes, H.B.N. 1974. The Biology of Polluted Waters. University of Toronto Press. 202 pp.

Kerri, K.D., M. Baad, E.C. Shirley, R.B. Howell, E. Torgenson, and G.R. Winters. 1975. Water Quality Manual V. Chemical, Bacteriological and Ecosystem Analysis of Water from Highway Sources for Environmental Impact Studies. Federal Highway Administration. Washington, D.C.

Merrit, R.W. and Cummins, K.W. 1978. General Morphology of Aquatic Insects. Pages 5-12. In R.W. Merrit and K.W. Cummins, eds. Aquatic Insects of North America. Dendall/Hunt Publishing Company, 441 pp.

Pennak, R.W. 1978. Freshwater Invertebrates of the United States, 2nd ed., John Wiley and Sons, Inc., New York. 796 pp.

U.S. Geological Survey. 1973. Methods for the Collection and Analysis of Aquatic Biological and Microbiological Samples. Book 5, Chapter A4. U.S. Print. Off. Washington, D.C. 165 pp.

Usinger, R.L., Ed. 1963. Aquatic Insects of California. Univ. of Calif. Press., Berkeley and Los Angeles. 508 pp.

Ephemeroptera

Burks, B.D. 1953. The Mayflies, or Ephemeroptera, of Illinois. Bull. Ill. Nat. Hist. Surv. 26:1-216.

Edmunds, G.F. Jr., R.K. Allen, and W.L. Peters. 1963. An Annotated Key to the Nymphs of the Families and Subfamilies of Mayflies (Ephemeroptera). Univ. Utah Biol. Series XII (1):1-55.

Edmunds, G.F. Jr., S.L. Jensen and L. Berner. 1976. The Mayflies of North and Central America. Univ. of Minnesota Press, Minneapolis. 329 pp.

Needham, J.G., F.R. Traver and Yin-Chi Hsw. 1935. The Biology of Mayflies. Comstock Pub. Co., Ithica, N.Y., 759 pp.

Pennak, R.W. 1978. Fresh Water Invertebrates of the United States, 2nd ed. John Wiley and Son's, Inc. New York. 803 pp.

Odonata

Kennedy, C.H. 1915. Notes on the Life History and Ecology of the Dragonflies (Odonata) of Washington and Oregon. Proc. U.S. Nat. Mus., 49:259-345

Needham, J.G., and M.J. Westfall, Jr. 1954. Dragonflies of North America. Univ. Calif. Press. Berkeley and Los Angeles. 615 pp.

Wright, M., and A. Peterson. 1944. A Key to the Genera of Anisopterous Dragonfly Nymphs of the United States and Canada (Odonata, Suborder Anisoptera). Ohio J. Sci. 44:151-166.

Plecoptera

Claassen, P.W. 1931. Plecoptera nymphs of America (North of Mexico). Thos. Say Foundation of the Ent. Soc. Amer., Publ. 3, 199 pp.

Frison, T.H. 1935. The Stoneflies, or Plecoptera, of Illinois. Bull. Ill. Nat. Hist. Surv. 20:281-371.

Frison, T.H. 1942. Studies of North American Plecoptera. Bull. Ill. Nat. Hist. Surv. 22:235-335.

Gaufin, A.R., A.V. Nebeker and J. Sessions. 1966. The Stoneflies (Plecoptera) of Utah. Univ. Utah. Biol. Series 14 (1):1-93.

Harper, P.P. 1978. Plecoptera. Pages 105-118. In R.W. Merrit and K.W. Cummins, eds. Aquatic Insects of North America. Kendall/Hunt Publishing Co., 441 pp.

Jewett, S.G., Jr. 1955. Notes and Descriptions Concerning Western Stoneflies (Plecoptera). Wasmann J. Biol. 91 (1):1-543.

Jewett, S.G., Jr. 1959. The Stoneflies (Plecoptera) of the Pacific Northwest. Ore. State Coll. Press, 95 pp.

Jewett, S.G., Jr. 1960. The Stoneflies (Plecoptera) of California. Bull. Calif. Insect Surv. 6 (6):125-177.

Tricoptera

Hickin, N.E. 1967. Caddis Larvae-Larvae of the British Tricoptera. Associated University Presses., Inc. Cranbury, N.J. 480 pp.

Hilsenhoff, W.L. 1970. Key to Genera of Tricoptera Larvae. Wis. Dept. Nat. Resources Research Dept. 67:38-67.

Pennak, R.W. 1978. Fresh Water Invertebrates of the United States, 2nd ed. John Wiley and Sons, Inc. New York. 803 pp.

Ross, H.H. 1941. Descriptions and records of North American Tricoptera. Trans. Amer. Entom. Soc. 67:35-129.

Ross, H.H. 1944. The Caddisflies, or Tricoptera of Illinois. Bull. Ill. Nat. Hist. Surv. 23:1-326.

Wiggins, G.B. 1977. Larvae of the North American Caddisfly Genera (Tricoptera). Univ. of Toronto Press, Toronto. 401 pp.

Lepidoptera

Lange, W.H. 1956. A Generic Revision of the Aquatic Moths of North America (Lepidoptera: Pyralidae Nymphulinae). Wasmann Jour. Biology. 14(1):59-114.

Neuroptera

Brown, H. 1952. The Life History of Climacia areblaris (Hagen), a Neuropterous "parasite" of Freshwater Sponges. Amer. Midl. Nat., 47:130-160.

Coleoptera

Bertrand, H. 1928. Les Larves Des Dytiscides, Hygrobiides, Haliplides. Ency Eng. (A):vi+266 pp., 33 pls. 207 text figs.

Boving, A.G., and F.C. Craighead. 1930. An Illustrated Synopsis of the Principal Larval Forms of the Order Coleoptera. Ent. Amer. 11 (1):1-80, incl. pls. 1-36.

Brown, H. 1970. A Key to the Dryopoid Genera of the New World. (Coleoptera, Dryoidea). Ent. News. 81:171-175.

Hinton, H.E. 1939. An Inquiry into the Natural Classification of the Dryopoidea, based Partly on a Study of Their Internal Anatomy. Trans. Royal Ent. Soc., London, 89:133-184, figs. 105, 1 pl.

Hinton, H.E. 1940. A Monographic Revision of the Mexican Water Beetles of the Family Elmidae. Novit. Zool., 42:19-396, 401 text figs.

Leech, H.B. 1948. Coleoptera: Haliplidae, Dytiscidae, Gyrinidae, Hydrophilidae, Limnebiidae. No. 11 In Contributions Toward a Knowledge of the Insect Fauna of Lower California. Proc. Calif. Adad. Sci., Ser. 4, 24:375 484, 2 pls.

Richmond, E.A. 1920. Studies on the Biology of the Aquatic Hydrophilidae. Bull. Amer. Mus. Nat. Hist. 42:1-94.

Pennak, R.W. 1978. Fresh Water Invertebrates of the United States, 2nd ed. John Wiley and Son's, Inc. New York. 803 pp.

Wilson, C.B. 1923. Water Beetles in Relation to Pondfish Culture with Life Histories of those Found in Fishponds at Fairport, Iowa. Bull. Bur. Fish., 39:231-345. 148 figs.

Diptera

Alexander, C.P. 1920. The Crane-flies of New York. Part II. Biology and Phylogeny. Mem. Cornell Univ. Agric. Exp. Sta., 38:691-1133.

Alexander, C.P. 1930. Observations on the Dipterous Family Tanyderidae. Proc. Linn. Soc. N.S.W., 55:121-130, 2 pls, 1 fig.

Berg, C.O. 1950. Hydrella (Ephydridae) and Some Other Acalyptrate Diptera Reared From Potamogeton. Ann. Ent. Soc. Amer., 43:347-389.

Cameron, A.E. 1926. Bionomics of the Tabanidae (Diptera) of the Canadian Prairie. Bull. Ent. Res., 17:1-42.

Curran, C.H. 1934. The Families and Genera of North American Diptera. New York. 512 pp.

Johannsen, O.A. 1934. Aquatic Diptera. Part I. Nemocera, Exclusive of Chironomidae and Ceratopogonidae. Mem. Cornell Univ. Agr. Exp. Sta. 164:1-70.

Johannsen, O.A. 1935. Aquatic Diptera. Part II. Orthorrhapha-Brachycera and Cyclorrhapha. Ibid. 177:1-62. 12 pls.

Johannsen, O.A. 1937. Aquatic Diptera. Part III. Chironomidae: Subfamilies Tanypodinae, Diamesinae, and Orthocladiinae. Ibid. 205:1-84. 18 pls.

Johannsen, O.A. 1937a. Aquatic Diptera. Part IV. Chironomidae: Subfamily Chironominae. Ibid. s10:1-56. 9 pls.

Mason, W.T., Jr. 1968. An Introduction to the Identification of Chironomid Larvae. Division of Pollution Surveillance, FWPCA, USDI, Cincinnati. 90 pp. (revised 1973).

Matheson, R. 1944. Handbook of the Mosquitoes of North America. 2nd edition.

Needham, J.G. 1908. Notes on the Aquatic Insects of Walnut Lake. In a Biological Survey of Walnut Lake, Michigan, by Thomas C. Hankinson. Mich. Geol. Surv. Rep. 1907:252-271.

Nowell, W.R. 1951. The Dipterous Family Dixidae in Western North America (insects: Diptera). Microentomology 16:187-270, figs. 74-88.

Quate, L.W. and W.W. Wirth. 1955. A Revision of the Psychodidae (Diptera) in America North of Mexico. Univ. Calif. Publ. Entom., 10:103-273.

Stone, A., C.W. Sabrasky, W.W. Wirth, R.H. Foote and J.R. Coulsen, Eds. A Catalog of the Diptera of America North of Mexico. USDA Handbook No. 276.

Sublette, J.E. 1960. Chironomid Midges of California. Part I. Chironomidae, Exclusive of Tanytarsini (Calosectrini). Proc. U.S. Natl. Museum, 112:197-226.

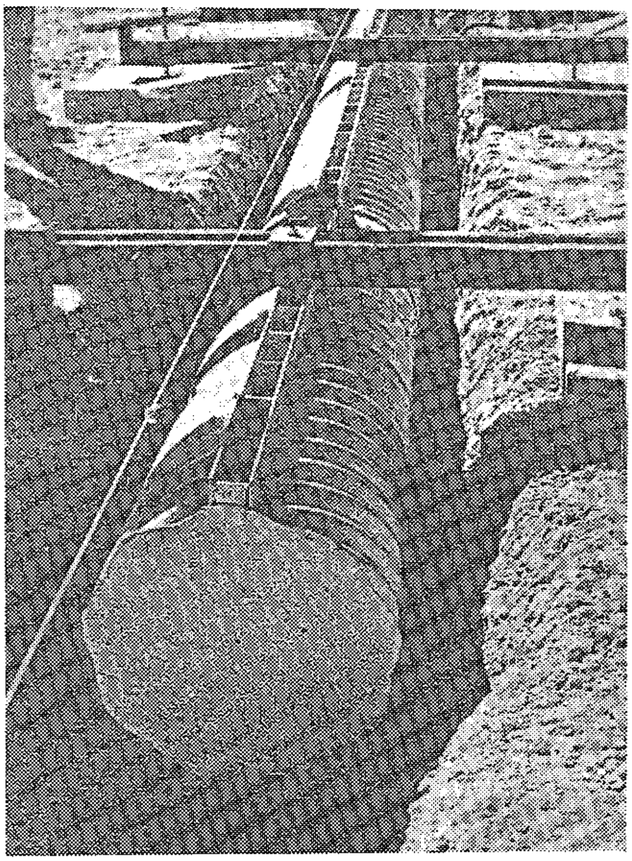
Sublette, J.E. 1964. Chironomid Midges of California. Part II. Tanypodinae, Podonominae, and Diamesinae. Proc. U.S. Natl. Museum, 115(3481:85-136).

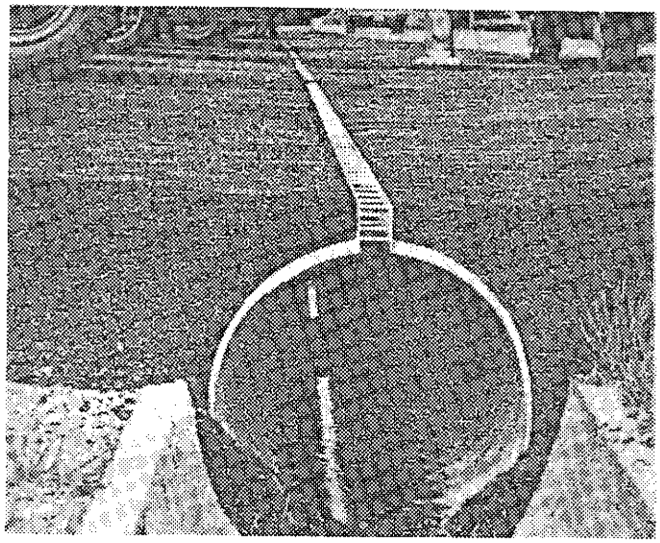
Thomsen, L. 1937. Aquatic Diptera, Part V. Ceratopogonidae. Mem. Cornell Univ. Agric. Exp. Sta., 210:57-80, 9 pls.

Williams, F.X. 1939. Biological Studies in Hawaiian Water-loving Insects. Part III. Diptera or Flies. B. Asteiidae, Syrphidae, and Dolichopodidae. Proc. Hawaii Ent. Soc., 10:281-315.

REPORT NO. FHWA/CA/TL-80/22

LOAD-CARRYING CAPABILITIES OF 18-INCH DIAMETER SLOTTED CORRUGATED STEEL PIPE DRAINS





FINAL REPORT
JUNE, 1980

NOTICE

The contents of this report reflect the views of the Office of Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA/CA/TL-80/22		

4. TITLE AND SUBTITLE
LOAD-CARRYING CAPABILITIES OF 18-INCH-DIAMETER SLOTTED CORRUGATED STEEL PIPE DRAINS

5. REPORT DATE
June 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
J. P. Dusel, Jr., J. R. Stoker, E. F. Nordlin, and D. H. Andersen

8. PERFORMING ORGANIZATION REPORT NO.
19601-636853

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT NO

11. CONTRACT OR GRANT NO.
D-4-146

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration for the project title: Load-Carrying Capabilities of 18-Inch-Diameter Slotted Corrugated Steel Pipe Drains.

16. ABSTRACT
Various designs of slotted pipe drains which have been used by the California Department of Transportation (Caltrans) were tested to determine their ability to withstand heavy wheel loads.

Fourteen laboratory quasi-ring compression tests were performed on short lengths of slotted drain to determine the relative strengths of various designs. Five 16-foot-long sections of drains having two different grate designs and various grate-to-pipe weld patterns, were installed using various backfill materials in a simulated roadbed section. While the vertical deflections were monitored, each drain was statically loaded to at least 30 kips over an area of 100 square inches. One drain was instrumented with 25 rosette strain gages in order to determine the magnitude and distribution of stresses in the loaded pipe. Pipe stresses were found to be substantially lower with soil cement as opposed to soil backfill used for bedding.

Recommendations are made to permit a greater variety of aggregate gradings, meeting other current Caltrans specifications, to be used in the soil cement bedding mix. No change in the present slotted drain design is suggested. A method of strengthening the grate of older existing slotted drains having single cross bar spacers is outlined. Cyclic loading of different slotted drains is suggested for future research to determine service life.

17. KEY WORDS
Slotted pipes, corrugated metal pipes, drainage structures, wheel loads, deflection tests, grates, fillet welds, bedding materials, strain gages, stress analysis

18. DISTRIBUTION STATEMENT
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	141	

DS-TL-1242 (Rev.6/76)

80-22

80-55

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

June 1980

FHWA No. D-4-146
TL No. 636853

LOAD-CARRYING CAPABILITIES OF 18-INCH DIAMETER SLOTTED CORRUGATED STEEL PIPE DRAINS

Study Made by .... Structural Materials Branch

Under the Supervision of .... E. F. Nordlin, P.E.

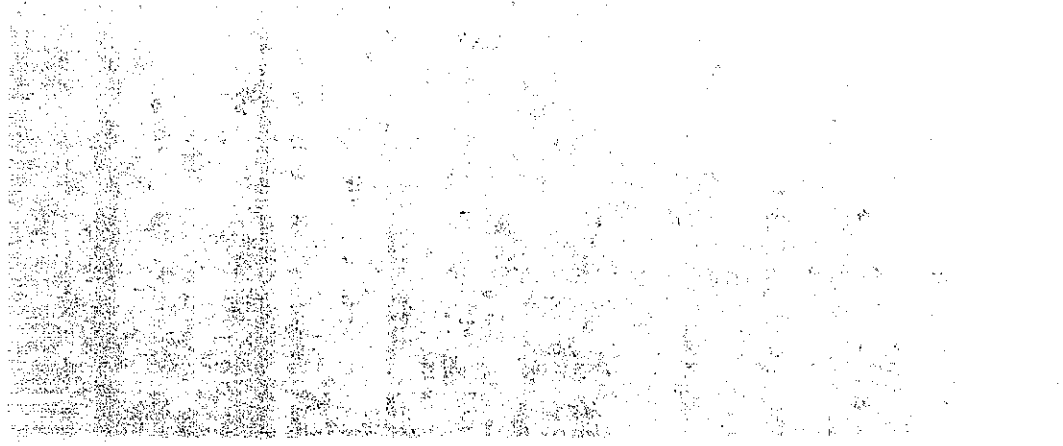
Principal Investigator .... J. R. Stoker, P.E.

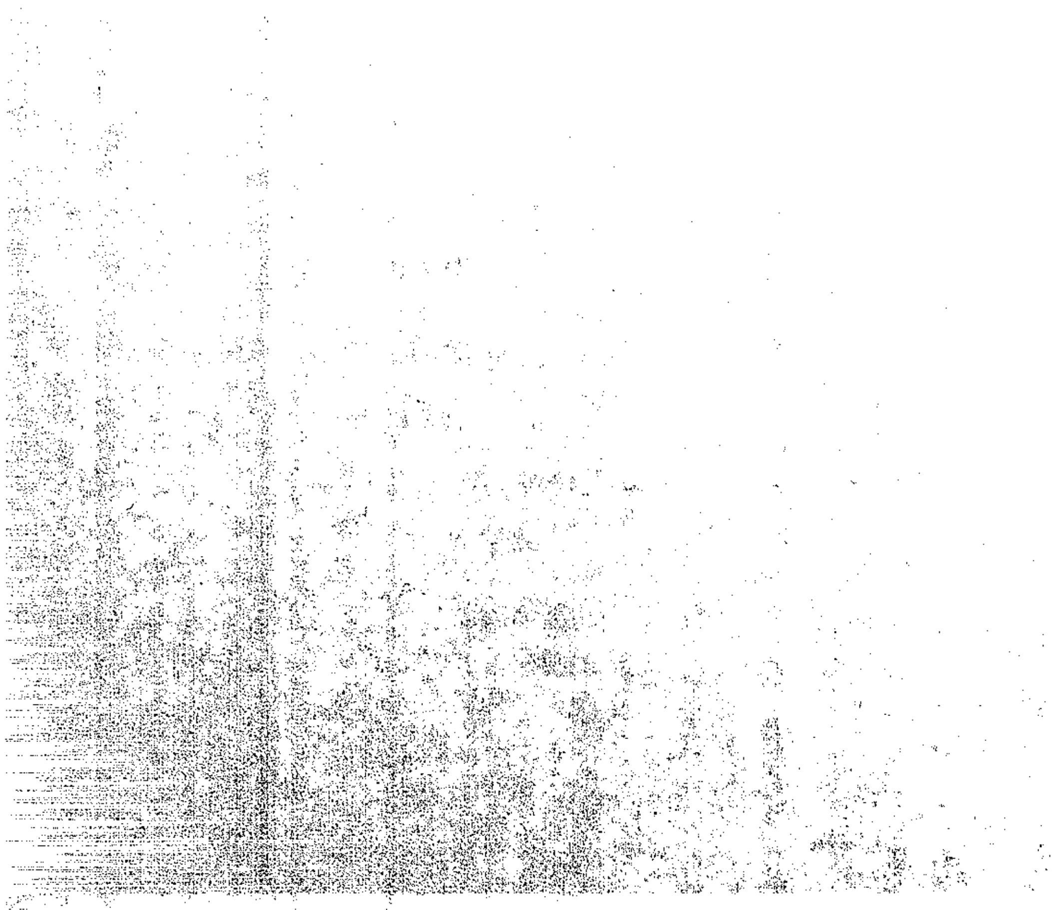
Co-Investigator .... J. P. Dusel, Jr., P.E.

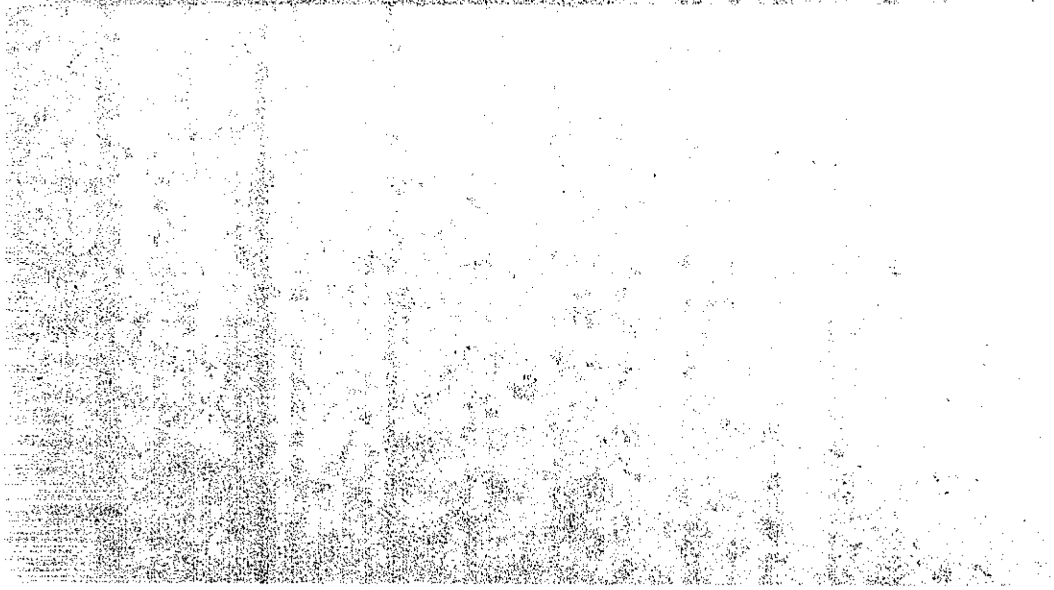
Report Prepared by .... J. P. Dusel, Jr., P.E. and
D. H. Andersen, P.E.

APPROVED BY

NEAL ANDERSEN
Chief, Office of Transportation Laboratory







CONVERSION FACTORS

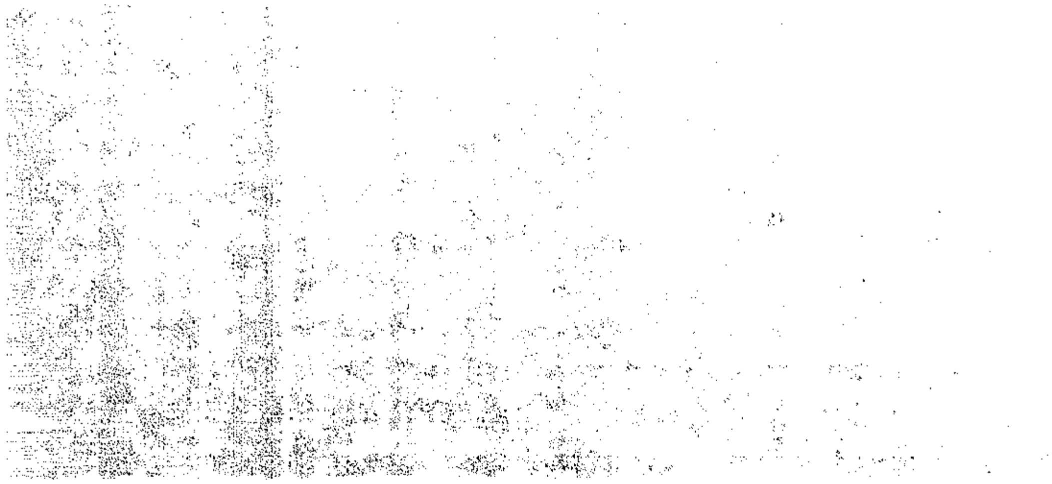
English to Metric System (SI) of Measurement

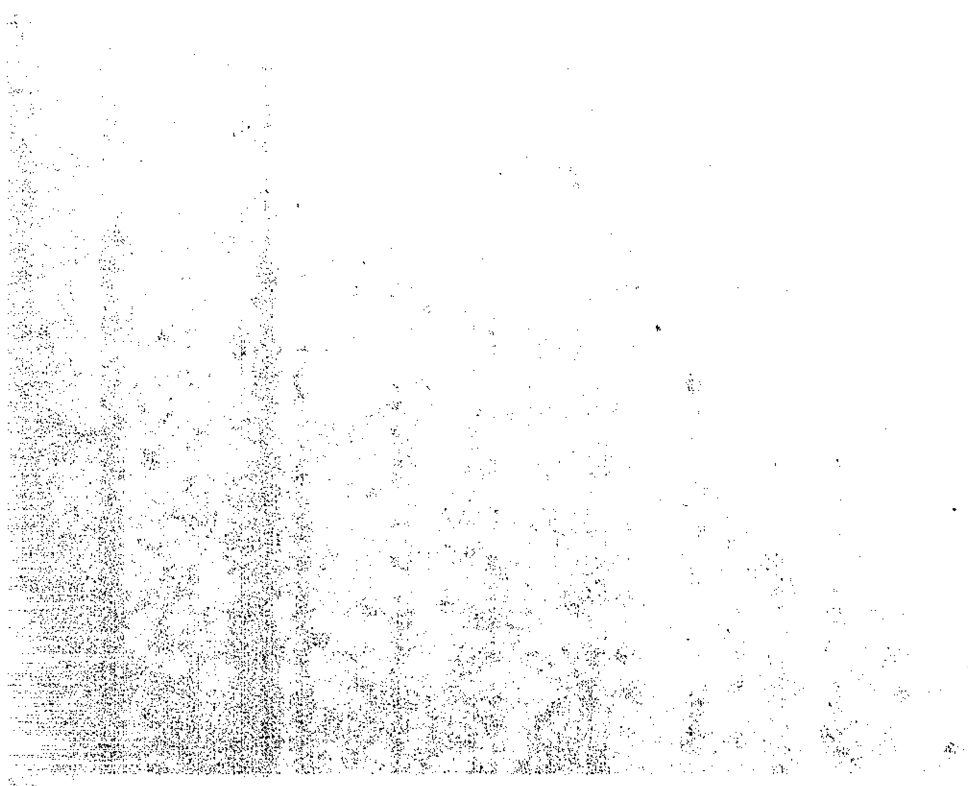
Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the assistance provided by the following staff members of the Transportation Laboratory in conducting the test program:

Laboratory Testing:	Roland Swirsky, P.E. Vincent Bartley
Field Testing:	Edward Budney Richard Snook Delmar Gans
Computer Programming:	Tai Lai, P.E.
Instrumentation:	Albert Sequeira, P.E. Richard Johnson Delmar Gans
Photography:	Robert Mortensen Lynn Harrison Edward Anderson
Typing:	Kathyrn Raymond Darla Bailey
Drafting:	Eddie Fong Elmer Wigginton Marion Ivester
Test Fixtures:	George Oki Edward Girdler Lauren Weyel





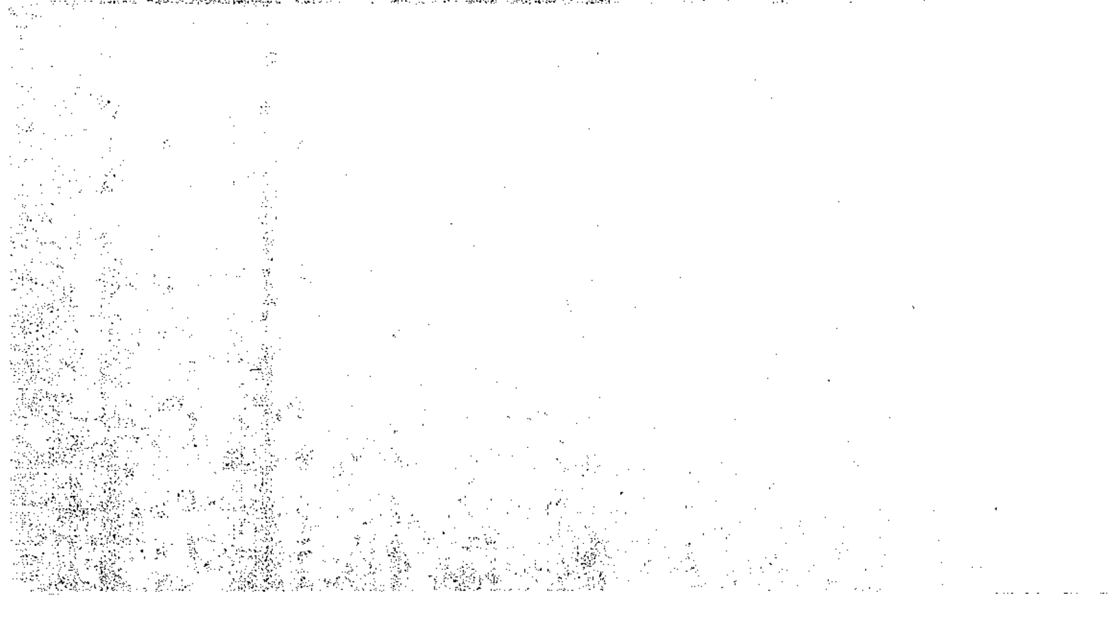


TABLE OF CONTENTS

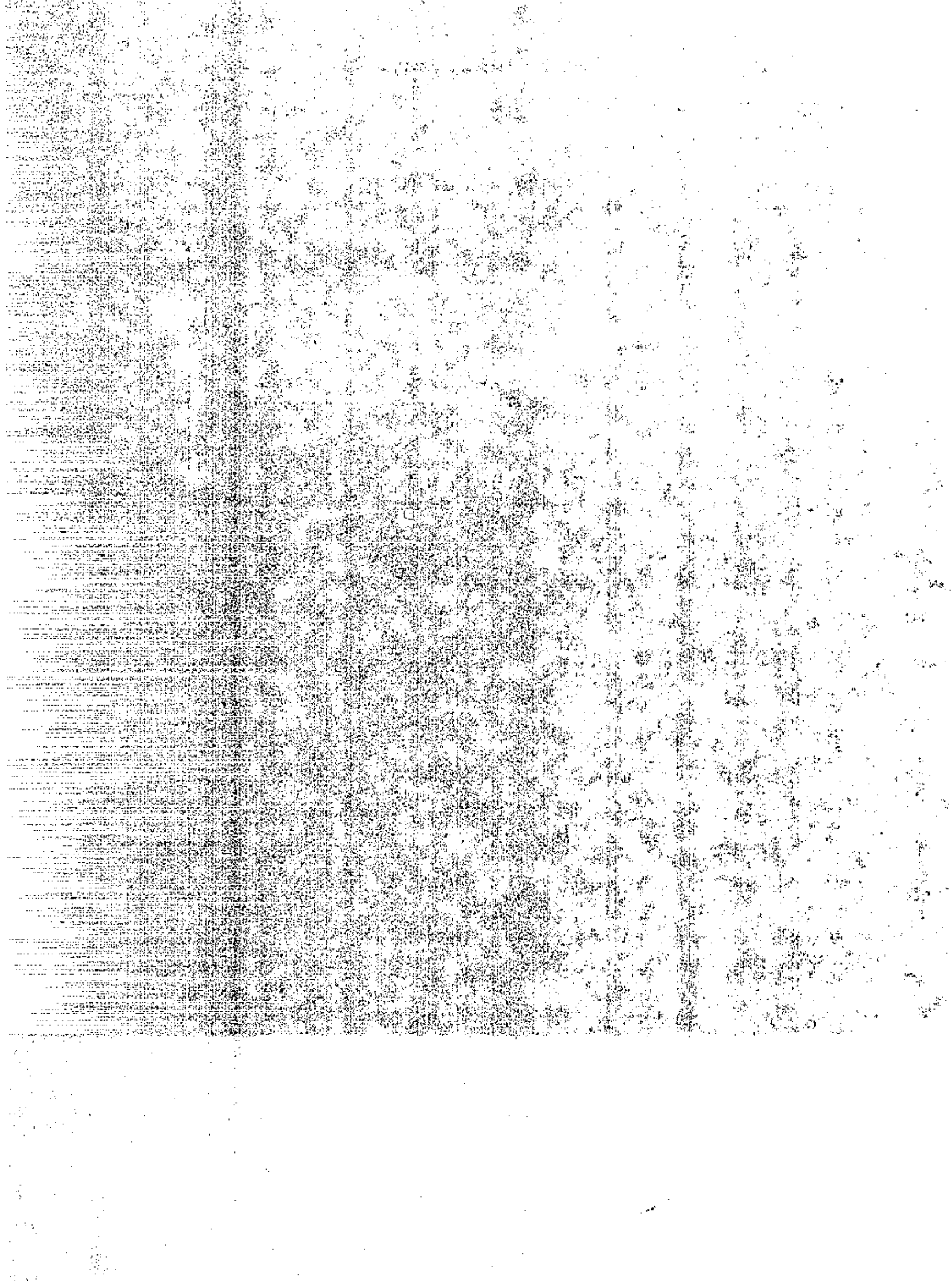
TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

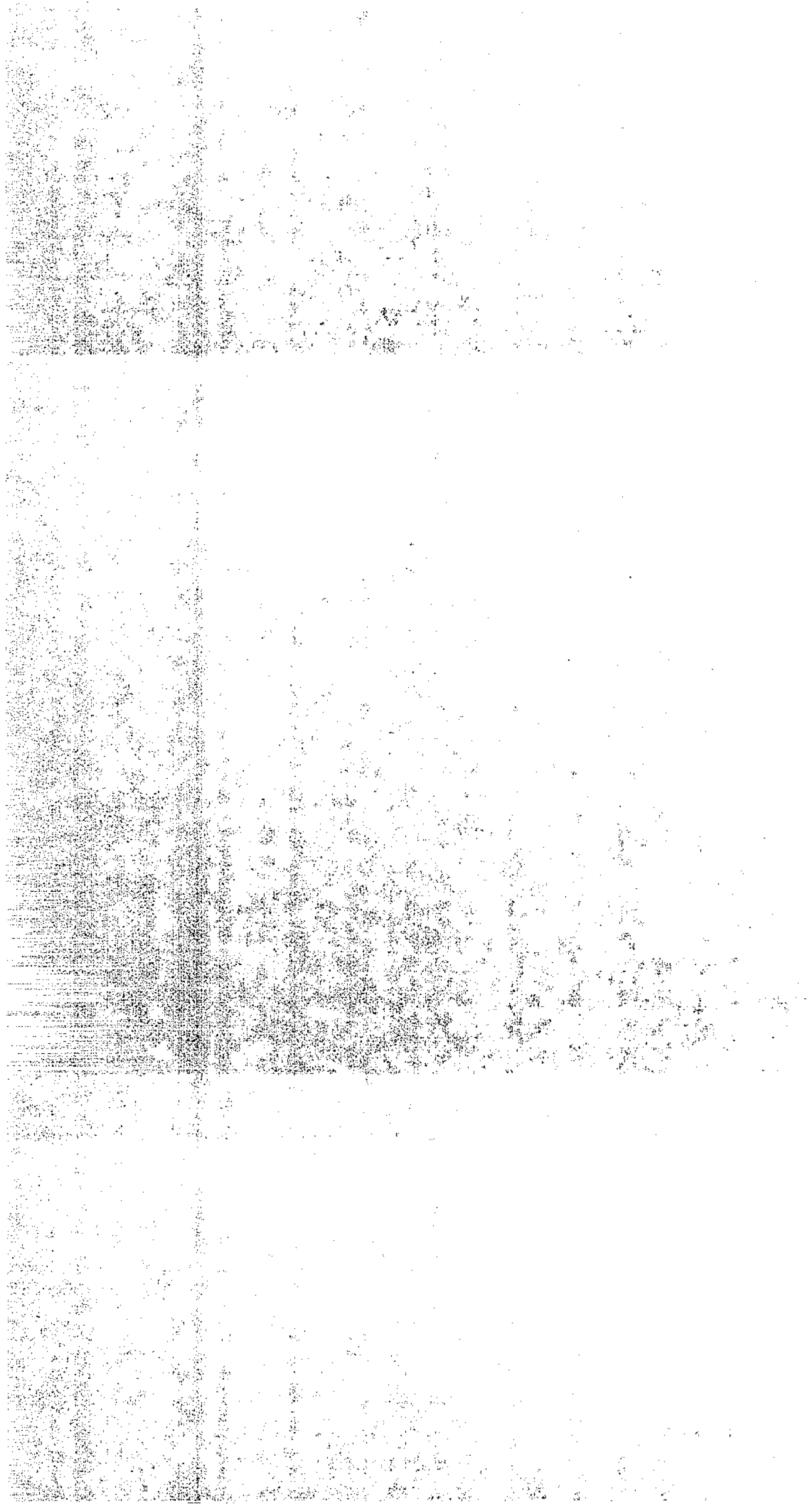
LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)



LIST OF FIGURES (Cont'd)

LIST OF TABLES



1. INTRODUCTION

An important element of the drainage system incorporated in California's highways today is a hydraulic structure called the Slotted Corrugated Steel Pipe (CSP) Drain. A slotted CSP drain is comprised of corrugated steel pipe with a steel grate structure fastened in a two-inch-wide slot cut from the top of the entire length of the pipe. Slotted drains are usually installed along the edge of and parallel to the roadway with the top of the grate structure at the same elevation as the surface of the pavement (see Figure 1).

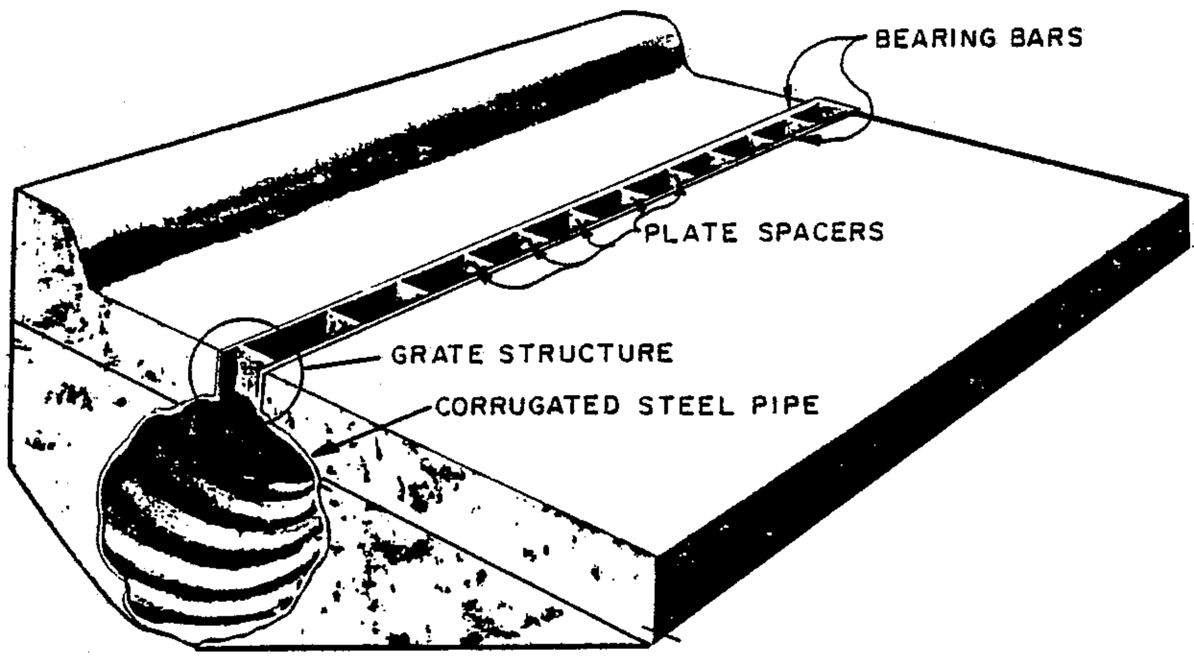


FIGURE 1 A SLOTTED CORRUGATED STEEL PIPE DRAIN

The prime purpose of the slotted drain is to intercept sheet flows of water before they cross the road surface and to quickly drain large volumes of water which might otherwise pond on the road surface during periods of heavy rainfall. Rapid removal of water from the road surface is imperative to prevent accidents caused by vehicles hydroplaning or being slowed down suddenly when encountering ponded water.

Since the conception of the original slotted CSP drain (see Appendix 7.1.1, page 98) in the 1960s in California, there have been continual improvements and changes made. The original design was not welded, but three welded grate design modifications evolved over the subsequent years with each an improvement over and superseding its predecessor. These designs in order of their development are:

(1) a grate consisting of a single row of hexagonal cross bar spacers (see Standard Plan D98-6, Appendix 7.1.2, page 99),

(2) a grate consisting of a double row of hexagonal cross bar spacers (see Standard Plan D98-9, Appendix 7.1.3, page 100), and

(3) a grate consisting of solid plate spacers (see Standard Plan D98-B.1, Appendix 7.1.4, page 101).

In addition to these major design changes in the grate structure, other improvements and changes have been made. Most of these changes have been made for three main reasons:

(1) to improve the hydraulic flow properties of the drain,

(2) to reduce manufacturing costs, and

(3) to strengthen the grate and drain structure.

Modifications made to the original design in order to improve hydraulics of the drain system include:

- Elimination of pipe or structural tubing spacers to increase the water flow through the grate.

- Increasing the slot width of the grate from 1-5/8 inches to 1-3/4 inches.

Changes made in the manufacturing process to reduce fabrication costs include:

- Eliminating bolts used in the grate structure and for attaching the grate structure to the pipe.

- Discontinuing the use of riveted, annularly corrugated CSP and employing either continuously welded or lock-seam-joined helically corrugated CSP.

- Removal of the requirement for hot-dip galvanizing the grate structure.

In order to perform the primary function of providing rapid surface water drainage from the traveled way, the slotted CSP drain must be strong enough to carry repetitive wheel loadings from heavy vehicles. Thus, many changes have been made to strengthen the grate and drain structure as follows:

- The pipe and tubing cross spacers, and single and double hexagonal crossbar spacers have been replaced by solid 3/16-in. by 1-3/4-in. by 2-5/16-in. plate spacers to make the grate structure more rigid.

- Intermittent fillet welds connecting the grate structure to the corrugated pipe have been lengthened from a minimum of 1 inch to 1-1/2 inches and their spacing reduced from about 7-1/2 inches to 6 inches.

- These grate-to-pipe welds have also been positioned at each plate spacer to provide a more direct load transfer from the grate structure to the corrugated pipe.

- A soil cement backfill is now required for bedding slotted drains (Sections 66-3.09 and 19-3.025C of the Caltrans 1978 Standard Specifications). This soil cement backfill has replaced a previously specified soil backfill, for which a wider trench was required to insure adequate compaction, and whose compressive strength was considerably less than that of the soil cement backfill.

These structural changes have strengthened the slotted CSP drain considerably, and have enabled the drain to be used in locations along highways where increased traffic volume and larger wheel loads from heavy vehicles have occurred. The development and use of flotation tires, which have enabled heavy trucks and maintenance vehicles to carry single wheel loads of as much as 11,000 pounds, have caused wheel loads applied to the slotted CSP drains to be much higher and more concentrated.

The effects of all these changes on the load carrying capacity of the 18-inch-diameter slotted pipe drain were unknown, and the ability of the different drain designs to withstand heavy loads was uncertain.

The purpose of this study was to evaluate the static load carrying capacity of the two most recent CSP drain designs having grates with double bars and plate spacers, and to determine if the current grate structure with plate spacers is strong enough to withstand occasional heavy vehicle traffic and large loads imposed by flotation tires. Variables considered important in this research project were the type of backfill, the length and location of the welds attaching the grate bearing bars to the corrugated steel pipe, the position and magnitude of the applied wheel load, and the type of spacers connecting the bearing bars of the grate.

In carrying out the research, independent grate sections were first tested to determine the actual tensile and shear strengths of welds attaching the bearing bars and crossbar spacers. Next, fourteen 4-foot-long sections of slotted CSP drains having various grate designs and grate-to-pipe weld patterns were tested in quasi-ring compression in a large universal testing machine to determine the relative strengths, vertical deflections, and grate angle deformations. The results of these preliminary tests are briefly summarized in Section 5.1, pages 62 to 65, of this report.

An asphalt-paved road having a structural section approximating that of a typical highway was then constructed, and five 16-foot-long, 18-inch-diameter slotted CSP drains were installed. The following parameters were varied for the five slotted drains tested: grate design; bar/plate spacing; grate-to-pipe weld length, location, and spacing; and backfill type.

Each slotted pipe drain was loaded at the third points using an 8-inch by 12-1/2-inch steel plate with a bearing area of 100 square inches. This is the bearing area of an 8-inch-wide flotation tire. The side of the plate having the longer dimension was positioned parallel with the grate bearing bars. Both a centered and an eccentric offset loading position were used to load the drains. One of the slotted pipe drains was also instrumented with 25 rosette strain gages to determine the stress distribution in the walls of the corrugated pipe, due to the applied simulated wheel load of a typical flotation tire.

In each test, the external load was increased while the vertical deflections inside the pipe were monitored and recorded. The effects of backfill type, grate type and weld pattern, and position of the load on the load carrying capability of each slotted drain are discussed in the following report.

2. CONCLUSIONS

2.1 Conclusions from Laboratory Tests Performed on 4-foot-long Sections of Slotted Pipe Drain

2.1.1 Slotted Pipe Drain Deflections

For the slotted pipe drain designs tested, the type of cross spacer in the grate made no clear difference in the deflections measured inside the pipe.

For the slotted pipe drain designs tested, the location of the grate-to-pipe welds with respect to the cross spacers or bearing bars did not noticeably influence the deflections measured inside the pipe.

A decrease in the spacing of grate-to-pipe welds from 3 to 2 corrugations per weld did not significantly decrease vertical pipe deflections as measured in laboratory testing.

2.1.2 Grate Rotation

When the pipe was loaded eccentrically in the laboratory tests, the grates rotated about the grate-to-pipe welds. These welds offered little resistance to bending and appear to be the weakest part of the slotted drain.

The use of plate spacers instead of bar spacers did not seem to reduce the downward vertical deflection of the grate under center loading, however, under eccentric loading, average angular rotation of the grate structure having plate spacers was reduced slightly because of its increased torsional stiffness.

2.1.3 Factors Affecting Maximum Load Capacity

Because of the limited number of drain specimens tested in the laboratory and the apparent inconsistency in the data obtained, no definite conclusions may be made with regard to the effect which many of the parameters have on the load capacity of the various slotted drains. Often the data appears to be conflicting, and against one's engineering judgment. This was partially due to the fact that slotted drains in the laboratory tests were only supported up to the spring line of the pipe, i.e., the sides of the grate and the upper half of the pipe had no external support.

- It is evident, however, that the slotted drain with a grate fabricated with single hex bar cross spacers was one of the designs least able to support higher vertical loads (the maximum load for Specimen No. 10, Table 7, page 63 was only 7,550 lbs).

- The effect of either (1) the spacing of the grate-to-pipe welds, or (2) their location with respect to the cross spacers on the ability of the short drain sections to withstand vertical compressive loads is not clear from the data obtained, nor is the effect of the location of these grate-to-pipe welds with respect to the crests and valleys of the corrugated pipe.

- Slotted drain designs had the least maximum load supporting capability when the load in the laboratory tests was applied eccentrically to the edge of the grate (Loading Method (3), Eccentric-Bearing on One Side of Grate).

- The two control sections of plain corrugated steel pipe withstood the highest average maximum applied loads of any specimens tested in the laboratory.

2.2 Conclusions from In-Situ Tests on 16-foot-long Drain Sections

It has been determined from the in-situ tests conducted, that the 18-inch-diameter slotted CSP drain with the current grate structure with plate spacers is strong enough to withstand occasional heavy vehicle traffic, provided that a soil cement bedding is used. The following are important findings which were determined from the test data in this research project.

2.2.1 Factors Affecting Maximum Load Capacity

- There was no apparent difference in the static strength of slotted pipe drains fabricated with grate designs employing either the double hexagonal cross bar spacers or the solid cross plate spacers.

- There were no apparent differences in the static strength of slotted drains attributable to the changes in the grate-to-pipe weld designs that were considered. Nonetheless, it is felt that the grate-to-pipe welds should be placed at the cross spacers to promote direct load transfer from the grate into the pipe walls and minimize grate distortion.

- The type of backfill had a dramatic effect on the vertical deflections and stress distribution in the pipe walls of the slotted pipe drain systems tested. The soil cement backfills carried a large portion of the applied load and decreased the vertical deflections and bending stresses in the slotted pipe drain. The ready-mixed lean concrete of the same cement factor proved to be considerably stronger than the site-mixed soil cement required by current specifications.

- In most cases, the deflection of the asphalt concrete pavement adjacent to the grate, rather than the acutal deflections of the slotted drain pipe grate, will probably limit the loading which the slotted drain installation can withstand. With an asphalt concrete thickness of approximately 2 inches next to the grate bearing bars, tolerable asphalt concrete deflections will vary between 0.040 inch (Traffic Index=6) and 0.017 inch (Traffic Index=11) depending on the expected traffic volume and the type and compaction of base material(16). Similar deflections of the slotted drain grate were obtained in Test 3B with single flotation tire static wheel loadings of 14 kips (0.040 inch) and 8 kips (0.017 inch) - see Figure 35, page 73.

2.2.2 Effect of Load Positions on Slotted Drain Deflections

Of the various load positions, the centerline parallel position of the loading plate caused the greatest vertical deflections with both bearing bars (grate side plates) deflecting the same amount. The eccentric parallel position of the loading plate caused the greatest grate rotation.

2.2.3 Effect of Different Types of Backfill on Stress Distributions and Vertical Deflections of the Slotted Drain

Slotted drains tested had greater deflections in soil backfill than in the soil cement backfill. Also, the soil backfill allowed the pipe to distort more under load, and transferred more load to the slotted drain than did the soil cement backfill. The magnitudes of bending stresses were greater in the slotted pipe drains which were backfilled with soil material than slotted drain with soil cement backfill. There seemed to be little difference in the strength of slotted drains backfilled with site-mixed soil cement and ready-mixed lean concrete of the same cement factor according to the vertical deflection data. However, the ready-mixed lean concrete had significantly higher 28-day compressive strength (1800 pounds per square inch) than did the site-mixed soil cement (720 pounds per square inch).

2.2.4 Effect of Various Load Positions on Stress Distribution in the Corrugated Steel Pipe of the Slotted Drain

The position of external wheel load which produces both the highest stresses and vertical deflections in the drain pipe is the centerline parallel loading for both soil and soil cement backfills. The highest bending stresses in the pipe wall occurred 45 degrees from the center of the grate with the corrugation crests in tension and the corrugation valleys in compression. For almost all load positions, stresses measured at the spring line in the pipe walls of slotted drain backfilled with soil cement were predominantly compressive.

3. RECOMMENDATIONS AND IMPLEMENTATION

3.1 Recommended Changes to Standard Specifications and Plans

Based on the observations and conclusions from the laboratory and in-situ testing of the 18-inch-diameter slotted drain, the following recommendations are made:

- Modify the Caltrans 1978 Standard Specifications(12), Section 19-3.025C to allow other gradings of aggregates to be used in soil cement bedding. The same minimum cement factor, 282 pounds of Type II Modified portland cement per cubic yard of soil cement backfill would be used for any of these aggregate blends. These other acceptable blends of aggregates and the respective sections of the current Caltrans Standard Specifications under which their requirements are explained are as follows:

  (1) 1-inch maximum combined aggregate gradings shown for portland cement concrete, Section 90-3.04

  (2) Class 2 AB, having a maximum coarse aggregate size of 3/4 inch, Section 26-1.02B

  (3) Class A CTB, Section 27-1.02

- Continue to manufacture slotted CSP drains in accordance with current Caltrans Standard Plan D98-B.1 (Appendix 7.1.4, page 101). Allow the use of this

18-inch-diameter slotted drain where occasional heavy vehicle traffic (maximum single flotation tire load of 11,000 lbs) will occur, provided that a soil cement bedding is required.

- Leave older style slotted pipe drains which have been installed in the past in service, provided that the slotted drains are not damaged and will not be subjected to heavy vehicle traffic or any bicycle traffic.

- Repair these older style bar spacer grates only when they show signs of fatigue or weld failure or when they will be subjected to heavy vehicle or bicycle traffic. When grate repairs are necessary, new solid plate spacers may be welded into the grate at 6-inch spacings while the drain is still installed in the ground in lieu of removing the old style drain and replacing with new. With the grate spacer plates at 6 inches on centers, bicycle wheel entrapment will not occur.

- Based on the stresses obtained in the pipe wall of the 18-inch-diameter drain tested in this project, the use of slotted pipe drains larger than 18 inches should be restricted to light traffic bearing areas only.

3.2 Future Research

In order to determine actual service life under moderate truck loading, it is recommended that any future testing include cyclic loading of slotted drains. It is suspected that many of the older style slotted drains having either single or double rows of plug welded hexagonal cross bar spacers may perform satisfactorily under static loading as performed in this research study. However, when subjected to repeated dynamic loading, either the plug welds attaching the hexagonal cross bar spacers to the bearing bars or the grate-to-pipe welds may fail. It is recommended that in future research, fatigue tests be conducted on slotted drains having grates manufactured with double hexagonal cross bars in addition to those with solid plate spacers to determine durability of welds under fatigue loading.

3.3 Implementation

The major finding of this research study has already been implemented. The improved grate structure in which solid steel spacer plates at 6-inch centers are used instead of hexagonal bars has been adopted as the standard design (see Appendix 7.1.4, page 101). It is expected that the recommendation to allow a broader variety of backfill material will soon be incorporated into the Standard Specifications(12).

4. DESCRIPTION OF EXPERIMENTAL PROGRAM

4.1 Testing Program - General Discussion

The objectives of this research program were to obtain a relative strength comparison between the various types or designs of slotted pipe drains tested, and to determine by static load tests if any of the types of slotted pipe drains would be suitable for use in areas where a moderate amount of heavy truck traffic is expected. To accomplish these objectives, the following parameters were considered important:

- Strength of the grate-to-pipe welds to resist tension, shear, and torsion.
- Strength of the grate structure to resist shear and to be able to carry ring compression.
- The type of loading which would induce the highest stresses in the slotted pipe drain.
- Type of backfill material so as to minimize stresses in the slotted pipe drain structure.

The physical characteristics of the slotted pipe drains tested along with certain geometric variables which were thought to influence the slotted drain's load carrying capacity are listed as follows:

• General description of slotted pipe drains:

Nominal pipe diameter: 18 inches
Lengths: (1) Laboratory tests: 4 feet
(2) In-situ tests: 16 feet
Pipe thickness: 0.064 inch (16 gauge)

• Pipe geometry:

Helix: 23.9°
Corrugation depth: 0.45 to 0.50 inch
Corrugation distance crest to crest: 2.65 inches normal to corrugation centerlines

• Pipe manufacturing process: Continuous helical welded seam

• Grate geometry:

Bearing bar dimensions: 2-1/2 inches high, 3/16 inch thick

Types of cross spacers tested:

(1) Single 5/16-inch-diameter hexagonal bars
(2) Double 5/16-inch-diameter hexagonal bars
(3) 3/16-in. by 1-3/4-in. by 2-5/16-in. solid plate

Spacing intervals of cross spacers:

(1) 4 inches
(2) 6 inches

Spacings of grate-to-pipe welds used:

(1) 6 inches
(2) 2 corrugations per weld
(3) 2-1/2 corrugations per weld
(4) 3 corrugations per weld

Lengths of grate-to-pipe welds tested:

(1) 1-1/2 inches
(2) 1-3/4 inches
(3) 2 inches

Positions of grate-to-pipe welds with respect to the cross spacers tested:

(1) at spacer
(2) at 1/4 points between spacers
(3) centered between spacers
(4) random - no relation to spacer position

Fourteen 18-inch-diameter, 4-foot-long slotted pipe drain sections were tested in quasi-ring compression in the laboratory to see how they would perform under both centered and eccentric loading and to verify the need for more extensive testing. The results from the laboratory testing were of some benefit in determining relative strength comparisons and were used mainly for information to aid in planning in-situ tests.

The in-situ testing was accomplished by applying a vertical load in different positions to five 18-inch-diameter, 16-foot-long slotted pipe drains installed in a simulated roadbed test section. Two different grate designs, one with double cross bar spacers and the other having solid plate spacers, were used in these five drains.

One of the five slotted drains having a grate with solid plate spacers was instrumented with 25 strain gages in order to gain knowledge about the distribution and magnitude of pipe stresses in a loaded slotted drain. This pipe was tested using both soil and soil cement backfill and applying loads in various positions.

4.2 Detailed Description of Test Phases

4.2.1 Laboratory Testing

In an attempt to determine the structural effects that different methods of loading and different grate designs would have on the relative abilities of the slotted pipe drains to resist vertical compression loading, fourteen 4-foot sections of 18-inch-diameter slotted drains were tested in the laboratory. A wooden cradle was constructed and used in all tests to give lateral support to the bottom half of the corrugated steel pipe as would a backfill material. In addition, two sections of plain corrugated steel pipe were tested so that the compressive loads attained could be compared with those from the various sections of slotted pipe drain.

The various parameters considered important in this series of laboratory tests included: (1) the method of applying the external load; (2) the type and spacing of the cross spacers; and (3) the spacing, length, and location of the grate-to-pipe fillet welds. These are outlined in Table 1.

TABLE 1 DESCRIPTION OF SHORT SECTIONS OF SLOTTED CSP DRAIN TESTED IN THE LABORATORY

Specimen Nos.	Methods of Loading (See Figure 11) Pg. 40	Type of Cross Spacer (Spacing, inches)	No. Corr. per Weld (Weld Spacing inches)	Length of grate-to-pipe Welds (in.)	Position of grate-to-pipe Side Welds With Respect to: Corrugations*	Spacers**
1	Eccentric Rod	Double Hexagonal Bar (6")	3 (9")	1-1/2	NCR	Between Spacers
7	Eccentric Block			1-3/4	C-V	Near Spacers
3	Eccentric Bearing on grate				C-V	Every Other Weld @ Spacer
11	Center on Plate					
15	Eccentric Block				C-V	Near Spacers
4	Eccentric Bearing on grate		2 5-3/4"		C-V	Near Spacers
5	Eccentric Block				Crest	At Spacer
12	Center on Plate				C-V	Near Spacers
16	Eccentric Block				C-V	At Spacer
10		Single (4") Hex. Bar	2-1/2 7-3/4"	1-1/2	NCR	Near Spacers
2	Eccentric Rod	3/16 Inch Plate (6")	2 5-3/4"	1-3/4	Crest	At Spacer
8	Eccentric Block				Crest	Near Spacers
9					Crest	Between Spacers
13	Center on Plate				Crest	Near Spacers
6	Eccentric Block	Unslotted Pipe	0	—	—	—
14	Center Block					

Note: * NCR : No Consistent Relationship
C-V : Crest to Valley

** Description of position of grate-to-pipe welds with respect to spacers is approximate.

Four different methods of applying incremental vertical loads to the sections of slotted pipe drain were used in the laboratory testing and are outlined as follows: (a) an eccentric load applied to a 16-inch-long rod, tack welded to the pipe wall 3.4 inches from the center of the grate; (b) an eccentric load applied to a 4-inch by 16-inch-long wooden block with a molded bottom to fit the pipe corrugations; (c) an eccentric line load applied to the top of one bearing bar only; and (d) a line load applied to a 2-1/2-inch by 16-inch-long steel plate resting on both bearing bars. Wooden blocks with molded bottoms were also used to apply the test loads to two sections of plain corrugated steel pipe. All of these loading methods are further described in Sections 4.4.1.1 and 4.4.1.2 and are shown in Figures 11 through 14 (pages 40-42) of this report.

4.2.2 In-Situ Testing

Five sections of slotted drains, each 16 feet long were installed in a simulated roadbed section and loaded to failure. These were tested in order to learn what magnitude of wheel loads slotted drains having grates with (a) double cross bar spacers and (b) solid plate spacers can withstand without deflecting significantly. The 130-foot-long, 10-foot-wide simulated roadbed was built on the grounds of the Transportation Laboratory. The roadbed cross section of 0.60-foot-thick asphalt concrete pavement placed on top of 2.4 feet of aggregate base and native clay basement soil with an R-value of 15 is depicted in Figure 2. It was designed according to Section 7-600 of the Highway Design Manual(14) assuming a Traffic Index of 12.0. After the roadbed was built, a 21-inch-wide x 21-inch-deep trench was dug the entire length and down its

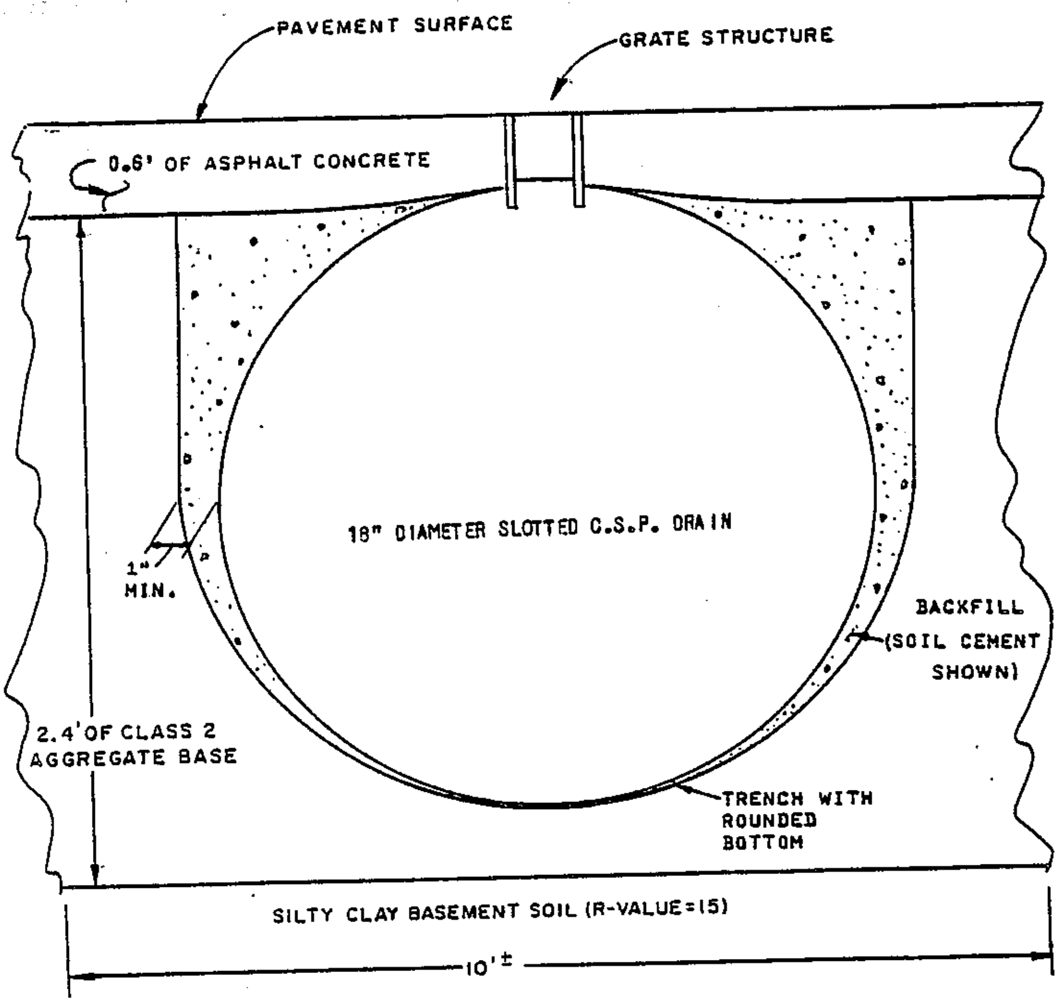


FIGURE 2. A CROSS SECTION OF THE SIMULATED ROADBED WITH A SLOTTED DRAIN INSTALLED.

center. The trench bottom was shaped to conform to the arc of the drain pipe. The five slotted pipe drains, manufactured according to the standard plans and specifications shown in Table 2, were installed in the trench and were assigned identification numbers 1 through 5. The slotted drains were placed six feet apart in the trench. Slotted Drain No. 1 was placed at the westernmost end with the other slotted drains placed numerically in order toward the eastern end of the trench. General procedures used to install and backfill the slotted pipe drains are given in Appendices 7.2.1 and 7.2.2 (pages 102-105). The trench was widened to 44 inches for Slotted Drains, Nos. 1, 2, and 3, where an untreated soil backfill was used, so that the backfill material could be compacted.

A description of the grate structure in each of the five slotted drains tested in situ, in addition to a description of the length and location of the intermittent grate-to-pipe fillet welds with respect to the corrugation crests and the cross spacers, is given in Table 2. The description of each standard plan used to manufacture the respective slotted drains, and the type of backfill used for each of the six test series, including Test Series 3A and 3B, is also listed.

4.2.2.1 Explanation of Test Series 1, 2, 4, and 5

The methods of conducting these four test series were identical. Two loading positions, numbers ① and ② as shown in Figure 3, were used in each of these four test series. In both loading positions, the 8-inch by 12 1/2-inch steel plate was always centered longitudinally on

TABLE 2. DESCRIPTION OF SLOTTED DRAINS TESTED IN SITU.

Slotted Drain No. and Location	1	2	3 *	4	5
Test Series Designation	1	2	3A(soil) 3B(soil cement)	4	5
Grate Spacer Type	3/16" PLATE	Double Hexognal Bar	3/16" PLATE	Double Hexognal Bar	Double Hexognal Bar
Distance Between Spacers	6"	6"	6"	6"	6"
Distance Between Welds Grate-To-Pipe	6"	One Every 3 Corrugations	6"	One Every 3 Corrugations	6"
Actual Intermittent Grate-To-Pipe Weld Lengths	1-3/4"	1-3/4"	2"	1-3/4"	1-3/4"
Grate-To-Pipe Weld Position	Corrugation Valley at Spacer	Crest to Valley	Crest to Valley at Spacer	Crest to Valley	Crest to Valley at Spacer
Cross Spacer Weld Type	3/16" x 1-3/4" Fillet Weld	Plug Weld	3/16" x 1-3/4" Fillet Weld	Plug Weld	Plug Weld
Standard** Plan No.	D98-B.1	D98-9	D98-B.1	D98-9	D98-9 (Modified)***
Type of Backfill/ Trench Width	SOIL/44"	SOIL/44"	Soil(Test 3A)/44" Site Mixed Soil Cement (Test 3B)/44"	Ready Mixed Lean Concrete/ 21"	Site Mixed Soil Cement/ 21"

* Strain gage instrumented slotted drain

** See Appendices 7.1.3 and 7.1.4, pages 100 and 101

*** A grate-to-pipe intermittent fillet weld spacing of 6 inches was used.

the closest grate spacer. The method of loading and the various positions are discussed in greater detail in Section 4.4.2.1, In-Situ Testing, General Equipment and Test Set-Up, pages 45 through 49 of this report.

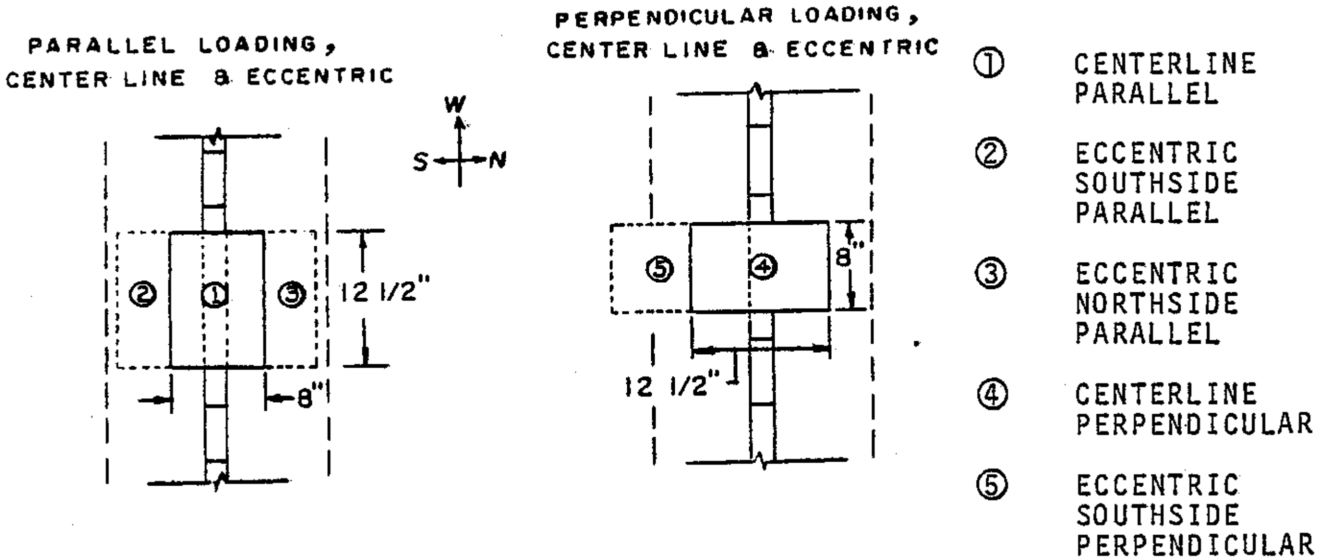


FIGURE 3. VARIOUS POSITIONS OF LOADING PLATE USED FOR IN-SITU TESTING.

In these four test series, two different load tests were run on each of the four slotted drains, one test 5 feet from the end of each drain at about the third point, using a different loading position in each case. These loading positions were called "Centerline Parallel" and "Eccentric Southside Parallel". The term "Centerline Parallel" loading means that the slotted drain was loaded with the long direction of the loading plate parallel with the grate bearing bars and with the middle of the loading plate positioned at the middle of a cross spacer. The term "Eccentric Southside Parallel" loading is similar except the steel plate is offset 4-3/4 inches to the "south" with one edge overhanging a grate bearing bar 1/4 inch.

In both load tests on each of the four slotted drains, the load was incrementally increased, and after each increase dropped to zero. This procedure was continued until noticeable permanent deformation or vertical deflection of the grate structure occurred. Vertical deflections at the base of both grate bearing bars and 2-1/2 inches to each side of the pipe invert were measured at each incremental loading step increase and again each time the load was reduced to zero. The same instrumentation was used to measure these vertical deflections in all load tests in Test Series 1, 2, 4, and 5, and is further described in Section 4.4.2, In-Situ Testing (page 45). The difference between each of these four test series are further explained in Table 2.

4.2.2.2 Explanation of Test Series 3A

In Test Series 3A, Slotted Drain No. 3 had a grate structure with solid cross plate spacers and was instrumented with 25 rosette strain gages. These gages were attached to the outside walls of the corrugated steel pipe near the longitudinal center of the 16-foot-long section of slotted drain. In this initial Test Series 3A, the slotted drain was bedded with untreated soil backfill, and was loaded incrementally to 15 kips at the longitudinal center of the pipe over the strain gages using both the "Centerline Parallel" and "Eccentric Southside Parallel" loading positions. Because this strain-gaged slotted drain would be loaded again in a future Test Series 3B, the maximum external loads applied in Test Series 3A were limited to 15 kips; hence, yielding of the steel in the pipe walls would be prevented and no damage would occur to the costly strain gages. The exact loading procedure is further discussed in Section 4.4.2, In-Situ Testing (page 45). A different instrumentation system was used for this test series than was used in Series 1, 2, 4, or 5. The instrumentation system for Test Series 3A was comprised of an electromechanical data acquisition system, which measured and recorded strains (differences in voltage potential) in three directions in each of the 25 rectangular rosette strain gage elements. The system also measured the corresponding incremental loads and the vertical deflections of the slotted drain as was done in Test Series 1, 2, 4, and 5. Also in this Test Series 3A, the deflected shapes of the upper half of the slotted drain were recorded at each incremental load level and at corresponding zero loads. This was done by photographing the positions of small black magnetic pins which were placed in front of a fine grid background positioned inside the pipe on a plane perpendicular to the axis of the pipe directly under the center of the loading plate. From this photographic data, shapes of deflected slotted drains were determined and drawn.

A computer program was written to calculate stresses from the strain gage data compiled for each loading case run in Test Series 3A and 3B. A copy of the computer program and a sample data printout are shown in Appendices 7.3.2 and 7.3.3 (pages 110-114).

4.2.2.3 Explanation of Test Series 3B

After the conclusion of Test Series 3A performed on the strain gaged Slotted Drain No. 3, the asphalt concrete paving around the grate structure and the untreated soil backfill surrounding the drain pipe were carefully removed. The same length of instrumented slotted pipe drain was then replaced in the trench and backfilled with soil cement bedding. In Test Series 3B, the slotted drain with strain gages was again loaded at its longitudinal center incrementally up to 15 kips in each of the five load positions previously shown in Figure 3, page 24.

The "perpendicular" loading case was so named because the longest side of the loading plate was perpendicular to the slotted drain grate bearing bars. The instrumentation for Series 3B tests was the same as that used on Test Series 3A. In the last test conducted in Test Series 3B, the slotted drain was loaded in the centerline parallel position to 32 kips. Further loading was discontinued at this point as this load level approached the dead weight of the concrete and steel ballasts set on the testing apparatus.

4.3 Materials

4.3.1 Slotted Drains

In the following section, materials used in the fabrication of slotted pipe drains tested in the laboratory and in the simulated roadbed test section are discussed. The slotted drains and their components were inspected at the vendor's yard and then tested in the laboratory for compliance to the Caltrans Standard Plans and the Standard Specifications before they were used for this research.

4.3.1.1 Material Properties

Required and measured properties of the various materials which were used in manufacturing the slotted pipe drain include:

Steel strength:

- Corrugated steel pipe met specifications in ANSI/ASTM A444 for copper steel. Also met material requirements in AASHTO M218.

- Minimum required strengths of flat galvanized culvert sheets:

$$\text{Yield Strength} = \sigma_y = 33{,}000 \text{ psi}$$
$$\text{Ultimate Tensile Strength} = \sigma_{ult} = 45{,}000 \text{ psi}$$

- Actual average strengths as determined from steel specimens cut from the tangent sections of the corrugated steel pipe:

$$\text{Yield Strength} = \sigma_y = 54{,}150 \text{ psi}$$
$$\text{Ultimate Tensile Strength} = \sigma_{ult} = 61{,}900 \text{ psi}$$

Cross plate spacer weld strength:

- Minimum required tensile force = 12,000 pounds normal to the longitudinal axis of the bearing bars.

- Actual tensile force measured exceeded 17,500 pounds, which is the capacity of the test fixture.

Corrosion protection of the corrugated steel pipe:

- The pipe section met the requirement for the average thickness of the hot-dip galvanized zinc coating of 2 ounces per square foot (total on both sides of sheet metal) required for the corrugated steel pipe. (AASHTO Designation: M218)

4.3.2 Backfill Materials

The five slotted drains installed in the 130-foot-long trench were backfilled with three types of materials: (1) a soil backfill (sand), (2) a site-mixed soil cement, and (3) a ready-mixed lean concrete. A sand was used for the soil backfill because its grading met that of the earlier specifications for soil backfill and it was readily available. This sand took more time to place than either the soil cement or lean concrete backfill. This was because the sandy backfill (see Figure 4) was difficult to compact and there was a much greater volume of material to compact since the trench had to be widened to 44 inches. The trench widening was necessary in order to provide enough room to operate foot compactors and nuclear instruments to measure relative compaction of the backfill material (see Figures 5 and 6). In comparison, two slotted drains, Nos. 4 and 5, with the lean concrete and soil cement respectively, required only a 21-inch wide trench as shown in Figure 7. The relative compactions of the compacted untreated soil backfill around two slotted drains Nos. 2 and 3 were determined using a nuclear gage according to procedures outlined in California Test 231(13) and averaged 96% and 97% respectively. Figure 8a gives the grading analysis for the sand used as untreated soil backfill.

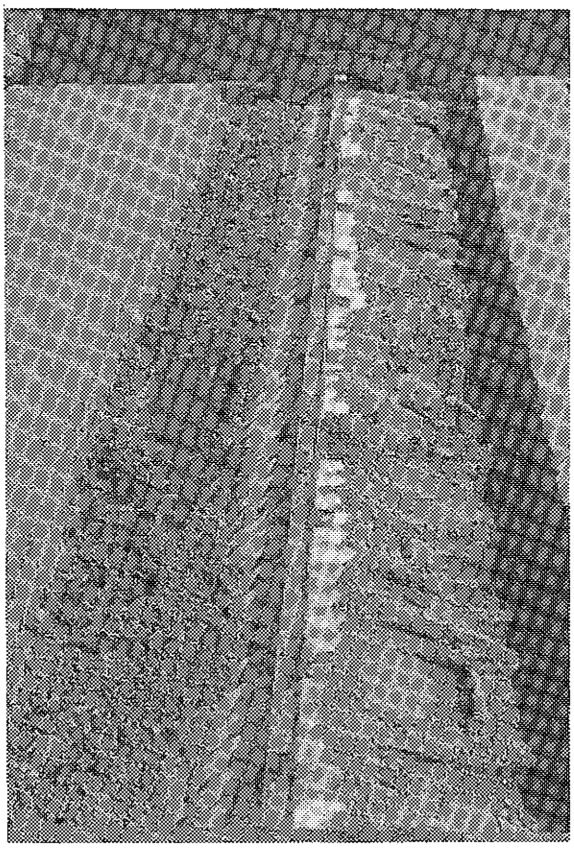


FIGURE 4. TYPICAL TRENCH FOR SLOTTED DRAIN BACKFILLED WITH SOIL.

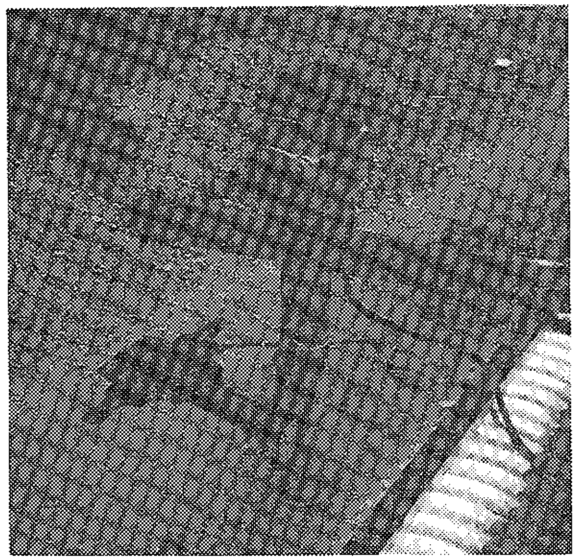


FIGURE 5. COMPACTION OF THE SOIL BACKFILL.

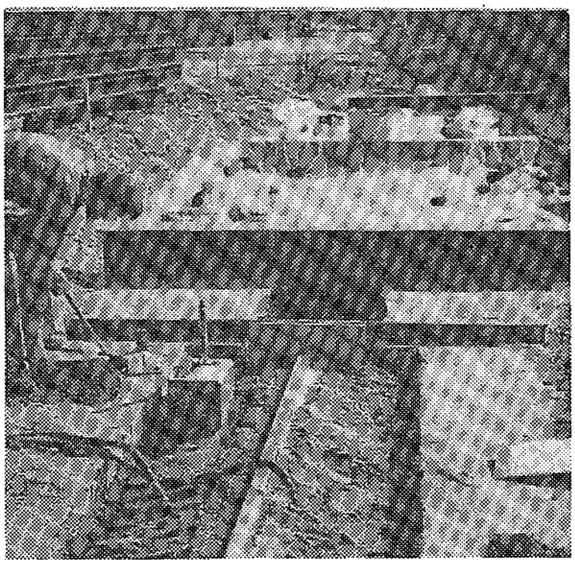


FIGURE 6. MEASURING THE RELATIVE COMPACTION OF THE SOIL BACKFILL WITH A NUCLEAR DENSITY-MOISTURE GAGE.

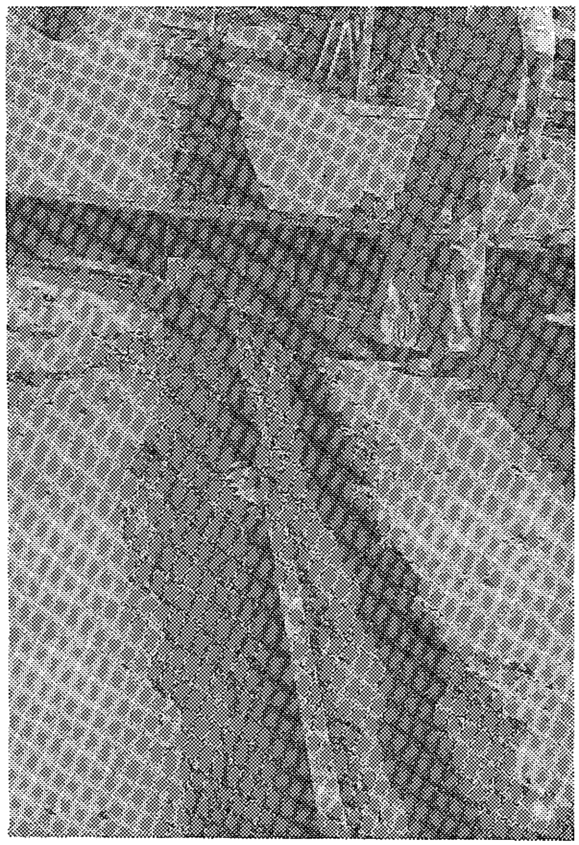


FIGURE 7. TYPICAL TRENCH FOR SLOTTED DRAIN BACKFILLED WITH SOIL CEMENT.

FIGURE 8a

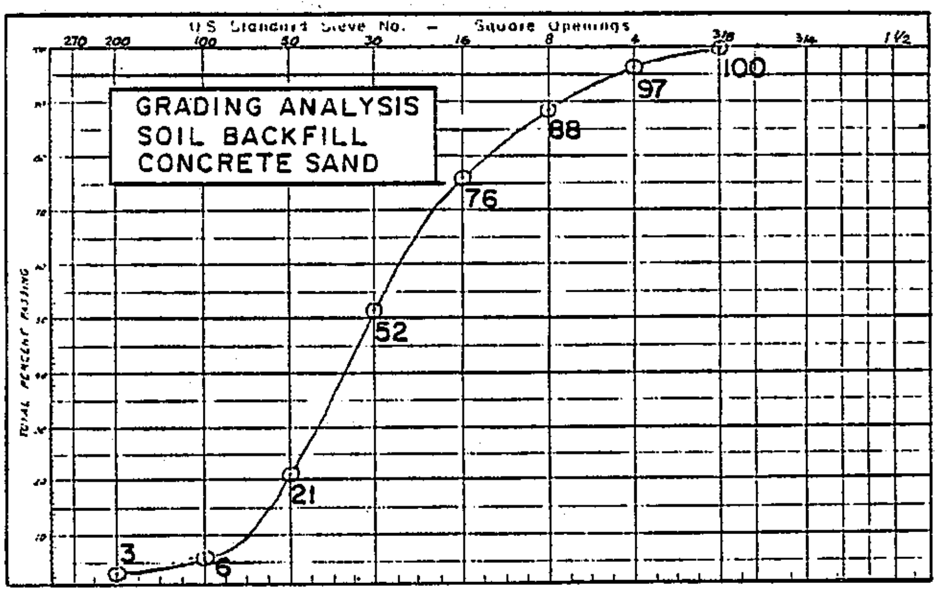


FIGURE 8b

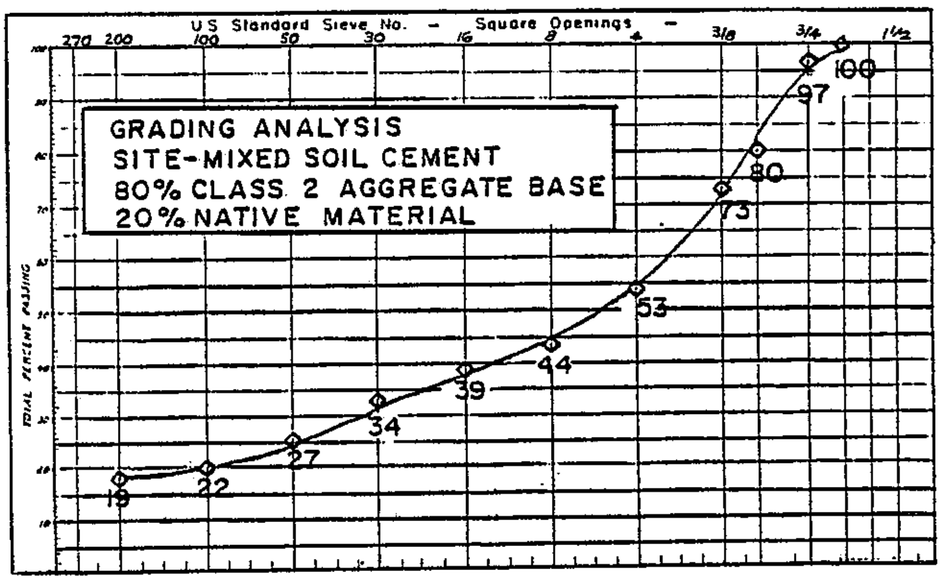


FIGURE 8c

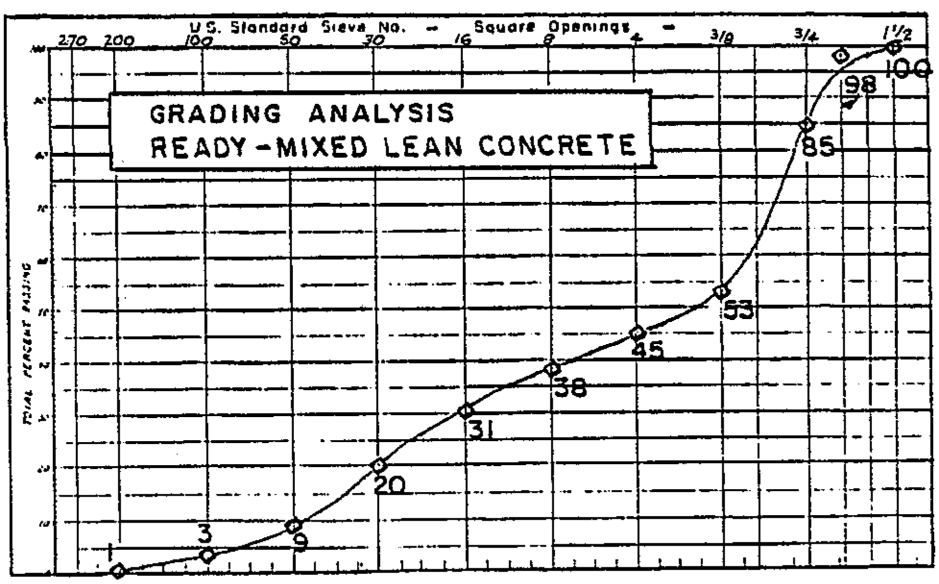


FIGURE 8. GRADING ANALYSES OF BACKFILL MATERIALS.

The first series of load tests (Test Series 3A) were performed on Slotted Drain No. 3, backfilled with a untreated soil (sand) material. This drain, instrumented with 25 rosette strain gages, was carefully removed after conducting load tests in Series 3A, and reinstalled in the same trench and backfilled carefully with site-mixed soil cement. This was done in order to determine the effect of a strong backfill on the stress distribution in the slotted drain.

The soil cement backfill, a blend of native silty clay soil, Class 2 aggregate base, and portland cement, was mixed in a 3-cubic-foot concrete mixer and then placed along the sides of the slotted drain and vibrated thoroughly. Each slotted pipe drain was adequately braced so it would not float out of place. The grading for the site-mixed soil is shown in Figure 8b, page 31 and Table 3. The mix design used for the soil cement backfill is shown in Table 5. This same soil cement design was used for the backfill material around Slotted Drain No. 5. The compressive strength of the site-mixed soil cement mix is displayed in Figure 9, page 36.

A lean concrete backfill (282 pounds of portland cement per cubic yard) was used for Slotted Pipe Drain No. 4. It was comprised of a readily available, well graded sand and coarse aggregate, and Type II Modified portland cement (see Tables 4 and 5). The lean concrete mix was brought to the site in a ready-mix truck, placed around the slotted drain, and then thoroughly vibrated. The purpose of the use of the lean concrete was to save time and labor in batching and mixing. Time and labor were indeed saved and also the lean concrete had a much higher

TABLE 3. AGGREGATE BLEND FOR SITE-MIXED SOIL CEMENT.

Sieve Size	Cl. 2 AB	Soil	Combined Grading	Limits
1 1/2"	-	-	-	
1"	100	-	-	100
3/4"	97	100	97	80-100
1/2"	81	99	80	60-100
3/8"	71	99	73	-
#4	51	98	54	50-100
#8	38	97	44	40-80
#16	30	96	39	
#30	23	95	34	
#50	15	91	27	
#100	10	83	22	10-40
#200	8	73	19	
Specific Gravity (S.S.D.)	2.70	2.65		
Blend:	80%	20%		

TABLE 4. AGGREGATE BLEND FOR READY-MIXED LEAN CONCRETE.

Sieve Size	1" x #4	Concrete Sand	Combined Grading	Limits
1 1/2"	100		100	100
1"	97		98	80-100
3/4"	72		85	60-100
1/2"	-		-	-
3/8"	14	100	53	50-100
#4	2	98	45	40-80
#8		85	38	
#16		69	31	
#30		45	20	
#50		20	9	
#100		6	3	
#200		3	1	
Specific Gravity (S.S.D.)	2.76	2.65		

TABLE 5. MIX DESIGNS FOR (A) THE SOIL CEMENT AND (B) LEAN CONCRETE BACKFILLS.

	(A) Ready-Mixed Lean Concrete	(B) Site-Mixed Soil Cement
• Volume of each batch	1 yd^3	3 ft^3
• Maximum size aggregates, inches	1	3/4
• Slump, inches	4-5	4-5
• Water-cement ratio - by weight	1.04	1.20
• Water-cement ratio - gallons/sack	11.67	12.90
• Water - pounds	292	36
• Water - gallons	35.0	4.3
• Cement - pounds	282	31
• Cement - sacks	3.0	1/3
• Fine aggregate - pounds	1524 (sand)	76 (silty clay)
• Coarse aggregate - pounds	1924 (gravel)	300 (Class 2 AB)
• Cement factor - sacks/$yard^3$	3.0	3.0
• Cement factor - pounds/$yard^3$	282	282

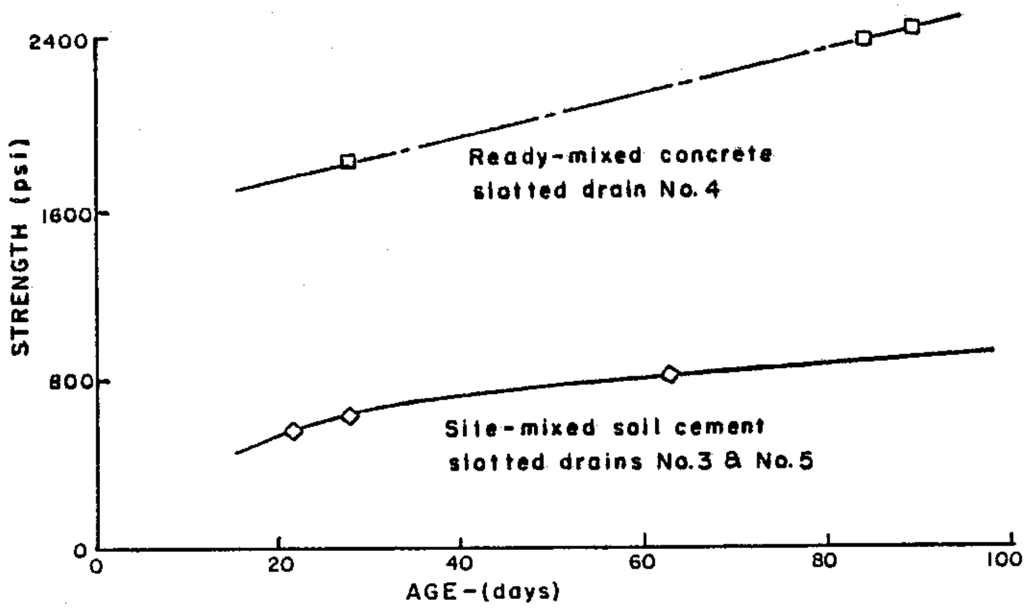


FIGURE 9. AGE VERSUS COMPRESSIVE STRENGTH FOR SOIL CEMENT AND LEAN CONCRETE USED AS BACKFILLS.

compressive strength than the soil cement backfill used. The 28-day compressive strength of the lean concrete as seen in Figure 9 was about 1800 pounds per square inch as compared to the 28-day compressive strength of the soil cement of 720 pounds per square inch. However, the readily available aggregate used to make the lean concrete, commonly used to make portland cement concrete, did not meet the gradation requirement for aggregate to be used for soil cement bedding as specified in Section 19-3.025C of the 1978 Standard Specifications(12). In order to meet current gradation requirements for soil cement backfill, a considerable amount of fine aggregate passing the No. 100 sieve would have to be added. This special blending would require considerable time, labor and expense.

4.4 Testing and Procedures

4.4.1 Laboratory Testing

4.4.1.1 Testing Equipment

Each of the 4-foot-long slotted drain specimens was tested in quasi-ring compression using a M.T.S. universal testing machine with a 1000 kip capacity. All specimens were loaded at a constant rate of 0.5 inch per minute. Before testing, a 500-pound preload was placed on each pipe to remove any initial movement prior to zeroing deflection instruments. All specimens were supported in a wooden cradle 20 inches high and 48 inches long, shown in Figure 10. The cradle was positioned on the lower platen of the testing machine.

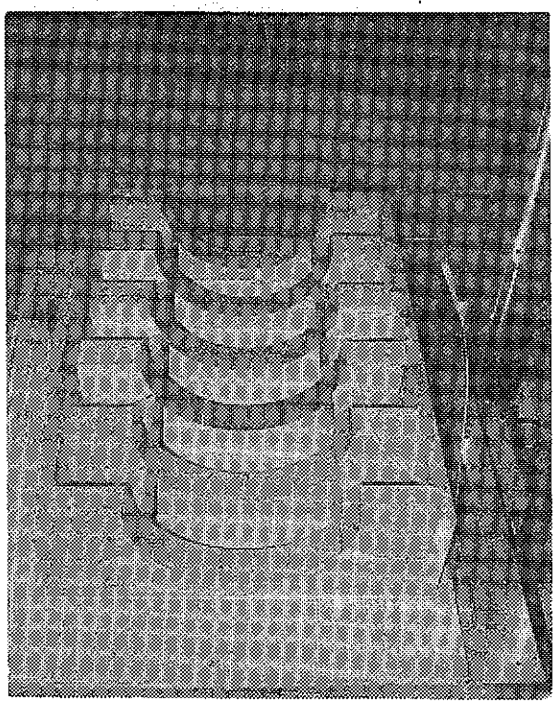


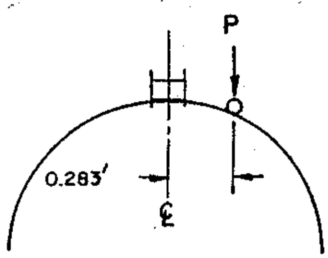
FIGURE 10. WOODEN CRADLE USED TO SUPPORT SHORT SLOTTED DRAIN TEST SPECIMENS.

4.4.1.2 Loading Methods Used in Laboratory Testing

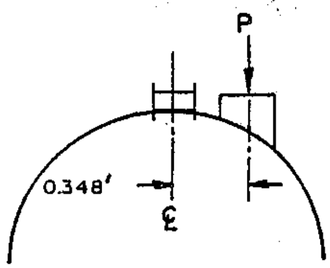
It was necessary to develop appropriate test equipment and load application methods for testing the short sections of slotted pipe drain in the laboratory using test procedures which would be relatively simple and easy to duplicate. These procedures were to approximate the same effects which a distributed wheel load of a heavy truck would impose on the slotted drain.

In the first stages of laboratory testing, a suitable method of applying an eccentric load to the slotted drains was sought. Initially, an eccentric load was applied through a 3/4-inch-diameter rod as shown in Loading Method (1), Figure 11a. This procedure was found to be unsuccessful, as the load was not distributed well and the resulting line load tended to cause buckling in the pipe wall directly under the loading bar. A side view of this unsuccessful Loading Method (1) is shown in Figure 12. Loading Method (2) also shown in Figure 11a, was found to work much better. By using a 4-inch-wide by 16-inch-long wooden block contoured to fit the corrugations of the slotted drain and cushioned over this contacting region with a thick sheet of neoprene rubber, the vertical load was applied evenly over a broader area. A photograph of this successful Loading Method (2) is shown in Figure 13. This method was used in the remaining tests to apply eccentric loads over the pipe corrugations adjacent to the grate structure of the slotted pipe drain, and also to apply loads to the lengths of the plain corrugated steel pipes (see similar Loading Methods (5) and (6) in Figure 11b).

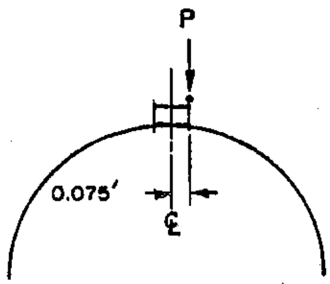
Two additional Loading Methods, (3) and (4), shown in Figure 11a, were simple to use. These were intended to represent a wheel load applied on top of and parallel to the grate section. Loading Method (4) approximated a wheel load centered over the grate bearing bars, and Loading Method (3), a slightly eccentric wheel load over one bearing bar only. A photograph of an end view of a slotted drain being tested using Loading Method (3) is shown in Figure 14.



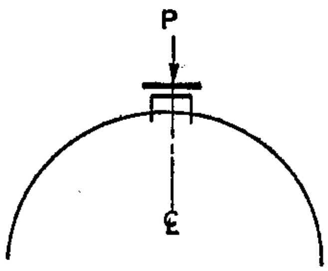
Loading Method (1)
Eccentric - Bearing on
a 3/4" Ø x 16" Rod Tack
Welded on the Pipe



Loading Method (2)
Eccentric - Bearing on
a 4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations

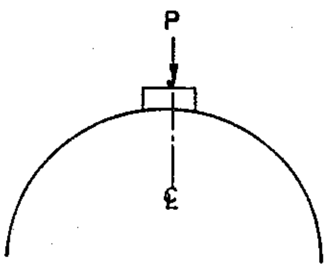


Loading Method (3)
Eccentric - Bearing on
One Side of Grate

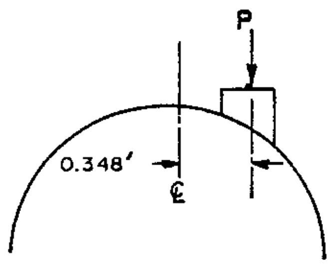


Loading Method (4)
Center - Bearing on a
Plate Set on the Grate

FIGURE 11a. LOADING METHODS USED IN THE LABORATORY ON SLOTTED DRAINS.



Loading Method (5)
Center - Bearing on a
4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations



Loading Method (6)
Eccentric - Bearing on
a 4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations

FIGURE 11b. LOADING METHODS USED IN THE LABORATORY ON PLAIN CORRUGATED STEEL PIPE.

FIGURE 11. LOADING METHODS USED IN LABORATORY TESTING.

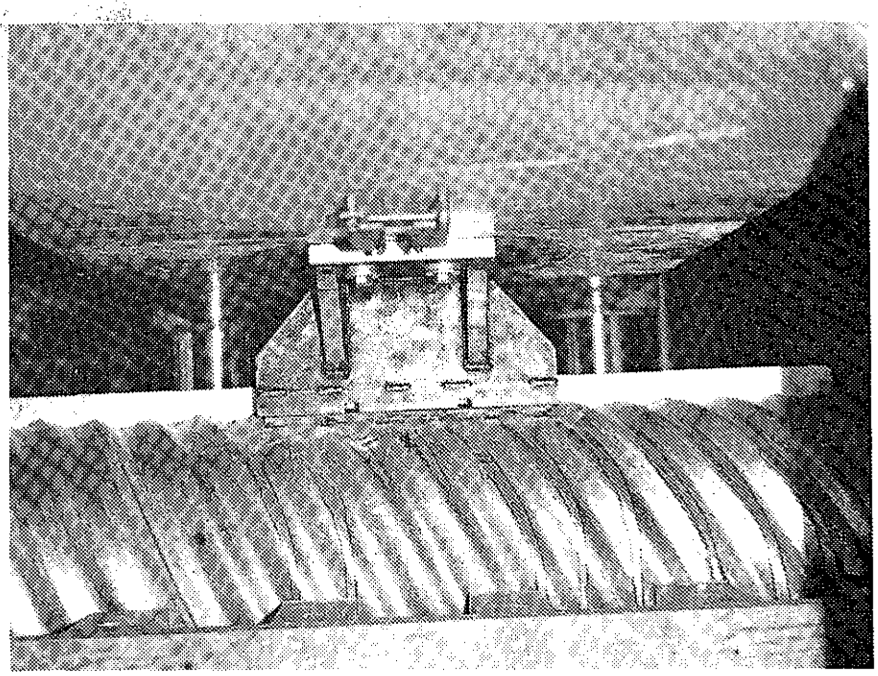


FIGURE 12. LOADING METHOD (1): ECCENTRIC LOADING APPLIED TO A ROD, TACK-WELDED TO CORRUGATED PIPE OF SLOTTED DRAIN.

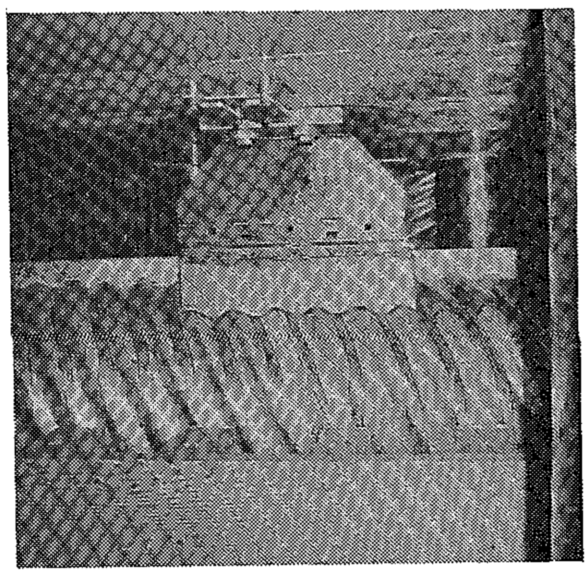


FIGURE 13. LOADING METHOD (2): ECCENTRIC LOADING APPLIED TO CORRUGATIONS OF SLOTTED DRAIN USING A CONTOURED BLOCK.

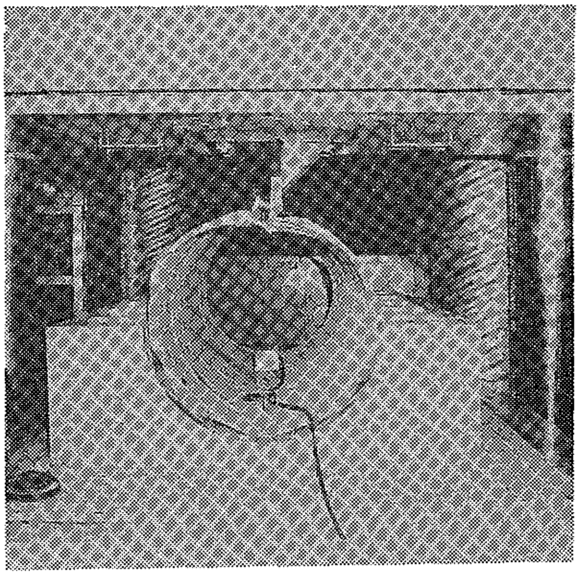


FIGURE 14. LOADING METHOD (3): ECCENTRIC LOADING APPLIED TO ONE BEARING BAR OF THE GRATE OF A SLOTTED DRAIN.

4.4.1.3 Measurements Made During Laboratory Testing

The measurements read and recorded were: maximum grate deflections, the testing machine platen deflection, applied loads, and grate angle changes.

The maximum grate deflection at the center of the bearing bar closest to the applied load was measured using a Houston Scientific Position Transducer shown in Figure 15. This instrument was a multi-turn rotary potentiometer, capable of measuring up to 13 inches of deflection with an accuracy of ±0.01 inch.

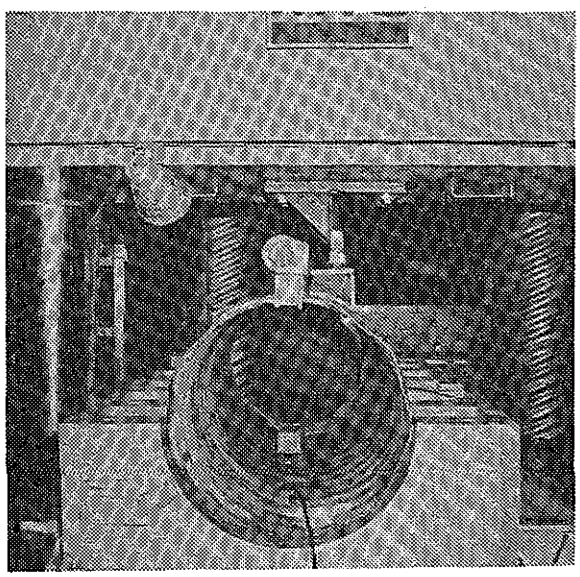


FIGURE 15. MEASUREMENT OF GRATE ANGLE CHANGE AND GRATE DEFLECTION.

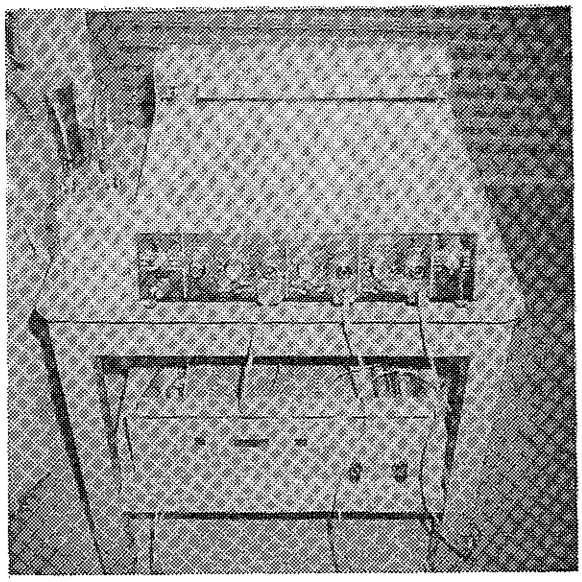


FIGURE 16. THE $X-Y_1-Y_2$ PLOTTER USED TO RECORD LOAD (P) VERSUS DEFLECTION (Δ), SHOWN WITH SUPPORTING ELECTRONIC EQUIPMENT.

The grate deflection (Y_1 axis) was recorded versus load (X axis) on a 10-inch x 15-inch chart. The testing machine platen deflection (Y_2 axis) was similarly recorded versus load (X axis) concurrently on the same chart. The recording instrument was a Hewlett-Packard dual stylus $X-Y_1-Y_2$ plotter shown in Figure 16. The grate angle change was read and recorded manually by observing a universal protractor plumb and level mounted on the grate, shown in Figure 15. These readings were recorded at the preload of 500 lbs and every 2000 lbs afterwards. The readings taken at or near 6000 lbs are tabulated in the data summary presented in Table 7, page 63, Section 5.1 of this report. The observations consisted of two angles, so noted in Figure 17.

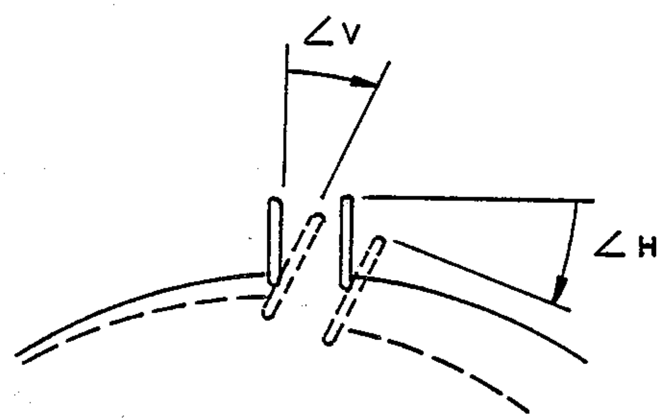


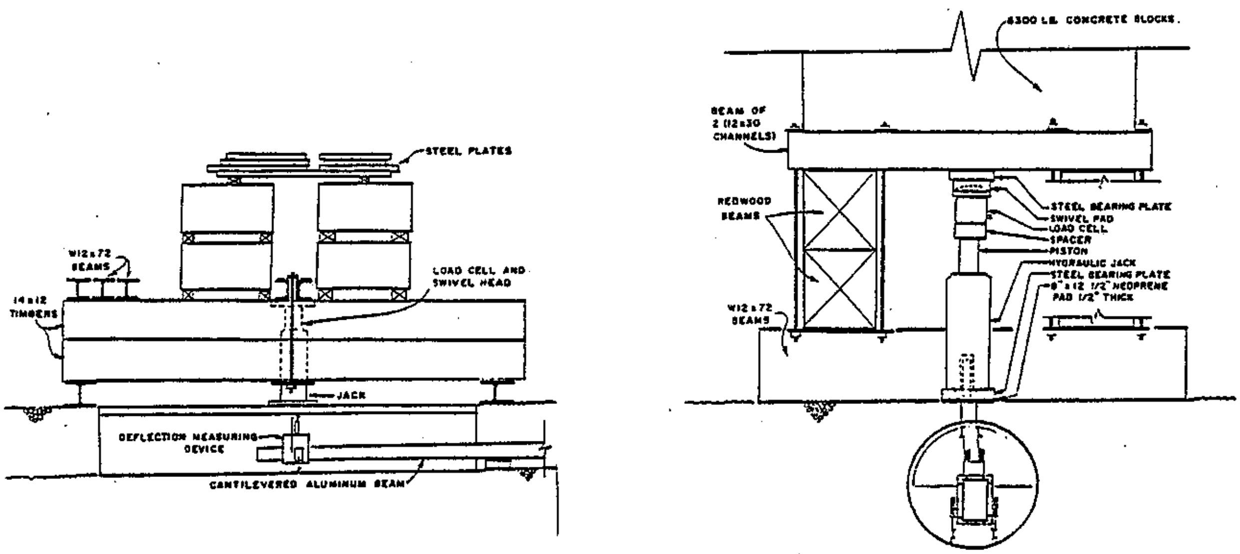
FIGURE 17. GRATE ANGLE CHANGES OBSERVED DURING THE LABORATORY TESTING OF SLOTTED DRAIN.

Other data recorded during laboratory testing included maximum load (P_{max}), grate descriptions, weld lengths, failure modes, and time and date of test. Photographs were taken of test fixtures, instruments, test specimens, and the loading methods used.

4.4.2 In-Situ Testing

4.4.2.1 General Equipment and Test Set-Up

Each of the field tests was conducted using the same general procedure and loading equipment with minor variations in the monitoring and recording instruments. The dead load testing frame which was used for all tests is shown in Figure 18. Four wooden timbers, 12 inches wide by 14 inches deep by 19 feet long, and having a total weight of 2300 pounds, were used to support dead load weights consisting of concrete blocks, steel "I" beams and steel plates. These timbers were stacked in pairs and were simply supported by two 10-foot-long W12x72 steel beams, one under each end of the two pairs of stacked timbers. The long wooden beams were used as a bridge so that the forces transmitted to the ground at their supported ends would not affect the stresses or deflections of the loaded slotted drain.



(a) SIDE VIEW (b) END VIEW

FIGURE 18. POSITION OF TEST EQUIPMENT.

Four 6300-pound concrete blocks were placed on the wooden beams and were centered about the section of the slotted drain to be loaded. Steel plates having a total weight of 11,400 pounds were placed on top of the concrete block to provide additional dead load. Three 10-foot-long

W12x72 steel beams, all weighing approximately 2300 pounds, were placed on one end of the wooden beams to provide additional dead load and to stabilize the system. The total available dead load including the weights of the three steel beams, four wooden beams, four concrete blocks, and steel plates was 41,100 pounds, against which a jacking force could be applied. The wooden beams were bolted together using a steel beam made up of two C12x30 channel sections, four long steel rods, and two steel end plates (see Figure 18b). A 120-kip capacity hydraulic jack, placed under the center of the composite steel channel beam, was used to apply the static load to the slotted drain. This system provided a means by which a controlled incremental load could be applied to the various slotted drains.

For applying the load to the slotted drains in situ, an 8-inch-wide by 12 1/2-inch-long neoprene pad 1/2-inch thick was placed directly on top of the asphalt surface and over the grate of the slotted drain in the various positions shown in Figure 19.

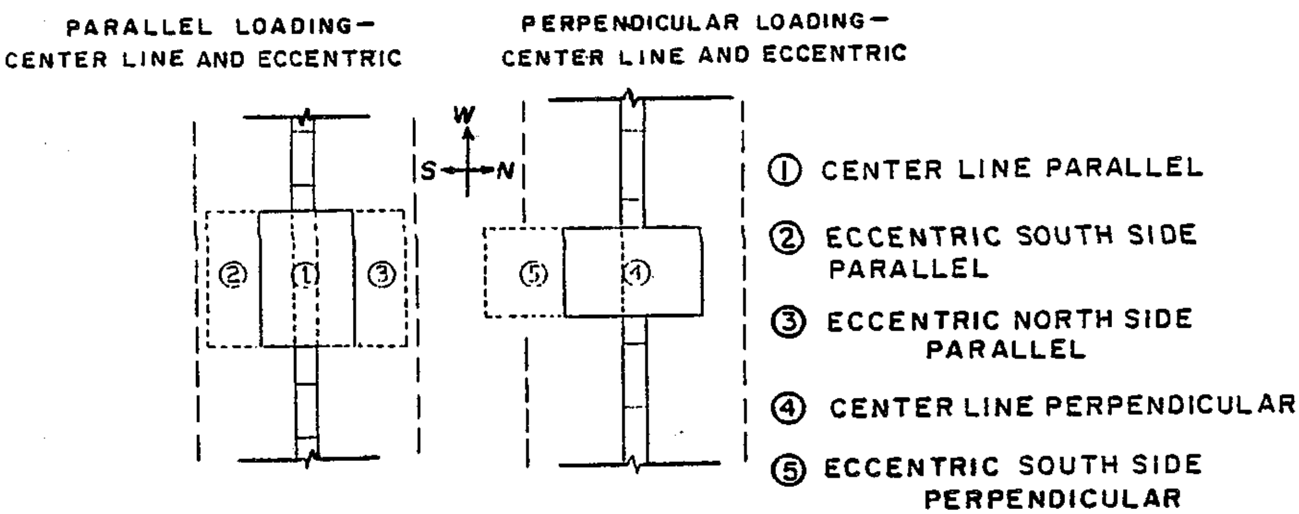


FIGURE 19. LOADING POSITIONS USED FOR IN-SITU TESTING.

A 1 1/2-inch-thick steel plate, having the same rectangular dimensions as the pad, was placed directly on top of the pad and distributed the applied jack load evenly over the surface of the neoprene. The 100-square-inch surface area of the pad represents the same approximate contact surface area as a commonly used pneumatic "flotation" truck tire. Loading positions ① and ② were used in Test Series 3A. In Test Series 3B, each of the five loading positions was employed. Only loading positions ① and ② however, were used in the load tests performed on the other four slotted drains.

In both the loading positions ① and ④, designated respectively as "centerline parallel" and "centerline perpendicular", the pad was simply centered on the grate either parallel or perpendicular to the grate bearing bars. For the other various loading positions designated either as "eccentric parallel", ② or ③, or "eccentric perpendicular", ⑤, the pad was placed with one of its edges overhanging a bearing bar of the grate by 1/4 inch, as shown in Figure 19.

The bottom of the hollow hydraulic jack was positioned over a solid steel pin which protruded up from the center of the steel bearing plate. A number of items were positioned on top of the jack ram. These included a hollow spacer cylinder, a load cell having a 200-kip capacity, a swivel seat, and a 2-inch-thick steel plate which bore against the channel beams when the jack was extended.

The load cell was calibrated for a range of 0 to 50 kips in a 60-kip-capacity universal testing machine. Calibration was verified just before each test with a resistance shunt calibration box.

The hydraulic system used to move the jack ram is shown in Figures 20, 21, and 22.

Both the fluid flow and pressure to the jack were controlled by a variable transformer which regulated the speed of the hydraulic pump. With this system, any magnitude of load could be applied to the slotted drain and held constant, while deflections and strain measurements were recorded.

4.4.2.2 Instrumentation-Deflections

A device was built to measure vertical deflections using linear displacement transducers (LDT's). LDT's are devices in which strain gages mounted on a coiled spring are used to determine the linear displacement of a small diameter steel shaft by changes in resistance. The deflection-measuring device, shown in Figure 23 was cantilevered on a 2-inch-wide by 5-inch-deep hollow rectangular aluminum beam. Vertical deflections, two at the grate bearing bars and two near the invert of the drain, were measured to the nearest ± 0.001 inch.

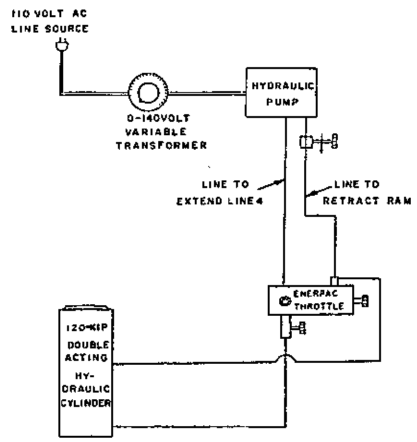


FIGURE 20. SCHEMATIC DIAGRAM OF HYDRAULIC SYSTEM.

Note: Digital load indicator was used to monitor load in testing of strain gage-instrumented drain.

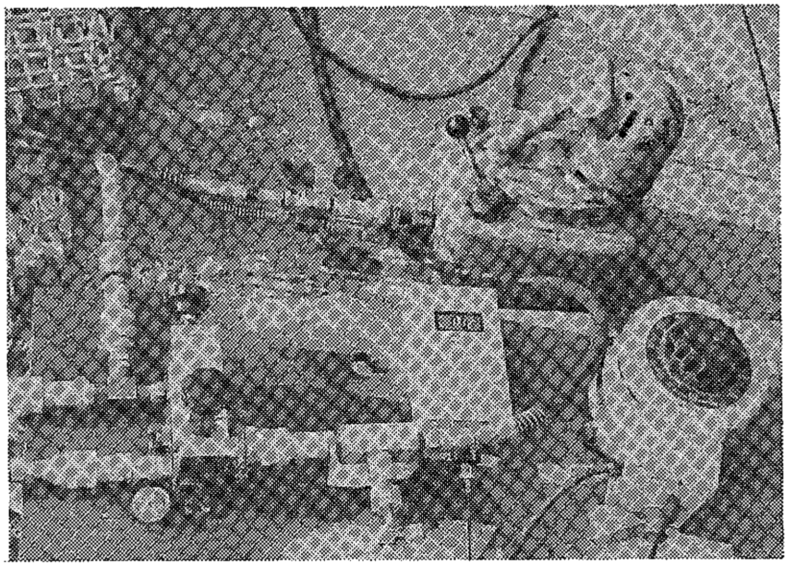
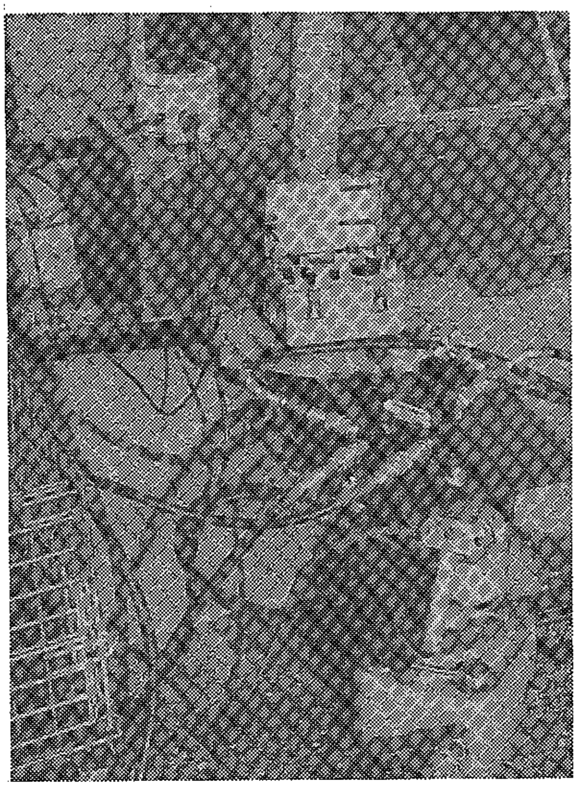


FIGURE 21. HYDRAULIC SYSTEM USED TO LOAD THE STRAIN GAGE-INSTRUMENTED SLOTTED DRAIN.



Note: Strainsert box used to monitor load in remaining tests.

FIGURE 22. HYDRAULIC SYSTEM USED TO LOAD SLOTTED DRAINS 1, 2, 4 AND 5, IN WHICH ONLY VERTICAL DEFLECTIONS AND LOADS WERE MEASURED.

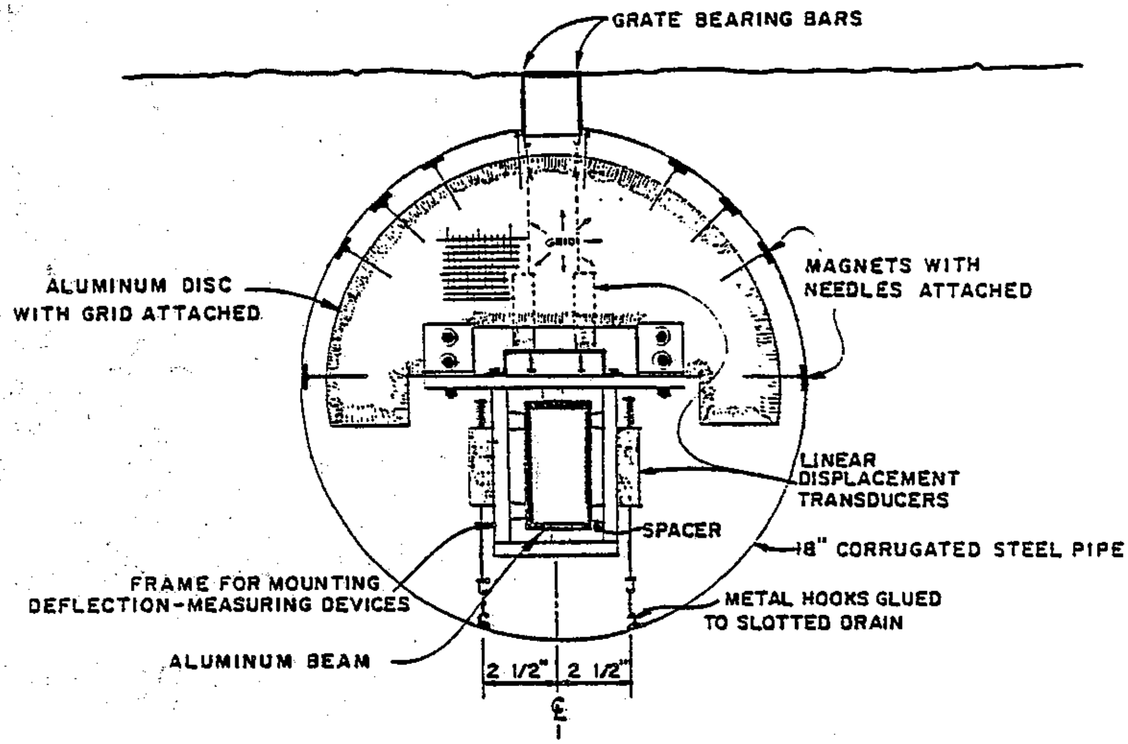


FIGURE 23. DEVICES FOR MONITORING DEFLECTIONS OF SLOTTED DRAINS, MOUNTED INSIDE OF DRAIN PIPE.

The deflection device shown in Figure 23 and used in all in-situ tests was mounted on the end of a 5-inch-deep, 2-inch-wide aluminum box beam which was cantilevered approximately five feet into the slotted drain pipe and supported just outside the slotted drain. When the device was in place, four small metal hooks were glued with epoxy, one each onto the bottom of both grate bearing bars and one onto each side of the drain invert where deflections were measured. Small diameter cables were then installed between each hook and its respective LDT. Care was taken that each of the four LDT's had sufficient travel in both directions to measure the expected vertical deflections. The locations of the points on the interior of the pipe at which the deflections were measured were the same for all tests.

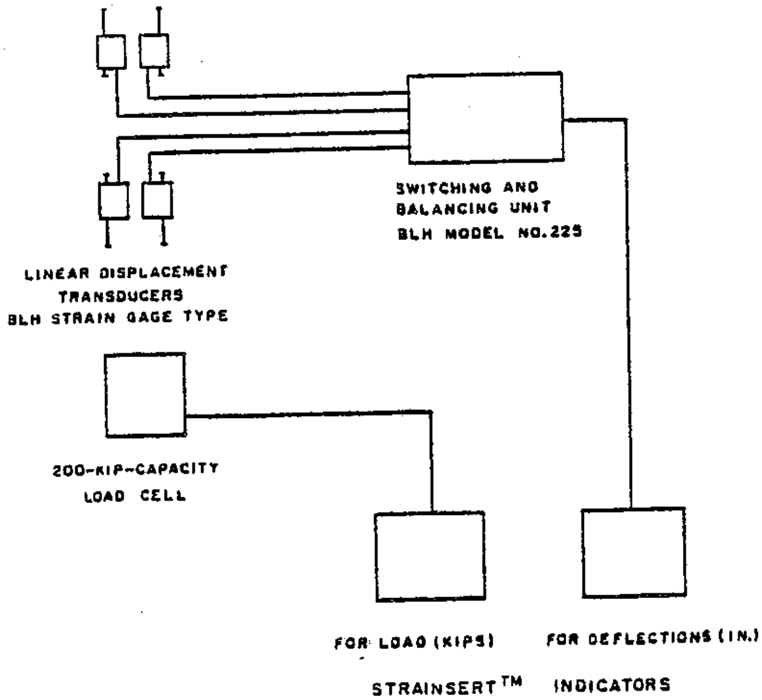


FIGURE 24. SCHEMATIC DIAGRAM FOR INSTRUMENTATION DEVICES USED FOR MONITORING VERTICAL DEFLECTIONS IN TESTS CONDUCTED ON SLOTTED DRAINS 1, 2, 4 AND 5..

The deflections at the grate and invert of the strain-gage-instrumented pipe and the pipe strains were recorded on punched tape using a binary number system, and also were printed on an additional tape (see schematic in Figure 24). The printed tape was used to quickly monitor the data during tests. A less sophisticated system using two Strainsert™ indicators and a resistance shunt calibration box was used to determine vertical deflections at the same locations in the remaining four slotted drains (see Figures 25 and 26, page 53). The LDT's were initially calibrated within a 0.2-inch range by using micrometer calibration board, and their accuracy was also quickly verified just before each test.