Measuring the Health of California Streams and Rivers

A Methods Manual for: Water Resource Professionals, Citizen Monitors, and Natural Resources Students

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Jim Harrington and Monique Born

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About the Authors
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Chapter 1
Introduction to the Manual

Background

Many of us enjoy flowing water for its intrinsic beauty and the serenity it brings. However, throughout history, streams and rivers have been primarily used by people to harvest food, ship products, produce energy, irrigate deserts and dispose of wastes. Additionally, much of the adjacent riparian areas have been destroyed to make more room for human habitat, as well as, their crops and livestock.

Few of us, of course, would argue against the need for water. On the other hand, past and present land use activities and water manipulations are spelling disaster not only for the health of aquatic systems, but ultimately for our own survival. Water quality issues are complex and there are no easy solutions. However, the problems and solutions begin and end with us since we each share some degree of responsibility through our consumptive habits or our lack of concern for the environment. This also means that each one of us has the power to make a difference by becoming involved with helping to improve the health of our streams and rivers.

Each one of us has the power to make a difference, by becoming involved to help our streams and rivers.

Are all of the nation's streams and rivers in poor health? Depending on the parameters studied, the conclusions can be that the health of our streams and rivers is getting both better and worse. From a purely chemical standpoint, many of the nation's streams and rivers are in better condition now than they were thirty or forty years ago. The creation of the National Clean Water Act (CWA) in 1972, initiated major clean up efforts of the most polluted water bodies. The newly implemented water quality regulations focused mostly on the elimination of raw sewage and toxic chemicals spewing from the ends of pipes otherwise known as **point-sources of pollution**. Industries and municipalities responsible for polluting the water were identified and then called upon to "clean up their act", by spending considerable money, both public and private, to solve the problems. Because of those efforts most of our major streams and rivers are now safer for human use, but in many instances, our careless and excessive utilization of these precious resources are still depriving aquatic systems of something very fundamental: LIFE.

Most of our major streams and rivers are now safer for human use, but in many instances, our careless and excessive utilization of these precious resources has deprived aquatic systems of something very fundamental: LIFE.

While chemical pollution was being tackled, an evolution in our understanding of aquatic systems and the effects of non-toxic pollutants was taking place. A new awareness surfaced and spread from the ranks of aquatic ecologists in the late 1980's, as we began to talk about the effects of physical manipulation on aquatic systems and how important habitat condition was to the health of streams and rivers - - water quality could not be separated from habitat integrity.

Although far from a new concept, it was mostly bounced around in the discussions held by academic types, and certainly was not a common topic in government water quality agencies. To fully address the primary objective of the CWA to "restore and maintain the chemical, physical and biological integrity of the nation's waters", meant that the U.S. Environmental Protection Agency (U.S. EPA) had to recognize sediment, nutrients and aquatic habitat destruction as the nation's most significant water pollution issues.

By the early 1990's, the attention of most water quality regulators started to drift away from point-source pollution, and move

towards that which does not necessarily flow from pipes - otherwise known as **non-point source pollution**. Non-point source pollutants are by and large the result of the cumulative effects of widespread, poor land-use practices and are more than likely fine sediment, nutrients and household contaminants.

Non-point source pollution is, and will continue to remain, one of the most challenging issues for water quality regulators.

The problems caused by this type of pollution are harder to solve because they, and the responsible parties, are harder to detect and track down. Non-point source pollution is, and will continue to remain, one of the most challenging issues for water quality regulators.

What is Bioassessment

Although water quality monitoring has long been a part of water resources management, its emphasis has been on assessing point-source, chemical pollutants. In the late 80's and early 90's, the U.S. EPA spent much time and effort to develop and promote standardized procedures called the "Rapid Bioassessment Protocols" (RBPs) for monitoring the physical/habitat and biological condition of streams and rivers. It has been more than 10 years since the original RBPs were introduced, and they have since proven to be a viable water quality monitoring tool.

Biological assessments (**Bioassessment**) is the use of biological community information along with the measure of the physical/habitat quality to determine, in our case, the integrity of a water body of interest. The U.S. EPA defines **biological integrity** as " the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitats of a region".

Most states have developed specific procedures based on these U.S. EPA guidelines in order to incorporate biological and physical standards or "criteria" into their water quality regulations. The U.S. EPA has even produced a volunteer or citizen-level protocol equivalent to the RBPs to help state regulators enlist the help of citizens to detect and monitor water quality problems.

The procedures presented in this manual can be used to assess the physical and biological conditions or integrity of wadeable streams. The approach follows the most recent revision of the California Stream Bioassessment Procedures (CSBP), first developed by the California Department of Fish and Game (DFG) in 1993 to conduct professional level assessments. DFG developed the CSBP for Citizen Monitors in 1996 as part of a U.S. EPA grant to organize citizen monitors in the Russian River watershed.

Since their initial development, both the professional and citizen level monitoring procedures have been refined, expanded and reviewed annually with the help of the California Aquatic Bioassessment Workgroup (CABW). Members of the CABW come from universities, consulting firms and industry, state and federal agencies and watershed groups. The members meet each fall in Sacramento as part of a bioassessment conference open to all interested people.

Why This Manual Was Written

Stream and watershed restoration projects have been touted as the solution for bringing back stream health and increasing fish populations. Millions of dollars are being spent each year for restoration projects. Yet, rarely is long-term monitoring a requirement for project funding - - perhaps it is easier not to know. Restoration projects may not have been as effective as we would like and planting hatchery fish is not always the solution to improving fisheries.

This is not to suggest that current restoration efforts are worthless. However, we must learn what works and what does not. We must learn which of our efforts are the most successful and why. We must prioritize our projects so that we can get the most results for the money. Without comprehensive assessment and monitoring programs in place, we will be unable to evaluate success, and we may be literally throwing money down the drain.

For the longest time, the term monitoring has had a bad connotation. Perceived merely as "research", it has been deemed unworthy of funding with public money. What the "public" wanted was visible projects, tangible goods, not a bunch of numbers and more reports that no one ever read. Yet, what $ense (misspelling intended) does it make not to monitor projects funded with public money?

Now the word is out - assessing the chemical, physical and biological condition of our nation's streams and rivers is imperative if we are going to restore and maintain their health.

Assessing the chemical, physical and biological condition of our nation's streams and rivers is imperative if we are going to restore and maintain their health.

Three premises drive this manual:

- The first is that the assessment of the physical/habitat and biological conditions of streams and rivers is the first step toward improving water quality and stream ecosystems.
- The second is that the techniques used to measure the physical/habitat and biological conditions of streams and rivers must be standardized to ensure that a state-wide effort will produce comparable information.
- The third is that concerned citizens are an essential component of water quality monitoring and an even more important component of solving water quality problems nation-wide.

Many of us in the field of aquatic science get frustrated at the slow progress made toward water quality improvement in California. The sad reality is that there are not enough government biologists to properly assess and monitor the health of all of our streams and rivers. Another reality is that the government's concern for the health of our streams and rivers will wax and wane with changes in administrations. By participating in water quality management, educated citizens can be the leveling and constant force behind the protection and improvement of our aquatic systems.

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The intent of this manual and the accompanying training workshops is to familiarize you with the problems facing our streams and rivers and to teach you how to document their physical/habitat and biological conditions. The manual outlines basic watershed and stream ecology principles, water quality regulation, and standardized bioassessment techniques. The information in this manual will guide you through the steps necessary to get our streams and rivers on a healthier course. Simply stated, the purpose of this manual is to:

Empower you with the knowledge necessary to collect real data that will quantify the biological and physical health of western streams and rivers; and encourage citizens to work with water resource agencies to restore and maintain the chemical, physical and biological integrity of western streams and rivers.

For Whom is This Manual Written For

The information in this manual will be useful to all water resource professionals, natural resources students, educators and environmentalists. The procedures described in the manual can be used by citizen monitors and by agency personnel and environmental consultants interested in using bioassessment to evaluate river and stream health.

Although environmentally aware and concerned citizens will benefit from reading this manual on their own, it is primarily intended to supplement and assist the training of those attending the Sustainable Land Stewardship Institute's (SLSI) Bioassessment Workshops for Citizen Monitors. Professionals might notice that the manual is slanted towards citizens. This is intentional since we have found that most natural resource professionals attending the training course are not familiar with new bioassessment techniques, and are quite often at the same level of knowledge as a typical citizen interested in the same subject.

The manual contains the most up-to-date taxonomic keys available to identify aquatic macroinvertebrates common to western streams and rivers.

Finally, It is important to remember that although the procedures were developed by the State with input from various water resource professionals, **the manual is not a government publication**. There are blunt statements about the inadequacy of water quality monitoring in California that do not necessary reflect all professional opinion. Hopefully, no one will take offense to the intent of this manual.

What the Manual Does and Does Not Cover

This manual contains all the necessary background on why and how to use the California Stream Bioassessment Procedures. The techniques are meant to be used in wadeable streams and not in deep water rivers, lakes, estuaries or the ocean. As previously mentioned, the manual is intended to supplement the SLSI training, so its use as a stand alone document might be limited. On the other hand, SLSI's trainees and other trained citizen monitoring program members should find this manual to be a very useful reference.

The manual contains the most up-to-date taxonomic keys available to identify aquatic macroinvertebrates common to western streams and rivers. **Since the taxonomy of aquatic macroinvertebrates changes frequently, the taxonomic keys in this manual are not meant to be copied and distributed separately from the manual and participants should make sure they are using the most recent set of keys.**

Using what is described in this manual as the Level 2 Taxonomic Effort monitoring groups will guarantee that they are able to communicate with each other, exchange data seamlessly, and ultimately share a state-wide database. Monitoring groups just getting started should use these procedures. Groups already using a different methodology should decide when and how to convert to these State standardized procedures.

The material covered in this manual can, and should, supplement the chemical monitoring activities currently conducted by some citizen monitoring groups. Although the importance of chemical monitoring is covered in sections of this manual, specific chemical monitoring techniques are not.

Citizen groups interested in watershed restoration will benefit greatly from incorporating bioassessment techniques into their restoration and monitoring activities. As part of a comprehensive assessment and monitoring effort, physical/habitat and biological assessment will help citizen groups to identify and prioritize potential rehabilitation sites within their watershed and

to monitor the success of their efforts. The inclusion of a monitoring component in watershed restoration projects will allow us to learn from all the work and money that has been invested in fisheries/stream restoration. These techniques, however, are not a substitute for quantitative fish habitat surveys and fish population estimates.

Chapter Summaries

Chapter 2

- Discusses the importance of citizens' involvement and offers recommendations for a person wishing to become involved as a volunteer citizen monitor.

Chapter 3

- Describes the natural state of streams and rivers.
- Discusses watershed hydrology and the various physical structures forming river systems.
- Introduces stream chemistry, both inorganic and organic components and how they contribute to the aquatic food web.
- Presents the River Continuum Concept, as a holistic view of interpreting benthic macroinvertebrates' (BMIs) function in the aquatic system.
- Introduces and briefly describes the world of BMIs.

Chapter 4

- Focuses on the new definition, types and sources of water pollution and how to detect problems stemming from it.

Chapter 5

- Offers an overview of the water quality regulations governing our nation and our state.
- Discusses Total Maximum Daily Loads.
- Introduces the concept of biocriteria.

Chapter 6

- Explores the concept and purpose of monitoring groups and which California government agencies can provide assistance.
- Lists some of the ways these agencies help citizen groups and two other entities within the state that may help monitoring groups work more effectively.
- Introduces the intent and major elements of the California Stream Bioassessment Procedure (CSBP) for Citizen Monitors and why monitoring groups would want to use the CSBP.

Chapter 7

- Presents the concept of watershed assessment and the components of a formal approach that citizen groups can implement.
- Discusses assessment of ambient water quality chemistry for rivers and streams and lists the parameters which are required of the CSBP and those which are optional.
- Details the level of physical/habitat and biological assessment.
- Explains how physical/habitat assessments for water quality differs form habitat surveys used for fisheries investigation.
- Outlines the characteristics of a good biotic indicator, along with reasons why the CSBP utilizes benthic macroinvertebrates for assessing the health of California water bodies instead of fish or algae.

Chapter 8

- Discusses the differences between point-source and non-point-source sampling design.
- Outlines the complete procedures to conduct a physical/habitat and biological assessment.

Chapter 9

- Discusses the three levels of benthic macroinvertebrate identification.
- Describes the two levels of taxonomic efforts recommended for citizen monitors.
- Explains how to maintain field and voucher samples and reference collections.
- Describes the steps to start a successful citizen laboratory and to develop standard operating procedures.

Chapter 10

- Explains how to process the data produced from the laboratory identification of the benthic macroinvertebrate samples
- Lists the biological metrics that can be produced from the Level 1 and 2 Taxonomic Level, along with how to calculate them.
- Covers basic statistics and how they apply to bioassessment.
- Discusses rules for examining the data for outliers and significance.
- Introduces advanced concepts such as integrating the data into a single score called an Index of Biological Integrity, comparing the biological data with physical/habitat data and electronic storing of the data.

Chapter 11

- Discusses Quality Assurance, or the process of guaranteeing that you are collecting credible data on the biological and physical condition of streams and rivers.
- Discusses the field and laboratory work, data analysis and report writing procedures to assure quality or Quality Control.

Chapters 12

- Presents background and introduction to taxonomy and the use of the dichotomous keys.
- Gives some helpful hints on invertebrate identification
- Lists professional taxonomic references and flyfishing entomology books of interest.

Chapter 13

- Presents taxonomic keys to the major groups of aquatic macroinvertebrates and descriptions of the non-insects

Chapter 14

- Presents the taxonomic keys and describes Mayfly families.

Chapter 15

- Presents the taxonomic keys and describes Stonefly families

Chapter 16

- Presents the taxonomic keys and describes Caddisfly families

Chapter 17

- Presents the taxonomic keys and describes Aquatic Fly families

Chapter 18

- Presents the taxonomic keys and describes the remaining insect orders and families.

Chapter 2
Introduction to Citizen Monitoring

Introduction to the Chapter

Although our nation has some of the strictest water quality regulations in the world, our aquatic resources are faring poorly. Chapter 2 discusses the importance of citizens' involvement in water quality monitoring along with a brief history of the movement on a national and regional scale. The chapter ends with a list of recommendations for citizen monitoring from an interagency task force on water quality monitoring and our list of recommendations for getting involved in local monitoring efforts.

Why Citizens Must Be Involved with Water Quality Regulation

The Clean Water Act (CWA) contains all the language necessary to improve our nation's water quality. However, as with most laws, it also contains the ambiguous language that can hinder progress toward environmental quality when the steps required are deemed too costly or likely to interfere with economic "progress".

If regulating water quality was left up to politicians, the people working for them, and the private powers influencing elected officials, there likely would be slow or no real progress toward clean water. Working toward developing and maintaining clean water presents complex scientific and social problems, and their associated costs. It is often much safer (in the context of maintaining one's political career) to do nothing and maintain the status quo.

Nowhere in the United States are water issues more complicated and more political than in California.

Nowhere in the United States are water issues more complicated and more political than in California. The first layer of complications stems from the fact that California is an arid state and rainfall is limited. Yet, California is the most populated state in the U.S., with an especially concentrated population in the southern, driest part of the State.

Environmentally speaking, southern California cannot support the water needs of its population. This results in complex water bidding processes, meant to provide southern California with water derived from watersheds in northern California and the Colorado River. In addition to water resource limitations, the fate of California's water is heavily influenced by political processes. Solving the "water wars" and delving into political processes are way beyond the scope of this manual. However, it does present an added challenge to Californians concerned with the ecological integrity of their waterways. It is important to be aware of political realities when dealing with water quality issues.

Another complication hindering progress toward clean water is the layer of bureaucracy burdening California's water quality agency. In some states, especially those smaller than California, a state agency, usually called the Department of Environmental Quality (DEQ), regulates and enforces water quality laws. These DEQs have chief administrative positions which answer to the governor and to the political agenda of the party in place, but most of the agency positions are staff scientists, engineers and field technicians.

In California, the water quality agency is the State Water Resources Control Board (SWRCB) and its nine Regional Water Quality Control Boards (RWQCB). The bottom level workers are similar to those states with a single environmental quality agency, as is the upper management answering to the current political administration. However, California has another political layer: the board members who are appointed by the Governor. Each decision must be approved by this board of appointed citizens who answer to the current administration. Although this system adds a level of accountability, it also

guarantees that most decisions concerning water quality are politically motivated.

The political nature of water quality regulation is probably not news to most informed citizens. Politics are just a fact of life in our society. The important thing to remember is that the political climate oscillates with changing administrations. Water quality regulation could be moving in one direction during the current administration and then take a totally different direction during the next. Educated citizens concerned about environmental quality must be the leveling power that keeps California rivers and lakes moving toward a state of improved health.

To see one's stream or river deteriorating can be frustrating, aggravating and lead to emotional outbursts. Citizens must realize that a no-nonsense platform, presented in a firm and unbiased manner is best. Ultimately, emotional opinions about the need for healthy rivers and lakes must be replaced with convincing facts and figures. The goal of this manual and training course is to educate you on water quality management and provide you with the tools necessary to effectively collect and present relevant data on the state of water quality in California.

Emotional opinions about the need for healthy rivers and lakes must be replaced with convincing facts and figures.

The U.S. Environmental Protection Agency's Role in Citizen Involvement in the Clean Water Act

Some sections of the CWA require water resource decisions to incorporate public input. Section 101 states that the public be included *"in the development, revision and enforcement of any regulation, standard, effluent limitation, plan, or program established by the administrator or any state under this Act."* Section 303, in discussing the development of water quality standards, requires the involvement of citizens in public hearings on proposed changes. Citizens should follow 12 steps when becoming involved with the water quality regulation of their area's rivers or streams. These steps are listed on page 5-8.

Since 1990, the U.S. EPA has required staff to produce documents on citizen involvement in water quality management and directions for state managers about volunteer involvement with water quality regulation. The U.S. EPA also funds development of citizen monitoring guidelines and a periodical for citizens called the Volunteer Monitor (see end of chapter for contact information.) Section 319(h) of the CWA provides funding for non-point source pollution management. The U.S. EPA allocates to each state a portion of the grant money available through that program, which allows the state to develop programs to involve citizens in water quality management.

A National Perspective on Citizen Monitoring

The tradition of citizens joining together to protect water quality started centuries ago in England where "Riverkeepers" were hired by anglers to guard the welfare of their favorite fishing streams. In the United States, the National Weather Service (NWS) was the first government agency to use citizen monitors. Starting at the end of the 19th century, the NWS had volunteers record temperature and rainfall data. This effort continues today with data from 97% of their weather stations being collected by citizens.

The first effort to survey water quality problems and pollution in the United States on a volunteer basis was organized by the Izaak Walton League of America in 1926. League members gathered information on water chemistry and pollution from various streams and reported the information to the government and the responsible businesses.

Maryland's Save Our Streams (SOS) program was probably the first well organized effort to monitor streams throughout an entire state. Beginning in 1969, the goal of the program was to teach volunteers to monitor streams in their own communities and to have all watersheds adopted by a citizen group. Although the Izaak Walton League developed and promoted the SOS program, its biggest boost occurred when the Maryland State Department of Natural Resources adopted the

program. Initially, SOS members collected only chemical data on their streams, but by 1976, they were using a simplified bioassessment technique to support the chemical data.

In 1985, several of the SOS program members wished to take on more of an advocacy role and decided to go their separate way from Maryland's Department of Natural Resources and return to their Izaak Walton League roots. At that point, SOS went national and incorporated a motor home equipped with water quality equipment as part of the program. At first, the program kept its methods simple and emphasized public awareness on river conservation issues. Eventually, the program developed more sophisticated bioassessment methods based on Ohio's Stream Quality Monitoring program and the U.S. EPA Rapid Bioassessment Protocols's Level II procedures, which require family level taxonomy. By 1990, the SOS program had a Quality Assurance/Quality Control Plan which was accepted by the U.S. EPA and helped to guarantee that their members were collecting sound scientific data.

All citizen-based water quality monitoring programs recognize that the solutions to river degradation, like the problems, are primarily local and that grass-roots efforts are essential.

Other national organizations such as the River Network, Global Rivers Environmental Education Network and the Adopt-a-Watershed Foundation are more recent arrivals to the water quality education and volunteer monitoring scene. All these programs recognize that the solutions to river degradation, like the problems, are primarily local and that grass-roots efforts are essential. All states have some type of voluntary monitoring program with a few very strong programs in some states. Nationwide, there are more than 340,000 volunteer participants in more than 500 volunteer monitoring programs. They monitor all types of water bodies and collect physical habitat, chemical, and biological data.

Citizen Monitoring in the Pacific Northwest and in California

Most of the national efforts organizing citizen monitors and producing procedures for biological monitoring are concentrated in the eastern states. In the Pacific Northwest, one of the most successful programs is the Adopt-A-Stream Foundation (AASF). Headquartered in Everett, Washington, it was established in 1985 to promote environmental education and stream restoration. The AASF has a small professional staff to conduct "Adopt-A-Stream," "Streamkeeper Field Training," and "Watershed Education" workshops for teachers and community group leaders.

In California, there are over 100 watershed groups or conservancies, with more than 70 in the Sacramento River watershed alone. Although some are more active than others, their cumulative resources could spawn a strong and powerful lobbying force. In terms of training, the Sustainable Land Stewardship International Institute (SLSI) has been promoting biological monitoring in California since 1995. Since then, SLSI has offered over 40 three-day workshops to citizen monitors and resource professionals state-wide. In addition, SLSI offers:

- watershed monitoring design;
- training;
- consultation;
- macroinvertebrate sampling;
- macroinvertebrate sample identification (citizen and professional levels); and
- biological and physical monitoring equipment.

SLSI has offices in Tasmania, Central America and Europe, and manages an

ecological reserve in Panama, hoping to promote bioassessment in Latin America.

The SWRCB supports citizen monitoring through its Citizen Watershed Assessment and Monitoring for California (CWAMCal) program. The purpose of the state-wide program is to ensure the long-term viability of local programs by delivering technical assistance to citizen groups, addressing data management issues, developing training programs, and doing outreach to areas with high priority water quality problems. CWAMCal has a variety of documents available to citizens, including Volunteer Monitoring Protocols for several chemical, physical, and biological parameters of water quality. The SWRCB website address is www.swrcb.ca.gov. A search of this website will link you to the CWAMCal program (www.swrcb.ca.gov/nps/html/volunteer.html)

National Task Force Recommendations for Citizen Monitoring

The Intergovernmental Task Force on Monitoring Water Quality (ITFM) was organized in 1992 to propose changes in water quality monitoring believed necessary to obtain a better return on public and private investments in monitoring, environmental protection, and natural-resources management. The ITFM, now called the National Water Quality Monitoring Council, thought that volunteer monitoring organizations could be strong partners in a nationwide monitoring strategy. They recommended integrating volunteer monitoring into existing and planned monitoring programs and improving the quality and utility of volunteer efforts, including the following:

> *Links between volunteer monitoring programs and water quality and planning agencies should be established at all levels of government to encourage cooperative planning, training, and data exchange between volunteer groups and agencies. These links may include State or Tribal associations or councils of volunteer program coordinators and agency representatives, agency-sponsored volunteer programs, and sharing and collaboration in such areas as volunteer training, data management, and resource sharing.*
>
> *Nationally consistent quality-assurance guidance should be developed for volunteer monitoring groups to help volunteer programs document their methods and quality-assurance protocols. This national guidance can be adapted to meet individual State, regional, Tribal, or local data requirements. The EPA is currently leading such an effort that involves other Federal, State, Tribal, and volunteer organizations. Such documentation has the following benefits: 1) Enhances credibility and replicability of volunteer methods; 2) Allows volunteer collection and analytical methods, site selection, and other volunteer program design characteristics to be understood by potential data users; 3) Allows volunteer data to be compared with those of other programs; and 4) encourages volunteer programs to practice sound quality-assurance methods.*
>
> *Standard volunteer monitoring field methods should be developed. Use of these methods cannot be mandatory because of differing needs, goals, capabilities, and resources of volunteer programs. However, their development and availability will provide a common baseline for many programs, thereby improving comparability among the programs.*
>
> *Nationwide training on laboratory, field, and quality-assurance methods for volunteers should be promoted. Such training helps encourage consistency in methods, increases the level of quality assurance for volunteer information, and promotes the exchange of ideas and the development of advanced methods.*
>
> *The incorporation of proper documentation of volunteer data into water-quality-data systems should be promoted to facilitate data sharing and*

use of volunteer data. Documentation in water-data systems of volunteer collection methods, analytical approaches, and quality-assurance protocols helps potential data users understand the limitations and strengths of volunteer data, thereby increasing confidence in its use.

Volunteer participation should be provided for on State, Tribal, watershed, aquifer, and regional water-monitoring teams. Volunteer programs will provide these teams with unique links to academic organizations, advocacy groups, civic associations, government, and private enterprise. Team members, including volunteers, will serve to integrate monitoring efforts to meet local, regional, and nationwide information needs.

Recommendations for Citizen Involvement in Biological Monitoring

SLSI has been actively training citizen monitoring groups in California since 1995. Although SLSI is more involved with teaching standardized bioassessment techniques, we have observed and been peripherally involved with the organizational struggles of many citizen groups. As government biologists and volunteers for a non-profit organization, we are accustomed to heavy workloads with limited resources and we deal with an array of groups and citizens on and off work hours. The following are recommendations for citizens, based on our experiences and the insight we have gained watching grass-roots organizations get started.

Demand action from the top and do not allow upper management to push the extra work down to staff - As you become more involved with your area's rivers, streams and lakes, you will probably become familiar with the biologists and field technicians doing the day-to-day work involved in understanding and protecting your local water resources. They could be the Fish and Game Warden who investigates poaching and pollution crimes, the DFG District Biologist who measures the condition of aquatic organisms, the RWQCB Environmental Specialists and Engineers who implement water quality regulation, and other representatives of a federal or state agency with special projects in your area. One nearly universal truth is that there is never nearly enough personnel to conduct field work.

Those in field positions are invariably overworked and in need of assistance, not in need of additional assignments. If you foresee a special need to measure the resources or improve the quality of your river or stream of interest, ask for help from upper management. As you become familiar with the extent of field personnel workload, share your insight with management, and acknowledge that the work cannot be done by the present limited field staff. Ask how money or new positions can be obtained to accomplish what you believe is necessary to improve your local water quality.

Be realistic with your offers to assist field staff - There is a natural desire for volunteer monitors to want to work in the field with government biologists. The work seems interesting and a good way for concerned citizens to learn more about their favorite river, stream or lake. Make certain you are well trained before you offer your services in the field. If a field biologist turns down your help, it is probably because he or she sees more work in training you, than can be gained by using you. Do not take it personally. Help in another way. Collect data with an organized citizen monitoring group and prove that you know what you are doing.

When dealing with water quality agencies leave your emotions and love for your favorite stream or lake at home. Always present information (preferably data) in a no-nonsense and unbiased manner - Most concerned citizens and volunteer monitors became involved because of the feelings they have for the beauty and tranquility that a river or lake provide. There is truly something magical about water and the plants and animals that live there. It is also what inspired most professional biologists to put in the time at school and live on low wages.

However, many field biologist can be a bit rough around the edges after years of witnessing and experiencing the problems first-hand and receiving minimal support from budget-minded upper management. Even the managers who have their roots in field work, get frustrated with the mountain of paperwork and, depending on the administration "du jour", lack of support from the Governor's office. What this means is that there is a tendency to discount or be negative about the requests of citizens wanting help for their polluted stream. To government scientists it can mean more work without additional resources, and they may have little left to give.

Be aware of this possible attitude from government representatives when attending stakeholder or informational meetings. Know that most government scientists do what they do out of their passion for the resources. They are on your side. However, you can forever tarnish your credibility by bleeding too much for your stream. That beautiful stream, unfortunately, can be just another commodity or liability in the halls of government and unless you have some very good political connections, you will need real data or a lawsuit to get things done.

Never accept the excuse that it will cost too much to do it right - Humans, like most other animals, tend to engage in what is called "conservation of energy". The tendency is to exert the least possible amount of energy to get things done. The excuse that an environmentally correct solution will cost society too much money should not be readily accepted. Without being forced to work or come up with a solution, nothing new will get proposed. There are several examples where innovative and environmentally correct solutions were developed when the easy way out was denied.

Don't be bought off with "guilt money" - We call "guilt money" any funds given to a citizen action group as part of the settlement of a lawsuit following some environmental wrong-doing. Quite often a citizen group will receive money for stream restoration projects. There are many settlements or grants given for environmental restoration without any requirement to monitor the restoration work as evidence that the work did some good. In the case of lawsuit settlements, generally the money is doled out as a pay off and there is little interest from the money source in seeing that the restoration is done properly.

Since the early 1980's, the trend has been to promote "on the ground" projects and not to spend money studying the problems. The idea is to throw money at a problem ostensibly to "do" something about it, while avoiding being responsible for the proper execution of the project or ensuring its long-term beneficial effects. A newer trend is to take the money and create a job for someone. This is even harder to resist since dedicated volunteers become tired of not being paid. Most volunteers would like to make a living doing what they have dedicated so much volunteer time to do. This is OK since someone who has put in a lot of free time should be rewarded. Resources are limited, so take the money from anywhere you can get it; however, remember why you became involved in the first place, and keep your convictions strong.

Be humble and resist the urge to invent things on your own - Most people involved with water quality monitoring want recognition and to continue making a living in the environmental field. However, try to resist the tendency to invent new or slightly different techniques to earn money and recognition for developing something new. Remember that standardization is ultimately important. There is probably an acceptable procedure already developed for most aspects of water quality monitoring.

Standardization does not mean "set in stone"; however, it does mean that when changes or revisions occur, they will be uniformly carried out. Do your research before inventing something new. Citizen monitors or resource professionals using unique procedures will fragment the efforts to have a strong unified movement to protect and restore the health of our streams and rivers. Contribute by becoming an active member of the California Bioassessment Workgoup (CABW). This

group meets once a year to review and refine existing protocols. It is the best possible forum to suggest changes or addition to current procedures. The CABW website address is www.dfg.ca.gov/cabw. A search of this website will link you to information on the upcoming meetings.

Don't ever say "I am not a biologist, but...." - Don't put yourself in a position where you are asking for something without having done your homework. Never make excuses for being "just a citizen". At public meetings, we have often heard citizens who make statements such as: "I am not a biologist, but I know there used to be big fish in this stream". This is where having sound data and scientific facts will impress the government or industry you are trying to convince of the problem. Actually, it will do more than impress someone, it will make or break your case. We are looking forward to the day when citizen monitors can go to a meeting, put the data on the table and simply say: "Here is the information to support our position. There is a problem with our stream. Deal with it."

Literature Used in Preparing This Chapter

The following references were used in preparing this chapter and would be good material to read for more detailed information on the subjects discussed:

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Chapter 3
The Natural State of Streams and Rivers

Introduction to the Chapter

The intent of this chapter is to describe the natural state of streams and rivers. It starts by discussing watershed hydrology and the various physical structures forming river systems. Next, we introduce stream chemistry, both inorganic and organic components and how they contribute to the aquatic food web. A recent development in stream ecology, the River Continuum Concept, is presented as a holistic view of how benthic macroinvertebrates (BMIs) function in the aquatic system. Finally, the world of BMIs is introduced and briefly described.

Watershed Hydrology

The understanding of watershed hydrology - or where the water in rivers and lakes comes from - did not take root until the late 1600s. The concept of rainwater falling to the ground, running over or under the surface of the land to the ocean, and then back again, is called the **hydrologic cycle**. The sun powers the "back again" portion of the hydrologic cycle by **evaporating** water from the surface of all water bodies, including streams and rivers and **transpiring** water from the surfaces of plants. Water from the combination of these two processes called **evapotranspiration,** rises into the atmosphere as vapor until it chills enough to form clouds which in turn release the water as precipitation (*Figure 3-1*).

> ***The concept of rainwater falling to the ground, running over or under the surface of the land to the ocean, and then back again, is called the hydrologic cycle.***

There are a variety of **precipitation systems** in California. Most of the state is known for its Mediterranean climate of warm, dry summers and mild, wet winters. Rain falls in coastal areas, inland valleys and low-elevation inland mountains in moderate to heavy amounts from late fall to early spring. Different precipitation patterns are important to recognize because they have significant effects on stream flow and aquatic life. Low clouds and fog in the coastal areas can produce a form of precipitation called **fog drip** which can be significant, even in summer months. Northern coastal mountains and mid-elevation Sierra mountains have rain and snow during the wet period. These areas can experience what is known as **rain on snow events** which can produce significant flooding when warm storms bring rain to areas that have a base of snow. The higher Sierra mountains have a snow-dominated weather system where most of the precipitation falls as snow during the wet season and thunder storms can bring localized heavy precipitation during the summer months.

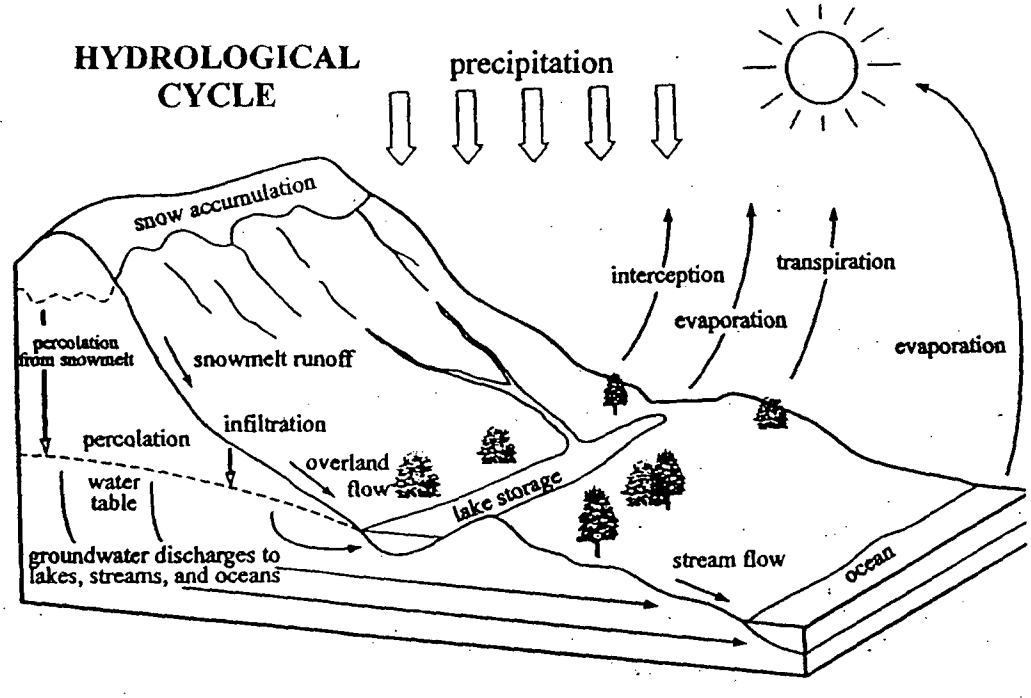

Figure 3-1: hydrological cycle

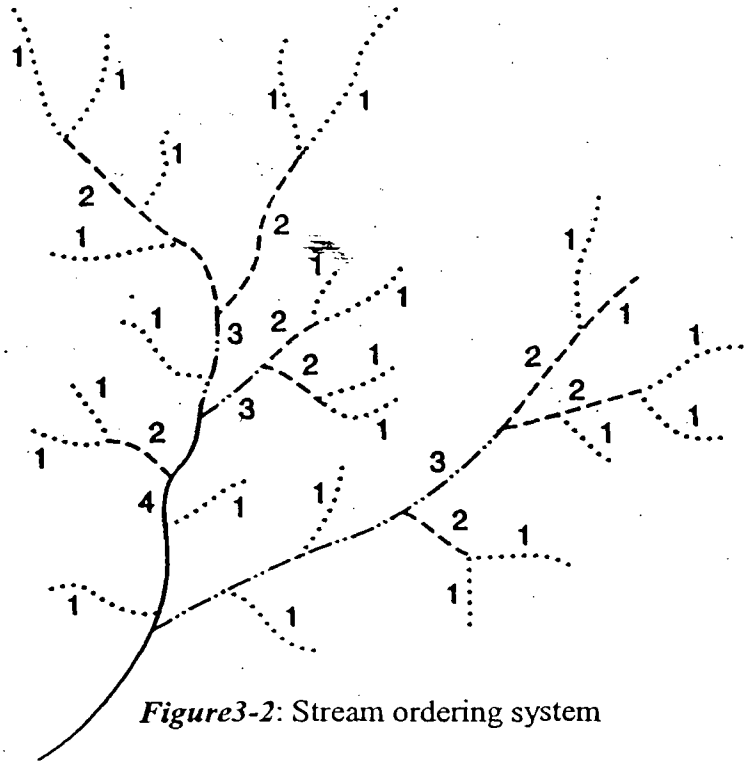

Figure3-2: Stream ordering system

Whenever rain falls on land, it forms a path heading downhill. Small rivulets become streams and streams become rivers which either empty into a lake or the ocean. The land mass that captures the rainfall and concentrates it into streams and rivers is called the catchment basin or **watershed**.

Watersheds are separated from each other by the ridge tops or watershed divides. A watershed can be as large as the Mississippi River watershed or as small as the watershed that forms the small creek in your backyard. Within the watershed, channels are classified according to size into **stream order**. A first order stream is the smallest rivulet usually located in the **headwaters** of the watershed. When two or more first order streams join they become a second order, and when two or more second order streams join they become a third order, and so on (***Figure 3-2***).

Most larger streams flow all year, even in the dry season, and are referred to as **perennial** streams. In California, many streams dry up naturally for part of the dry season and are referred to **intermittent or ephemeral** streams. Stream communities have evolved with these intermittent surface flows. Even though all or part of the stream appears to dry up, it is usually flowing below the stream bed and sometimes surfacing in pools. Intermittent streams are a very important component of a watershed's stream system.

The size and shape of the watershed as well as its location in California determine the amount of water that is transported through its network of stream channels. The amount of water that flows in the stream channel is called the **water discharge** and is usually expressed as cubic feet per second (ft^3/s). The discharge is determined by measuring the velocity of water through the cross-sectional area of the channel. Discharge varies with time of year and the weather. The continuous record of discharge plotted against time is called a **hydrograph**. (***Figure 3-3***)

Hydrographs can be used to show annual flow or rainstorm events and can reveal important information about a stream or its watershed. The U.S. Geological Survey (USGS) and the Department of Water Resources (DWR) maintain **gauging stations** on some streams that continuously record stream discharge. Visit website (www.usgs.gov and http:cdec.water.ca.gov) to see hydrographs of your watershed.

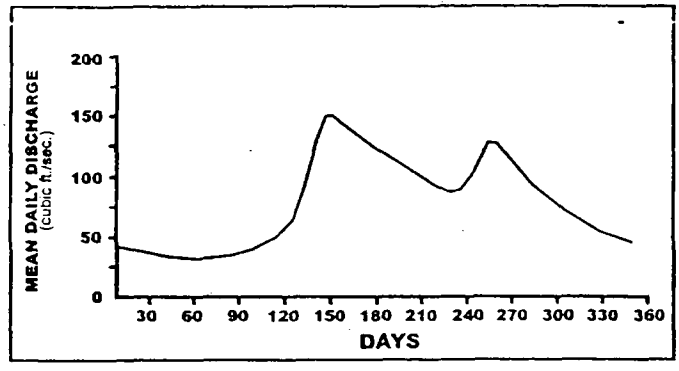

Figure 3-3: Stream Hydrograph

The Structure of Streams

Over millennia, stream channels are formed by the erosion of the land surface and transport of the resulting sediment to the ocean. A familiar and grandiose example is the water discharge of the Colorado River which over time has formed the Grand Canyon. The study of **fluvial geomorphology** has shown us that even on a yearly basis, stream channels and the network of streams within a watershed are constantly changing and adjusting based on the extent of erosion and deposition of sediment.

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The extent of erosion and deposition of sediment in a watershed is dependent on supply of sediment and the velocity of the water transporting the sediment. Large storm events result in by far the most erosion and transport of sediment. Flood flows can result in channel relocation and/or the formation of new channels throughout the valley floor. In their natural state, rivers form a series of complex channels entangled with rocks and plant material transported in stream flow from upstream portions of the watershed.

Stream channel shape is related to the amount of flow and the **gradient** or slope of the channel. Gradient is measured by dividing the length of channel by the drop in elevation and is usually expressed in percent. On the watershed scale the channel gradients are defined as steep (4-10 %) in the headwaters, moderate (2-4 %) in the middle,

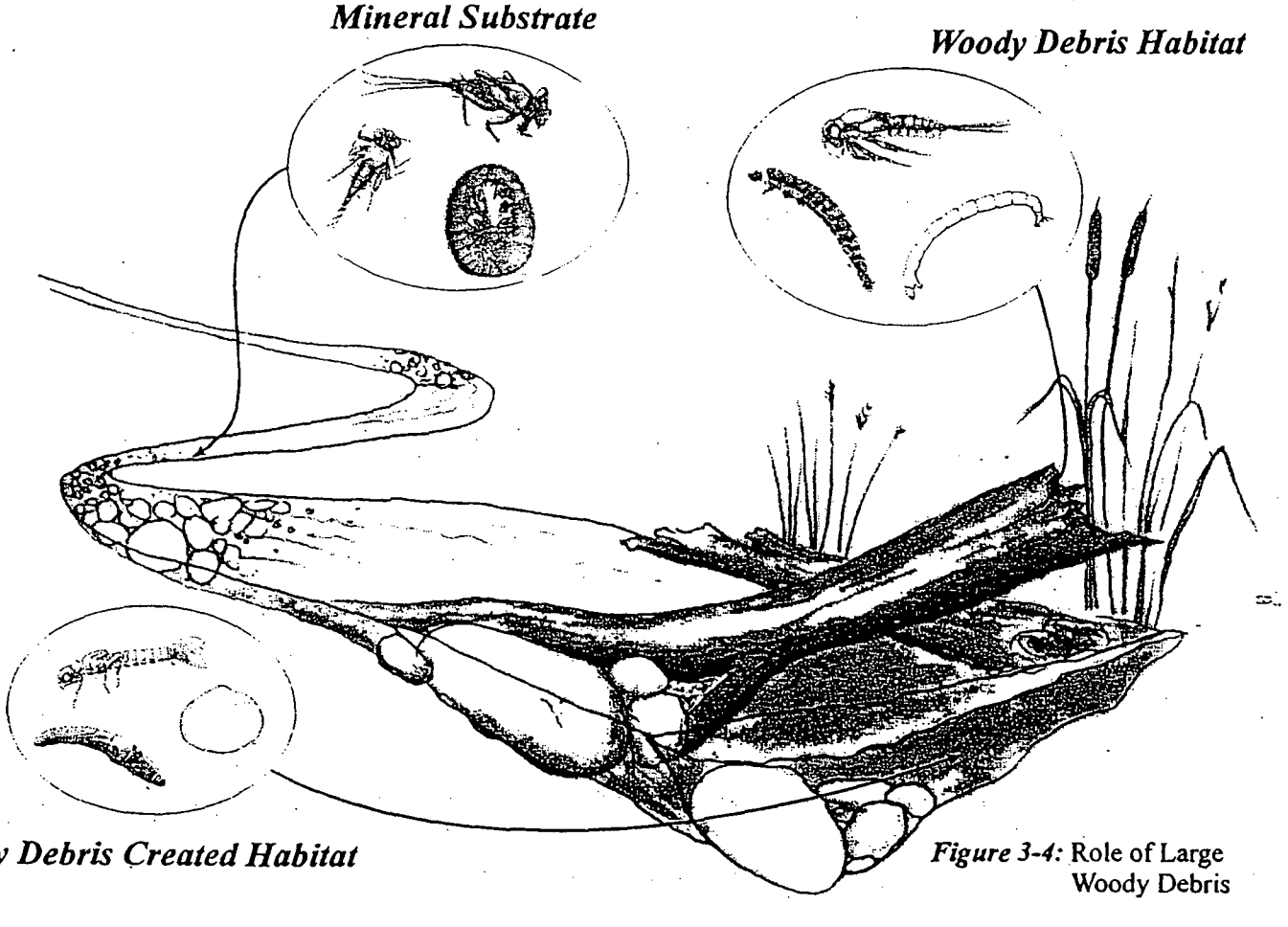


Figure 3-4: Role of Large Woody Debris

and low (<2 %) in the valley floor.
On a smaller scale, most sections of a stream have a regular sequence of **riffles, pools and runs**. Riffles form in higher gradient areas where the water is shallow and flows faster and is one of the most oxygenated area of a stream. Pools form in lower gradient areas where the water is deeper and flows slower. Instream structure such as fallen tree trunks (large woody debris, or LWD) and/or large boulders are essential in the formation of stream pools (***Figure 3-4***).

The **substrate** or material on the bottom of the channel is coarse gravel, cobble and boulders in riffles and fine sand and sediment in pools. There are some streams which will not exhibit this riffle/pool sequence such as deep water rivers with no riffles or shallow areas. Some channels are dominated by coarse substrates and some are dominated by fine substrate.

The quantity and quality of the water that flows in streams and rivers are the product of not only human alterations, but also the climate, topography, geology and vegetative characteristics of that watershed. Understanding and knowing your watershed is the most important thing you can do to protect your stream.

Stream Water Chemistry

As rain water falls on the land it either infiltrates into the ground or runs over the surface gathering dissolved and suspended material with it. Water is referred to as the universal solvent because it has the ability to dissolve anything including the earth's rocks. The geology of the region, the vegetation types and the climatic conditions of the watershed determine the chemical make-up of its rivers and streams. The natural water chemistry can be unique for different regions of California and individual watersheds, influencing the biotic make-up of streams and rivers.

> ***The geology of the region, the vegetation types and the climatic conditions of the watershed determine the chemical make-up of its rivers and streams.***

The chemistry of the freshwater environment can be divided into:
- dissolved gasses;
- dissolved inorganic chemicals;
- nutrients; and
- dissolved and suspended organic material.

Dissolved Gasses - There are many gasses in our atmosphere, but only oxygen (O_2), carbon dioxide (CO_2) and nitrogen (N_2) dissolve in water to any significant extent. Of the three, N_2 is the least important to aquatic organisms (except as a nutrient which will be discussed later). **Dissolved oxygen (DO)**, on the other hand, is very important. Many biological processes depend on DO. With the exception of anaerobic bacteria, all aquatic organisms require some level of DO to live. There is much less CO_2 in the atmosphere, but because of its chemical properties, it dissolves better in water or is more **soluble** than O_2. The amount of O_2 and CO_2 that can dissolve in water depends on the temperature of the water and the altitude of the stream. The maximum amount or **saturated concentration** of DO at sea level in the coldest streams will be about 14 mg/L or **parts per million (ppm)** and the saturated concentration of DO in the warmest steams will be about 6 or 7 ppm. Under the same conditions, CO_2 will be 1.1 ppm in the coldest and 0.4 ppm in the warmest streams.

As altitude increases, the weight of air above the surface of the earth decreases, so the pressure of that weight exerted on the earth's surface decreases. This decrease in **atmospheric pressure** decreases the ability of O_2 and CO_2 to be dissolved in water. Therefore, the higher up the mountain you go, the lower the saturation point of DO and CO_2 will be, regardless of the temperature of the water.

Despite the fact that plants **photosynthesize** during the day producing DO and **respire** at night producing CO_2 , the concentration of DO and CO_2 in smaller streams with abundant

areas of turbulent riffles will always be at the saturation point. Although organisms can use or produce DO and CO_2, exchange of the gases with the atmosphere will maintain an equilibrium. The concentration of DO and CO_2 in larger rivers can be less than the saturation point because there is less turbulence and little surface area for these gasses to be in contact with the water. The concentration of DO and CO_2 in larger rivers will also fluctuate according to the season and the time of day, especially if there are aquatic plants present.

Dissolved Inorganic Chemicals - When **inorganic** chemical compounds such as salts and metals (collectively called minerals) dissolve in water, they break down into their **ionic** components. Table salt (NaCl) becomes sodium (Na^+) and chloride (Cl^-) ions and metals such as copper will oxidize forming copper (Cu^{2+})and oxide (O^{2-}) ions. The positively charged ions are **cations** and the negatively charged ions are **anions**. Ions enter the stream through rain water and ground water which picks up more chemicals through weathering of sedimentary rocks and soils.

First order headwater streams will usually have the lowest concentration of dissolved chemicals. As the stream network grows within the watershed, and streams become rivers, evaporation causes chemicals to become more concentrated. Although each watershed can have its own unique composition of dissolved chemicals, the anions, bicarbonate (HCO_3^-), chloride (Cl^-) and sulfate (SO_4^{2-}) will make up more than half of the ionic concentration of most streams and rivers. The other major ions found in streams and rivers are: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) and silicon dioxide (SiO_2).

Dissolved chemicals in stream water are measured in a variety of ways. Measures for the total concentration of chemicals in water include: **total dissolved solids (TDS)** which is the measure of all the major dissolved ions listed above and is expressed in mg/L; **salinity** which is the measure of all the salts contained in water and is expressed in parts per thousand (ppt); and **conductivity** which is actually the measure of the electric conductance of water and is measured in microSeimens per centimeter (μS/cm). TDS can be calculated from conductivity, but the formula includes a conversion factor which must be determined on a regional basis.

On a watershed basis, the total amount of all dissolved chemicals, a specific chemical, or any substance in water can be expressed as the **load** by combining its concentration with water discharge. Since water discharge is expressed as the volume of water (ft^3 or m^3) per second, the amount or weight of the material in that volume can be estimated from the concentration (mg/L), then summed for a given period of time to produce the total weight (kg or lbs) of a material that is transported by the stream on a daily or yearly basis.

Another important chemical property of water is the **pH** which is a measure of the hydrogen ion (H^+) concentration. Although pH can range from $-\infty$ to $+\infty$, in most instances you will find pH ranging from 0 to 14. Units are on a logarithmic scale, which means that every unit changes 10 fold. Neutral pH solutions are numerically equal to 7, increasing numerically to alkaline solutions and decreasing with acid solutions. The primary source of hydrogen ions in natural streams comes from rainwater which is slightly acidic due to CO_2 and SO_4 gasses dissolving in water (H_2O) forming carbonic acid (H_2CO_3) and sulfuric acid (H_2SO_4).

In most watersheds, the infiltration of rain into the soil neutralizes the water before it enters the stream. However, even when acidic water enters streams, it is neutralized by the stream's **buffering system**. The alkaline compounds, bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxide (OH^-) which are usually abundant in most natural waters, are primarily responsible for this very important system. **Alkalinity** is a measure of the these compounds and is expressed as mg/L $CaCO_3$. Another important measure of water chemistry, sometimes incorrectly equated with alkalinity, is **water hardness**. Hardness is the measure of Ca and Mg salts

which usually occur with HCO_3^-, but can form also with Cl^- and SO_4.

Nutrients - There are many chemicals found in water that are essential for life. Their concentrations can influence the abundance of plants and animals in water. All of the chemicals mentioned above, and many more called **micronutrients**, are utilized by aquatic organisms. They are required in low concentrations, are readily available in streams and rivers, and are usually not limiting to aquatic plants and animals. Phosphorus, nitrogen and carbon are the nutrients which most influence life in water (and in terrestrial ecosystems). They are called **macronutrients**. Carbon is readily available as dissolved CO_2, but phosphorus and nitrogen can be limiting in aquatic systems. Phosphorus exists as phosphate (PO_4^{3-}) and nitrogen exists as ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-). Nitrogen can enter the aquatic system from atmospheric gas (N_2), but the most common way that nitrogen and other nutrients enter the aquatic system is as **inorganic forms** dissolved in rain water, or incorporated into wind blown dust, and as **organic forms** incorporated in the tissue of leaf litter and dead animals. The ratio of phosphorus to nitrogen averages 1:16, but is highly variable from watershed to watershed and among sections of streams and rivers.

Input of new nutrient sources to the aquatic system is small compared to how much is utilized. Nutrient concentrations are maintained at a high enough level to maintain aquatic life by **nutrient cycling**. The inorganic forms of nutrients are incorporated into plant tissue by direct uptake by the plant. Nutrients in the organic form (as plant tissue) are eaten by animals which further cycle the nutrients when they excrete waste and when they die. Eventually dead plants and animals are decomposed by bacteria and the nutrients are converted back to the inorganic forms.

Nitrogen cycling is a bit more complicated than phosphorus cycling because of the different forms of nitrogen. The important differences are that nitrogen can be fixed by bacteria from atmospheric gas (N_2) and converted to NH_3 as bacterial biomass. There is another group of **nitrifying bacteria** which converts NH_3 into NO_2^- and yet another group of bacteria that converts NO_2^- to NO_3^- which is the form used by plants.

The term nutrient cycling is more appropriately used with still water environments where the process occurs in place. In streams and rivers, nutrients are cycled while being transported downstream as dissolved ions or attached to suspended organic particles. This added downstream component results in more of a **nutrient spiral**. It is a complex process that can limit nutrient availability in small, fast moving reaches and concentrate them in the larger, slow moving reaches.

Dissolved and Suspended Organic Material - The last category of non-living matter that provides energy or food to stream organisms is the organic material that is transported downstream in suspension. Although in the suspended state this material is more available to organisms, it is also stored in various places along the length of the stream such as in bottom sediment. It can be resuspended during major hydrologic events.

There are two sources of organic material to the stream system:
1) one which is produced within the stream by suspended algae or **phytoplankton**, aquatic vascular plants or **macrophytes**, and the community of algae and microorganisms that grow on substrate or **periphyton**; and
2) one which is produced outside the stream such as leaf litter.

Organic matter produced within the stream is called **autochthonous** material and organic matter that comes from outside the stream is called **allochthonous** material. Allochthonous material is by far the most important source of organic material. The amount entering the aquatic environment and then transported downstream will vary with the growing season and during storm events.

Organic energy supplies to the stream environment can be categorized according to size into: coarse particulate organic matter (CPOM) which is greater than 1mm; fine

particulate organic matter (**FPOM**) which is from 1 mm to 0.0005 mm, and dissolved organic matter (**DOM**) which is less than 0.0005 mm.

CPOM enters the stream primarily as leaves and needles. This supply of allochthonous material is most important to small woodland and headwater streams where light for photosynthesis is limited. Other sources of CPOM are dead portions of aquatic plants, woody debris (twigs and logs), other portions of plants (flowers, fruit and pollen), and feces and carcasses of animals.

FPOM comes primarily from the processing of CPOM. Leaves and woody debris are broken down mechanically from tumbling in the stream, but also by stream organisms that use it as a food source. **Microbes** (bacteria and fungi) are the first to colonize leaves, starting the decaying process. Larger organisms further break down the CPOM by chewing it into smaller pieces and eventually eliminating it as feces in the form of FPOM. FPOM can also enter the stream in runoff through forest litter and soil during storm events.

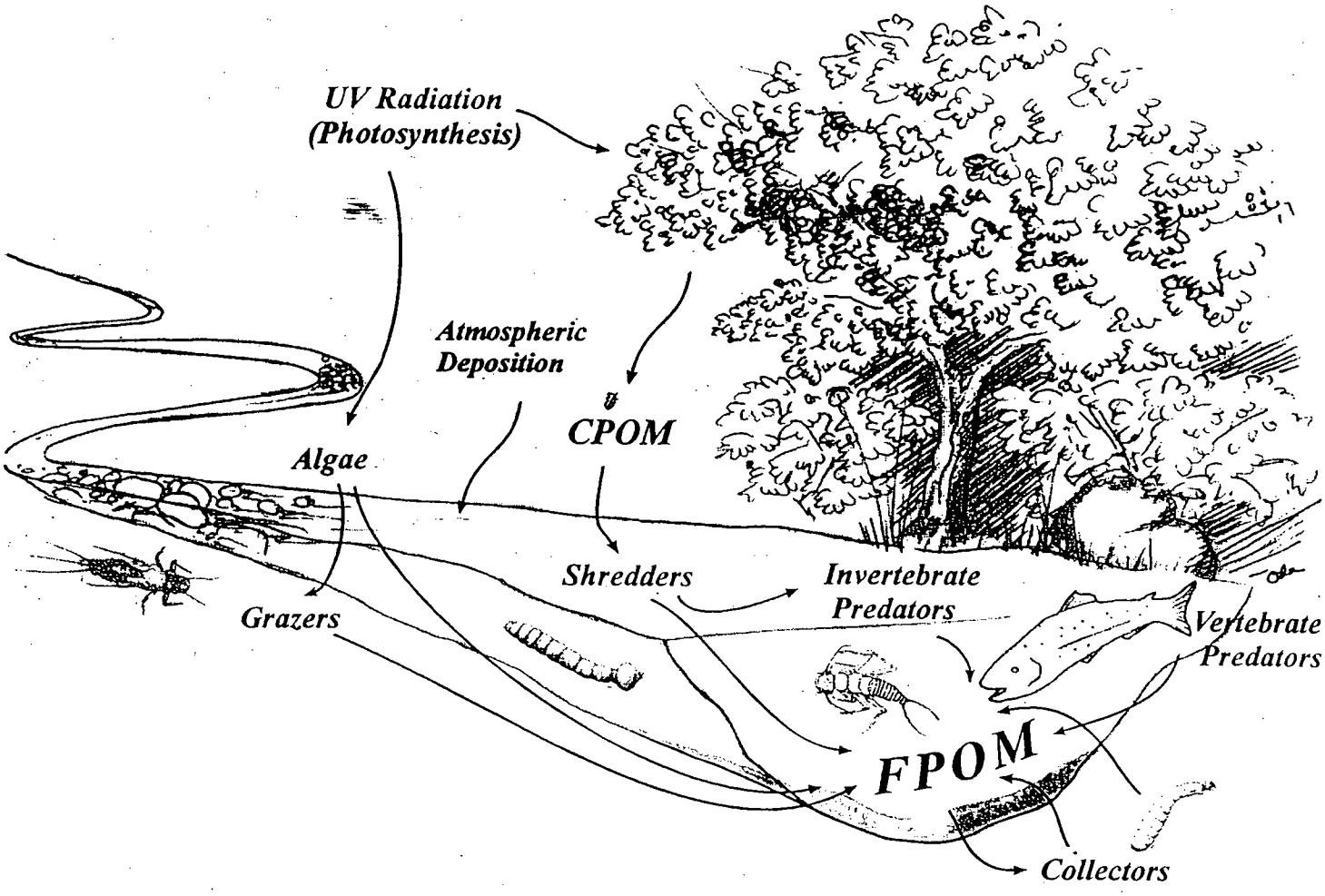
DOM has fairly complicated pathways in the aquatic environment. DOM, which is usually the largest source of organic matter, enters the stream directly from groundwater, runoff and atmospheric deposition and from leaching of CPOM. DOM is also converted to FPOM through microbial uptake associated with the periphyton community which then sluffs it off as dead tissue.

The Aquatic Food Web

In the past, ecologists described the way energy or food passes through the environment in terms of a food chain with layers or **trophic levels** representing groups of organisms that eat the same type of food. The categories used to describe the food preference of aquatic organisms are: **herbivores** or those that consume algae and other aquatic plants; **detritivores** or those that consume decaying organic matter; and **carnivores** or those that consume animal tissue. Ecologists now refer to energy flow and utilization as a **food web** because they recognize the interdependency of the different trophic levels and how food resources flow back and forth between levels. They also realize that the food habits of organisms are too complex to categorize into rigid trophic levels. For example, invertebrates that eat leaf litter or CPOM are also ingesting the bacteria and fungi that have colonized the material. In addition, some animals will eat detritus and capture prey while others will eat one type of food in their early life stages and change to another type as they mature. For these reasons, it is better to categorize organisms into **feeding guilds** of species that obtain a common food source in a similar manner. The most common feeding guilds are:

- **Shredders** which are organisms that collect, breakdown and consume CPOM such as leaves, twigs and branches. Most invertebrate shredders are detritivores, herbivores and sometimes carnivores.
- **Filterer-collectors** which are organisms that collect suspended FPOM using filtering apparatuses or nets. Most invertebrate filterer-collectors are detritivores and herbivores.
- **Collector-gatherers** which are organisms that gather up deposited FPOM by browsing or burrowing in sediment. Most invertebrate collector-gatherers are detritivores, herbivores and sometimes carnivores.
- **Scrapers or grazers** which are organisms that scrape periphyton or algae from the surface of rocks and logs. Most invertebrates scrapers are herbivores and detritivores.
- **Predators** which are organisms that consume other animals by biting and piercing their prey. A large proportion of fish and a smaller proportion of invertebrates are carnivores.

The aquatic food web for a running water or **lotic** environment (lakes or still water



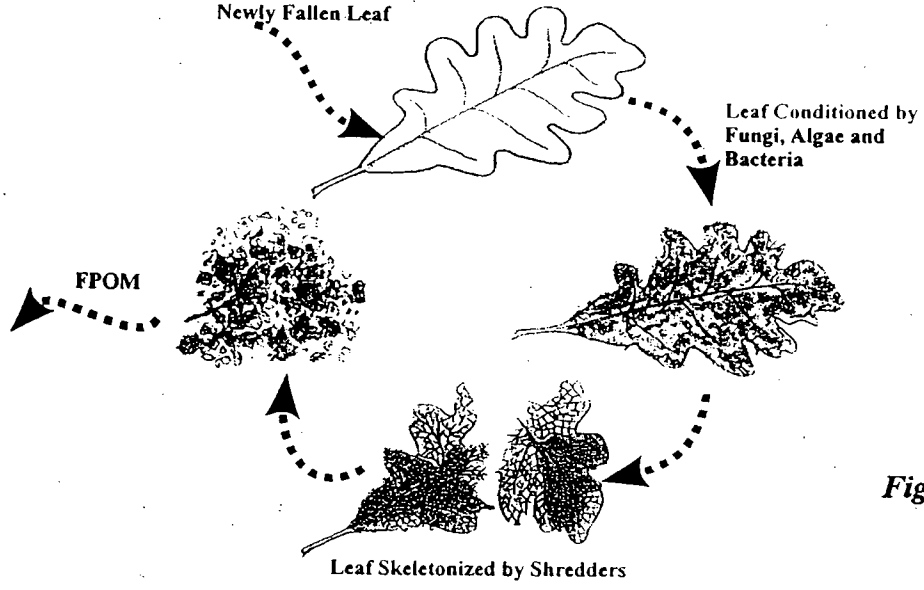


Figure 3-5: Aquatic Food Web

environments are called lentic environment) is illustrated in ***Figure 3-5***. There are three entry points into the aquatic environment:

- terrestrial sources of CPOM;
- atmospheric deposition of DOM and FPOM; and
- sunlight.

Sunlight powers photosynthesis in algae, macrophytes or periphyton. These **primary producers** slough off DOM and FPOM as dead algal cells and are eaten by scraper invertebrates. DOM contributes to FPOM which is filtered or gathered by collector invertebrates. CPOM is colonized by microbes to begin the decay process. Shredder invertebrates eat the CPOM and both the microbes and the invertebrates contribute FPOM as feces. At the bottom of the web are the predatory fish and invertebrates which eat other invertebrates.

The River Continuum Concept

The food web is a well accepted ecological concept in stream ecology. In the 1980's, another ecological concept aimed at better understanding the dynamics of lotic environments was developed. Called the **River Continuum Concept (RCC)**, it attempts to describe in one conceptual model, the ecological functioning of a river relative to the physical structure and energy inputs that occur from headwater streams to the largest rivers (see ***Figure 3-6***).

The physical structure is measured by stream order which is also related to discharge and watershed size. The ecological function is measured by energy or food availability and the corresponding assemblages of organisms. To further explain the RCC, we will loosely define three areas (headwaters, mid-sized

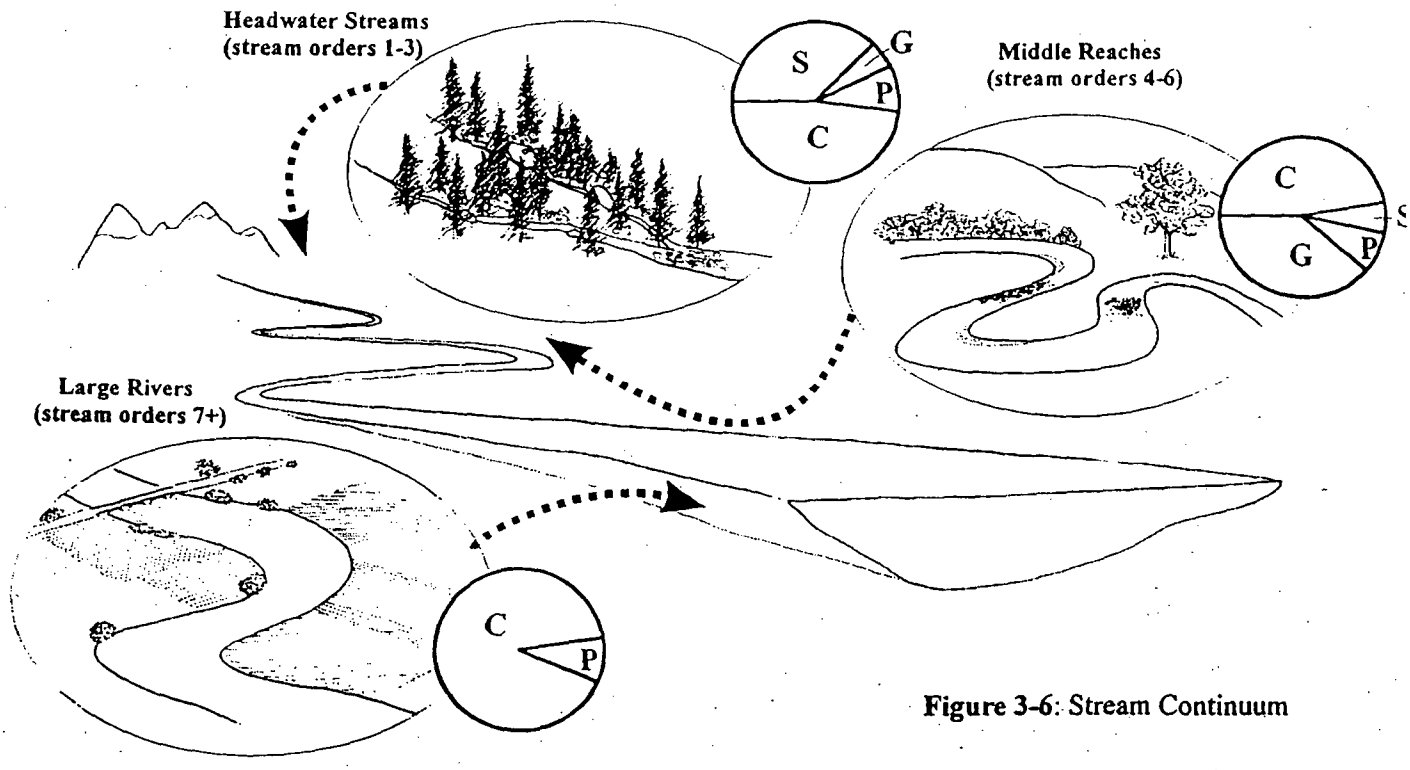


Figure 3-6: Stream Continuum

streams and large rivers) along the continuum of the river and give examples of the corresponding assemblage of **benthic macroinvertebrates (BMIs)** which would predictively occur to utilize the available energy sources. BMIs are aquatic invertebrates that are at least 0.5 mm in length and live primarily on the bottom substrate of streams and rivers. The RCC also describes fish assemblages, but we will concentrate on the BMIs because as explained in following chapters, they are of primary concern in biological assessments. We will also use the term **functional feeding group** which corresponds to the feeding guild that a BMI belongs to:

Benthic Macroinvertebrates (BMI) are aquatic invertebrates that are at least 0.5 mm in length and live primarily on the bottom substrate of streams and rivers.

- *Headwater:* First to second order headwater forested streams are characterized by a narrow, steep gradient channel with a dense canopy of deciduous and coniferous trees. The stream substrate is primarily boulder, cobble, and gravel and the water temperature is cool. The predominant functional feeding groups in the headwater reaches are shredders which process the abundance of CPOM from leaf litter and forest debris, and collectors which process the FPOM from shredder excrement and breakdown CPOM. There are very few scrapers due to the limited amount of algal growth in the stream. Predators are found in low numbers.

- *Mid-Sized Streams:* Third to fifth order streams are characterized by a somewhat wider, more moderate gradient channel with a more open canopy lined with riparian vegetation. The stream substrate is cobble and gravel with a highly variable stream temperature depending on riparian cover. The predominant functional feeding groups in mid-sized streams are scrapers taking advantage of the increased algal growth from a more open canopy, and collectors utilizing the high amount of FPOM from upstream processing of CPOM drifting downstream. The numbers of shredders are low due to the decreased input of CPOM. Predator numbers are low, similar to the headwater areas.

- *Large Rivers:* Sixth and higher order streams are characterized by wide, low gradient channels with no canopy except for the margins of the water. The benthos of large rivers is fine sediment with occasional sand or gravel bars and the water temperature is consistently warm. The predominant functional feeding group is collectors because of the high amount of FPOM (from upstream processing) available to them. Shredders are absent due to the lack of CPOM. Scrapers are absent due to the minimal algal growth resulting from the reduced water transparency to sunlight and the lack of suitable substrate. Predator numbers are low, but somewhat higher than headwater and mid-sized stream sections.

Disturbances that affect the natural input of nutrients, the physical stream habitat and the surrounding watershed can cause a shift in the biological processes normally found at a given location along the river continuum.

The RCC is a conceptual model of a natural, undisturbed river in a forested ecosystem. It has been proposed as a framework for predicting the effects of unnatural disturbances. Disturbances that affect the natural input of nutrients, the physical stream habitat, and the surrounding watershed can cause a shift in the biological processes normally found at a given location along the river continuum. These shifts can be estimated by assessing the new biological conditions created by the disturbance.

The RCC has stimulated considerable research and investigations into stream ecology and has encouraged a holistic view of how rivers work. Anyone interested in streams and rivers should understand the theory of the RCC and also its practical limitations. For example, determining the balance of functional feeding group assemblages is difficult since the precise designation for all BMIs is not known. Also, the RCC is not a predictable model for all stream systems.

General Ecology of Benthic Macroinvertebrates

Most people are somewhat familiar with the animals that live in and around streams and rivers. Mammals such as beavers, river otters, racoons and the deer that frequent the water's edge for drink and food are the most obvious inhabitants. Birds, fish and amphibians are probably the next most familiar types of river residents. However, some of the most important members of the aquatic community, BMIs, often go unnoticed because it takes an inquisitive naturalist to probe the stream bottom to find them.

Types of Benthic Macroinvertebrates - The taxonomy of BMIs is discussed in depth in chapters 12 through 18. There are nine major orders of aquatic insects that are important in stream systems. They are:

Order: Ephemeroptera (Mayflies)
Order: Plecoptera (Stoneflies)
Order: Trichoptera (Caddisflies)
Order: Diptera (Aquatic Flies)
Order: Megaloptera (Dobsonflies and Alderflies)
Order: Coleoptera (Aquatic Beetles)
Order: Odonata (Dragonflies and Damselflies)
Order: Hemiptera (True Bugs)
Order: Lepidoptera (Aquatic Moths)

Other groups of BMIs such as aquatic worms (Oligochaeta), clams and snails (Mollusca), and freshwater shrimp (Amphipoda) can also be found in the stream benthos.

Life Cycle - Most BMIs spend the majority of their life cycle in water. During the aquatic stage, the macroinvertebrate feeds and develops into a more mature organism. Maturation can take as little as two weeks or as long as several years, depending upon the organism and the environmental condition. During maturation, each macroinvertebrate goes through a number of **instars** or distinct periods of growth. Following the final instar, the organism will either emerge as an adult from the last nymphal skin **(exuvium)** or develop into a **pupa** and then emerge. Incomplete metamorphosis (***Figure 3-7***) is the term which describes the former, and complete metamorphosis (***Figure 3-8***) describes the latter.

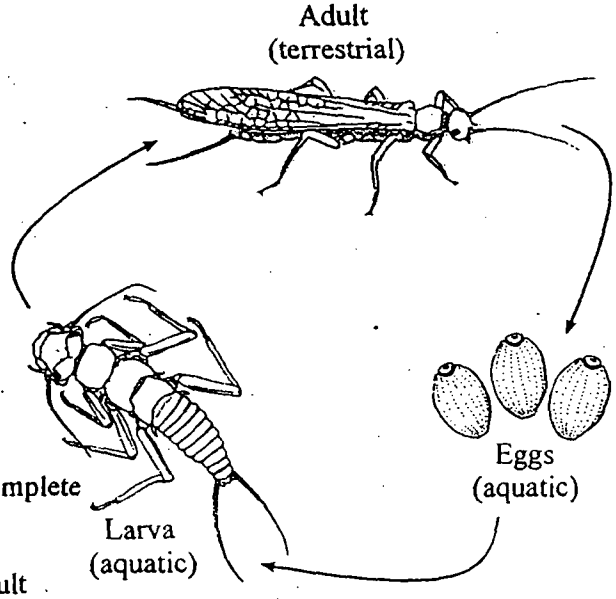


Figure 3-7: Life cycle for BMI groups having incomplete metamorphosis

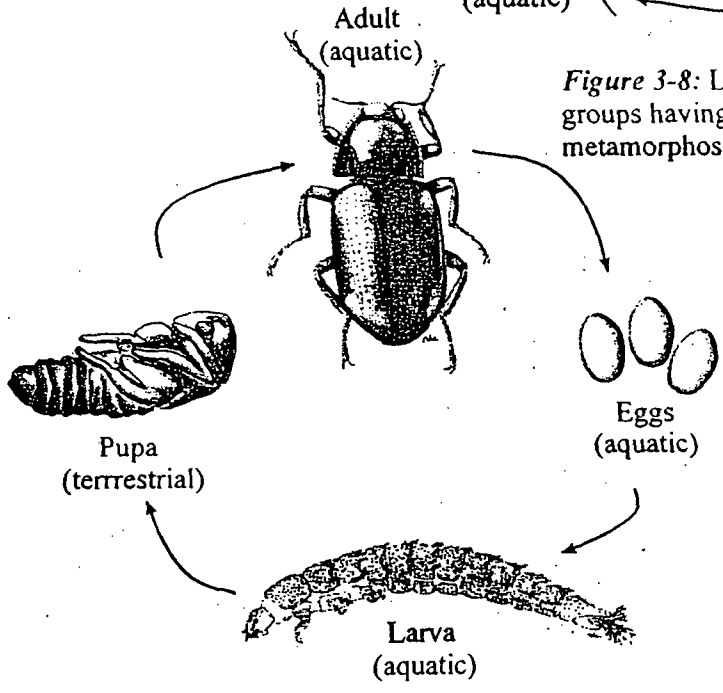


Figure 3-8: Life cycle for BMI groups having complete metamorphosis

Chapter 4
Sources of Water Pollution and Habitat Degradation in Streams and Rivers

Introduction to the Chapter

Chapter 4 covers human-induced water pollution and habitat degradation in streams and rivers. The intent of this manual is to discuss pollution in much broader and more relevant terms that are supported by language in the National Clean Water Act. Also in this chapter, the effects of nutrients, inorganic sediment and chemical contaminants to aquatic systems are discussed, along with the means used to control wastewater discharges. Finally, a long list of pollution types and sources are discussed, as well as ways of detecting water pollution.

Defining Water Pollution for the Twenty-first Century

A typical life science dictionary would define water pollution as the presence of significant amounts of unnatural substances or abnormally high enough concentrations of natural substances in the aquatic environment to cause undesirable effects. Working on this definition, any substance in high enough concentrations can be a pollutant. Metals such as copper, zinc and arsenic which are essential for aquatic life in trace amounts are detrimental to fish and invertebrates at higher concentrations. Heavy leaf litter falling into headwater streams during the autumn low flow period can cause depletion of the dissolved oxygen as microbes start the decay process. However, as soon as the rains come, aerating the water, the increased nutrients help to produce a flourishing community of aquatic invertebrates. In this case, the natural system has evolved to accommodate temporary undesirable effects for the long-term health of the system. In the case of leaf litter, the term pollution event should not apply.

A better definition of pollution should describe an event involving only the chemical substances, energy inputs or land-use practices involving human beings. In other words, humans should always be a part of the formula which defines pollution. However, just as pollution involves humans, the undesirable effects of pollution are usually defined in terms of human values such as hazards to human health, interference with beneficial uses of the environment by humans and damage to the aesthetics of the environment which people enjoy. Altering the structure of a stream by removing timber and other debris for aesthetic reasons, or removing riparian vegetation for swimming or watching the "river go by" will benefit humans, but not the aquatic organisms living in those habitats. The effects of pollution on non-human utilization must not be minimized, even if they are in conflict with human uses, values and sense of aesthetics. The effects of pollution to ecological systems and damage to environmental structures should drive our definition of pollution.

The effects of pollution on non-human utilization must not be minimized, even if they are in conflict with human uses, values and sense of aesthetics.

In this chapter and throughout this manual, we will focus on the effects of pollution on environmental health, not human health. We do not mean to lessen the importance of human health concerns, but that is not necessarily the subject of bioassessment. The microorganisms or **pathogens** that cause disease in humans are simply another source of food to the aquatic system. On the other hand, there is a link between human health and environmental health, and protecting stream health from chemical contaminants will benefit the humans using the water for drinking. But our bottom line is that even though we may not see or even use a specific aquatic system, we will benefit, as a society, from protecting any stream from pollutants.

Another critical component people have often left out of their definition of water pollution is the loss of habitat and the pervasive effects of

non-toxic substances such as nutrients and inorganic sediment. The U.S. EPA has recently acknowledged that these types of pollution are more detrimental to water quality and stream ecosystem health than toxic substances. Since the 1970's, when laws were created to protect the environment and work began on cleaning up pollution in the U.S., all the efforts and funding were put into eliminating toxic contaminants from industrial and municipal **wastewater** or **effluent** discharged into the aquatic environment.

This is an example of **point source pollution** where the pollutant is coming from a well-known source, usually the end of a pipe. Hence, because most of the water quality work focused on toxicity and largely ignored the "organic" pollution events, these types of pollution have become a major problem.

In the early 1970's, chemical engineers were hired by water agencies throughout the U.S. to design pollution elimination systems. Although this work created its own set of problems (such as the proliferation of what were considered "ideal" channels such as cement conduits), at least a significant amount of pollution originating from point sources was eliminated. However, the non-toxic sources were never tackled and will no doubt be one of the greatest water quality challenges of this century.

Non-toxic sources will no doubt be one of the greatest water quality challenges of this century.

Non-toxic substances such as nutrients and inorganic sediment usually enter aquatic systems as natural erosion or runoff from land-surface disturbed by practices such as agricultural, logging and grazing. In contrast to a pipe coming from a factory or water effluent plant, non-point source pollution is hard to trace back to any one particular entity. This type of pollution is called **non-point source pollution** and it has developed into probably the most serious threat to stream health.

Inorganic sediment can be contaminated, but even if clean, it will degrade stream habitat by filling in pools and the interstitial spaces between riffle cobbles where invertebrates live and fish spawn. Efforts to address this type of pollution started in earnest in the 1990's and will be the most significant water quality and stream health concern of this century. Of equal concern, is aquatic habitat destruction by physical means such as removal of riparian trees, gravel mining, road building or hydrologic means such as water withdrawal, water transport and urban storm water discharge.

Destruction of an aquatic habitat can be considered pollution since it may impair the physical integrity of streams and rivers. Indeed, this concept of pollution which will be so important in dealing with water quality in this century is taken from the Federal Clean Water Act (CWA) which defines water pollution as "man-made or man-induced alteration of the physical, chemical, biological or radiological integrity of water." It is important that citizens and resource professionals recognize all types of water pollution and help control it by insisting that water quality laws be enforced. Throughout this manual, we will use the term "water quality" to convey the larger context of the health of an entire stream's ecosystem.

The Effects of Nutrients and Inorganic Sediment

As mentioned in the last chapter, nutrients such as nitrogen and phosphorus are balanced to support the food wed that has evolved for a particular aquatic system. Because nutrients in the natural aquatic system are precariously balanced, the extent to which enrichment pollutes the water depends on the amounts and proportions of the nitrogen or phosphorus inputs. The term used for the enrichment of water by inorganic nutrients is **eutrophication**.

The most obvious effect of eutrophication is the decrease of species richness and the dominance of particular types of organisms such as those that function as collectors and filterers. Additionally, the **biomass** or total weight of the biological community (both

plant and animal) will increase, sometimes causing large die-offs that will deplete the water of dissolved oxygen when the aerobic bacteria begin to decompose the material. This effect, which is called the **biochemical oxygen demand,** is measured in the laboratory by determining the amount of DO that is depleted from a sample of water incubating for five days at 20°C. The final effect of eutrophication is an increase in the turbidity of the water caused by the increased production of phytoplankton and dissolved and suspended organic material. **Turbidity,** measured in nephelometric turbidity units (NTUs), is the measure of the ability for light to penetrate water or water clarity.

Fine inorganic sediments as a pollution source can come from the atmosphere as dust particles blowing off exposed land, from water eroding the exposed land surface and entering the stream as runoff, and from large spills and natural or human-induced landslides.

For fish, the effects of transported sediment can range from minimal to lethal depending on the duration of exposure. Fish can usually avoid sediment discharge events by relocating, assuming a suitable habitat exists. BMIs on the other hand, are not very mobile, and are usually killed directly by suffocation or erosion of their very delicate gill surfaces.

Sediment is most detrimental to the aquatic environment when it is no longer suspended and deposits on the stream substrate. Deposition of sediment can fill pools used as habitat by fish and interstitial areas of riffle gravels used for spawning. Healthy communities of BMIs which depend on a diverse substrate size, available interstitial spaces, and a complex habitat can be significantly affected or eliminated by sediment deposition. Eventually, fish, amphibians, and many terrestrial animals will be affected when BMIs biomass decreases, causing a disruption to the natural food web.

The degree of impairment to fish and BMIs are related to the extent and duration of sedimentation. Recolonization of affected areas by some organisms can occur rapidly. However, reestablishment of the aquatic community to its original productive assemblages can take from one to four years after conditions improve.

The Effects of Chemical Contaminants

Although non-toxic substances such as nutrients and inorganic sediment are important contributors to water quality problems, toxic pollutants can be more spectacular, especially from a major spill in the environment. The following list shows the major types of toxic pollutants that can enter the aquatic environment primarily from industrial, agricultural, urban, and municipal wastewater discharge:

Metals - lead, nickel, cadmium, zinc, copper and mercury.

Organic Compounds - organochlorine pesticides and herbicides, polychlorinated biphenols (PCBs), chlorinated aliphatic hydrocarbons, solvents, surfactants, petroleum hydrocarbons, polynuclear aromatics, chlorinated dibenzodioxins, organometallic compounds, phenols and formaldehyde.

Gases - chlorine and ammonia.

Anions - cyanides, fluorides, sulphides and sulphites.

Acids and Alkalis - any compound that changes the pH of water.

The science that measures the effect of toxic compounds in water is called **aquatic toxicology**. It is necessary to understand at least some of the terminology to better understand the severity of water contaminants. The potential danger of a substance to the aquatic environment is dependent on its toxicity, how long it remains toxic in water or **persistence**, and its potential to bioaccumulate. **Bioaccumulation** occurs

wastes are discharged in excessive amounts, it can cause high BOD which can also produce fish kills. Industrial waste is often warmer than the receiving waters and therefore can elevate ambient water temperature. The effluent may also have the ability to change the DO, pH or other ambient water quality parameter.

Mineral Mining Wastes - Mineral mining for gold, silver, and mercury has been going on in California since the 1840's. Most people are aware of the devastating results that hydraulic mining had on the rivers and mountains of the Sierra and the vast piles of rocks left on the banks of rivers from placer mining. Much of this damage is still evident today in the form of altered stream channels and stream beds laden with mercury. There are several locations in California where abandoned mines are still polluting streams and rivers. Waste treatment can be quite expensive and when there is no responsible party, it is up to the government, which is reluctant to pay the bill. Modern mining is less damaging to the physical component of the river, but discharge of chemical wastes through surface and groundwater sources can still be a concern.

Acidification of surface water which drains to streams and rivers can be the most serious threat to the aquatic environment. Reduction in the pH can dissolve metals forming more toxic compounds. Acute effects of the acidic and metal contaminated wastes from mining operations can totally kill a section of stream. However, in most cases where high concentrations of contaminants have been discharging into a stream for an extensive period of time, all but a few organisms will be gone. There always seem to be some types of very tolerant invertebrates that continue to exist in even the most polluted streams. Chronic effects of mine pollution have been shown to cause altered community composition of fish and invertebrates with lowered growth and reproductive rates.

Municipal Wastewater Discharge - The first pollution problem a society has to deal with is the waste from humans. The most significant effect of municipal wastewater is its threat to cause diseases in humans such as typhoid fever, cholera and dysentery. Human pathogens are bacteria that are detected in wastewater or the water body receiving human waste by the presence of indicator organisms. The coliform indicator *Escherichia coli* or *E. coli*, detected from a fecal coliform test, is most commonly used for testing wastewater. All human wastewater is treated to kill human pathogens by chlorinating the water. Since chlorine is highly toxic to aquatic organisms, the chlorinated water is dechlorinated using hydrogen sulfide before it is discharged.

The most significant alteration that municipal wastewater has on stream hydrology is to increase the base flow of streams and small rivers. Some streams that are normally intermittent become perennial because of the increased discharge from municipal wastewater treatment plants. This has become a particular problem in some parts of California where fish populations have developed in streams that had none because it was normally dry in the summer. These **effluent dominated streams** will have fish kills on occasion when the complex effluent becomes toxic. The question becomes: "should the discharger be responsible for killing fish in a stream that did not have fish to begin with?" The answer is "yes" because the California Department of Fish and Game (DFG) has laws that protect aquatic communities that have been established by humans.

The primary components of municipal wastewater are nutrients and dissolved and suspended organic matter. Most of the nutrients are discharged as phosphorus and nitrogen in the form of NH_3 and NO_3^-. Acute effects to aquatic organisms usually occur when there is an accidental spill of chlorine or when the system becomes overloaded and too much of the nutrients are in the form of ammonia. However, excessive plant growth stimulated by nutrients and excessive suspended organic matter can cause occasional high BOD and resulting fish kills. Chemical contaminants from household use,

or when industrial discharge is routed through the municipal wastewater treatment plant, can cause occasional acute and chronic effects to aquatic organisms in the receiving waters. Municipal wastewater is often warmer than the receiving waters and therefore can elevate ambient water temperature. The discharge may also have the ability to change the DO, pH, or other ambient water quality parameters.

Fish Hatchery Discharge - People usually enjoy visiting a state or federal fish hatchery because they think of it as an environmentally good thing to add trout or catfish to streams and lakes. Indeed, most people would never be able to catch a fish and many streams would not have salmon if it were not for fish hatcheries. There are two categories of state and federal fish hatcheries:

Enhancement hatcheries which produce both catchable fish for planting in streams and lakes as part of a "put and take" fishery, and young fish which will grow and add to the resident population.

Mitigation hatcheries which produce fish, usually salmon, to mitigate for human activities that have destroyed fish habitat, usually spawning grounds above a dam.

There are also many private fish hatcheries that grow fish for the commercial market. Recently fish planting activities have come under intense scrutiny from angling clubs that want to promote wild trout and do away with hatchery fish, and from some environmentalists who believe high Sierra streams and lakes that were "fishless" should remain so or be converted back to fishless by curtailing fish planting in those streams. You hear the phrase "rainbow trout pollution" used today to refer to the spread of non-native trout species in streams and lakes where they originally did not occur.

Warmwater fish such as catfish and bait minnows are grown in ponds and coldwater fish such as trout and salmon are grown in raceways. Usually the water used in ponds is pumped from wells and the water discharged into a nearby river or stream when the fish are harvested. With raceways, the water comes in the top end and exits at the bottom. Raceways contain large quantities of fish that require cool, highly oxygenated water so it usually comes from a nearby stream, spring, or rarely, pumped from a well. The same amount of water that comes in, goes back into a river or stream after it passes over the fish once. Only a few coldwater fish hatcheries recirculate the water. Some hatcheries have water treatment systems that usually consist of settling ponds receiving the water before it is discharged into the receiving waters.

Even though fish hatcheries are fun to visit since they are often located in beautiful mountainous areas, as far as water quality is concerned, they are nothing more than a fish factory or farm. They produce effluent similar to a municipal wastewater treatment plant, but without the human pathogens, and are usually regulated by the RWQCB and issued an NPDES permit. Hatchery effluent contains primarily dissolved inorganic chemicals, nutrients and dissolved and suspended organic matter that comes from fish excrement and uneaten food. This material is consistently discharged in coldwater hatcheries, and is much more concentrated when the raceways are cleaned and flushed of waste, including the algae that grows on the surface of the raceways.

There are rarely acute effects from hatchery effluent. However, nutrients and excessive suspended organic matter can cause excessive periphyton growth in the receiving waters and occasionally high BOD. Hatchery effluent can also contain chemicals used in disease treatment, salt, and fish pathogens. These substances can have chronic effect on aquatic organisms and may alter the ambient water quality parameters of streams and rivers.

Agricultural Practices - Agriculture is a large and important industry in California. Similar to mineral mining, most of the permanent damage from agriculture has already occurred in the form of land and water acquisition. Most of the wetlands in California have been drained or filled and the riparian areas around streams and rivers have been removed to make room for agriculture.

Only a few rivers in California have not been dammed at least once to store water for delivery to agricultural operations. Whether the dam is managed for irrigation water, drinking water, or flood control, it affects the aquatic environment in many ways including the prevention of upstream movement of migrating aquatic organisms, alteration to the natural hydrology and the disruption of energy or food distribution and sediment transport to the downstream river. Besides large dams, there are many smaller, lower impoundments or **run-of-river dams** that are used to regulate flow from larger dams and to divert flow into irrigation channels. Management of these dams can include flushing of accumulated sediment by releasing water from the bottom of the reservoir. Although there are always more plans for obtaining more water, most of the large scale projects funded by the government to support agriculture have been completed.

Activities that can affect the aquatic environment from the actual operation of the farm come from:
1) compacting and exposing soil on cropland;
2) withdrawing water from adjacent water bodies;
3) channelizing adjacent streams and rivers; and
4) producing return water containing salts, nutrients, inorganic sediment, and contaminants.

Farm operation activities have hydrologic consequences that can affect the physical integrity of streams and rivers. The capture of streamflow from rivers with dams decreases peak flows during the rainy period which prevents flushing of sediment from pools and gravel bars and prevents the natural sorting of substrate gravel. Concurrently, compacted soils on croplands increase runoff to smaller streams increasing peak flows during the rainy period and the likelihood of floods. During the irrigation season, water withdrawal can reduce streamflow and lower the water table. All these alterations to the hydrology of streams and rivers cause loss of habitat for aquatic organisms. Additional loss of habitat results from removing the riparian vegetation and large woody debris when streams adjacent to farmland are channelized.

Irrigated land usually has return water or excess irrigation water that discharges as an effluent into adjacent water bodies. The return water can be collected in drains and discharged as point source pollution or it can infiltrate through the groundwater or many different places along a stream as non-point source pollution. Return water is a complex effluent containing dissolved inorganic chemicals, nutrients and dissolved and suspended organic matter that was picked up from the soil and concentrated through evaporation. It can also contain traces of the fertilizers and pesticides used in growing the crops. All these chemicals can have an acute or chronic effect on aquatic organisms and will alter the ambient water quality parameter of streams and rivers. Horticulture and greenhouses compound the problem with additional output of concentrated pesticides and fertilizers.

Backyard Animal Husbandry - This pollution source is defined as the keeping of large animals as pets or for breeding as a side-business. It is much smaller an enterprise than commercial farming, but on a cumulative local basis can be a significant source of waste. Animal husbandry can be keeping a horse on your rural property, raising a couple beef cows or breeding and boarding dogs. The problem with the waste comes when it is not disposed of properly. Accumulating waste can infiltrate into the water table of a near-by stream or run directly into the stream during rain events, and when cleaning animal stalls. The most severe problems occurs when several rural lots, located along side a stream have horses or other large animals with untreated waste.

The primary components of the wastewater from backyard animal husbandry are nutrients and dissolved and suspended organic matter. Most of the nutrients are discharged as phosphorus and nitrogen in the form of PO_4^{3-} and NO_3^-. Acute effects to aquatic organisms are rare, but become more likely in the fall when the water flow is low and the water

temperature is at its highest. Acute effects are usually in the form of toxicity from NH_3 or high BOD levels. Most commonly, the waste results in excessive plant or periphyton growth stimulated by nutrients and excessive suspended organic matter. The wastewater may also have the ability to change the DO, pH or other ambient water quality parameters.

Road Surface Discharge - The building of roads is a component of many different land-use activities and the total amount of road surface area in California is staggering. Stream and riparian habitats are routinely destroyed while building roads because many roads wind their way through stream corridors. In the process, many streams are channelized to prevent erosion of stream banks that now have roads built on top. Roads contribute to increased runoff and increased delivery of contaminants and inorganic sediment to streams and rivers. Compacted gravel or dirt and paved asphaltic roads are all **impervious surfaces** or land surfaces that allow no infiltration and where virtually all the rainwater is runoff. Rain water, especially during the first few rain storms of the rainy season, carries with it all the oil, grease, and other chemicals that have fallen and accumulated on the road surfaces during the dry season.

Roads can also deliver large volumes of inorganic sediment to streams and rivers, especially from poorly maintained rural and forest roads. **Mass wasting** or the delivery of large volumes of soil to the stream through land slides is a symptom of poorly built roads or well-built roads on unstable geology. One large factor contributing to mass wasting is when two or more channels upslope of a road are combined through one culvert under the road and directed into one of the stream channels downslope of the road. This is usually done with smaller streams, but doubling or tripling the flow through a channel will inevitably cause mass erosion of the channel that can take large sections of road with it, and delivers enormous amount of sediment to a stream channel.

Urban Stormwater Discharge - Concentration of humans in urban areas affects the aquatic environment in a multitude of ways. All modern urban areas collect human waste and treat it in municipal wastewater treatment plants. Whatever industrial wastes are produced within the urban areas is treated through a municipal plant or a private treatment facility. One of the biggest concerns of the effects of urbanization on water quality is with the discharge of its **stormwater**. Stormwater discharge is one of the leading environmental problems in the U.S. and the management of stormwater is just now surfacing as an important activity of urban government. Stormwater in urban areas is the combination of runoff from all impervious surfaces including roads, parking lots, and other surfaces which do not have vegetation growing on them. Stormwater contains all the contaminants that fall on the road and parking lot surface, and of even more concern, all the house and lawn chemicals that are used by home owners, often in illegal concentrations. Home owners can contribute more fertilizers and toxic chemicals to streams and rivers than even industries and agriculture because they are not as rigidly regulated or educated on the use of landscape chemicals.

Stormwater discharge is one of the leading environmental problems in the U.S. and the management of stormwater is just now surfacing as an important activity of urban government.

Besides the problem with contamination, stormwater can cause hydrologic impacts and sedimentation problems. Concentration of runoff into storm drains will cause more episodic flow events with higher peak flows. Any natural stream channel receiving stormwater will have higher erosion and sedimentation of downstream reaches of the stream. Some stormwater discharge is treated typically by flowing into stormwater basins for settling of sediment and contaminants before it goes to the receiving waters. There are new environmental regulations on stormwater discharge and eventually it will all be treated. The RWQCB regulates stormwater discharge and a few NPDES permits have been issued to city governments or stormwater agencies.

Forestry Practices - The cutting of trees for timber products has been a dominant land-use practice in the mountainous portions of central and northern California since the mid 1800's. Although a higher volume of timber has been cut since the 1950's, most of the devastation caused by timber harvests goes back to early years. Early forestry practices used splash dams to push logs downstream with a tidal wave of water, ripping up the stream bed and riparian area at the same time. Stream zone timber was removed because it produced the largest trees that could be dropped directly into the stream for transport. Even with the less destructive methods of timber harvest and more protection for the stream zone, streams will need a long time to recover from the damage caused by past forestry practices.

The biggest impact to the aquatic environment today stemming from past forestry practices is the lack of large trees within the stream zone. These trees, when left to die a natural death and fall in the stream, help produce a healthy aquatic environment (see figure 3-4). **Large woody debris (LWD)** refers to the old-growth trees that littered the forested streams creating a stair-step effect of riffle areas and plunge pools that provided good spawning and rearing habitat for fish and a diverse aquatic community. It will take hundreds of years before the trees presently growing within the forested stream zone get to the size necessary to become stable instream habitat.

Other activities associated with forestry practices that can pollute the aquatic environment are: road construction, timber harvest, and the use of fertilizers, herbicides, insecticides, and fire retardants in forestry land management. Forestry practices are usually a non-point source of pollution and the RWQCB does not normally regulate its effect on water quality or issue NPDES permits. However, the California Department of Forestry and Fire Protection (CDF) does regulate forestry practices including promoting practices to protect fish and wildlife.

Forestry practices can affect the aquatic environment in the following ways:
1) destruction of instream and riparian habitat;
2) increased surface runoff;
3) increased input of inorganic sediment;
4) increased water temperature;
5) decreased, over time, input of nutrients and dissolved and suspended organic matter; and
6) water contamination with toxic chemicals.

Present regulations of forest practices gives some protection to fish-bearing streams. However, the emphasis is on perennial streams and the protection is less for intermittent streams. In most cases, instream and riparian habitats may not be directly destroyed, but most of the habitat destruction comes from increased delivery of inorganic sediment to the stream.

Water runoff to the stream is increased from soil compaction produced by timber harvest equipment such as tractors. The increased runoff going over exposed soil from dragging of logs over the ground or **yarding,** and surfaces of log storage areas or **landing,** brings sediment with the runoff. Additionally, large volumes of sediment can enter the stream when disturbed land, and in particular dirt roads built for timber harvest, slide into the streams. Studies have demonstrated that forest roads deliver more sediment to streams than any other forestry activity. As stated in previous sections, sediment deposition can fill pools used as habitat by fish and interstitial areas of riffle gravels used for fish spawning and living space for BMIs.

When trees in the riparian areas of streams are removed, it allows for sunlight to reach the stream and increase water temperature. The increase sunlight can also increase primary production which results in more periphyton growth on stream substrate. Immediately after timber harvest, the nutrient and dissolved and suspended organic matter increases when the debris from logging and the nutrients in the disturbed soil enters the stream with the increased runoff. This dissolved, readily available, material will

stimulate the increased periphyton growth. However, eventually the flow of nutrients will decrease with the loss of trees from the watershed and ensuing loss of leaf litter and decomposing trees.

Nutrients can be added to the ecosystem by forest managers that want to stimulate new tree growth. These nutrients are in form of urea or other chemicals containing NH_3 or NO_3. Other chemicals that can be added to the new forest ecosystem are herbicides to reduce the growth of competing vegetation, insecticides for control of diseases that can spread rapidly through new growths of single species forests, and fire retardants that are used to control wild fire that can harm the new forest. These chemicals can have an acute effect to aquatic organisms if the material is accidentally spilled during application or when unexpected rains deliver active contaminants to the stream. Chronic effects can occur when contaminants infiltrate into the stream or are delivered as residue on COPM.

Grazing Practices - Although forestry practices are a primary land-use activity in the northern portion of California, grazing practices dominates most of all the non-urban portions of the rest of California. Cattle and sheep grazing on western rangeland has been going on since the 1800's. Grazing practices have altered California's natural vegetation resulting in the spread of non-native grasses and weeds. By the 1930's, the devastation of the natural integrity of western grassland was so well documented by the U. S. Forest Service that congress created the U.S. Grazing Service (now called Bureau of Land Management) to manage the nation's rangelands.

Although there have been efforts to curb overgrazing, riparian corridors of most rangeland streams are still in bad shape. Livestock tends to congregate in the stream zone because it offers water, shade, cooler temperatures, and more food. Grazing is still a significant land-use activity in California and occurs on private, public, and even in wilderness areas. Grazing practices are strictly a non-point source of pollution and the RWQCB does not normally regulate its effect on water quality or issue NPDES permits.

Grazing practices can affect the aquatic environment in the following ways:
1) destruction of instream and riparian habitat;
2) increased surface runoff;
3) increased input of inorganic sediment;
4) increased water temperature and;
5) increased input of nutrients and dissolved and suspended organic matter.

Livestock in the riparian area and stream channel leads to denuded stream banks, wider and shallower channels, **downcutting** of the stream channel and elimination of undercut banks and instream woody debris. Soil compaction throughout the watershed leads to decreased infiltration rates through the soil and therefore increased runoff, leading to increased likelihood of flood events. Increased overland runoff and higher peak flows in combination with riparian and stream bank disturbance lead to higher input of inorganic sediment which further destroys instream habitat. A denuded riparian zone allows more sunlight to reach the stream which results in increased water temperatures. Finally, overland flow of wastewater and direct deposit of livestock waste into the stream channel can increase nutrients and dissolved and suspended organic matter.

The most serious threat of pollution from grazing practices comes from habitat destruction and increased sedimentation. Livestock contributes to chronic effects that result in loss of environmentally sensitive plants and animals, a dominance of tolerant plants and animals, an overall decrease in community diversity and a functional imbalance in the food web. Chronic effects of livestock waste comes in the form of excessive plant or periphyton growth stimulated by nutrients and excessive suspended organic matter. Obvious acute effects of grazing practices is rare, but could most likely occur in the fall when water flow is low and the temperature high. In this case,

toxic levels of NH_3 from livestock waste or a high BOD level from die off of excessive plant growth could cause death to aquatic organisms.

Flood Control Practices - People usually do not think of flood control measures as a type of pollution. When a devastating flood rips through a community of humans, they decide that nothing else matters except to save property and prevent the possibility of human death. The objective of any flood control project is to conduct water through the community as fast as possible. The compounding effect of urban stormwater discharge contributing to rapid peak discharge, makes flood control even more difficult. The land-use activities associated with flood control are building of upstream dams, removing of riparian vegetation, and channeling of stream corridors. All these activities alter the physical integrity of rivers and streams and as result, are considered water quality impairment or pollution.

The building of dams, which has also been addressed in the Agricultural Practices section, is the most detrimental component of flood control. Most dams are multipurpose, and the ones used for storage of irrigation water for agriculture are also used for flood control. The management of flood control dams will alter the natural hydrology of rivers and streams by holding back winter high flows and artificially increasing flow when dams need to be drained in anticipation of excessive flows. Riparian habitat is always removed by flood control engineers because the vegetation reduces the velocity of the water and can contribute debris that may clog up channels or harm bridge abutments. Some flood control districts will use herbicides on a regular basis to prevent riparian vegetation from growing back. Overall, most traditional flood control practices have undermined the function and value of flood plains, and may contribute, in the long run, to catastrophic events. The history of flood suppression and wild fire suppression have many interesting parallel lessons to teach us.

Hydroelectric Projects - The use of water to produce electricity is termed a **hydroelectric project**. These projects which involve a complex manipulation of streams and rivers is regulated by the Federal Energy Regulator Commission (FERC). There are many projects throughout California and each has a licence which is renewed every 50 years. Between 1993 and 2010, fifty-one projects representing 213 dams will be in review or will be up for re-licensing. The re-licencing process does allow the public an opportunity to review the impacts that the project causes to the aquatic system and to request that some of those impacts be mitigated or eliminated.

The effects of dams on the physical and biological health of streams and rivers has been addressed in the Agricultural and Flood Control Practices sections. The extent of the problems associated with hydroelectric projects are directly related to the amount of flow regulation associated with the project. Some projects have small dams that can take a considerable volume of the stream flow and divert it through a flume or pipe to an electric power generator. The amount of power generated is a product of water volume and elevational drop to the generator. Projects with a larger elevational drop can reduce flow or de-water a long section of the stream channel.

Large dams that produce electricity at their base can cause a change in the discharge by orders of magnitude within a twenty-four hour period. This cycling of the water to produce power at opportune times of the day is called **peaking**. The predominant negative effect of peaking flows is to the downstream aquatic community that are unable to adapt to the artificial flow regime and unstable habitat conditions. Filter-feeding organisms that are usually very abundant below impoundments will disappear because they are unable to capture food in a reliable manner. The most severe effects will be stranding or dessication of aquatic organisms due to periodically reduced flows. The ambient water chemistry conditions can also be impaired from the water cycling.

Navigational Improvement Activities - Most of the long-term damage to the aquatic environment from navigational improvement activities has already occurred in the form of habitat destruction. Streams and rivers in their natural state are littered with LWD and their complex channels consist of oxbows, multiple channels and small impoundments. Navigational engineers on the other hand, want a deep, straight channel with no snags to harm boat hulls and propellers. Most of the channelizing of navigational rivers occurred in the last century and today most of the activities consist of maintaining those channels and dredging the accumulated sediments that inhibit navigation. Another recent problem to navigation has been the proliferation of exotic aquatic weeds such as water hyacinth or hydrilla. Dense mats of aquatic plants can impede water travel and are usually removed by chemical means. Herbicides used for aquatic plants must be applied directly on the floating portion of the plant which means there is always a chance of acute and chronic toxicological effects to aquatic organisms.

Gold Dredging - Gold dredging is a popular sport and commercial venture, particularly in the gold country of northern California and the Sierra mountains. The activity occurs in the stream bed as a process of sucking up the substrate in a hose and separating the gold. The substrate is usually returned to the bed, but not in the same place. Gold panning is usually a small scale activity that can take material from outside the stream channel, quite often from the stream bank, for processing in the water. The effects of gold dredging and panning are:

1) direct killing of aquatic organisms;
2) habitat destruction, and;
3) input of inorganic sediments.

There are regulations for gold dredging which try to protect spawning fish and incubating eggs by dictating during which months dredging operations can occur.

BMIs are picked up from the substrate by the suction hose and either killed or discharged with the return water. Dredgers often say that they are benefitting the fish because they congregate near the return water to eat the bugs. This activity does not benefit anything, of course, when it causes the energy flow in stream to be disrupted. The size of the dredging operation and the size of the stream will determine the severity of the impacts. A large dredge in a small stream could significantly alter the stream community, but the impact would be minimal in a larger river. Dredging can produce considerable suspended sediment or turbidity during the operation which will deposit in downstream pools and riffle substrates.

Sand and Gravel Mining - Sand and gravel mining has a direct effect on the morphology of the stream bed since the activity requires earth moving machinery to be in the channel extracting the substrate. Sometimes the material is extracted from sand and gravel bars that form away from the active channel or from gravel pits that are dug in old river beds and with a levee built to prevent the active channel from flowing into the pits. Regardless of where the material is extracted, the channel will have to adjust to compensate for it. The adjustment can be in the form of increased meandering, widening of the channel, altering the pool-riffle sequence, and down-cutting of the channel bed. Quite often the adjustment will undermine human made structures such as bridge abutments.

Detecting Problems from Water Pollution

Acute and chronic effects from wastewater are best detected through ambient water quality monitoring. This may or may not be done by the RWQCB. Water quality monitoring can be quite expensive and there is insufficient money in government budgets to do an adequate job. The RWQCB usually depends on the dischargers with NPDES permit to report monitoring data which they collect themselves or have a consulting firm collect for them. Occasionally, there is special project money or grants that RWQCB's staff can apply for, usually from the U.S. EPA, to monitor waters of special

concern. Additionally, citizen monitors can collect the data that the government does not have the time or money to do. This is the topic of this manual and is discussed in depth in other chapters.

A sound ambient water quality monitoring program should measure the chemical, physical, and biological components of the water body receiving the wastewater. The chemical components consist of the routine water quality parameters (water temperature, DO, pH, conductivity, water hardness, turbidity and alkalinity), chemical contaminants (metals and organic toxins) and toxicity testing of water samples. Physical components consist of the near shore and instream structures which allow the water body to function naturally. The biological components consist of diversity, structure and function of the plant and animal community. Procedures for measuring the chemical, physical and biological integrity of stream and small rivers are discussed in depth in Chapter 8.

Literature Used in Preparing This Chapter

The following references were used in preparing this chapter and would be good material to read for more detailed information on the subjects discussed:

An Ecosystem Approach to Salmonid Conservation (TR-4501-96-6057). 1996. Brian C. Spence, Gregg A. Lomnicky, Robert M. Hughes and Richard P. Novitzki. National Marine Fisheries Service, Portland, Oregon.

Stream Ecology - Structure and Function of Running Waters. 1995. J. David Allan. Chapman and Hall, New York.

Chapter 5
Introduction to Water Quality Control and Regulation

Introduction to the Chapter

Although our Nation's lakes and rivers were not well protected from pollutants until the last half of the 20th century, the U.S. currently has some of the strictest water quality regulations in the world. Chapter 5 offers an overview of national and state water quality regulations. Sections of the National Clean Water Act and California's Porter-Cologne Act that you should be familiar with are described in detail. Water quality regulations involving beneficial uses, listing of impaired water bodies and total maximum daily loads (TMDLs) are discussed. The concept of biological criteria is explored using two separate, stand-alone documents, which lay out how California can develop and implement those criteria. Finally, this chapter lists 12 steps that citizens should follow to become involved with water quality regulation.

History of the Federal Clean Water Act

Legal authority for water rights and uses has been recognized for as long as laws and regulation have existed in this country. In California, water rights were first established by Spanish law as long ago as 1769.

The early focus on water use was primarily as a drinking supply and for conveyance of municipal and industrial wastes. Water quality became an issue only when the waterway deteriorated to the point that it no longer could be used for drinking. At that point, the standard used to judge the degree of pollution was whether it had become a public nuisance. Never was the concern for destroying aquatic life even considered, until many waterways began to loose their ability to support commercial fisheries.

Around the turn of the century, sanitation districts were established in some large eastern cities where water was becoming seriously polluted. Some cities such as Chicago started collecting data on the effects of waste to fisheries. However, the emphasis on collecting the water quality data was to protect cities from possible lawsuits for damaging commercial fisheries, and not necessarily because of wanting to protect fish and wildlife. In fact, it was stated that public nuisance could still be avoided even when all the fish were dead due to lack of sufficient oxygen in the water.

Enacted in 1948, the first federal water pollution control law was called the Federal Water Pollution Control Act. This legislation attempted to define potential uses for water in broad terms. The law stated: " ... regard shall be given to improvements which are necessary to conserve such waters for public water supply, propagation of fish and aquatic life, recreational purposes, and agriculture, industrial, and other legitimate uses". Although most of these uses only benefit humans, there was mention of protection for propagation of fish and aquatic life. However, it was never specified whether fish and aquatic life meant gamefish and commercially important invertebrates, or all aquatic life. Another inadequacy of this early law was that there was no agreed upon means of showing that these uses were being conserved.

The issue of whether all aquatic life was to be protected from water pollution or just those species that were economically beneficial to humans, was addressed in the 1972 amendment to the Federal Water Pollution Control Act. Public law 92-500, which we call the **National Clean Water Act (CWA)**, stated that its primary goal was to *"restore and maintain the chemical, physical, and biological integrity of the Nation's waters"*. The secondary goal for the CWA was stated as *"wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish,*

and wildlife and provides for recreation in and on the water be achieved by July 1, 1983". While this second goal may not have been achieved, it did state that fish and wildlife should be protected. Again, even in 1972, some government officials thought that protecting natural integrity of aquatic systems without regard to the need of the beneficial uses of humans was "unnecessary, uneconomical and undesirable from a social, economic or environmental point of view."

Despite the objections of many regulators and politicians, the CWA did have an ecological component. For the first time, law defined a beneficial use of water for the sake of the environment and not just as an economical benefit to humans. With critics hot on the trail, the next objective of Congress was to define "integrity". A 1972 House Committee on Public Works defined integrity as a *"concept that refers to a condition in which the natural structure and function of ecosystems is maintained."* They also added that *"on that basis we could describe that ecosystem whose structure and function is 'natural' as one whose system are capable of preserving themselves at levels believed to have existed before irreversible perturbation caused by man's activities. Such systems can be identified with substantial confidence by scientists."*

The CWA that we have today is a product of several "midcourse corrections" and amendments (the 1987 amendment was the most significant) to the original law. It is not perfect and is always under attack for being too protective or weak, but it is what we must work with. It is important for all those who are environmentally concerned to understand it.

Significant Features of the Clean Water Act

The National Pollutant Discharge Elimination System (NPDES) - The intent of Section 301 of the CWA is to regulate all pollutants from all facilities into virtually all waters of the U.S. Permits, issued by the U.S. EPA or state water quality agencies, are required for **point source discharge** which is defined as *"any discernable, confined and discrete conveyance from which pollutants are or may be discharged."* There is some special language in this section such as:
1) agricultural runoff and return flows from irrigation are exempt from the definition of point source;
2) all discharges to **publicly owned treatment works (POTW)** such as industrial discharge, must be pre-treated; and
3) that "navigable waters" include territorial seas and wetlands.

Technology and Water Quality Based Limitations - The CWA has a complex system of pollutant regulation for each industry category based on technology applicable to that industry. It starts with industries being held to the **best practicable control technology (BPT)** which is defined as *"the average of the best existing performance by well operated plants"* and it must consider cost-benefit considerations. There is the next step up for those dischargers of known toxic pollutants such as benzene and asbestos. They must achieve **best available technology economically achievable (BAT)** which is defined as *"very best control and treatment measures that have been or are capable of being achieved"*. This section also says:
1) nonconventional, nontoxic pollutants are regulated by BAT; and
2) it requires secondary treatment for all POTWs and give specific ambient water quality limits for their discharge.

Water Quality Standards - Section 303 of the CWA states that the technology based limitations are a national standard, but that more stringent water quality standards should

be developed for protecting water qualtiy in specific bodies of water. The authority to develop these standards is given to the states, subject to review by the U.S. EPA. There are six components to this section:

1) all water bodies must be designated by "best actual or possible use";

2) standards must be set for various water pollutants based on criteria developed by the U.S. EPA. Criteria are *"based on the latest scientific information on the relationship that the effect of a constituent concentration has on particular aquatic species and/or human health,";*

3) there must be a review of water quality standards at least once every three years and when necessary, standards must be revised or new ones adopted;

4) a list of water bodies that are not expected to meet water quality criteria, even with the best treatment of point source discharges, must be submitted to the U.S. EPA by 1989;

5) strategies to reduce discharge of toxins in the water bodies listed as not achievable water quality standards must be submitted to the U.S. EPA by 1992; and

6) a state-wide antidegradation policy must be enforced where instream uses and a high-quality water is maintained and protected.

A state can not normally downgrade the beneficial uses of water bodies if that would result in a less stringent water quality standard. On the other hand, states are encouraged to upgrade the beneficial uses where appropriate.

Non-point Source Discharges - The NPDES program does not regulate discharges which do not come out of a pipe or which are subject to confinement and treatment. Section 208 of the CWA requires states to identify waste treatment management areas where substantial water quality control problems exist, usually because of an urban/industrial concentration of pollutants. Section 319 requires states to identify waters, that without control of non-point source pollution, will not meet water quality standards. A management program using **best management practices (BMP)** to deal with the pollution must be submitted to the U.S. EPA. Section 402(p) requires the issuance of stormwater discharge permits under the NPDES program to municipal areas with populations over 100,000. These permits can be issued on an area-wide basis, such as city-wide instead of on an outfall-by-outfall basis.

Enforcement - Section 308 of the CWA authorizes states and the U.S. EPA to issue compliance orders, impose fines, prosecute criminally, imprison and blacklist from federal contracts, dischargers who violate water quality standards or provisions of the CWA. Under Section 505, citizens are allowed to sue any person in violation of an effluent standard, limitation, or provision of the CWA. The citizen must prove direct injury which can include loss of recreational resources.

Federal Financial Assistance and Grants - Under section 202, the original CWA provides up to 75% funding to communities to build municipal wastewater treatment plants. After 1984, the funding was dropped to 55% and as of 1990 a revolving loan program is used to help finance construction of municipal pollution control projects. Section 104(a)(3) makes grants to states, water pollution control agencies, interstate agencies, and other public or nonprofit private agencies, institutions, organizations, and individuals to conduct and promote research into the effects, extent, prevention, reduction and elimination of pollution. Section 106 authorizes grants to states for the prevention, reduction and elimination of pollution. These grants provide funding for the states to administer the provisions of the CWA.

Water Quality Control in California

Controlling water quality and protecting aquatic life in California lakes and rivers has always "taken a back seat" to water acquisition. In other words, water quantity issues usually take precedence over water quality issues.

Nearly all streams and rivers in the state have been either dammed, diverted, channelized

and in many cases, pumped completely dry to supply water for industry, agriculture, and residential uses. On the other extreme, some streams which would naturally have no surface flow during part of the year are flowing all year with treated effluent. These are called **effluent-dominated streams.**

Both water withdrawals and water additions will alter the natural hydrology of streams and rivers thus degrading its aquatic resources. Hydrologically altered water bodies are even more susceptible to point and non-point sources of toxic wastes and inorganic sediment. Because of California's excessive thirst for water, it is not hard to understand why almost every water body in the state fits the CWA's definition of polluted.

California had its own water quality laws long before the CWA was enacted. The California Department of Fish and Game was the first agency to enforce pollution violations using their Fish and Game Code 5650 established in the late 1800's.

Although most early California water laws protected water rights and flood control, in 1928 the state constitution was amended to require that all water use be "reasonable and beneficial". This was a starting point which eventually lead to the creation of the State Water Resources Control Board (SWRCB) in 1945 and the enactment of the Porter-Cologne Act in 1969.

The Porter-Cologne Act designated nine Regional Water Quality Control Boards (RWQCB) to set regional water quality standards, issue and enforce the terms of permits, monitor pollution control efforts, and implement nonpoint source pollution programs. The RWQCB's which were established by the major watersheds of the state include:

North Coast (Region 1);
San Francisco (Region 2);
Central Coast (Region 3);
Los Angeles (Region 4);
Central Valley (Region 5);
Lahontan (Region 6);
Colorado River basin (Region 7);
Santa Ana (Region 8); and
San Diego (Region 9).

Although the Porter-Cologne Act was considered a model for the CWA, the protective authority of the federal law supercedes state law. Presently, the SWRCB and the RWQCB's regulate water quality under the authorities of both the Porter-Cologne Act and the CWA.

The U.S. EPA regulates water quality at the federal level, but when the CWA says that the state is responsible, that means it falls under the SWRCB and the RWQCB as the designated agencies representing the state. Much of the funding to operate the SWRCB and the RWQCB comes from Section 104 and 106 grants.

The responsibilities of SWRCB and the RWQCB's that should be of particular interest to all those concerned with water quality are:

1) designate beneficial uses for water bodies;
2) issue and periodically review NPDES permits for water dischargers;
3) establish the Section 303(d) list of impaired water bodies for California;
4) regulate storm water and urban runoff;
5) determine **Total Maximum Daily Loads (TMDLs)** for the impaired water bodies; and
6) develop and adopt water quality management strategies for implementing TMDL reduction programs.

You should be aware of other water quality programs the RWQCB's are conducting in your area. You might even want to contact them to find out how they are protecting water quality for your neighborhood stream or river. And finally, ask the RWQCB how you can participate in water quality control in your area. But first, it is imperative to understand the following responsibilities of the RWQCB's.

Beneficial or Designated Uses - The first responsibility of the RWQCB is to designate for all water bodies their best actual or

possible use. Of course, this quite often means best use by humans, but you can look in the document that describes the water quality goals and objectives for the area within the jurisdiction of each RWQCB or the **Basin Plan** to see how their water body of interest is designated. Beneficial uses for water bodies in California include:

- Municipal and domestic supply
- Agricultural Supply
- Industrial Service Supply
- Industrial Process Supply
- Ground Water Recharge
- Freshwater Replenishment
- Non-contact Water Recreation
- Water contact Recreation
- Hydropower Generation
- Navigation
- Aquaculture
- Warm Freshwater Habitat
- Cold Freshwater Habitat
- Commercial and Sport Fishing
- Estuarine Habitat
- Wildlife Habitat
- Preservation of Biological Habitats of Special Significance
- Migration of Aquatic Organisms
- Rare, Threatened, or Endangered Species
- Shellfish Harvesting
- Spawning, Reproduction, and/or Early Development

Although the basin planning process is open for public review, there was little outside involvement with the original designation of most streams and rivers. If you disagree with the designation that has been given to your stream of interest, then find out how you could have input in the next review of the basin plan.

Beneficial or designated uses for California water bodies was based on "best professional judgment" at the time of issuing. You will find that very little "real" data was collected to determine the "best actual or possible use" for a particular stream or section of stream. It is important to collect and distribute new data so that it can be included to support or amend uses. Also remember the CWA has an antidegradation policy which says that beneficial uses cannot be downgraded, but should, hopefully, be upgraded over time.

NPDES Permitting - The primary way that the CWA controls water quality and protects the beneficial uses of a water body is by issuing NPDES permits which contain the standards by which the discharger can guarantee that they are not polluting the water. The RWQCB's issue these permits in California and they are a matter of public record. Each permit lists water quality criteria for the substances that are being discharged, and in the case of municipal wastewater treatment plants, the specific ambient water quality limits or water quality objectives for the receiving waters.

The discharger is required to monitor its discharge using techniques that will prove that their discharge is not degrading the chemical, physical, and biological integrity of the receiving waters. All concerned parties can review the permit and monitoring data to ensure that dischargers are not polluting or degrading the beneficial use of the receiving waters.

Establishing the Section 303(d) List - Not all NPDES permits are effective at preventing water pollution. Industry and POTWs can have problems achieving water quality standards and their self-monitoring techniques are not always effective enough to show if their discharge is indeed not affecting the chemical, physical, and biological integrity of the receiving waters. Under Section 303(d) of the CWA, the SWRCB, with the assistance of the RWQCB's, publishes a list of water bodies that are designated as **Water Quality Limited Segments (WQLSs)**. This list is revised every two years and is published in the "California Report on Impaired Surface Waters", by the SWRCB.

Determining TMDLs for Impaired Water Bodies - A Total Maximum Daily Load (TMDL) is the amount of a pollutant that can be discharged into a water body and still maintain water quality standards. The formula for a TMDL is:

TMDL = WLA + LA + MOS; where

WLA = waste load allocation from all point sources;

LA = load allocation from non-point sources and natural background levels; and

MOS = margin of safety to account for uncertainty.

The product or endpoint of a TMDL can be expressed in mass or pounds of a substance being discharged to the water body per time, such as daily or annually. When this endpoint is determined, then the amount of the substance being discharged at each point source can be adjusted so that the water quality standard for that substance is met. The TMDL process occurs after the WQLSs are established and prioritized according to need and interest. A public hearing allows citizens and dischargers to contribute to the prioritizing of water bodies. Performing a TMDL is technical and, as you will see in the next section, controversial. However, it is important for all concerned to understand what a TMDL is and how it can be used to control water pollution.

History and Implementation of TMDLs

Immediately following the passage of the CWA, all of the effort in pollution control was directed toward cleaning point-source discharges and determining water quality standards or criteria. U.S. EPA had little interest or time to force states to comply with features of Section 303(d). In fact, those elements of Section 303 would be necessary only if water quality standards could not be met through point-source discharge control.

Eventually, complaints started pouring in stating that water pollution was not being eliminated in some water bodies by controlling point source discharge. States started to establish 303(d) lists, usually not based on real or accurate data. Some states were very liberal in listing water bodies hoping to attract more U.S. EPA grant money to fix the problems. However, in most cases, states were not fast in performing the subsequent TMDLs and the U.S. EPA was not fast in requiring them. U.S. EPA was so overwhelmed in dealing with point source dischargers and establishing water quality standards, that the lack of state submission of TMDLs was welcomed. If states did not submit TMDLs, then the U.S. EPA did not have to deal with reviewing and approving them.

This avoidance mentality by the U.S. EPA lasted until citizens, tired of heavily polluted water bodies not being cleaned up, began suing under Section 303(d). There were several lawsuits throughout the country challenging the quality of the states submissions under Section 303(d) and the adequacy of the U.S. EPA's response.

The first lawsuit to reach judgment was in the state of Idaho, where the Idaho Sportsmen's Coalition sued the state water quality agency through the U.S. EPA for not dealing with water quality problems. Ultimately the state was given five years to adequately assess water quality conditions on 962 WQLSs and to produce TMDLs. This judgment was given in August 1996 and, by early 1997, most states submitted a list of WQLSs in the hope of avoiding similar lawsuits and judgments.

In the coming years, challenges to the quality of the data used to establish 303(d) lists and adequacy of the science used to determine TMDLs will inevitably continue.

Although the formula used for determining TMDLs looks quite simple, it involves quantifying very complex processes. Simple case scenarios where the calculations might be conceivable would be:

1) if there is only one pollutant being discharged in a water body,
2) if the U.S. EPA has listed the criteria for that substance, and
3) if the non-point sources or background levels are minimal, or
4) if the hydrology of the water body is simple.

The formula becomes more complicated when the pollutants are non-toxic themselves, but contribute to toxic conditions. Some examples are inorganic sediment and nutrients. And of course, real world situations of complex hydrology, unknown quantities of the substance in non-point sources and background levels, and a complex environmental fate of the substance, add to the difficulties of obtaining accurate endpoints for the TMDL.

As a result of lawsuits, TMDLs are being developed by the U.S. EPA and the corresponding RWQCB's for a few California streams. One lawsuit is for Newport Bay in southern California and several other lawsuits are for northern California streams. In Newport Bay the pollutant is nutrients, and in the northern California streams, it is sediment.

To avoid more lawsuits, the SWRCB submitted a TMDL process to the U.S. EPA in 1992. The process described in the "California Report on Impaired Surface Waters" was approved by the EPA and consists of the following major activities:

1) perform a **Water Quality Assessment (WQA)**;
2) identify the highest priority waters;
3) prepare action plans or TMDL Worksheet; and
4) conduct periodic reviews and updates.

This California style TMDL is different than the simplistic model of a TMDL outlined above. The SWRCB says the TMDL formula from the model will not work because it primarily depends on allocating load-to-point source discharges. In California, most of the pollutants have a non-point source origin and controlling point source dischargers will not be sufficient to achieve water quality objectives.

The WQA is a catalog of the state's major water bodies and descriptions of their general condition based upon review of current information and public and agencies' input. The action plans or TMDL Worksheets provides a summary of the problem, the location, the water quality target, and the activities intended to meet the target.

There are three major sections of the TMDL Worksheet:

1) location description including areal extent, pollutants, sources and a narrative explaining the magnitude of the problem;
2) the "Quantifiable Target" or goal which will improve, restore, or protect the beneficial use that was identified as being adversely affected. The SWRCB intends for this to be a replacement for the TMDL or what they call a "phased TMDL"; and
3) the implementation and monitoring strategy which includes a combination of studies, monitoring, basin planning, permits and demonstration projects.

Finally, there is a review process every two years which includes participation from the SWRCB and EPA staff, as well as the public.

Other Federal Laws That Govern Water Quality

In 1972 when the CWA was passed, there was another important law enacted, the **Safe Drinking Water Act**, which set specific limits for contaminants in drinking water. Although this law pertains to the protection of human health, it helped to control the pollution of the nation's water ways.

In 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Known as the "Superfund Act", it was created to clean up contaminated sites, including abandoned mines. Contrary to its name, this program is underfunded, but some of the most heavily polluted areas of the country that no one wanted to take responsibility for, have eventually been addressed.

In 1990, the Coastal Zone Act Reauthorization (CZARA) required that coastal states develop plans to control non-point pollution to restore and protect coastal waters. In the Act, Congress declared that

runoff is "a significant factor in coastal water degradation" and that "there is a clear link between coastal water quality and land use activities along the shore". California stated in 1995 that the existing non-point controls satisfy CZARA.

Recommended Steps for Getting Involved in Water Quality Regulation

Aquatic systems in California are in need of help. The legal process to protect and enhance water quality is complex and with all the demand for water in a dry-climate state, help for the aquatic environment can be hindered. Well educated citizens with a no-nonsense approach to water quality issues will be able to accomplish a great deal to improve our state's rivers and lakes. Those wanting to become involved with water quality regulation should follow these steps:

1) read the CWA or at least a summary of the significant features of the Act.

2) identify and locate the RWQCB in your area.

3) ask for a copy of the Basin Plan and have your name put on the mailing list for a schedule of any public hearings dealing with your area's streams or rivers.

4) determine which watershed you live in.

5) determine the beneficial uses designated for your area's stream and rivers or the segments you are interested in.

6) determine whether the stream segment has been listed as a Water Quality Limited Segment.

7) if it has been included on the 303(d) list, then obtain a copy of the "California Report on Impaired Surface Waters" and read the Water Quality Assessment that was performed on the stream segment.

8) With assistance from the RWQCB, find out what type of data were collected to ensure that the stream segment was properly listed or not listed on 303d list.

9) with assistance from the RWQCB, determine whether there was enough good quality data to determine the chemical, physical, and biological integrity of the stream.

10) put your emotions aside and deal with the RWQCB on a no-nonsense basis. Ask them whether a TMDL or its equivalent is scheduled to be conducted on the stream segment and how you could participate.

11) whether or not your favorite stream is listed as an impaired water body, get involved with, or form a citizen watershed group that will help to assess the chemical, physical and biological integrity of the stream segment. This is a critical way you can help to improve the water quality on your stream or obtain the information to convince the RWQCB that a problem exists.

12) promote the use of physical and biological assessments as part of an effective water quality monitoring program. Once you have collected sound and reliable data on the biological condition of your stream, then ask the RWQCB what the physical and biological standards should be for your stream. If they cannot answer your questions, then ask them why. Persistence is often essential for success.

Developing Biological Criteria for Regulating Water Quality in California

In more than a quarter century of the CWA, water quality has undoubtedly improved in some heavily polluted streams and rivers, but in general, water resources are still in decline. Water resource problems are not just associated with chemical contaminants coming from point source discharges. Most problems with our water resources, especially in California, are associated with water withdrawal and sediment and nutrient pollution. The consequences are biological in nature and the evidence of polluted water

bodies is measured in lack of biological diversity, elimination of sensitive species of plants and animals, proliferation of alien species, and in some cases, extinction of native or indigenous species.

The U.S. EPA has conducted most of the studies documenting the physical and biological deterioration of our nation's rivers and lakes. They started addressing these concerns in the mid 1980's by developing physical and biological monitoring techniques and by encouraging states to develop biological criteria. These are similar to chemical criteria and will establish biological water quality standards. Only a few states have started developing biocriteria in earnest. California, for example does not have a formal biocriteria program. However, many efforts to promote biocriteria development are underway.

The purpose of this manual is to introduce biological monitoring techniques using benthic macroinvertebrates (BMIs) to the citizens of California. The goal is to solicit concerned citizens and resource professionals to support biocriteria as a water quality regulatory tool in California. The following six premises present the foundation to support the development of a state-wide physical and biological monitoring program using BMIs and eventually implementing biocriteria. *(The following premises have been modified from a DFG and CalFed document and, with the accompanying references in Appendices A and B, can be a stand-alone document and copied from this manual without copyright infringement)*:

Premise 1: Physical and biological monitoring and biocriteria are mandated by the Clean Water Act - The primary objective of the National Clean Water Act (CWA) is to: "restore and maintain the chemical, physical and biological integrity of the nation's waters". To comply with the CWA, the U.S. Environmental Protection Agency (EPA) has requested that all water resource management programs evaluate the effects of human activities on the chemical, physical and biological components of water resources. The EPA further cites the CWA in supporting their request that states develop biological criteria. Section 303(c)(2)(B) of the CWA states that: "States shall adopt criteria based on biological monitoring or assessment methods" and Section 304 (a)(1) states that: "States shall develop and publish criteria for water quality accurately reflecting the latest scientific knowledge... on the effects of pollutants on biological community diversity, productivity and stability" (Gibson 1996).

Premise 2: Integrating biological measures with physical and chemical measures provides a more relevant assessment of water resource condition - Water quality has traditionally been assessed with indirect measures of aquatic health, emphasizing chemical and toxicity testing. As a result, water resource agencies in California have only developed criteria and standards for some chemical contaminants. Criteria based on biological communities should be used in water resource management because they add a direct assessment of ecological health. Biological assessments of water resources integrate the effects of water quality over time, are sensitive to multiple aspects of water and habitat quality and provide the public with more familiar expressions of ecological health than the results of chemical and toxicity tests (Gibson 1996). Furthermore, when integrated with physical and chemical assessments, biological assessments better define the effects of point-source discharges and provide a more appropriate means for evaluating discharges of non-chemical substances (e.g. sedimentation and habitat destruction).

Direct measurements of ambient biological communities including plants, invertebrates, fish, and microbial life have been used for the past 150 years as indicators of sanitation, potable water supplies and the health of water for fisheries and recreation. During the past decade, the following four tools have been developed on a national level to transform biological assemblage data into numeric criteria and standards (Davis and Simon 1995):

- providing a functional definition of biological integrity to serve as an understandable and practical water resource goal;
- minimizing the problems with interpreting the natural geographic and temporal variability of data by aggregating within regions of ecological similarity;
- using multiple reference sites within ecological or faunal regions to obtain assemblage expectations, or reference conditions for specific geographic areas; and
- combining several assemblage attributes (or metrics) to produce a single numeric measure of biological integrity.

Even without the development of standards, the concept of biological criteria can be used as a watershed management tool for assessment, surveillance and compliance of land-use best management practices. Combined with measurements of watershed characteristics, land-use practices, in-stream habitat, and water chemistry, bioassessment can be a cost-effective tool for base-line and long-term trend monitoring of watershed condition.

Premise 3: The Index of Biological Integrity (IBI) and the River Invertebrate Prediction and Classification Scheme (RIVPACS) model are demonstrated tools for expressing the condition of water resources - The U.S. EPA defines biological integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitats of a region". Karr (1981) first published an Index of Biological Integrity (IBI) as a consistent means of measuring the societal goal of biological integrity. Based on a combination of tested biological attributes of water resources, the IBI provides a cumulative site assessment as a single score value (Davis and Simon 1995). The IBI is the end point of a multi-metric analytical approach to biological assessment which has been successfully used by many state water resource agencies (Davis and Simon 1995).

RIVPACS and its derivatives (Simpson et al. 1996) are empirical models that predict the aquatic macroinvertebrate fauna that would be expected to occur at a site in the absence of environmental stress (Barbour et al. 1997). With few exceptions the sampling strategies and end product are similar with either the multi-metric and multi-variate approaches. According to the EPA, the use of biological endpoints can enhance the following water resource assessment activities (Barbour et al. 1997):.

- determine the status of the water resource.
- evaluate the cause of degraded water resources and the relative contributions of pollution sources.
- report on the progress of activities to assess and restore water resource integrity.
- determine the effectiveness of control and mitigation programs.
- measure the success of watershed management plans.

Premise 4: The benthic macroinvertebrate community is the most common and often the best measure of biological integrity - Half of the states' water resource agencies (26) use fish assemblages in assessing the quality of their rivers and streams (Davis et al. 1996). However, integrating metric values for fish into one number representing an IBI score is difficult for aquatic systems west of the Rocky Mountains and especially in California. Moyle and Marchetti (1998) describe some of the difficulties as:

1) inherent low species richness especially within trout streams;
2) abundance of introduced fishes even in pristine waters; and
3) altered natural assemblages resulting from fish stocking and angling pressure.

Recent work in the Cosumnes River (DFG 1998) has also indicated difficulties in the use of fish IBI scores, especially on a stream reach-scale assessment of water resources. Rivers and streams with anadromous fish species present a unique problem since the health of these populations is additionaly affected by problems outside the watershed such as ocean conditions, commercial harvest, predation and a deteriorated estuary.

Water resource monitoring using benthic macroinvertebrates (BMI) is by far the most popular method used throughout the United States (Barbour et al. 1997). Forty-four states use BMI assemblages in assessing the quality of their rivers and streams (Davis et al. 1996). Besides integrating the effects of environmental stresses similar to other biological measures, BMIs are ubiquitous, relatively stationary and their large species diversity provides a spectrum of responses to environmental stresses (Rosenberg and Resh 1993). Individual species of BMIs reside in the aquatic environment for a period of months to several years and are sensitive, in varying degrees, to temperature, dissolved oxygen, sedimentation, scouring, nutrient enrichment and chemical and organic pollution (Resh and Jackson 1993). Finally, aquatic invertebrates represent a significant food source for aquatic and terrestrial animals and provide a wealth of evolutionary, ecological and biogeographical information (Erman 1996).

Premise 5: EPA guided standardized methodology for measuring biological condition of water resources exists for California including procedures for citizen monitors - In 1993, DFG introduced standardized field sampling, laboratory identification and quality assurance/quality control (QA/QC) procedures for assessment of wadeable streams using benthic macroinvertebrates. These California Stream Bioassessment Procedure (CSBP) were developed from U.S. EPA guidelines (Plafkin et al. 1989) and input from aquatic biologists throughout California involved with biological monitoring. The CSBP is continually reviewed and refined through annual meetings of the California Aquatic Bioassessment Workgroup (CABW) sponsored by DFG, the SWRCB and U.S. EPA. Now in its third revision, the CSBP is a regional adaptation of the U.S. EPA Rapid Bioassessment Protocols (Barbour et al. 1997) and is listed by the U.S. EPA as the protocol being used in California for biocriteria development (Davis et al. 1996).

The CSBP is being used by environmental consulting firms and state water resource agencies throughout California in point-source assessment of waste discharges, evaluation of toxic spill events and ambient bioassessment programs. Watershed based assessments using the CSBP include the Cosumnes River, Sacramento River, Russian River, Morro Bay watershed, Guadalupe River, and all the major watersheds within the boundaries of the San Diego RWQCB.

A CSBP document entitled "Habitat and Biological Assessment for Citizen Monitors" was introduced in March 1996. The procedure is a generalized state guideline to

help citizen monitors produce high quality, reliable assessments of stream habitat and biological condition. Since 1997, several groups throughout California's watersheds have been trained by the Sustainable Land Stewardship Institute. Some of these groups received grants for equipment and for QA/QC and validation sample analysis which will be used to test their effectiveness and accuracy in assessing the biological condition of their local streams.

Premise 6: Information on the distribution and taxonomy of benthic macroinvertebrates and their sensitivity to natural and human induced perturbations will further improve the use of benthic macroinvertebrates as a biological measure of water resource conditions - Bioassessment is a water resource management tool and does not provide the detail of information necessary to understand species distribution. A recent status report on the Sierra Nevada ecosystem noted that there are many endemic species of aquatic invertebrates known nowhere else in the world and that there are probably many more endemic species to the Sierra Nevada unidentified due to the lack of adequate invertebrate surveys (Erman 1996). Research is needed on benthic macroinvertebrate taxonomy and distribution to improve bioassessment as a water resource management tool.

Some biological metrics used in developing an IBI require information on the sensitivity of benthic, macroinvertebrate species to organic enrichment, chemical contamination, sedimentation and habitat degradation. Reliable relationships have been developed for many invertebrates, but the research was not conducted in the west. Research is needed to develop relationships based on western species of benthic macroinvertebrates. [1]

[1]Appendix A contains the references for this document.

The Conceptual Basis for Implementing Biocriteria in California

The three conceptual models presented in this document present the framework for developing a water resource monitoring tool that eventually can evolve into a biocriteria program for California. The first presents the general concept of biocriteria and the other two present a watershed or regional-scale model and a stream reach-scale model. Together, these models provide the framework with which to build a successful program for California. A single flow chart (Figure 5-1) summarizes and illustrates how the three conceptual models are linked together.

(The following conceptual models have been modified from a DFG document and with the accompanying references can be a stand-alone document and copied from this manual without copyright infringements)

Conceptual Model 1: Biological Criteria for California

The concept of biological criteria was developed by the U.S. EPA for establishing water quality standards based on the integrity of biological communities. However, before standards based on biological information are implemented, the concept of biocriteria can be applied to problem identification to help prioritize watershed improvement projects, project evaluation, and monitoring long-term trends in water resource condition. The U.S. EPA (Gibson 1996) proposed a conceptual model for implementing a biological criteria program for state water resource agencies. The following elements were summarized from the U.S. EPA to model the development of biological criteria as a monitoring tool for California:

1) Formulate an approach to develop biological criteria - The SWRCB, the RWQCB, and interested state agencies must officially outline a proposal to develop

criteria for California watershed streams based on biological communities. The approach should be formulated with input from the U.S. EPA and integrated with various state, federal and stakeholder-based water quality, watershed management and ecosystem restoration programs.

2) Select Reference Sites or Conditions - The attainable biological integrity of aquatic systems should be described using reference streams or stream reaches. A reference stream or reach is either in pristine condition or minimally impaired by human-induced activities. These conditions need to be partitioned into homogenous units within the U.S. Forest Service's sub-ecoregion designations (Baily et al. 1994). Reference conditions can be established for areas where minimally impaired streams are not available by using historic data and best scientific judgment.

3) Establish Standard Protocols - Standard protocols for biological criteria development have already been established. The California Stream Bioassessment Procedure (CSBP) was developed from U.S. EPA guidelines (Plafkin et al. 1989) with input from aquatic biologists throughout California involved with biological monitoring. Now in its third revision, the CSBP is the regional adaptation of the U.S. EPA Rapid Bioassessment Protocols (Barbour et al. 1997) and is recognized by the U.S. EPA as California's standardized bioassessment procedure (Davis et al. 1996).

4) Refine Protocol by Addressing Technical Issues - The CSBP is continually reviewed and refined through annual meetings of the California Aquatic Bioassessment Workgroup (CABW) sponsored by DFG, the SWRCB and U.S. EPA.

5) Characterize Biological Integrity and Establish Biological Criteria - After sampling the BMI communities of reference streams and collecting physical/habitat information, the data can be analyzed to establish a range of values that will characterize biological integrity. Once biological integrity has been characterized and the geographical units established, expectation of the biological condition can be determined for each region within California.

6) Evaluate and Revise Biological Criteria as Needed - As monitoring data becomes available from the reference sites, information on changes in natural condition and better understanding of natural variability may provide a basis to adjust biological criteria.

Conceptual Model 2: Watershed or Regional-Scale Evaluation of Biological Condition in California

The intent of a watershed-scale evaluation is to identify and document biological consequences of human-induced disturbances, non-point sources of pollution and to understand natural disturbances within an entire watershed or region. These programs will be initiated utilizing cooperative efforts of federal and state agencies but will eventually be turned over to watershed stakeholder groups to continue long-term monitoring. The following elements were summarized from U.S. EPA (Gibson 1996) to model the development of biological criteria as a monitoring tool for California:

1) Conduct Biological Surveys- Surveys for determining biological condition should be conducted on a watershed by watershed basis. These surveys will consist of several sampling stream reaches throughout the watershed and require two years of data before an evaluation of biological condition can be completed. The sites should be chosen by a panel of watershed stakeholders and be based on water resource interest, reasonable access, knowledge of human-induced disturbances and potential reference conditions.

2) Evaluate Biological Condition and Diagnose Causes of Impairment - After two years of conducting biological surveys, the data can be evaluated based on regional biological criteria to determine impairment. These results should be linked to the natural and human-induced disturbances to determine the degree of biological impairment produced by particular land-use activities.

3) Determine Remedial Actions - A watershed-scale evaluation of water resource impairment will help prioritize projects to improve water quality. By linking the biological condition to physical/habitat and chemical information, the type of impairment can be identified to help determine remedial actions. Since excessive inputs of sediment and nutrients and habitat destruction are all often significant sources of pollution, assessing biological condition might provide the most valuable information in determining remedial actions.

4) Continue Monitoring - Whether or not significant impairment is determined through a watershed or regional-scale monitoring program, it is imperative to continue the monitoring efforts. To reduce the cost of monitoring and to help educate watershed stakeholders on water resource issues, some of the monitoring should include citizen monitoring groups. Citizen monitoring using BMIs has been shown to be successful throughout the U.S. (Firehock and West 1995; Penrose and Call 1995) and standard protocols for citizen monitoring have been established in California (SWRCB 1997).

Conceptual Model 3: Project or Stream Reach-Scale Evaluation of Biological Condition in California Watershed Streams

The intent of project or stream reach-scale evaluation is to monitor the success of water resource improvement projects. There is considerable money available through grants to improve upslope and instream habitat and water quality. Some of this money should go to evaluating the success of these restoration projects while contributing to the watershed or regional-scale monitoring. The sampling effort will require more intensity for stream reach-scale monitoring than for watershed or regional-scale . The following elements were summarized from the U.S. EPA (Gibson 1996) to model the development of biological criteria as a monitoring tool for California:

1) Determine Pre-project Biological Condition - Pre-project or baseline biological condition will be determined using data obtained from the watershed or regional-scale. The following elements were summarized

from the U.S. EPA (Gibson 1996) to monitoring and from additional sampling collected prior to the start of the project. Sampling sites will be located above, within and below the project site to better define the biological condition of the project area.

2) Conduct Post-project Evaluation - Monitoring of established sites in the project area should be conducted annually for at least five years after the project is completed to evaluate changes resulting from the project activity.

3) Evaluate the Consequences of Project Activity on Biological Condition - Eventually the biological condition of the project area should approach the biological criteria established for the region in which the project belongs. Attainment of expected biological condition can be used to evaluate the success of the water resource improvement project. Corrective action to improve the effectiveness of the project can be implemented until the project area meets biological criteria.

4) Incorporate the Monitoring into the Watershed-scale Program - Once a project has been determined to be successful, the monitoring stations can become part of the watershed-scale program and become the

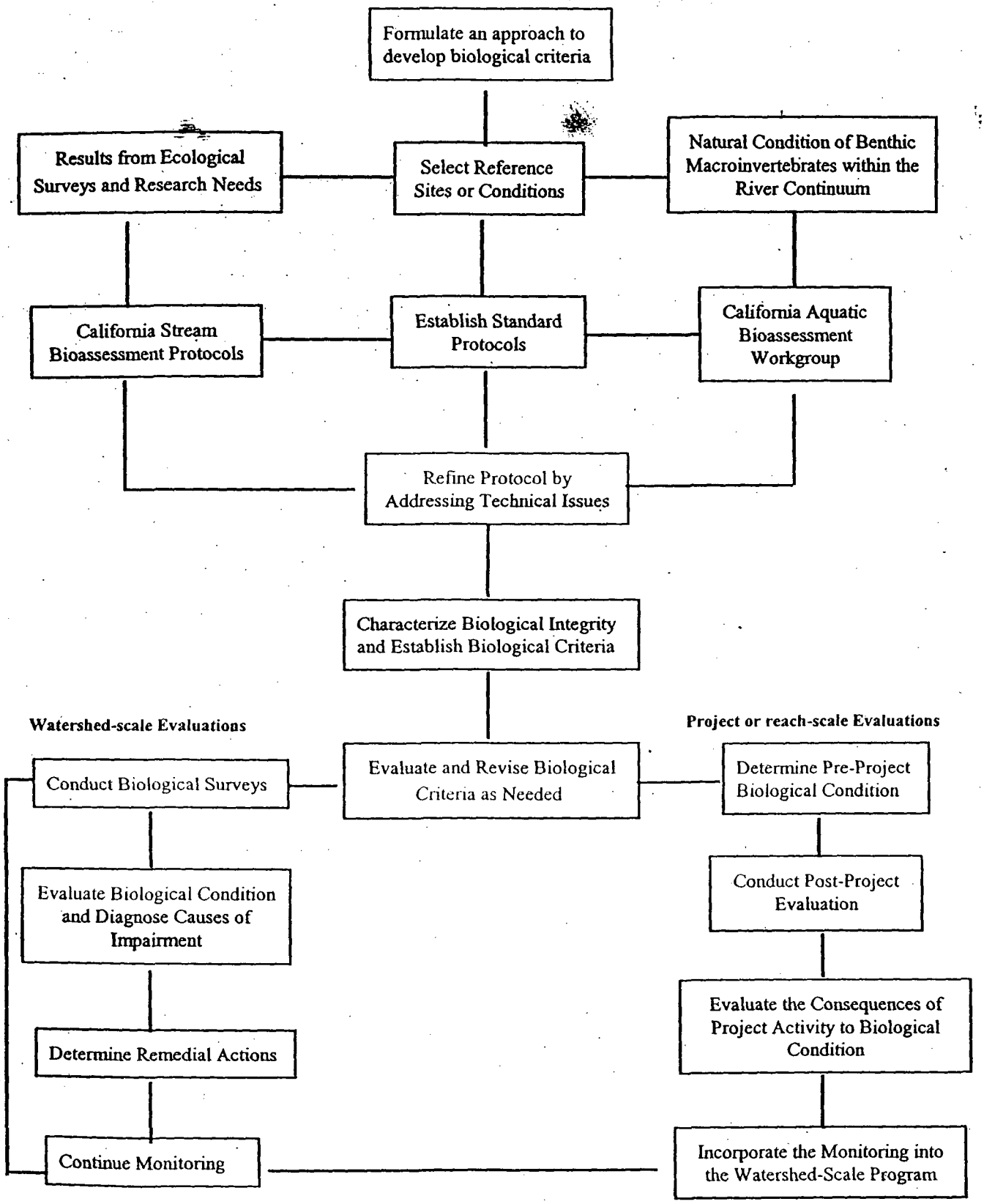


Figure 1. General Conceptual Model (modified from EPA 1990) for using Benthic Macroinvertebrates as a Monitoring Tool for Evaluating CALFED Program Goals and Objectives

responsibility of the watershed stakeholder group to continually monitor[2].

Literature Used in Preparing This Chapter

The following references were used in preparing this chapter and would be good material to read for more detailed information on the subjects discussed:

TMDLs, The Resurrection of Water Quality Standards-Based Regulation Under the Clean Water Act. 1997. Oliver A. Houck. The Environmental Law Reporter 27: 10329 - 10344

TMDLs, Are We There Yet?: The Long Road Toward Water Quality-Based Regulation Under the Clean Water Act. 1997. Oliver A. Houck. The Environmental Law Reporter 27: 10391 - 10401

The Clean Water Act - Updated For 1997. 1997. Water Environment Federation. Alexandria, VA.

Biological Assessment and Criteria: Tools for Resource Planning and Decision Making. 1995. Davis, W. S. and T.P. Simons, eds. Lewis Publishers. Boca Raton, FL.

Biological Criteria: Technical Guidance for Streams and Small Rivers (EPA 822-B-96-001). 1996. Gibson, G.R. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Layperson's Guide to California Water. 1997. Water Education Foundation, Sacramento, CA..

Layperson's Guide to Water Pollution. 1996. Water Education Foundation, Sacramento, CA.

[2]Appendix B contains the references for this document

Chapter 6
Getting Organized

Introduction to the Chapter

Chapter 6 explores the concept and purpose of monitoring groups and the California government agencies those groups should be most interested in coordinating their activities. It identifies how these agencies can assist citizen groups, as well as it identifies two other entities that may help monitoring groups work more effectively. Finally, the chapter introduces the intent and major elements of the California Stream Bioassessment Procedure (CSBP) for Citizen Monitors and why monitoring groups would want to use the CSBP.

The Concept and Purpose of Watershed Groups

The need for high quality water and healthy stream ecosystems for use by people and wildlife is a concern for everyone. With the multiple and escalating demands on the state's water resources and the limited availability of financial resources necessary to protect water quality, fish and wildlife agencies and concerned citizens must join forces to protect our rivers and lakes. Right now, citizens must depend on their government to know the condition of California's streams and lakes and to protect them from environmental degradation. Although few would debate that public servants take the concept of public trust seriously, the reality is that there are too few state biologists to monitor the myriad of our state's aquatic habitats.

Informed citizens must realize that government sways with political preferences and realities, and the wise-use of the state's water resources is not always a primary objective for politicians. At some point, it becomes necessary for concerned citizens to become involved with water quality monitoring and protection.

Usually, people become interested in stream monitoring or are part of a watershed group for one of two reasons:

The first reason can be because of a major pollution spill, or because of a concern with effluent dischargers in their "backyard." In this situation, what precipitates citizens' involvement often lead to emotional outbursts and many unproductive meetings. What citizens need to understand is that regulatory agencies need hard, defensible data to direct their actions. If a pollution event gets you the attention of the government, then the best way to capitalize on this attention and to have a successful outcome, is to provide them with the information they need to make informed decisions.

Regulatory agencies need hard, defensible data to direct their actions.

The second reason to get involved with water resource issues stems from the need to be environmentally active and to work in an element one enjoys: nature.

Regardless of the reason to become involved, it does not take long before informed and concerned citizens will realize that a group can be more effective than an individual at getting attention and getting things done. Many of these groups become political themselves and legal action is often used to stop poor water resource management and force the government to address the problem.

Understanding the root of the problem, however, is essential and requires that the citizens separate themselves from the emotions driving them, and concentrate on data gathering. The data necessary to assess water quality problems and formulate a solution is difficult for government agencies to produce, let alone a citizen group. Hence, if California is to promote, develop, and nurture successful citizen monitoring groups, water and other natural resources agencies need to allocate the funds necessary to monitor water quality with citizen participation. But first, citizen groups must evolve to a level where they understand water resource processes and how to monitor the physical, chemical, and biological conditions.

This evolution, from a citizen group to a monitoring group, empowers citizens and allows them to contribute to the protection of California's water resources.

The first challenge of a watershed group, is to become organized and educated. Once established, the next challenge is to obtain operating funds. Some groups are self-sufficient, operating with funds resulting from a lawsuit or other mitigation from a major pollution spill. Usually, groups are dependent on funds from some government program. Eventually, most monitoring groups should link up with a government agency with the power to assess (and effect changes in) water quality.

Monitoring groups interested in water quality protection and stream health should coordinate their activities primarily with the SWRCB and one of the RWQCBs.

California Water Quality Agencies Involved with Citizen Monitoring

The State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB) regulate water quality in California. The SWRCB has state-wide volunteer monitoring coordinators and provides assistance to start-up citizen groups. They maintain a web site and have produced several documents including "A List of Volunteer Monitoring Groups in California" and "A Start-up Manual for Volunteer Monitors." Each RWQCB has a volunteer monitoring program and usually a contact person. The Central Valley RWQCB has been one of the most active through their Sacramento River Watershed program which has helped organize monitoring groups throughout the watershed and has provided money to equip and train them in water quality monitoring.

The Department of Fish and Game (DFG) has its own water quality laws which go back to the late 1800s. Through its wardens and its Office of Spill Prevention and Response, DFG investigates and prosecutes pollution violators throughout California. DFG has been involved with biological monitoring and water quality assessment since its conception and has been instrumental in developing monitoring techniques for fisheries, wildlife and water quality investigations.

There are other federal and state agencies that have an interest in protecting water quality and restoring aquatic habitats, but their efforts are usually guided by a national agenda (U.S. EPA, U.S. Forest Service, U.S. Geologic Survey) or serve to mitigate for their resource use projects (U.S. Army Corps of Engineers, CA Department of Boat and Waterways, CA Department of Water Resources, Department of Pesticide Regulation). Although these agencies may have special programs and/or funding and have important monitoring data available, a monitoring group interested in water quality protection and stream health should coordinate their activities primarily with the SWRCB and one of the RWQCB's.

The SWRCB and the nine RWQCB's have recently instituted a Watershed Management Initiative which emphasizes a watershed management approach to water quality protection. Although principles of watershed management have been around for a long time, the concept has only recently become popular with regulatory agencies. Monitoring groups should capitalize on this by taking the next evolutionary step -- form or join a local watershed group. Even if the monitoring group's primary interest is in a small stream or even a section of stream, by becoming a stakeholder in a larger watershed group, they will be able to work more effectively. Of course, their stream of interest should be within that watershed.

In addition to working with a government agency, a group can increase its sphere of influence by joining forces with other groups. The key is to maximize your influence. Avoid becoming involved in areas which do not focus on your primary objective -- to maintain

or achieve a healthy stream ecosystem. Some of the groups you may want to become involved with include your local Resource Conservation Districts (RCD) and various regional Coordinated Resource Management Planning (CRMP) groups.

Some RCDs have stepped forward in California to assist watershed groups become organized and receive funding. There are 103 RCDs within California and most counties have an office. These government entities have been around since 1938 and have been involved with resource issues on a watershed basis from the start. They are free to be as active as they want but have only limited powers to levy taxes for operating funds, so not all can help watershed groups monetarily. The more active RCDs are often responsible for planning and implementing watershed restoration projects within their county. They may even have resource education programs and often coordinate volunteer monitoring efforts.

Other organizational entities in California are local CRMP groups. A CRMP initiates a problem-solving management process that attempts to draw all stakeholders in an area to improve its resource management. Remember when a large group of people organizes, things can become political, polarized and sometimes fail. Nonetheless, watershed groups should contact their local RCD to see what programs are available and explore any local CRMP to see if they should join.

The Intent of the California Stream Bioassessment Procedure (CSBP) for Citizen Monitors

The California Stream Bioassessment Procedure (CSBP) for Citizen Monitors was written and distributed by DFG in June 1996 and subsequently revised. The protocol was developed in response to increased interest of citizens groups to:
1) investigate potential problems with their streams and rivers,
2) monitor the long term health of their streams and rivers, and
3) to document the recovery of their streams and rivers resulting from restoration projects or from improved land use practices.

The intent of the CSBP for Citizen Monitors is to provide citizens with a standardized procedure to produce real water quality data. The procedure, which utilizes a nationally standardized physical/habitat measure and the use of benthic macroinvertebrates (BMI) as a biological measure, will help a monitoring group assess the physical and biological condition of their rivers and streams. If conducted correctly using the CSBP protocol, the data produced will not only contribute to a state-wide effort to monitor the biological health of all of California's rivers and streams, but will also provide citizen groups with the data needed to convey any concerns to the SWRCB or RWQCB's.

The CSBP for Citizen Monitors directly follows the CSBP used by professional biologists and water quality agencies throughout California. There are three components to both the professional and citizen level CSBP:
1) field sampling procedures,
2) laboratory procedures, and
3) quality assurance/quality control procedures (QA/QC) for both field and laboratory activities.
The field procedures for professionals and citizens are identical. What is expected of the professional is also expected from citizens.

The CSBP for Citizen Monitors directly follows the CSBP used by professional biologists and water quality agencies throughout California.

The primary differences in the CSBP between procedures for citizen monitors and the ones for professionals are the laboratory procedures. The CSBP has three levels of BMI identifications or taxonomic efforts which have been designed to flow from the first to the third level, culminating in a professional level analysis.

The taxonomic effort Level 1 does not require identification beyond the major taxonomic groups, except for the important insects in the

orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) which are only separated by morphological differences. Level 1 is a faster, less technical analysis of the BMI sample and is ideal for citizen groups that are just getting started, or for high school projects that are stressing education, more than long-term monitoring goals.

The Level 2 taxonomic effort, which is the preferred level for citizen monitors, requires identifying all orders of insects to the family level of taxonomy.

Level 3 taxonomic effort is the professional level equivalent and requires identification of most groups of BMIs to the lowest possible taxon, usually to genera and/or species level. The QA/QC procedures can be more stringent for citizens than for the professional because of the simple fact that there will be more scrutiny of data from citizens than from professionals.

Why Citizen Groups Would Want to Use the CSBP

The actual procedures for collecting bioassessment data are presented in Chapters 8 through 10. First, there should be a discussion on why citizens would want to use the CSBP for Citizen Monitors. A citizen monitoring group thinking about using the CSBP for Citizen Monitors should be beyond the beginning stage of environmental awareness. In other words, they should want to use bioassessment as a monitoring tool and not just as an educational tool. There are simpler, probably more effective techniques for water stewardship education. This level of citizen monitoring can be difficult and most certainly, requires a strong commitment to produce quality data.

A citizen monitoring group thinking about using the CSBP for Citizen Monitors should be organized and actively collecting chemical water quality data on a river or stream in their area. Such groups may have several years of data and may have been organized by a local RCD or their RWQCB, and now want to incorporate biological and physical measures of water quality to enhance their chemical data. Citizen groups that rely on chemical measures to monitor the quality of their river or stream might have discovered that either sedimentation, nutrients, habitat destruction or all three, are their leading water pollution problems. These groups now realize they need an alternative to chemical measures to more thoroughly monitor water quality.

Another important reason a citizen group would want to use the CSBP for Citizen Monitors is if they received funds from a 319(h) grant for non-point pollution projects or a pollution spill settlement to monitor a restoration project or other water quality improvement activity. A group may not be organized yet, but has a need to begin work on a restoration project and has the financial resources to start a comprehensive monitoring program. A grant usually involves spending requirements such as a project completion date deadline, along with monitoring results to be provided in a report format.

Whatever the reason groups use the CSBP for Citizen Monitors, the difference between chemical monitoring and bioassessment and how the two work together must be recognized.

Major Elements of the CSBP for Citizen Monitors

To reiterate, citizen groups wanting to use the CSBP for Citizen Monitors must be beyond the education stage. This is not to downplay the role of education in a watershed stewardship program. In fact, educating citizens to be good watershed stewards is probably the most important job of a citizen group. Eventual improvements in water quality will only be accomplished by educated and involved citizens. What is meant by "beyond the education stage" is that the citizen monitoring group must emphasize collecting, processing and distributing high quality data. The education aspect of the monitoring program is an on-going part of this

process and may have to be supplemented with programs above and beyond what is presented in this manual.

There are four major elements of the CSBP for Citizen Monitors:

1) The Project Advisor - Each monitoring group must be under the direction of a project advisor. A project advisor should be a professional aquatic biologist/entomologist or a representative from a water quality agency, but can be anybody who feels competent to advise a monitoring group and who can communicate with DFG and the RWQCB on the technical components of bioassessment. The project advisor must be appropriately trained in the use of the CSBP and thoroughly understand the principle of bioassessment and how it is used in California. Although not absolutely necessary, it would benefit the project advisor to be familiar with aquatic invertebrate taxonomy.

The **group coordinator** is another important position within a monitoring group. This position is not a requirement of the CSBP, but is recognized as a vital part of a successful citizen monitoring group. The job of a group coordinator is to bring the group together and keep them together. This position is quite often a paid position with an RCD, the RWQCB or is paid with grant money. It is the first and probably the most important position for a citizen group interested in implementing restoration projects and monitoring water quality.

The duties of a group coordinator must not be confused with the duties of the project advisor. Furthermore, the qualities of a good group coordinator are not necessarily the qualities of a good project advisor. A project advisor with good coordinating and people skills can do both jobs, but will eventually become over worked. A group coordinator with no technical skills who also tries to be a project advisor will eventually become overwhelmed and frustrated. This is not to say a group coordinator could not pick up the skills of a project advisor. With technical assistance and persistence, a group coordinator with technical aptitude could become a good technical advisor. However, it will take time and money to acquire these skills.

2) Standard Operating Procedures (SOP) and Quality Assurance Project Plan (QAPP) - The CSBP for Citizen Monitors is a state guideline for bioassessment. It presents a standardized method to collect physical/habitat and biological data to assess the condition of rivers and streams. However, each monitoring group and each watershed in California is unique and requires unique instructions on how to implement the CSBP. Each group must develop Standard Operating Procedures (SOP) and a Quality Assurance Project Plan (QAPP) for their specific monitoring program and project. The SOP consists primarily of the field, laboratory and QA/QC portion of the CSBP with enough added detail to conform specifically to your group. For example, an urban stream monitoring group might have unique safety considerations such as watching out for glass and other sharp objects embedded in stream substrates and using a diluted chlorine solution to watch their hands after sampling. Rural stream monitoring groups might need to watch out for poison oak and rattle snakes. SOPs can be as specific as to mention particular individuals being assigned to specific tasks.

The QAPP is a requirement of any project or program receiving an U.S. EPA grant. There are specific guidelines contained in the 1996 document "The Volunteer Monitor's Guide to Quality Assurance Project Plans" (EPA 841-B-96-003) that need to be followed. The bulk of a QAPP is contained in the SOP as long as all the components of this manual are addressed. Some additional information specific to each monitoring group and project are the monitoring objectives, qualifications of group members and the type of training each member has received. The Adopt-A-Stream Foundation's "Streamkeeper's Field Guide" has an excellent step-by-step description of the requirements of a QAPP.

3) Laboratory Identification of Benthic Macroinvertebrates - The CSBP for Citizen Monitors has two levels of taxonomic identification available, with the preferred level being identification of BMIs to the family level of taxonomy. Proper taxonomic identification of organisms will be the most difficult task for citizen monitors. Hopefully, this manual and its taxonomic keys to the macroinvertebrates common in western streams and rivers will help citizens learn invertebrate taxonomy. However, hands-on training is essential, and a project advisor knowledgeable in invertebrate taxonomy will be instrumental. Chapter 9, on laboratory procedures, describes other options available to a monitoring group to produce quality data without having to perform invertebrate identification. Chapter 9, in the maturing laboratory section, describes how to go beyond the family level of identification while remaining standardized with other monitoring groups throughout California.

4) Validation Samples - The CSBP for Citizen Monitors describes the creation of "validation samples" as a regular part of performing water quality assessments. There are two types of validation samples: taxonomic and bioassessment. Taxonomic validation is an internal QA/QC procedure which is further described in Chapter 11. It is a tool used by the project advisor to validate the competence of the invertebrate identification and to pinpoint problem areas that the project advisor will need to work on with the laboratory group. The taxonomic validation can be conducted by a member of the group that is a professional taxonomist or by an independent bioassessment laboratory. Ultimately, it is the responsibility of the project advisor to guarantee that the taxonomy is correct.

Bioassessment validation is an external form of QA/QC and must be conducted by an independent laboratory which has no personal connection to the monitoring group. By following the CSBP, each sample collected and processed by citizen monitors will have its integrity preserved and can be reconstituted into its original condition. This is explained further in chapters 10 and 11, but briefly, each sample submitted for bioassessment validation will be as if it were just collected. The professional bioassessment laboratory will process the sample according to the level 3 taxonomic effort and submit the results to both the monitoring group and to DFG. Many citizen groups are only collecting BMI samples and performing physical/habitat assessment, and sending all of their samples to a professional laboratory for a level 3 taxonomic effort.

Information from the bioassessment validation samples contributes to the state-wide bioassessment program and will allow DFG to evaluate and demonstrate the comparability of professional and citizen level bioassessment data. The level of bioassessment validation can range from 20% to 100% and the particular samples submitted for validation can be chosen at random or selected to help verify a water quality problem detected by the monitoring group.

Chapter 7
Getting Started - Overview of Chemical, Physical/Habitat and Biological Assessments

Introduction to the Chapter

Chapter 7 presents the concept of watershed assessment and the components of a formal approach that citizen groups can implement. We briefly discuss assessment of ambient water quality chemistry for rivers and streams and list the parameters which are required of the CSBP and those which are optional. Since this manual emphasizes physical and biological assessment procedures, we give a detailed overview of the level of physical/habitat and biological assessment. We will show how physical/habitat assessments for water quality differ from habitat surveys used for fisheries investigation. Finally, the virtues of a good biotic indicator are discussed along with reasons why the CSBP utilizes benthic macroinvertebrates (BMI) for assessing the health of California water bodies instead of fish or algae.

The Concepts of Watershed Analysis and Assessment

Monitoring efforts at any level are best approached on a watershed scale. The watershed can be large such as the Sacramento River watershed or one of its tributary streams such as Butte Creek. Most groups may want to begin with a smaller area such as a sub-basin or a tributary to Butte Creek. In fact, watersheds with areas of approximately 20-200 square miles are generally the most practical for conducting watershed assessments.

Definition of Watershed Analysis Versus Watershed Assessment

The concept of **watershed analysis** has been around for several years and has generally been used to describe a method of looking at larger landscapes (e.g., an entire watershed) for a specific planning purpose. Watershed analysis is not a decision-making process but rather it is a stage-setting process. Analysis is intended to be based primarily on existing information with the addition of a minimum of data gathering or field inventory. Watershed analysis is conducted by interagency/interdisciplinary teams of qualified resource specialists with involvement by the state and local governments and the general public.

Watershed analysis theory was advanced by the Federal government when seven federal agencies collaborated to focus and redefine watershed analysis needed to implement the Aquatic Conservation Strategy set forth in the President's Northwest Forest Plan in 1993. Their efforts produced a procedure that characterizes the human, aquatic, riparian and terrestrial features, conditions, processes and interactions (collectively referred to as ecosystem elements) within a watershed. Federal agencies are the primary users of this approach which is outlined in details in "Ecosystem Analysis at the Watershed Scale - Federal Guide for Watershed Analysis - Revised August 1995, version 2.2". The federal analysis process has six steps to "tell a watershed story":

- characterization of the watershed;
- identification of issues and key questions;
- description of current conditions;
- determination of reference conditions;
- synthesis and interpretation of information; and
- recommendations.

The results of a watershed analysis establish the context for subsequent decision making processes, including planning, project development, and regulatory compliance.

A **watershed assessment** is the systematic review of specific resources such as macro-invertebrates or fish and their habitat and riparian areas in a watershed-scale context. The scale used in the assessment can vary from the entire watershed to a specific

sub-basin depending upon a group's clearly defined objectives. Whatever the scale chosen, it needs to include a spatial, as well as temporal element, because watershed processes that shape the landscape and form streams and river systems are dynamic and constantly changing over time.

Like watershed analysis, watershed assessment is a stage-setting process intended to be based primarily on existing information. Any required data collection and field inventory is focused to key sensitive sites within the assessment area. The location of these sites is determined by thoroughly reviewing existing information sources, using personal experience, and interviewing people having site specific knowledge about the area. The results of a watershed assessment establish the context for subsequent evaluations and analysis of cumulative watershed effects. A watershed assessment serves the following four major functions:

1) **Addresses cumulative effects within the watershed.** A watershed assessment will provide the means to identify all of the major land-use activities and natural disturbances and attempt to describe the effects of those multiple activities on aquatic habitats and biological communities.

2) **Provides for more ecologically sound resource planning.** A watershed assessment will provide the means to assess current conditions and identify existing resource problems so that future resource activities within the watershed can be planned properly. This information is essential to determine the focus of environmental education programs and to target restoration projects at the appropriate problems.

3) **Identifies and helps to protect environmentally sensitive areas.** A watershed assessment provides the means to identify specific portions of the watershed highly sensitive to human disturbances so that protection plans or "best management practices" can be implemented.

4) **Develops the information to produce ecoregion or basin level standards or criteria.** A watershed assessment helps to refine our understanding of physical and biological processes and how these vary within the watershed. This information allows for better regulation of land-use practices and development of water quality criteria.

A comprehensive watershed assessment requires the involvement of qualified resource specialists, appropriate government agencies, landowners, the citizens that live in the watershed and, of course, sufficient money to fund the work. To date, adequate funding has not been available. This is where an active and mobilized watershed group could become the catalyst for initializing a watershed assessment by drawing attention to their stream and asking what needs to be done to assess whether or not it is healthy. In many instances, a citizen group may be the only available work force to start a watershed assessment.

How does a citizen group get started if it wants to implement a watershed assessment or just wants to gather some information to augment existing monitoring activities? There are ten basic steps to conducting a watershed assessment:

- establish clear goals and objectives;
- determine size of assessment area;
- gather existing information;
- review, compile and analyze existing information;
- determine field assessment needs;
- choose appropriate field assessment techniques;
- locate field sites;
- conduct field assessment;
- review, compile and analyze field data; and
- combine results and form conclusions about existing conditions and cumulative effects.

Ultimately, watershed group members need to become intimately familiar with the watershed. This can be done by visiting useful web sites (SLSI's web site,

www.slsii.org, has links to several useful web sites), exploring the stream, talking with neighbors, and visiting appropriate government offices. Members should concentrate their information gathering on the following six watershed features:

1) land alterations;
2) roads;
3) riparian buffers;
4) channel modifications;
5) water use; and
6) water quality.

U.S. EPA, in their methods manual for "Volunteer Stream Monitoring," outlines a formal approach to conducting a watershed survey by performing a background investigation and a visual assessment. They list the following information to include in the background investigation:

1) Location of the stream's headwaters, its length, where it flows, and where it empties.

2) Name and boundaries of the watershed within which the stream occupies, the population of humans in the watershed, and the communities through which the stream flows.

3)Roles of various jurisdictions in managing the stream and watershed.

4) Percentage of watershed land area in each town or jurisdiction.

5) Land uses in the stream's watershed.

6) Industries and others that discharge to the stream.

7) Current uses of the stream such as fishing, swimming, drinking water supply, and irrigation.

8) Historical land uses.

9) History of the stream.

For the visual assessment, U.S. EPA recommends that volunteers regularly walk, drive and/or boat along a defined stretch of the stream. The observed water and land conditions, land and water uses, and changes over time are recorded on maps and on a visual assessment data sheet which is provided in the U.S. EPA manual. Detailed procedures for watershed surveys are not part of this manual. You can find specific procedures which follow U.S. EPA's basic format described in the Adopt-A-Stream Foundation's Streamkeeper's manual and the SWRCB's Volunteer Monitoring Protocols manual.

Assessment of Ambient Water Quality Chemistry for Rivers and Streams

In this manual, we emphasize procedures for physical/habitat and biological assessment which together is referred to as bioassessment. We will not emphasize procedures for chemical assessment even though it is a very important component of water quality monitoring.

Some monitoring groups interested in bioassessment have already conducted some sort of chemical monitoring and are familiar with techniques and interpretation. For those of you who are not familiar, we will briefly discuss (and list in Table 7-1) the water quality measurements that are required or optional for each bioassessment sampling event, those that are better monitored on a continual basis, and those that would be best collected and analyzed by professionals.

Dissolved oxygen (DO), temperature, conductivity, and pH should be collected whenever a bioassessment sampling event occurs. Conductivity and pH are the most important of the four to collect. They remain relatively constant over time unless affected by a pollution discharge. In reality, measuring DO and temperature is simply a field sampling custom; they do not mean much more than simply noting what the concentration was when the sampling event occurred. Temperature is better collected using a continuous recording device such as a HoboTemp. These recorders are inexpensive

Dissolved oxygen (DO), temperature, conductivity and pH should be collected whenever a bioassessment sampling event occurs. Conductivity and pH are the most important of the four to collect.

so several can be placed in strategic locations throughout the watershed. DO is better collected on a diurnal basis at critical times of the year. As discussed in Chapter 3, DO is influenced by various chemical parameters and can be at its lowest level in the early morning hours before sunrise. Additional chemical parameters which would be beneficial to collect whenever a bioassessment sampling event occurs are: biochemical oxygen demand (BOD), turbidity, total orthophosphate, nitrate, total solids and alkalinity. Other chemical parameters such as metals, pesticides and ammonia are better collected and analyzed by professionals.

For a more detailed discussion of chemical monitoring and for specific procedures, refer to the State Water Resources Control Board's Volunteer Monitoring Protocols Manual, U.S. EPA, and Adopt-A-Stream Foundation's Streamkeeper's Manual.

Assessment of the Physical/Habitat Condition of Rivers and Streams

As we discussed in earlier chapters, chemical contaminants are not necessarily the most important pollutants affecting water quality. Throughout the country, sediment is the leading pollutant affecting the health of rivers and streams. There is no chemical test to measure the concentration of sediment and allow us to determine its effect on aquatic biota. Turbidity has been erroneously used to measure and regulate sediment. However, turbidity is merely a measure of the transparency of water and is only lethal to aquatic organisms at extremely high concentrations sustained for several days. Suspended sediment has its most detrimental effect when it settles, filling in pools and interstitial areas of stream substrate where fish spawn and invertebrates live. This is one of the reasons why we emphasize physical/habitat and biological monitoring techniques in this manual.

The procedures to measure physical/habitat conditions are covered in the next chapter. Two distinct uses of physical/habitat measures will be described: one to measure the physical/habitat condition or quality of a stream reach, and one to measure physical/habitat characteristics of the bioassessment sample site. These two uses must not be confused. The first is a requirement of the CSBP and utilizes a nationally standardized way to describe a stream reach as excellent to poor based on a known reference condition. The other measure is primarily used to help the project advisor to interpret possible anomalies in the biological data. There are a few required measurements, but most parameters used are up to the monitoring group to choose and are usually determined by their equipment budget and supplemental monitoring objectives, such as conducting a fish habitat survey.

Federal and state agencies and even some citizen groups interested in fish populations, especially anadromous fish, have been conducting intensive physical/habitat surveys for more than twenty years. This interest has intensified with the listing of chinook and coho salmon and steelhead trout as endangered in portions of California. The physical/habitat measures described in this manual are related to water quality monitoring and should not be confused with the more intense measures associated with fish habitat surveys. Although most of the parameters are similar, the measurements need to be more quantitative with fish habitat surveys. In most cases, the quality and quantity of the physical/habitat parameters are measured by their ability to support all life history stages of fish. Quite often these measures become substitute indicators for fish abundance and the streams' ability to support fish. In water quality monitoring, we only need to know if the physical condition of the river or stream is impaired.

If a monitoring group is measuring physical/habitat parameters for the purpose of conducting a fish habitat survey, they will have sufficient information to provide the project advisor to help interpret biological data and there should be no problem assessing physical condition or quality using the

standardized technique discussed in the next chapter.

of all water bodies. Therefore, water quality monitoring should have a measure of biological condition. This is the emphasis of this manual and before we present the procedures in the next chapter, we will give an overview of biological monitoring and bioassessment.

Table 7-1. Water quality measurements that are required or optional for each bioassessment sampling event, those that are better monitored on a continual basis and those that would be best collected and analyzed by professionals.

Water Quality Constituents	Measured at each Sampling Event		Continual Measurements	Professional Collection and Analysis
	Required	Optional		
DO	yes		yes	
BOD		yes		yes
Temperature	yes		yes	
pH	yes			
Turbidity		yes		
Total Orthophosphate		yes		
Nitrate		yes		
Total Solids		yes		
Conductivity	yes			
Total Alkalinity		yes		
Metals		yes		yes
Pesticides		yes		yes
Ammonia		yes		yes

Assessment of the Biological Condition of Rivers and Streams

As mentioned in Chapter 5, the Clean Water Act requires that states monitor the physical, chemical and biological integrity

The three terms: biological monitoring, biological assessment and biological criteria are commonly used interchangeably in discussions of biology and water quality. This can be confusing and may lead to some misunderstanding. The definitions of the terms are as follows:

- **Biological monitoring** (biomonitoring) refers to the measurement of biological organisms present in an aquatic system. Biological monitoring programs may investigate the distribution and abundance of a single species, or may involve larger

inventories of the entire biotic assemblage, including terrestrial communities in the riparian zone.

- **Biological assessment** (bioassessment) refers to the use of biological information to determine whether a water body of interest has been affected by a disturbance, often a specific one. Bioassessment requires comparison of data from the disturbed site to a minimally disturbed reference condition or similar control site.

- **Biological criteria** (biocriteria) are numeric values or narrative expressions that describe the preferred biological condition of aquatic communities based on designated reference sites.

In summary, biological monitoring is a broad term simply referring to an environmental investigation that includes measures of aquatic biota. The intensity of the measurements and type of biota studied will be dependent on the questions being asked, such as:

- What is the population of resident rainbow trout in the American River?
- What is the biomass of invertebrates available as food for young-of-the-year steelhead in the section of the American River between Watt and Hazel Avenue?
- What kinds of invertebrates do young-of-the-year steelhead eat?
- Which species of invertebrates are endemic to the American River drainage?

These questions would be answered using study designs and procedures different from those used in bioassessment.

Bioassessment should not be confused with an ecological study. The question to be answered is always "What is the effect of human-induced disturbance to the biota of a specific water body?" The CRBP follows the guidelines of U.S. EPA Rapid Bioassessment Procedures because they have prompted much research and development into standardized bioassessment techniques. Furthermore, we are interested in water quality issues and protection, and believe biology should be a part of water quality standards and criteria (biocriteria).

The CRBP follows the guidelines of U.S. EPA Rapid Bioassessment Procedures because they have prompted much research and development into standardized bioassessment techniques.

Since many groups may not have the time or money to assess the entire biotic community that is dependent on a healthy aquatic environment, we will need to find an indicator species or community. This **biotic indicator** must exhibit particular preferences with regard to our established set of chemical and physical/habitat parameters. These preferences must be strong enough such that changes in those chemical and physical/habitat parameters will result in changes to the presence/absence, numbers, morphology, physiology, or behavior of the biotic indicator. An ideal biotic indicator should have the following characteristics:

- The taxonomy of the biotic indicator should be well understood and it would help if it can be easily recognized by the nonspecialist.
- The biotic indicator must be ubiquitous with a wide distribution in all types and sizes of water bodies.
- The biotic indicator must be numerically abundant so that sampling will not affect its populations.
- The biotic indicator must have low genetic and ecological variability, thus avoiding its adaptation to aquatic disturbances.
- The biotic indicator must have a relatively large body size so it can be captured with easy to operate sampling equipment and identified using conventional laboratory equipment.
- The biotic indicator must have limited mobility to prevent it from avoiding the effects of aquatic disturbances.
- The biotic indicator must have a relatively long life history so that disturbance and recovery of the aquatic environment can be better documented.
- The ecological characteristics of the biotic indicator must be well known so that the effects of natural variability and of man-induced disturbances can be better understood.
- The biotic indicator should be suitable for use in laboratory studies so that effects of toxicants on its life history and phases can be developed.

Several individual biotic indicators and community of biotic indicators have been tried with varying degrees of success over the years. The types of biotic indicators which have been used most frequently and with the most success are fish, algae, and invertebrates. U.S. EPA recommends using multiple assemblages of these three types of aquatic organisms and to look at them on the community level.

Fish communities are the most desirable biotic indicators to use in water quality monitoring programs because they are common, are commercially and recreationally important, and are used as food by many people. Additionally, they are popular with people. Most people enjoy fish and are appalled by pollution events that kill significant numbers of fish. However, some of the major problems with using fish as biotic indicators are:

- They can be difficult to sample;
- They can avoid some pollution events;
- They are not present in all water bodies (due to seasonal low flow as might occur in intermittent streams); and
- They can be limited in the number of species and numeric abundance.

A particular problem with using fish as biotic indicators in California is that much of the state's rivers and streams are dominated by anadromous fish which only spend part of their life in freshwater. This complex life history makes them vulnerable to additional problems not related to inland water quality. A river or stream could be in good chemical and physical/habitat condition, but anadromous fish numbers could be low because their populations were affected by commercial fishing within and outside California or because of lowered food abundance in the ocean.

Additionally, California has many sensitive and important water bodies which are either naturally fishless or are dry at some time of the year. Water quality regulation is still crucial for these waters since they have important environmental value and with the case of intermittent streams, provide habitat for aquatic invertebrates, amphibians, riparian birds, and other wildlife. Streams that are periodically dry may at other times be used for fish spawning and rearing of juvenile fish.

Algae and in particular, aquatic invertebrates are the most common organisms recommended for use in assessing water quality. Benthic macroinvertebrates (BMI) are organisms that inhabit the bottom substrates of freshwater habitats for at least part of their life cycle and are at least a half millimeter in size. BMIs act as continuous monitors of the water they inhabit, enabling long-term analysis of both regular and intermittent discharges, variable concentration of pollutants, single or multiple pollutants, and even synergistic or antagonistic effects.

The advantages in using BMIs for bioassessment are:

- They are ubiquitous and affected by environmental perturbations in many different types of aquatic systems and habitats.
- The large number of species involved offers a spectrum of responses to environmental stresses.
- Their sedentary nature allows effective spatial analysis of pollutants or disturbance effects.
- They have variable life cycles (a month to four years) which allows accurate interpretation of temporal changes caused by perturbations.
- Qualitative sampling and sample analysis can be done using simple, inexpensive equipment.
- The taxonomy of many groups is well-known.
- Many data analysis methods have been developed for community level bioassessment.
- Responses of many common species to different types of pollution have been established.

The disadvantages in using BMIs for bioassessment are:

- High numbers of samples are required to precisely estimate population abundance.
- Precise processing and identification requirements can be costly and time-consuming and certain groups are taxonomically difficult to identify.
- Distribution and abundance of benthic macroinvertebrates can be affected by factors other than water quality.
- Seasonal variations in abundance and distribution may create sampling problems during specific periods of the year or in specific habitats.
- Drift behavior can carry benthic macroinvertebrates into areas in which they do not normally occur.

Most of these disadvantages are not unique to BMIs. Other potential biotic indicators have these and many more problems such as the ones discussed for fish. The CSBP is designed with these disadvantages in mind and you will learn how to mitigate for them.

Benthic algae, especially diatoms, are also sensitive indicators of environmental changes in rivers and steams. They are similar to BMIs in their advantages and disadvantages for use in bioassessment and they can be identified by experienced biologists. U.S. EPA recommends using multiple assemblages of biotic indicators to strengthen bioassessment data. Most states do not use algae simply because of a lack of algae taxonomists and the public is less familiar with algae in rivers and streams. Furthermore, citizen monitoring groups would probably have more problems identifying algae species. California's professional bioassessment efforts include investigating the use of algae in its state-wide program. Eventually, there may be a CSBP for benthic algae and perhaps a version for citizen monitors.

Literature Used in Preparing This Chapter

"Freshwaterwater Biomonitoring and Benthic Macroinvertebrates" 1993. Rosenberg and Resh. Johnson et al. (Eds) Chapman and Hall, New York.

Chapter 8
Field Sampling Procedures for Physical/Habitat and Biological Assessment in Wadeable Streams

Introduction to the Chapter

Chapter 8 discusses the differences between point-source and non-point source sampling design and outlines the complete procedures to conduct a physical/habitat and biological assessment, both for citizen monitors and resource professionals.

Sampling Strategies for Use with the California Stream Bioassessment Procedure (CSBP)

There are three basic sampling designs used with the California Stream Bioassessment Procedure (CSBP); they are point source, non-point source and ambient. The sampling unit is an individual riffle, or riffles within a reach of stream depending on the type of sampling design used. Riffles are used for collecting biological samples because they are the richest habitat in wadeable streams. What constitutes a riffle and what is a wadeable stream are discussed in Chapter 3. Collecting Benthic Macroinvertebrate (BMI) samples within riffles, measuring of physical/habitat characteristics of a riffle and determining physical/habitat quality of a stream reach is discussed later in this chapter.

Riffles are used for collecting biological samples because they are the richest habitat in wadeable streams.

Point Source Sampling Design

Use the point source design when there is either a discernable perturbation such as an impacting structure, effluent discharge or a spill of a toxic substance originating at a discrete point and flowing into the stream. **The sampling units for this design are individual riffles.** The following step-by-step procedures will help you locate the sampling riffles for a point source sampling design *(Figure 8-1)*

- **Step 1.** Locate the source of pollution and determine where it enters the stream.

- **Step 2.** Proceed downstream of the point source of pollution and locate the closest downstream riffle. Measure the required physical/habitat characteristics (procedures will be described later in this chapter). This riffle will become your standard to measure other riffles within the stream. Making sure that it is fairly representative of the type of riffles in that section of stream will help your ability to find the series of homogeneous sampling riffles required in the following steps.

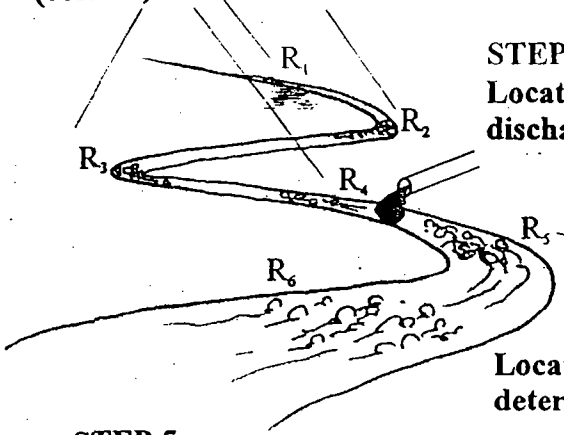
- **Step 3.** With this information in hand, proceed upstream to locate possible control riffles. A control riffle will be used to compare the affected riffles, so it should have similar physical/habitat characteristics to the other riffles. The control riffle must also be out of the influence of the disturbing structure or pollutant. More than one riffle, within as close a proximity of the source of pollution, is preferable. In case there is no unaffected upstream area available, locate riffles in a similar nearby stream to collect your control samples.

- **Step 4.** Next, walk back downstream below your first riffle within the affected area and look for more homogeneous riffles. One or more riffles should be sampled in the affected reach. The number of riffles sampled will depend on the amount of detail required to document downstream impacts or recovery. Flag the riffles and measure their distance downstream of the point of pollution. This distance will depend on

Use the point source design when there is either a discernable perturbation such as an impacting structure, effluent discharge or a spill of a toxic substance originating at a discrete point and flowing into the stream.

Point Source Design

STEP 3
Locate one or more upstream (control) riffles



STEP 1
Locate point-source discharge

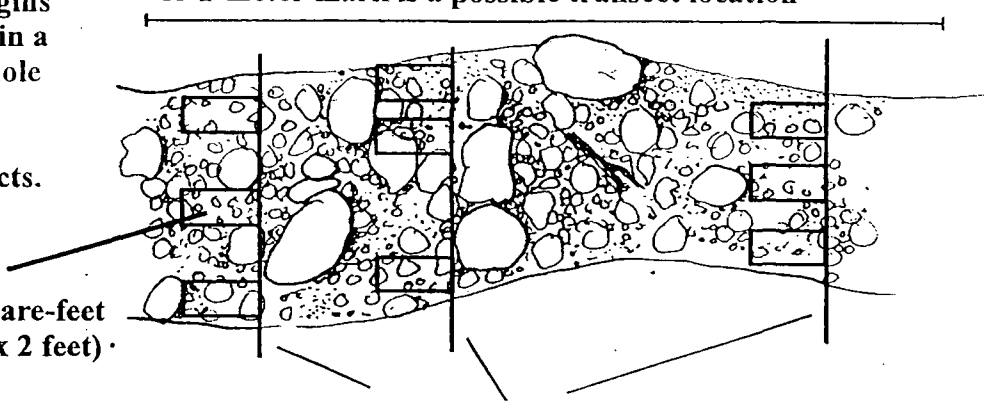
STEP 2
Locate closest downstream riffle from discharge point.

STEP 4
Locate as many downstream riffles as necessary to determine the extent of the disturbance.

STEP 5

For each transect, collect and combine from both margins and the thalweg, to obtain a representation of the whole width of the riffle.
Do this for each of the 3 randomly chosen transects.

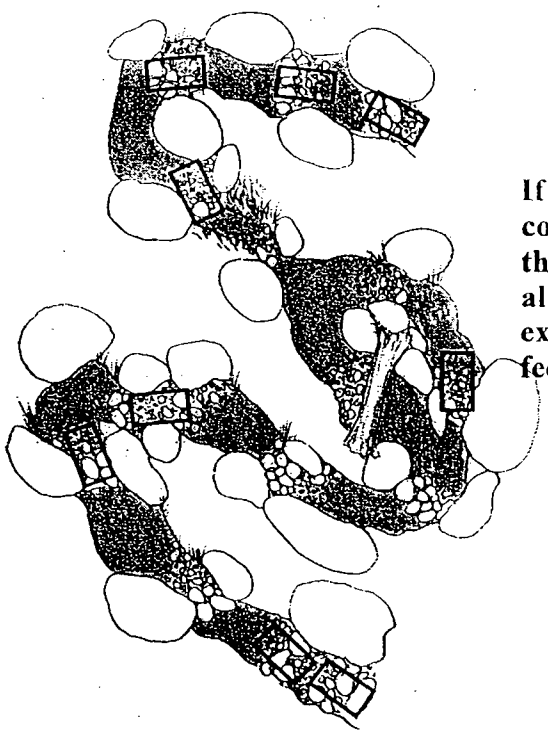
Measure the entire riffle, each 3-foot section or 1-meter mark is a possible transect location



3 randomly selected transects

Excavate a total of 2 square-feet (1 net width (12 inches) x 2 feet) at each point

Riffle



If the stream width is too narrow or too complex to collect three net-widths across, then randomly pick 9 1x2 feet areas from all the possible 1x2 areas in the riffle. In the example on the left, there are 14 possible 1x2 feet sampleable areas.

Figure 8-1: Point-source Sampling Design

where a comparable riffle is located and may not be in equal or logarithmic increments.

- **Step 5.** Collect three replicate BMI samples within each riffle (procedures are described later in this chapter). Collect physical/habitat characteristics at each riffle. Now you have a series of homogenous riffles to be sampled, one which is the most affected by the source of pollution, one or more upstream of the source of pollution or in another comparable stream and several at variable distances downstream of the source of pollution. These last sites are optional and only used if you are interested in estimating the extent of the disturbance and to monitor the recovery of the aquatic once the pollutant is no longer entering the stream. Documenting recovery will require resampling all the sites in intervals of no less than 2-3 weeks.

Non-Point Source Sampling Design

Use the non-point source sampling design when there is no obvious point of perturbation or discharge into the stream. **With the non-point source sampling design, the sampling unit is not a single riffle, but a family of riffles within a reach of stream.** This allows you to extrapolate physical and biological conditions to a larger area of the stream. The advantage is that an entire watershed can be assessed through several optimally located sampling reaches. Many citizen monitoring groups will be using this sampling design since they are typically interested in the health of an entire watershed and not just the effects of a particular perturbation or discharge into the stream.

Use the non-point source sampling design when there is no obvious point of perturbation or discharge into the stream.

Unlike the point source, the non-point source sampling design does not use easily obtained control sites. Ideally, the assessment site will be compared to a reference stream or condition. The reference stream or stream reach must be similar in physical/habitat condition and be within the same ecoregion or watershed as the impacted site. Historical data or expert consensus on biological and physical condition could be substituted if a reference stream is unavailable. Your RWQCB or local DFG office may have information or suggestions for an appropriate reference stream or condition for your region.

Bioassessment Sampling Designs

Point source
Non-point source
- Stratified random
- Non-random by physical/habitat characteristics
- Non-Random Selection Based on Available Access

Ambient

There are several strategies for setting up a sampling program for a large geographical area such as a single basin, larger river system or an entire region. Three common strategies for determining sample site locations are:
1) stratified random selection,
2) non-random selection based on physical/habitat characteristics, and
3) non-random selection based on available access.

The two non-random strategies for selecting sampling locations are recommended for citizen monitoring programs because they are more practical and effective in assessing watershed condition.

Stratified Random Selection

This strategy for selecting sampling site locations is used primarily for larger river systems or even an entire common region such as a national forest. It is used to determine the biological and physical condition of the entire river system or region and assumes that all the sampling locations are similar and affected by the same type of land-use practice. It can work well for a wilderness river system or a national forest where logging is the primary land-use practice. The U.S. EPA uses this type of strategy in its Environmental Monitoring and Assessment Program (EMAP) where they are interested in the water quality of the entire United States or large regions such as the western states. A

THREE METHODS FOR SELECTING A RANDOM NUMBER

1) Using the Table of Random Numbers in Appendix C, place a finger on the page with your eyes closed. From that number go down the column looking at the last two digits (for up to 99 transect numbers) for a usable number(s). When the column ends, move your finger to the right and proceed up the column. Continue this pattern until all number(s) are selected

2) Use a random number generator available on most calculators.

3) Carry numbered pieces of paper in your pockets or in a bag. Usually 20 numbers will work. Remember to limit your numbers to the numbers of available riffles.

computer in Corvallis, Oregon, selects sites at random from all the thousands of possible streams.

Since there are so many possible sampling locations in a river system or region, it is common to stratify all the possible locations into major groups. The U.S. EPA selects sampling sites from two major types of streams; intermittent and perennial stream. Another common stratification is by stream order. A topographic map or GIS layer can be used to identify all the stream sections by their stream order (discussed in Chapter 3, see ***Figure 3-2***) and then randomly selecting a percentage of each. This procedure requires considerable resources such as accurate maps, computers and an extensive reconnaissance effort to determine if the randomly selected sites can be actually sampled. The major drawback is that random selection does not allow you to chose problem areas and may, by chance, not provide even coverage of the watershed or region.

Non-Random Selection Based on Physical/Habitat Characteristics

This sampling strategy requires unlimited access to the entire watershed. It uses stream order and channel type to divide the stream into similar sections. The advantage of this strategy is that it limits the possible variability in biological and physical condition by grouping them into more comparable stream sections. The following step-by-step procedures will help you locate the sampling units using this strategy (***Figure 8-2***):

- **Step 1**. Starting from downstream, survey the entire stream determining the channel type and identifying all riffles within each. This information will be generated by using DFG's stream survey procedure described in "California Salmonid Stream Habitat Restoration Manual" or the formal stream survey procedure described in EPA's Volunteer Monitors Manual. This information may be available through DFG or other resource agency conducting fish and fish habitat surveys.

- **Step 2**. Designate a stream order to each channel type. Each channel type with a different stream order will become a unique sampling reach. Randomly (see box for random sampling procedures) choose 3 riffles from each sampling reach. If there are many riffles within a large reach of uniform channel, divide the stream reach into smaller reaches.

- **Step 3**. Collect the samples. One sample from the upstream third of the riffle will be collected from each of the randomly chosen riffle. The step-by-step instructions to actually collect the samples is discussed later in this chapter.

Non-Random Selection Based on Available Access

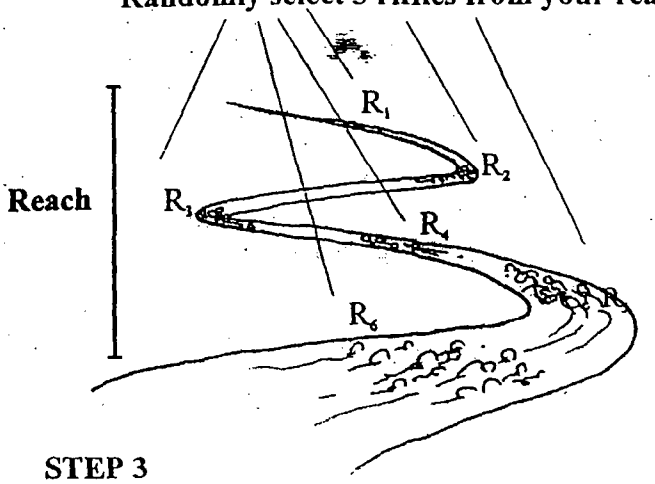
This is the most practical strategy for selecting sampling locations. It does not assume that access is unlimited; This sampling strategy takes into account that private property or steep and dangerous conditions will prevent you from walking the entire stream. The following step-by-step procedures will help you locate the sampling units using this strategy (***Figure 8-2***):

- **Step 1**. Divide the watershed into tributary basins and then each basin into upper, middle and lower sections. Determine road access and property ownership for the watershed and designate the best possible access points in each of these sections.

Non-Point Source Design

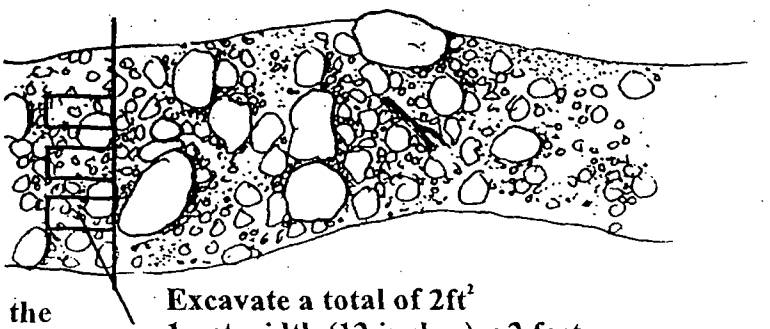
STEP 1

Randomly select 3 riffles from your reach



STEP 2

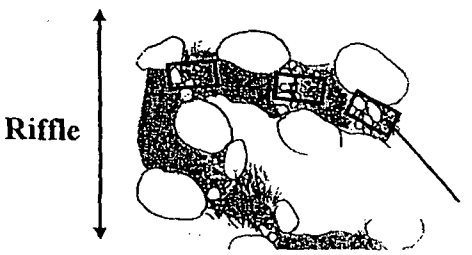
Randomly select 1 transect within the top 1/3 of riffle



Excavate a total of 2ft^2
1 net width (12 inches) x 2 feet
at each point

STEP 3

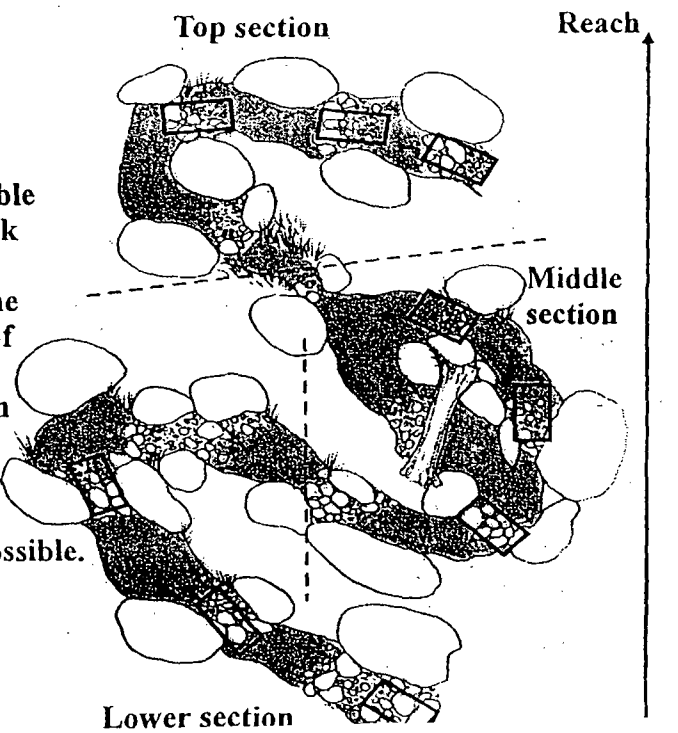
Collect and combine from both margins and the thalweg, to obtain a representation of the whole width of the riffle.
Do this for each of the 3 randomly chosen riffles.



If the stream's width is too narrow to collect three net-widths across, then randomly pick 3- 1x2 square-foot areas from all the possible 1x2 sampleable areas in the riffle.

One of the 3- 1x2 areas sampled out of 5 possible areas.

If your reach does not contain "traditional" riffles, then divide the reach into top, middle and lower sections. Within each section, identify all possible 1x2 square-foot sampleable areas, and randomly pick 3 of these areas from which to collect your sample. The 3 areas within your section are combined into one representative sample. Repeat the process for each of the three section.
Remember that in this situation, the sections function as your "riffles".



9- 1x2 areas sampled out of 14 possible.

Figure 8-2: non-point source sampling design

request, add another 10% to your total to cover any increases that may take effect from the time your grant is submitted to the time it is approved.

When preparing to sample, it is important to produce the labels for each sample event before you go into the field (see Sample Label box). Without specific instructions and some oversight, different sampling teams will produce amazingly similar labels making the sorting of the samples very confusing later. Make sure each team has a current California Bioassessment Worksheet (CBW) for the field and a Chain of Custody (COC) form. Access DFG's Aquatic Bioassessment Lab's web site at www.dfg.ca.gov/cabw/cabwhome.html to ensure you have up-to-date protocols.

INSTRUCTIONS FOR FILLING OUT SAMPLE LABELS

1) Develop a Sampling Identification Number system that indicates stream, reach (for non-point design) and riffle. The example below uses an abbreviation for the stream (AR for American River), an abbreviation for the reach (UP for upper section) and a number for the riffle (001).

2) Record the following information on the labels before going into the field: Sampling Identification Number followed by -01,-02, etc. (to identify each transect sampled from a riffle or riffles in a reach), stream name, date and the sampler's initial. Always use a pencil and water-proof paper.

3) While in the field, other descriptive information about the sampling unit can be recorded on the back side of the label.

4) Place the label inside the jar after the sample material and ethanol have been added.

Bioassessment Sample Label
Sample Identification Number: AR-UP001-01
Stream Name: American River
Date: 09/27/98
Samples by: JH and MB

Collecting Benthic Macroinvertebrates (BMI) for the Point Source Sampling Design

Now it is time to approach the sampling unit. As described earlier in the chapter, the number of replicate samples collected at each riffle depends on the type of sampling design. With the point source design you will collect replicate samples within a riffle to estimate the community characteristics of the population of BMIs within the riffle. The statistical reasoning behind replication is discussed further in Chapter 10.

The following procedures will help you collect a BMI sample from each sampling unit for a point source sampling design:

- **Step 1.** Place the measuring tape along the bank of the entire riffle while being careful not to walk in the stream. Each meter or 3 foot mark represents a possible transect location. Select 3 transects from all possible meter marks along the measuring tape using a random number table (see box on page 8-4 for random number selection). Walk to the downstream transect before proceeding to Step 2.

- **Step 2.** Inspect the transect before collecting BMIs and imagine a line going from one bank to the other, perpendicular to the flow. Choose 3 locations along that line where you will place your net to collect BMIs. If the substrate is fairly similar and there is no structure along the transect, the 3 locations will be on the side margins and the **thalweg** of the stream. When looking at a cross-section of a stream, the thalweg is the deepest part of the stream, and not necessarily the center of the stream. If there is substrate and structure complexity along the transect, then as much as possible, allow the 3 collections to reflect it.

- **Step 3.** After mentally locating the 3 areas, collect BMIs by placing the D-shaped kick-net on the substrate, perpendicular to the flow, and disturbing a 1X2 foot portion

of substrate upstream of the kick-net to approximately 4-6 inches in depth. The 1-foot part of the 1x2 foot section corresponds to the width of your net. Pickup and scrub large rocks by hand under water in front of the net. Be sure to pick up the substrate in front of the net and do not scoop it into the net. Let the flow bring the materials into the net. Maintain a consistent sampling effort (approximately 1-3 minutes) at each location along the transect. Combine the 3 collections within the kick-net to make one "composite" sample.

- **Step 4.** Place the contents of the kick-net in a standard size 35 sieve (0.5 mm mesh) or white plastic or enameled tray. Remove the larger twigs, leaves and rocks by hand after carefully inspecting for clinging organisms. Also inspect your net and carefully remove all clinging organisms with a pair of forceps. If the pan is used, pour the material through the sieve to remove the water before placing the material in the jar. Place the sampled material and label in a jar and completely fill with 95% ethanol. Never fill a jar more than 2/3 full with sampled material and gently agitate jars that contain primarily mud or sand.

- **Step 5.** Proceeding upstream, repeat Steps 2 through 4 for the next two randomly chosen transects within the riffle.

Collecting Benthic Macroinvertebrates (BMI) for the Non-Point Source Sampling Design

As described earlier in the chapter, the number of replicate samples collected at each riffle depends on the type of sampling design used. With a non-point source design you will collect a sample of BMIs from randomly chosen riffles to estimate the community characteristics of BMIs within a reach of stream. The statistical reasoning behind replication is discussed further in Chapter 10. ***Figure 8-2*** illustrates the non-point source sampling design.

The following procedures will help you collect a BMI sample from each sampling unit for a non-point source sampling design:

- **Step 1.** Randomly choose 3 of the 5 riffles within the stream reach using the random number table (see box on page 8-4 for random number selection).

- **Step 2.** Starting with the downstream riffle within the reach of stream, place the measuring tape along the bank of the entire riffle while being careful not to walk in the stream. The upstream third of the riffle will be used for collecting a BMI sample. Determine which transect will be used by counting the number of meter or 3-foot marks, divide by 3 and randomly choosing one from the upper third of the riffle.

- Step 3. Inspect the transect before collecting BMIs and imagine a line going from one bank to the other, perpendicular to the flow. Choose 3 locations along that line where you will place your net to collect BMIs. If the substrate is fairly similar and there is no structure along the transect, the 3 locations will be on the side margins and the **thalweg** of the stream. When looking at a cross-section of a stream, the thalweg is the deepest part of the stream, and not necessarily the center of the stream. If there is substrate and structure complexity along the transect, then as much as possible, allow the 3 collections to reflect it.

- **Step 4.** After mentally locating the 3 areas, collect BMIs by placing the D-shaped kick-net on the substrate, perpendicular to the flow, and disturbing a 1X2 foot portion of substrate upstream of the kick-net to approximately 4-6 inches in depth. The 1-foot part of the 1x2 foot section corresponds to the width of your net. Pickup and scrub large rocks by hand under water in front of the net. Be sure to pick up the substrate in front of the net and do not scoop it into the net. Let the flow bring the materials into the net. Maintain a consistent sampling effort (approximately 1-3 minutes) at each location along the transect.

Combine the 3 collections within the kick-net to make one "composite" sample.

- **Step 5.** Place the contents of the kick-net in a standard size 35 sieve (0.5 mm mesh) or white plastic or enameled tray. Remove the larger twigs, leaves and rocks by hand after carefully inspecting for clinging organisms. Also inspect your net and carefully remove all clinging organisms with a pair of forceps. If the pan is used, pour the material through the sieve to remove the water before placing the material in the jar. Place the sampled material and label in a jar and completely fill with 95% ethanol. Never fill a jar more than 2/3 full with sampled material and gently agitate jars that contain primarily mud or sand.

- **Step 6.** Proceeding upstream, repeat steps 2 through 5 for the next two randomly chosen riffles within the stream reach.

Assessment of the Physical/Habitat Condition of Rivers and Streams

In Chapter 7, we presented an overview to assessing the physical/habitat condition of rivers or streams. We explained that there are two distinct uses of physical/habitat measures; one to measure the physical condition or quality of a reach of stream and one to measure physical characteristics of the bioassessment sample site to assist the project advisor with data analysis. We further explained that each group will have to decide whether quantitative measures of physical/habitat characteristics such as a fish habitat survey is a major objective of their monitoring effort. We recommend combining bioassessment with every fish habitat survey, but the level of detail needed for fish habitat measurement is not a requirement of the CSBP.

Measuring Chemical and Physical/Habitat Characteristics

There are many chemical constituents of stream water that can be part of a ambient water quality monitoring program, but there are only four that should be collected whenever a bioassessment sampling event occurs. They are dissolved oxygen (DO), temperature, conductivity and pH. Conductivity and pH are the most important of the four to collect. There are affordable meters and colormetric devices that can be used to collect these basic chemical measurements. In Chapter 7 we discuss chemical characteristics of stream water in more detail.

Table 8-1 lists the physical/habitat characteristics which are either required or recommended to be collected at each riffle where BMIs are collected. If your monitoring group is collecting habitat data for a fish habitat survey, then you probably have enough information. Check Table 8-1 to make sure the required parameters are being collected to support your bioassessment work. Monitoring groups not collecting habitat data for a fish habitat survey need to measure the required characteristics and should try to incorporate those that are recommended when the need arises or budget allows. Refer to DFG's "California Salmonid Stream Habitat Restoration Manual" if you want to measure these or additional physical/habitat parameters more precisely.

Measurements of the physical/habitat parameters should be conducted after the BMI sampling has been completed. If you have the extra personnel and want to save field time, then physical/habitat measurements can be taken simultaneously, as long as you are careful not to disturb the riffle upstream of the transects. All measurements are of the riffle, but weighed toward the transects. Always make note in the comment section of the CBW if the characteristics of the transects where the BMI sample was taken is considerably different than that of the riffle as a whole. The following procedures will help you measure the required physical/habitat characteristics of a riffle:

- **Step 1.** Water temperature, specific conductance, pH and dissolved oxygen should be measured at the sampling site

using approved standardized procedures and instruments.

- **Step 2.** Record the riffle length, and depending on the design, choose either 1 transect within the top third of the riffle (non-point source design), or 3 transects within the entire riffle (point-source design). Estimate the average riffle width by averaging several measurements along its length. Measure the riffle depth by placing the stadia rod or measuring stick at several places within the riffle and averaging the measurements.

- **Step 3.** Estimate or measure the entire length of the reach where the three riffles are chosen as part of the non-point source sampling design.

- **Step 4.** Estimate the riffle velocity by floating a twig, leaf or other organic object such as an orange, and timing its travel down the length of the riffle. Repeat this several times and divide the distance by the time in seconds. Riffle velocity can be more accurately measured with a flow meter. Place the meter in front of the three locations along the transect(s) where you collected the BMI samples and average the readings.

- **Step 5.** Estimate canopy cover by observing how much of the riffle surface is covered by shade from streamside vegetation. Canopy cover can be more accurately measured using a densiometer at several places along the riffle and averaging.

Table 8-1. Required and recommended physical/habitat characteristics to be collected at each riffle when collecting BMI samples.

Physical/Habitat Characteristics	Required	Recommended
Riffle length	yes	
Average riffle (ft) width	yes	
Average riffle depth (in) along the transects	yes	
Riffle velocity (ft/s) using timed floating object	yes	
Riffle velocity (ft/s) using flow meter at transects		yes
% Canopy cover using visual method	yes	
% Canopy cover using densiometer		yes
Substrate complexity using RBP Habitat Parameter 1	yes	
Embeddedness using RBP Habitat Parameter 2	yes	
% Substrate composition using fines (< 0.1") gravel (0.1-2"), cobble (2-10"), boulder (>10") and bedrock (solid)	yes	
Substrate consolidation using loosely, moderately or tightly cemented	yes	
% Gradient of riffles using stadia rod and level	yes	

- **Step 6.** Determine substrate complexity and embeddedness by applying Parameters 1 and 2, respectively on the Physical/Habitat Quality Form to the riffle where the BMI sample was collected. Use the entire riffle to assess these parameters and make note if the area along the transect(s) is considerably different from the rest of the riffle.

- **Step 7.** Visually estimate the percent of riffle in each of the following substrate categories: fines (<0.1"), gravel (0.1-2"), cobble (2-10"), boulder (>10") and bedrock (solid). Use the entire riffle to assess this parameter and make note if the area along the transect(s) is considerably different from the rest of the riffle.
- **Step 8.** Estimate substrate consolidation by kicking the substrate with the heel of your wader boots to note whether it is loosely, moderately or tightly cemented. The estimate should also take into consideration the hands-on experience obtained from collecting the BMI sample(s).

- **Step 9.** Measure the gradient or slope of the riffle using a stadia rod and hand level. There is really no better or cheaper way of doing this. A stadia rod which is simply a long (> 8 ft) measuring stick, can be purchased or made. A hand-held level is a small telescope with a bubble level inside. First you measure the height of your eye on the stadia rod and then have someone take the rod to the top of the riffle while you make a level reading of the rod. The difference in height between your eye and the top of the riffle divided by the length of the riffle times 100% equals the percent gradient. **It is important to measure gradient from the surface of the water and not the stream bottom.**

Using the California Bioassessment Worksheet (CBW)

A California Bioassessment Worksheet (CBW) (**Appendix C**) should be filled out for each individual riffle when following the Point Source Sampling Design and for the entire reach when using the Non-point Sampling Design. Use the following step-by-step procedures for filling out the CBW:

- **Step 1.** Enter the watershed and stream name, date and time of sample collection, name of the monitoring or watershed group collecting the samples, sample identification number(s), and a short site description on the CBW.

- **Step 2.** Enter the names of each crew member in the Crew Member Box.

- **Step 3.** Determine the longitude and latitude coordinates and elevation from a GPS unit or watershed topographic map. Determine in which California ecoregion or sub-ecoregion the site is located by using the U.S. Forest Service map obtained by visiting the California Aquatic Bioassessment web site www.dfg.ca.gov/cabw/cabwhome.html. Record this information and any other comments on the sampling site in the Site Location Box.

- **Step 4.** Record the water temperature, specific conductance, pH and dissolved oxygen measurements in the Chemical Characteristics Box.

- **Step 5.** Record the physical/habitat characteristics in the Riffle/Reach Characteristics Box. For the Point Source Sampling Design, record the riffle length, the 3 transect locations along the riffle and the physical/habitat characteristics information (starting with Ave. Riffle Width) on the lines below the "riffle 1" column. For the Non-point Source Sampling Design, record the reach length, the total score from the Physical/Habitat Quality Form and all physical/habitat characteristics information on the lines below the "riffle 1" through "riffle 3" columns.

- **Step 6.** Record the location of the laboratory being used by your group to process the samples. If the group will be

contracting out the laboratory work, then record the name and address of the Bioassessment Laboratory that received the samples along with the laboratory-issued sample numbers if they are different from the field sample identification numbers.

Assessing Physical/Habitat Quality of a Stream Reach

Appendix C contains the Physical/Habitat Quality Forms for high gradient streams. These forms and procedures are used to assess the entire reach where the BMI samples are collected as part of a non-point source sampling design. Since the CSBP is for sampling riffles in wadeable streams, the high gradient is the procedure to use for most stream reaches. Only for valley rivers and some mountain meadow streams would the low gradient procedure be used.

Some of the parameters in this procedure do not apply to a single riffle, so this procedure is usually not performed as part of the point source sampling design. The parameters just discussed are usually enough to demonstrate that the riffles used for a point source investigation were homogeneous. Refer to the DFG's California Stream Restoration Manual" if you want to take more quantitative measures of physical/habitat conditions. However, there is no substitute for this assessment; it must be performed as part of a bioassessment program. Read the following procedures taken from the U.S. EPA's Rapid Bioassessment Procedures document before conducting the physical/habitat quality evaluation.

1. Epifaunal Substrate/Available Cover - Includes the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, and undercut banks, available as refugia, feeding, rearing or sites for spawning and nursery functions of aquatic macrofauna. A wide variety and/or abundance of submerged structures in the stream provides macroinvertebrates and fish with a large number of niches, thus increasing habitat diversity. As variety and abundance of cover decreases, habitat structure becomes monotonous, diversity decreases, and the potential for recovery following disturbance decreases. Riffles and runs are critical for maintaining a variety and abundance of insects in most high-gradient streams and serving as spawning, rearing and feeding refugia for certain fish. The extent and quality of the riffle are important factors in the support of healthy biological conditions in high-gradient streams. Riffles and runs offer a diversity of habitat through variety of particle size, and, in many small high-gradient streams, will provide the most stable habitat. Snags and submerged logs are among the most productive habitat structures for macroinvertebrate colonization and fish refugia in low-gradient streams. However, "new fall" will not yet be prepared for colonization.

2a. (High Gradient) Embeddedness - Refers to the extent to which rocks (gravel, cobble, and boulders) and snags are covered or sunken into the silt, sand, or mud of the stream bottom. Generally, as rocks become embedded, the surface area available to macroinvertebrates and fish (shelter, spawning, and egg incubation) is decreased. Embeddedness is a result of large-scale sediment movement and deposition, and is a parameter evaluated in the riffles and runs of high-gradient streams. The rating of this parameter may be variable depending on where the observations are taken. To avoid confusion with sediment deposition (another habitat parameter), observations of embeddedness should be taken in the upstream and central portions of riffles and cobble substrate areas.

2b. (Low Gradient) Pool Substrate Characterization - Evaluates the type and condition of bottom substrates found in pools. Firmer sediment types (e.g., gravel, sand) and rooted aquatic plants support a wider variety of organisms than a pool substrate dominated by mud or bedrock and no plants. In addition, a stream that has a uniform substrate in its pools will support

far fewer types of organisms than a stream that has a variety of substrate types.

3a. High Gradient) Velocity/Depth Combinations - Patterns of velocity and depth are included for high-gradient streams under this parameter as an important feature of habitat diversity. The best streams in most high-gradient regions will have all four patterns present: (1) slow-deep, (2) slow-shallow, (3) fast-deep, and (4) fast-shallow. The general guidelines are 0.5m depth to separate shallow from deep, and 0.3 m/sec to separate fast from slow. The occurrence of these four patterns relates to the stream's ability to provide and maintain a stable aquatic environment.

3b. (Low Gradient) Pool Variability - Rates the overall mixture of pool types found in streams, according to size and depth. The four basic types of pools are large-shallow, large-deep, small-shallow, and small-deep. A stream with many pool types will support a wide variety of aquatic species. Rivers with low sinuosity (few bends) and monotonous pool characteristics do not have sufficient quantities and types of habitat to support a diverse aquatic community. General guidelines are any pool dimension (i.e., length, width, oblique) greater than half the cross-section of the stream for separating large from small and 1 m depth separating shallow and deep.

4. Sediment Deposition - Measures the amount of sediment that has accumulated in pools and the changes that have occurred to the stream bottom as a result of deposition. Deposition occurs from large-scale movement of sediment. Sediment deposition may cause the formation of islands, point bars (areas of increased deposition usually at the beginning of a meander that increase in size as the channel is diverted toward the outer bank) or shoals, or result in the filling of runs and pools. Usually deposition is evident in areas that are obstructed by natural or manmade debris and areas where the stream flow decreases, such as bends. High levels of sediment deposition are symptoms of an unstable and continually changing environment that becomes unsuitable for many organisms.

5. Channel Flow Status - Measures the degree to which the channel is filled with water. The flow status will change as the channel enlarges (e.g., aggrading stream beds with actively widening channels) or as flow decreases as a result of dams and other obstructions, diversions for irrigation, or drought. When water does not cover much of the streambed, the amount of suitable substrate for aquatic organisms is limited. In high-gradient streams, riffles and cobble substrate are exposed; in low-gradient streams, the decrease in water level exposes logs and snags, thereby reducing the areas of good habitat. Channel flow is especially useful for interpreting biological condition under abnormal or lowered flow conditions. This parameter becomes important when using more than one biological index period for surveys or the timing of sampling is inconsistent among sites or annual periodicity.

6. Channel Alteration - Measures large-scale changes in the shape of the stream channel. Many streams in urban and agricultural areas have been straightened, deepened, or diverted into concrete channels, often for flood control or irrigation purposes. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when artificial embankments, riprap, and other forms of artificial bank stabilization or structures are present; when the stream is very straight for significant distances; when dams and bridges are present; and when other such changes have occurred. Scouring is often associated with channel alteration.

7a. (High Gradient) Frequency of Riffles (or bends) - Measures the sequence of riffles and thus the heterogeneity occurring in a stream. Riffles are a source of high-quality habitat and diverse fauna,

therefore, an increased frequency of occurrence greatly enhances the diversity of the stream community.

7b. (Low Gradient) Channel Sinuosity - For areas where distinct riffles are uncommon, a run/bend ratio can be used as a measure of meandering or sinuosity. A high degree of sinuosity provides for diverse habitat and fauna, and the stream is better able to handle surges when the stream fluctuates as a result of storms. The absorption of this energy by bends protects the stream from excessive erosion and flooding and provides refugia for benthic invertebrates and fish during storm events. To gain an appreciation of this parameter in some streams, a longer segment or reach than that designated for sampling may be incorporated into the evaluation. In some situations, this parameter may be rated from viewing accurate topographical maps. The "sequencing" pattern of the stream morphology is important in rating this parameter. In headwaters, riffles are usually continuous and the presence of cascades or boulders provides a form of sinuosity and enhances the structure of the stream. In "oxbow" streams of coastal areas and deltas, meanders are highly exaggerated and transient. Natural conditions in these streams are shifting channels and bends, and alteration is usually in the form of flow regulation and diversion. A stable channel is one that does not exhibit progressive changes in slope, shape, or dimensions, although short-term variations may occur during floods.

8. Bank Stability (condition of banks) - Measures whether the stream banks are eroded (or have the potential for erosion). Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks, and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Eroded banks indicate a problem of sediment movement and deposition, and suggest a scarcity of cover and organic input to streams.

9. Bank Vegetative Protection - Measures the amount of vegetative protection afforded to the stream bank and the near-stream portion of the riparian zone. The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. This parameter supplies information on the ability of the bank to resist erosion as well as some additional information on the uptake of nutrients by the plants, the control of instream scouring, and stream shading. Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or those shored up with concrete or riprap. This parameter is made more effective by defining the natural vegetation for the region and stream type (i.e., shrubs, trees, etc.). In areas of high grazing pressure from livestock or where residential and urban development activities disrupt the riparian zone, the growth of a natural plant community is impeded and the disruption can extend to the bank vegetative protection zone.

10. Riparian Vegetative Zone Width - Measures the width of natural vegetation from the edge of the stream bank out through the riparian zone. The vegetative zone serves as a buffer to pollutants entering a stream from runoff, controls erosion, and provides habitat and nutrient input into the stream. A relatively undisturbed riparian zone supports a robust stream system. Narrow riparian zones occur when roads, parking lots, fields, lawns, bare soil, rocks, or buildings are near the stream bank. Residential developments, urban centers, golf courses, and rangeland are the common causes of anthropogenic degradation of the riparian zone. The presence of "old field" (i.e., a previously developed field not currently in use), paths, and walkways in an otherwise undisturbed riparian zone may be judged to be inconsequential to destruction of the riparian zone. In some regions of the country, an increase in the specified width of a desirable riparian zone is warranted.

Photodocumentation of Sampling Riffle and Stream Reach

Documenting the condition of each riffle and stream reach in a visual format is very important. The minimal effort should be to photograph the riffle where each sample was obtained by standing at the bottom end and taking the photo looking upstream. When not using a digital camera, you should use a wide angle lense and develop the photograph in print format. A more complete documentation would also include separate photographs of each stream bank and a close up of the substrate where the sample was collected. Substrate photographs should be taken before the sample is collected so the natural state of the stream bottom is visible. Further documentation could include photographing problem areas or videotaping the entire stream or stream reach.

Filling Out the Field Paperwork

Before leaving the field, make sure all the paper work is completed and accurate. You should have a Physical/Habitat Form for each reach surveyed and a CBW for each riffle sampled. The person assigned to monitoring the paperwork should take an inventory of the samples, worksheets and forms before leaving the field. Make sure you have all the equipment accounted for -- it is incredible how things disappear in the field, especially forceps. This is a good time to make notes on sampling difficulties and possible modifications to your field sampling SOPs. Also, note problems with the abilities of the crew members. There is always a job for everyone, but not everyone is made to work in the field.

Finally, start to fill out the Chain of Custody (COC) form (**Appendix C.**) The COC is actually a QA/QC and legal form used to track the samples on their way to the laboratory. This is covered further in Chapter 11. If you are a one person operation, then, theoretically, it is not necessary to fill out a COC because the sample will never be out of your control. However, we recommend using it for organizational reasons, which become clear in the next chapter. One COC card should be filled out for each field visit, which means every day unless you are spending the night in the field.

On the front side of the COC card, fill in the program name, watershed name, date/time (when filling out the form), sample identification numbers, and a brief description of all the samples collected on that visit. Following chapters cover when to fill in the Bioassessment Lab and BioLab No. lines.

On the backside of the COC card, fill in the name, address, telephone number and signature of one of the crew members. Usually the name of the person monitoring the paperwork is included on the bottom. The project advisor's information can be filled in at any time. On the top of the back side, a crew member who participated in the sampling must put their signature and the date of signing (field visit date) in the "Sampled by" box. Then, if that person delivers the samples to the laboratory where the samples will be stored and processed, there will be one more signature by the either the project advisor or group member assigned to laboratory organization. They will sign the "Relinquished by" box. If the sampler gives the samples to someone else to deliver, then that person signs the "Received by" box. For every link along the way to the laboratory, there will be a "Received by" box signed and dated. Finally, at the end of the trail the samples will be relinquished to the laboratory person and the "Relinquished by" box will be signed and dated. The COC is very important and should always be used when sampling. Its purpose and importance are discussed further in Chapter 11.

Chapter 9
Laboratory Procedures for Analyzing BMI Samples

Introduction to the Chapter

Chapter 9 discusses the three levels of benthic macroinvertebrate identification. The two levels of taxonomic efforts recommended for citizen monitors and the third level for professionals are also described. The chapter also explains how to maintain field and voucher samples and reference collections. Finally, steps in starting a successful citizen laboratory, developing standard operating procedures, and the evolving laboratory are presented.

The Three-Level System of Benthic Macroinvertebrate (BMI) Identification

Once the BMI samples are collected, they will need to be processed in a laboratory and identified to a specific level of taxonomy. There are three levels of BMI identification: **Level 1 Taxonomic Effort** requires subsampling 100 BMIs from the sample, sorting those 100 BMIs into the major taxonomic groups and then separating the mayflies, stoneflies and caddisflies into their different morphologic forms; **Level 2 Taxonomic Effort** requires subsampling 100 BMIs from the sample, sorting those 100 BMIs into the major taxonomic groups and then identifying those groups to the family level of taxonomy; and **Level 3 Taxonomic Effort**, which is the professional level equivalent, requires subsampling 300 BMIs from the sample, sorting those 300 BMIs into the major groups and then identifying those groups to the lowest possible taxon, usually to genera and/or species level.

The three levels of taxonomic effort are not independent; they are designed to flow from the first to the third level, culminating in a professional level analysis. Level 1 does not require identification beyond the major groups, except for the important insects in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) which are only separated by morphological differences. Level 1 is a faster, less technical analysis of the BMI sample and is ideal for groups just getting started, or for high school projects stressing education as well as long-term monitoring goals. However, serious citizen monitors will eventually want to take the extras steps required to know the taxonomic names of BMIs they collect. Level 3 and the transition from Level 2 to Level 3 are discussed later in this chapter in the evolving citizen laboratory section.

Although Level 2 is the preferable taxonomic level for citizen groups and is emphasized in this manual, citizen groups could simply collect samples and have a professional BMI laboratory perform Level 3 Identification. Visit DFG's website (www.dfg.ca.gov/cabw/cabwhome.html) for a list of qualified BMI laboratories and taxonomists. Still, we suggest that monitoring groups at least attempt to conduct the laboratory portion of the CSBP a few times to help educate your group. You may be using this manual as part of the training you received through the SLSI. If not, contact the SLSI at slsi@cwnet.com or visit its website (www.slsii.org) for information on future training opportunities. Remember that the training is only an introduction, and you must continue to practice to become proficient with BMI taxonomy.

Remember that the training is only an introduction, and you must continue to practice to become proficient with BMI taxonomy.

Laboratory Log Book

BioLab #	Sample ID #	Sample Description
BL-001	AR-UP001-01	American River Project, upper section reach, lowermost riffle
BL-002	AR-UP001-02	American River Project, upper section reach, mid-reach riffle
BL-003	AR-UP001-03	American River Project, upper section reach, uppermost riffle

Laboratory Requirement for Analyzing BMI Samples

Monitoring groups deciding to pursue BMI taxonomy will need the participation of a well-equipped high school, junior college, or university laboratory. You will need a laboratory facility with good dissecting microscopes with multiple powers to identify the BMIs. Some microscopes have two or three fixed powers which could be 1X, 2X or 4X. Better microscopes have zoom lenses which can range from 0.7X to 3.0X. With either microscope, the eye piece or ocular power should be 10X, which means the total power will be 10 times the lense number (7X to 30X in the case of the zoom lense). The type of materials you will need is listed in the Laboratory Equipment and Supplies box on this page and the quantities and approximate costs of these materials for a typical monitoring group can be found on SLSI's web site (www.slsii.org). Chapters 16 through 22 contain the taxonomic keys to the identification of BMIs common in western streams and rivers. Those chapters also contain considerable information on the habit and habitats of BMIs. Each group member should read these chapters thoroughly.

The laboratory procedures presented in this manual are organized to help facilitate the workshop presented by the authors. This format has been refined from considerable experience in training monitoring groups and can be used to set up the basic format of your laboratory. It is based on having 12 people working for approximately 12 hours over two days. During that time, 6 BMI samples are fully processed by people working in this laboratory format for the first time. Of course, each monitoring group may have to adjust this format to accommodate the actual number of members participating and the number of consecutive hours the laboratory is available. Options for setting up a laboratory and advice for the maturing laboratory can be found at the end of this chapter.

Bringing Field Samples into the Laboratory

After collecting the BMI samples in the field, they are transported to the laboratory, under Chain of Custody procedures described in the previous chapter. The Physical/Habitat Quality Form for each stream reach and a CBW for each set of BMI sample must accompany the samples along with the COC. The project advisor or an assigned group member should be in charge of laboratory organization and their signature should be the last one on the COC in the "Relinquished by" box. There should also be a Laboratory Log Book established to help with organization (see Laboratory Log Book box on page 9-1). The following procedures will help the laboratory person receive samples into the laboratory:

- **Step 1.** Open each jar, inspect the label and link it to each sample identification number on the COC. **Resolve any problems with sample identification at this time.**

LABORATORY EQUIPMENT AND SUPPLIES

Dissecting microscope
standard size #35 Tyler sieve (0.5mm)
Gridded white pan
Wide-mouth glass jars and lids
Plastic petri dish
Vials
Taxonomic keys
70% ethanol/5% glycerin solution
Fine forceps
Vial tray
List of standardized taxonomic levels
Water-proof paper and pencil
Laboratory benchsheets
Random number table
Chain of Custody Form

- **Step 2.** Record the sample identification number and sample description for each sample into the Laboratory Log Book using a sequential numbering system for your laboratory (for example, the Dry Creek

Conservancy monitoring group would use DCC-001 through infinity).

- **Step 3.** Place the samples into a secure Sample Depository facility for storage until they can be further processed. Place the COC, Physical/Habitat Form and CBW in a file located in a safe place, but not necessarily with the samples.

Subsampling Procedure for Levels 1 and 2 Taxonomic Effort

Now that the samples are logged in and safely stored, the first task in processing the samples is to clean and then subsample 100 BMIs for eventual sorting and identification. Now is the time to introduce another important piece of paperwork, the laboratory benchsheet. **Laboratory benchsheets** are forms that contain all laboratory notes and tallies of the BMIs identified for each sample. The laboratory benchsheets are the only forms used throughout the laboratory portion of the CSBP and retained as official documents. There is a two-sided benchsheet used throughout the entire laboratory portion for Level 1 Taxonomic Effort. There will be more than one benchsheets for the Level 2 Taxonomic Effort. There will be a two-sided benchsheet for Level 2 subsampling and sorting procedures and a set of four separate benchsheets for Level 2 final identification. **Appendix C** contains the benchsheets used in SLSI's training. Each monitoring group will probably have to customize their own benchsheets, but these provide an example and a good place to start.

For our training, we use teams of 2 people to work on each sample. The following step-by-step procedures should be used to clean and then subsample BMIs:

- **Step 1.** Remove the sample jar from the Sample Depository and empty its contents into the # 35 sieve (0.5 mm mesh) making sure that all debris is rinsed from the jar and into the sieve. Place the label back into the jar and set it aside for later. Use rinse water from a laboratory sink or in a plastic tub using a hose. Rinse in a manner not to splash debris out of the sieve. (Note: check with the school for their policy on dumping chemicals into the drain. The sample can be strained into a separate container for disposal, but should not be recycled for field use since the concentration is unknown and field ethanol must be 95%.)

- **Step 2.** Once the sample is rinsed, begin to clean and remove debris larger than ½ inch (10 mm). Remove green leaves, twigs and rocks but do not remove filamentous algae and skeletonized leaves. This is best done by rubbing the material underwater and inspecting it with the naked eye or under a 10X magnifying lens. The debris can be discarded. (Note: this is the only time in this procedure that material from the sample will be discarded; make sure you are confident with you cleaning abilities.)

- **Step 3.** After cleaning is complete, place the material into a plastic tray with equal sized, numbered grids (approximately 2 X 2 inches or the width of a single edge razor blade). Do not allow any excess water into the tray. This is best done by tapping the sieve containing the drained material into the tray. The remaining material can be removed from the sieve by using the flow of water to force the material into the rim, and pushing it into the tray with the blunt end of the forceps or a spoon. Spread the moist, cleaned debris on the bottom of the tray using as may grids necessary to obtain an approximate thickness of ½ inch (10 mm). The tray we use in the training has 24 grids. However, more or fewer grids can be used to spread out the material into the required thickness by using an additional gridded tray or using fewer grids in a single tray.

- **Step 4.** Fill in the laboratory number, sample identification number and sample description on your benchsheet. Choose six or more grid numbers using the random numbers table (**Appendix C**, see Chapter 8 for procedures on random number selection) and record the numbers in the boxes of the Subsampling Notes benchsheet.

- **Step 5.** Starting with the first grid, remove all the material from the grid and place it in a clean petri dish. Then, going through the petri dish systematically, remove, count and place macroinvertebrates into another clean petri dish containing 70% ethanol/glycerin. Using as many additional grids as necessary, remove a total of 100 macroinvertebrates from the sample. Use the benchsheet to tally the organisms found in each grid. Once 100 organisms are counted, continue to count the remaining organisms in the last grid used to reach 100 and place them in a separate vial or petri dish. Each picked grid should be retained for the QA/QC procedure described in Chapter 11.

- **Step 6.** Use the Subsampling Notes benchsheet to total the number of organisms found in each grid and the number of grids used to collect the macroinvertebrates. Place the remaining contents of the tray into a wide mouth pint jar (clean and store the original plastic jar for future field work) with the sample label and enough 70% ethanol/glycerin solution to fully cover the contents. Also place the leftover macroinvertebrates from your last grid (what is left after you have removed your 100th bug) in the sample jar. (Note: be careful not to discard anything from the original sample except the clean debris produced in Step 2 of the subsampling procedures.)

Level 1 Taxonomic Effort for Citizen Monitors

Now that you have a petri dish with 100 BMIs and the remainder of the sample safely set aside in a jar, it is time to separate them into their taxonomic categories. With the Level 1 Taxonomic Effort, you will sort the BMIs into the major groups and then further separate only the mayflies (order: Ephemeroptera), stoneflies (order: Plecoptera), caddisflies (order: Trichoptera) by their morphological characteristics. At that point, you are finished with the laboratory portion and will go to data analysis. You will continue to use the benchsheet that you used for subsampling, the set of keys to the Major Groups of Aquatic Macroinvertebrates found in Chapter 13 and the mayfly, stonefly and caddisfly illustration charts found in Chapters 14-16. **Taxonomic keys** are systematic procedures that lead you through a set of questions or illustrations, which by answering in reference to the morphology of the BMI, will categorize it according to its scientific name. Chapter 12 on taxonomic nomenclature should be thoroughly read before attempting BMI identification.

For our training, the people who cleaned and subsampled the sample will continue to work together to finish BMI identification using the following procedures:

- **Step 1.** Take the petri dish with 100 BMIs and either split them roughly in half and work separately or work as a team with one person sorting and the other person reading the keys and tallying the BMIs into the taxonomic categories.

- **Step 2.** Using the dissecting microscope, begin with one of the BMIs, examine it for distinguishing characteristics and then use the keys starting at the first couplet to identify it. Answer the questions until you end up with the taxa name. Find the taxa name on the bottom half of the Level 1 laboratory benchsheet and record a tally mark.

- **Step 3.** Put that specimen in a clean vial with ethanol/glycerin solution. Put the vial in the vial tray to prevent it from falling over and spilling its contents all over the table. Using a pencil, write the taxa name on a specimen label. At this point just slip the label under the plastic strip on the vial tray directly in front of that vial.

- **Step 4.** Before proceeding to another specimen, search the petri dish for others with similar characteristics. Place all specimens belonging to the same order or taxon into the same labeled vial. Move on to another specimen and repeat Steps 1 through 4. Disregard the direction to go to a particular chapter when the key prompts you to do it - that is for the Level 2

Taxonomic Effort. You may want to go to the listed illustration to confirm your identification.

- **Step 5.** Continue until all 100 BMIs are identified.

- **Step 6.** Take the vials labeled mayflies (order: Ephemeroptera), stoneflies (order: Plecoptera), caddisflies (order: Trichoptera) and empty them individually into a clean petri dish. Be sure that no specimens remain in the vial. Using a long and narrow-neck squeeze wash bottle filled with ethanol will help you get all the specimens out. Examine all the specimens and sort them according to their different morphologic characteristics. Use the corresponding illustration charts and Chapters 14-16 to become familiar with the groups. Once they are separated, tally them on the bottom of the benchsheet referring to the different groups as mayfly taxa 1, mayfly taxa 2, etc..

- **Step 7.** Make sure the paperwork is in order. Tally all rows of the major groups and the mayflies, stoneflies and caddisflies and sign the bottom of the benchsheet. Fill out a Final Identification Label as illustrated in the Label Box on page 9-7. Write the Sample Identification Number, a short description of the site and the date the sample was collected on the front of the label. Write the taxonomic name of the identified specimen, the number of specimens in that family, the Laboratory Number, and the initials of the taxonomist on the back side. Place the label in each vial and snap on the lid **tightly** when you are done.

- **Step 8.** Rubber-band your vials together and put them where the rest of your sample is stored. As an extra precaution, you may want to place the vials inside a wide-mouth jar. Gather your paperwork and proceed to Chapter 10 for data analysis.

Sorting Samples into Major Groups of BMIs for Levels 2 Taxonomic Effort

Now that you have a petri dish with 100 BMIs and the remainder of the sample safely set aside in a jar, it is time to separate them into their taxonomic categories. With the Level 2 Taxonomic Effort, you will sort the BMIs into the major groups and then in another phase, identify the mayflies (order: Ephemeroptera), stoneflies (order: Plecoptera), caddisflies (order: Trichoptera), beetles (order: Coleoptera), true flies (order: Diptera), hellgrammites (order: Megaloptera), true bugs (order: Hemiptera) and dragonflies and damselflies (order: Odonata) to the family level of taxonomy. You will continue to use the benchsheet used for subsampling in this next sorting phase and the set of keys to the Major Groups of Aquatic Macroinvertebrates found in Chapter 13. **Taxonomic keys** are systematic procedures that lead you through a set of questions or illustrations. Reference to the morphology of the BMI will lead you to answers that will categorize the specimen according to its scientific name. Chapter 12 on taxonomic nomenclature should be thoroughly read before attempting BMI identification.

During the training, the people who cleaned and sub-sampled the sample continue to work together to sort the sample into major groups. The following procedures should be used to sort the BMIs:

- **Step 1.** Take the petri dish with 100 BMIs and either split them roughly in half and work separately or work as a team with one person sorting and the other person reading the keys and tallying the BMIs into the major groups.

- **Step 2.** Using the dissecting microscope, begin with one of the BMIs, examine it for distinguishing characteristics and then use the keys starting at the first couplet to identify it. Answer the questions until you end up with the taxa name. Find the taxa name on the bottom half of the Level 1 laboratory benchsheet and record a tally mark.

- **Step 3.** Put that specimen in a clean vial with ethanol/glycerin solution. Put the vial in the vial tray to prevent it from falling over and spilling its content all over the table. Using a pencil, write the taxa name on a specimen label. At this point just slip the label under the plastic strip on the vial tray directly in front of that vial.

- **Step 4.** Before proceeding to another specimen, search the petri dish for others with similar characteristics. Place all specimens belonging to the same order or taxon into the same labeled vial. Move on to another specimen and repeat Steps 1 through 4. Disregard the direction to go to a particular chapter when the key prompts you to do it. You will do this during the next phase. You may want to go to the listed illustration to confirm your identification.

- **Step 5.** Continue until all 100 organisms are identified. Make sure the paperwork is in order. Tally all rows of the Subsampling and Sorting benchsheet and sign the bottom. Write the total number of specimens in each vial on its Sorting Label, place the label in the vial and snap on the lid tightly. **It is very important to have the labels properly filled out because you may be giving the vial to another group for final taxonomic identification.**

Identification of the Major Groups into Families for Level 2 Taxonomic Effort

The final product of sorting the samples is a completed Subsampling and Sorting benchsheet and several labeled vials containing the 100 BMIs. Now we will proceed to the more technically difficult assignment of completing the Level 2 Taxonomic Effort: identifying the BMIs using the family level of taxonomy. During the training we divide the 12 participants into 4 groups: mayflies, stoneflies, caddisflies and others. This means the original 6 groups will split up for a while. To avoid confusion, the original 6 groups need to make sure that their paperwork and sample jar are correctly labeled and put in a safe place.

There might be some resistance to breaking out into groups. At first, most people want to do it all and not be limited to working with a particular group of organisms. The problem is that there is a lot of work involved in fully processing a BMI sample and it must be kept well organized. Through experience, we have found that the work gets done faster and more accurately when the group specializes. You will usually realize this in time and find that there will be opportunities to check in on other groups and take a peek at a few nice specimens.

We try to divide participants with some taxonomic experience into each of the 4 groups. Experienced taxonomists are especially helpful in lending assistance to identify the "others" group. There will be a set of new benchsheets for each group. This time though, each group will be given one benchsheet for each sample, which in the case of our training workshop is a total of 6. The following procedures should be used to perform the final taxonomy of the BMIs:

- **Step 1.** Examine each of the vials you obtained from the 6 subsampling and sorting groups. You will usually have at least one vial from each group. Look through the glass vial to make sure each has a label with the Sample Identification Number. Write the Sample Identification Number and description of the sample on the header of each of the 6 benchsheets.

- **Step 2.** Open a vial, remove the label and pour all specimens in a petri dish. Add ethanol if necessary. **Do not allow specimens to dry out.** Place the label inside or close to the petri dish while you identify the BMIs. Using the appropriate chapter for the major group indicated on the label, identify all the specimens in the vial. During the training workshop, the mayfly, stonefly and caddisfly groups will only need to use the key and illustrations found in Chapters 14, 15 and 16, respectively, The "Other" group should first verify the vials containing the major groups which need no further identification and then go to the appropriate chapters for the insect orders.

- **Step 3.** Put specimens from each family in a separate clean vial with ethanol/glycerin solution. This means that the specimens within the original vial you obtained from the Sorting group could be split into several new vials. Discard the Sorting label and fill out a Final Identification Label as illustrated in the Label Box on this page. Write the Sample Identification Number, a short description of the site and the date of the sample was collected on the front of the label. Write the taxonomic name of the identified specimen, the number of specimens in that family, the Laboratory Number and the initials of the taxonomist on the back side. Place the label in each vial when complete.

- **Step 4.** Continue until all Sorting vials are divided into the final taxonomic levels. Make sure the paperwork is in order. Tally all rows of the Final Identification benchsheet for each of the 6 Sorting groups and sign at the bottom. Make notes on all misidentifications you might have discovered so the Sorting groups understand any discrepancies between the number of specimens they gave you and what you returned.

After the Mayfly, Stonefly, Caddisfly and Other groups are finished and the paperwork is in order, return the vials and benchsheets to the people in the original 6 groups. Each of the 6 groups should gather up the vials and go over the 4 benchsheets (mayfly, stonefly, caddisfly and other) looking for discrepancies. If you gave one vial with 45 specimens to the mayflies taxonomy group, you should have received 45 specimens, perhaps in as many as 10 vials since there are that many families of mayflies, in return. If you received less than 45, you should try to determine why. Only when you are satisfied with the paperwork, should you move on to the chapter on data analysis.

Storing and Maintaining Field and Voucher Samples

After the field samples have been fully processed they should be put into storage. Make sure that each original label is in the appropriate jar and the ethanol level is near the top. The sample jar should have all the material collected in the field except for the rocks, twigs and leaves removed during the cleaning portion of the subsampling procedure and the vials with the 100 identified BMIs. The ideal storage unit for field samples should have a lock and be refrigerated. However, any storage locker or cabinet which can be kept at room temperature will work. It is important not to store samples in a metal structure in direct sunlight where the temperature can be scorching during the summer.

The voucher samples should be stored along with the field samples. The voucher samples are the vials with the 100 identified BMIs. The vials should be the snap-on type and the ethanol level should be near the top. The vials should be secured with a rubber band, and it is best to keep then in a plastic or glass Mason jar. The Mason jar does not need to contain ethanol, but it should have a new gummed lid. Both the field and voucher samples should be checked periodically (every year if refrigerated and every 6 months if at room temperature) to make sure the ethanol has not evaporated.

It is important to maintain and keep both the field and voucher samples in good shape for future use. Possible future uses for field samples include: QA/QC procedures described in Chapter 11, advanced laboratory procedures described in the evolving laboratory section of this chapter, and as evidence if your results are ever used as part of a lawsuit. Possible future uses for the voucher samples include: QA/QC procedures described in Chapter 11, for reexamination in case taxonomy changes, as evidence if your results are ever used as part of a lawsuit, and to develop reference collections.

Developing Reference Collections

Each bioassessment laboratory and citizen group working in a particular stream or watershed should develop and maintain a reference collection of common and rare BMIs from their area. Specimens of all taxonomic

groups should be selected by the project advisor during sample identification, from going through the voucher samples, or better yet, from samples collected specifically to build a reference collection. Specimens should be in particularly good shape and represent various life stages. Also, genera within the various families of BMIs should be represented to show the range of taxonomic characteristics for that group. Voucher samples sent to a bioassessment laboratory for taxonomic validation are an excellent source of potential reference specimens. Specimens in a reference collection which were not selected from taxonomic validation samples should be verified by an outside laboratory. It is important to record in a database or the laboratory log book which voucher samples the reference specimens were selected from.

Reference collections can be used for training new citizen monitors, but only under the guidance of the project advisor. When people have free access to the reference collection, there will inevitably be quality control problems such as destroying specimens and/or putting specimens back in the wrong vials. This can be avoided by closely supervising the access to the reference collection and by creating a reference collection from samples specifically collected for that purpose. This will ensure that you maintain the integrity of the other samples collected for data purposes. Rare specimens and specimens in excellent condition probably should not be used for training.

Steps in Starting a Successful Citizen Laboratory

By far, the laboratory portion of the CSBP is the most difficult assignment for a citizen monitoring group. The initial stages of building a successful citizen laboratory should incorporate the following general guidelines:

1) Assemble a laboratory organizational meeting after all the field work has been completed. The purpose of this meeting is to organize the field samples, make sure the paperwork is in order and to create the Laboratory Log Book. The project advisor should look for a natural leader with good organizational skills to be assigned as laboratory supervisor. Also determine important details such as where to keep paperwork and where to store field samples and work in progress. The project advisor should keep one set of photocopies of all paperwork. Before ending the meeting, discuss how to structure future laboratory meetings. Plan a series of meetings that most people might be able to attend, such as a Saturday morning, once or twice a month.

2) Make the meeting well-structured, but fun. Start with the structure outlined in this chapter. As a group, complete all subsampling before going to sorting, then develop specialized taxa groups (mayfly people, stonefly people, etc.) for the final identification. Most important, rotate the duties to provide treats during the meeting and try to get together afterwards to socialize and recap the day's activities.

3) The project advisor or, if it is a different person, the taxonomic advisor should float between the groups helping with identification. To avoid frustration and wasted time, it is important not to allow anyone to spend too much time on a difficult identification. Refer to the intelligent guessing section of Chapter 12 when necessary.

4) As soon as some of the samples are completely identified, have them taxonomically validated by an outside laboratory. Report the information to the group to verify they are identifying the BMIs correctly or if there is a problem, make the necessary corrections.

5) The project advisor should pay close attention to the comments of the group, how each person works with others, what each person is best at doing, and make the necessary adjustments.

Developing Laboratory Standard Operating Procedures (SOP's)

Development of SOPs for all aspects of a citizen monitoring program is a requirement of the CSBP. This is especially important for the laboratory procedures. As previously stated, the laboratory procedures presented in this manual are organized to help facilitate a three-day training workshop. Although, the general structure outlined in this chapter should be followed to help organize and manage a citizen laboratory, the step-by-step procedures will need some modification for each group. Remember that SOPs should be kept in a loose-leaf notebook and frequently be updated.

The Evolving Citizen Laboratory

It is important to understand that the CSBP for Citizen Monitors is designed to produce data that can be used in a state-wide bioassessment program. As previously pointed out, there could be much easier and effective educational procedures for involving citizens with BMI sampling and analysis. But, if working in the laboratory, using microscopes and identifying BMIs is a strong desire for your group, then, indeed the procedures described in this manual would be the best use of the groups volunteer time. However, once your citizen group performs the Level 2 Taxonomic Effort successfully, you should be thinking about evolving toward the Level 3 Taxonomic Effort.

The first and most important move is to subsample 300 organisms instead of 100. This will require more time and since subsampling is tedious, probably more quality assurance (covered in Chapter 11). The next move is to take the family level identification to genera or species. This is the biggest jump in skill and expertise. It will be more successful with citizen groups that have a qualified taxonomist on staff and when the participants have the appropriate background. It will also be an easier move with groups working in urban streams where the diversity is less and the chance to concentrate on limited groups of BMIs is greater.

Alternatives to Performing Laboratory Portion of the CSBP

After completing the SLSI course, you will know that conducting the Level 2 Taxonomic Effort is not easy - not all citizen monitoring groups will be able to do it. In fact, it is important to remember that most citizens who get involved with a watershed groups do want to have fun when volunteering their time. Although we believe that experiencing the laboratory portion of a bioassessment project is important, the following alternatives could be considered when organizing a citizen group:

1. Emphasize the sampling and physical/habitat quality portion of the CSBP for the citizen involvement and send the sample to a professional laboratory. BMI sampling is a fun exercise that can be accomplished in a weekend or within a short period of time. It is also the portion of the CSBP that can be conducted by citizens with the highest degree of success. The physical/habitat quality procedure does require extensive training, a lot of practice and considerable communication skills to be performed successfully. However, these requirements lend themselves well to having fun and getting a citizen group to interact. Furthermore, the interaction, when supervised properly will be a great way to truly understand the importance of a healthy stream and how it functions.

2. Have the group work on one set of duplicate samples while the other set from the reach are sent to a professional laboratory. This alternative is highly recommended for large ambient bioassessment programs conducted by a government agency that is using volunteer groups. It will cost more money, but it takes the responsibility of producing data off the backs of the volunteers until they have developed the expertise to process the samples on their own. It will also give the group a chance to compare their work to that of a professional.

3. Have the group perform only the subsampling and/or sorting portion of the laboratory procedure. This alternative simply limits the efforts of a citizen laboratory to the portions of the protocol that require the least expertise. The partially processed sample is then sent to a professional laboratory to be finished. The learning curve for subsampling is high so after a short period of time, the group will be confident with their work. They can also go a bit further and try sorting the organisms to the major groups of BMIs (described in Chapter 12). Of the two, the subsampling is the portion of the procedure that can save the most money when using a professional laboratory. Either way, the citizens should work with 300 BMIs since it is not worth having a professional laboratory analyze samples to just the Level 2 Taxonomic Effort.

Literature Used in Preparing This Chapter

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Chapter 10
Data Development, Analysis, and Storage

Introduction to the Chapter

Chapter 10 covers the processing of data produced from the laboratory identification of the benthic macroinvertebrate (BMI) samples. The biological metrics that can be produced from the Level 1 and 2 Taxonomic Level are listed along with how to calculate them. Basic statistics and how they apply to bioassessment are also covered in this chapter. Using a fictitious set of data, rules for examining the data for outliers and significance are discussed. The chapter ends with several advanced sections covering integration of the data into a single score called an Index of Biological Integrity, comparing the biological data with physical/habitat data, and how to electronically store the data.

Describing Benthic Macroinvertebrate Assemblages

We are now going to take the 100 BMIs that were identified, and describe them in meaningful terms that will allow us to assess the biological condition of the stream where the samples were taken. We call these meaningful terms a **biological metric** which defines a characteristic of the BMI assemblage that changes in some predictable way with increased human disturbance. Biological metrics are categorized into four types:

- **Richness Measures** - These metrics reflect the diversity of the aquatic assemblage where increasing diversity correlates with increasing health of the assemblage and suggests that niche space, habitat and food sources are adequate to support survival and propagation of a variety of species.

- **Composition Measures** - These metrics reflect the relative contribution of the population of individual taxa to the total fauna. Choice of a relevant taxon is based on knowledge of the individual taxa and their associated ecological patterns and environmental requirements such as those that are environmentally sensitive or a nuisance species.

- **Tolerance/Intolerance Measures** - These metrics reflect the relative sensitivity of the community to aquatic disturbances. The taxa used are usually pollution tolerant and intolerant, but are generally nonspecific to the type of stressors. Percent Hydropsychidae and Baetidae (tolerant families) are regional metrics that have evolved to be particularly useful in California. The metric values usually increase as the effects of pollution in the form of fine particulate organic matter and sedimentation increase.

- **Functional Feeding Groups** - These metrics provide information on the balance of feeding strategies in the aquatic assemblage. The functional feeding group composition is a surrogate for complex processes of trophic interaction, production, and food source availability. An imbalance of the functional feeding groups reflects unstable food dynamics and indicates a stressed condition.

There are numerous ways to describe the ecological structure of BMI assemblages, and as a result, there are numerous biological metrics. They are all based on well accepted ecological principles and some general observation of the ecology of BMIs. The basis of many of the biological metrics is the ecological principle that diversity is good. There are dozens of formulas that have been devised to quantify diversity. Some ecologists swear by one or the other, but all diversity measures are highly correlated and based on the general formula that one individual of many different species will have the highest diversity value and many individuals of one species will have the lowest value. Another ecological principle used to produce biological metrics is that a balanced food web is good and as explained with the River Continuum Concept, human

and natural disturbances will cause a shift in the type of available food and as a result a shift in the feeding guild structure. Finally, no matter what the disturbance is, even with some toxic chemicals, there will be a drastic change in the species composition which will favor a particular BMI. There are always a few types of tolerant BMIs that can thrive on any given pollutant substance.

What follows are two lists of the common biological metrics that have proven useful in measuring human disturbance to the BMI community of streams and rivers. The number of biological metrics are limited for the Level 1 Taxonomic Effort since many metrics cannot be determined without at least family level identification.

LEVEL 1 TAXONOMIC EFFORT		
Biological Metrics	**Description**	**Response to Disturbance**
Richness Measures		
Taxa Richness	Total number of individual taxa	decrease
Ephemeroptera Taxa	Number of mayfly taxa	decrease
Plecoptera Taxa	Number of stonefly taxa	decrease
Trichoptera Taxa	Number of caddisfly taxa	decrease
EPT Taxa	Number of taxa in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	decrease
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	decrease
Tolerance/Intolerance Measures		
Percent Dominant Taxa	Percent composition of the single most abundant taxon	increase
Percent Stoneflies	Percent of organisms in the highly intolerant stonefly order	decrease

LEVEL 2 TAXONOMIC EFFORT

Biological Metrics	Description	Response to Disturbance
Richness Measures		
Taxa Richness	Total number of individual taxa	decrease
Ephemeroptera Taxa	Number of mayfly families	decrease
Plecoptera Taxa	Number of stonefly families	decrease
Trichoptera Taxa	Number of caddisfly families	decrease
EPT Taxa	Number of families in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	decrease
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	decrease
Sensitive EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae with Tolerance Values of 0 through 3	decrease
Percent Hydropsychidae	Percent composition of caddisflies in the more tolerant family Hydropsychidae	increase
Percent Baetidae	Percent composition of the mayflies in the more tolerant family Baetidae	increase
Tolerance/Intolerance Measures		
Tolerance Value	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) and intolerant (lower values)	increase
Percent Intolerant Organisms	Percent of organisms in sample that are highly intolerant to impairment as indicated by a tolerance value of 0, 1 or 2	decrease
Percent Tolerant Organisms	Percent of organisms in sample that are highly tolerant to impairment as indicated by a tolerance value of 8, 9 or 10	increase
Percent Dominant Taxa	Percent composition of the single most abundant taxon	increase
Trophic Measures		
Percent Collectors (CG)	Percent of macrobenthos that collect or gather fine particulate matter	increase
Percent Filterers (FC)	Percent of macrobenthos that filter fine particulate matter	increase
Percent Scrapers (SC)	Percent of macrobenthos that graze upon periphyton	variable
Percent Predators (P)	Percent of macrobenthos that feed on other organisms	variable
Percent Shredders (SH)	Percent of macrobenthos that shreds coarse particulate matter	decrease

Calculating Biological Metrics for Level 1 Taxonomic Effort

Before starting the following steps, gather your Subsampling Notes benchsheet, Level 1 Taxonomic Effort benchsheet and the Laboratory Worksheet for Level 1 Taxonomic Effort (**Appendix C.**) The Laboratory Worksheet is a two-sided document. All of the information on the Level 1 Taxonomic Benchsheet is recorded on the back side and values of the biological metrics are recorded on the front side. Remember benchsheets are your laboratory notes and an official document, but should be your actual notes, with alcohol stains and all. The Laboratory Worksheet is meant to be neat and clean. It is an official document you will keep, but it is also used to copy and pass out to interested parties (this will be explained further in a later section).

For our training, the people who subsampled and finish the BMI identification continue to work together to calculate the biological metric values using the following instructions:

- **Step 1.** Copy the total number of organisms for each taxa from your benchsheet onto the back side of the Laboratory Worksheet. Do not duplicate the tally marks;

- **Step 2.** Count the number of all the organisms you listed on the back side of the Laboratory Worksheet and record it in the column **Total Number of Organisms**. (Note: Although you thought you subsampled 100 organisms, rarely will you end up with that number);

- **Step 3.** Determine the **Taxa Richness** by counting the total number of taxa (distinct groups) listed on the back side of the Laboratory Worksheet. Record that number on the front side of the Laboratory Worksheet;

- **Step 4.** Determine the **Ephemeroptera Taxa** (mayflies), **Plecoptera Taxa** (stoneflies) and **Trichoptera Taxa** (caddisflies) by counting the total number of taxa listed for each of these taxonomic groups. Record the number for each group separately on the front side of the Laboratory Worksheet;

- **Step 5.** Determine the **EPT Taxa** by counting the number of taxa in all three families - Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) together. Record that number on the front side of the Laboratory Worksheet;

- **Step 6.** Calculate the **EPT Index** by adding the number of organisms in the caddisfly, mayfly and stonefly orders and divide it by the total number of organisms and then multiply by 100%. Record that number on the front side of the Laboratory Worksheet;

- **Step 7.** Calculate the **Percent Dominant Taxon** by dividing the number of organisms for the most abundant taxon by the Total Number of Organisms and then multiply by 100%. Record that number on the front side of the Laboratory Worksheet;

- **Step 8.** Determine the **Percent Stoneflies** by dividing the total number of organisms in all the stonefly taxa by the total number of organisms and then multiply by 100%. Record that number on the front side of the Laboratory Worksheet;

- **Step 9.** Calculate **Abundance** by dividing the total number of organisms in subsample grids by the number of grids used for the subsampling and multiply that number by the number of possible subsampling grids. This number can be left alone or divided by the number of square feet of substrate sampled (normally 6) to determine organism/ft^2. Record that number on the front side of the Laboratory Worksheet;

- **Step 10.** Record on the front side of the Laboratory Worksheet any problems with the taxonomic identification of the organisms, especially the morphologically based identification. This will help in future identification and in recognizing potential problems with the data.

You will only be able to determine nine biological metrics when using the Level 1 Taxonomic Effort. There are 19 biological metrics which can be determined using the Level 2 Taxonomic Effort. Taxonomic identification to the family level more than doubles the number of metric you can use to assess the biological condition of the stream you sampled. We recommend the Level 2 Taxonomic Effort as the standard level for citizen monitors.

Calculating Biological Metrics for Level 2 Taxonomic Effort

Before starting the following steps, gather your Subsampling Notes benchsheet, Level 2 Taxonomic Effort Sorting benchsheet, all four of the Final Identification benchsheets and the Laboratory Worksheet for Level 2 Taxonomic Effort (**Appendix C.**) The Laboratory Worksheet is a two-sided document. All of the information on the Level 2 Taxonomic Benchsheets will be recorded on the back side and values of the biological metrics will be recorded on the front. Remember benchsheets are your laboratory notes and an official document, but should be your actual notes, with alcohol stains and all. The Laboratory Worksheet is meant to be neat and clean. It is an official document you will keep, but it is used to copy and pass out to interested parties (this will be explained further in a later section).

For our training, the people in the original six groups that subsampled together get back together to calculate the biological metric values using the following instructions:

- **Step 1.** Copy the total number of organisms for each taxa from your four benchsheets onto the back side of the Laboratory Worksheet. Do not duplicate the tally marks;

- **Step 2.** Count the number of all the organisms you listed on the back side of the Laboratory Worksheet and record it in the column **Total Number of Organisms**. (Note: although you thought you subsampled 100 organisms, rarely will you end up with that number);

- **Step 3.** Determine the **Taxa Richness** by counting the total number of taxa (distinct groups) listed on the back side of the Laboratory Worksheet. Record that number on the front side of the Laboratory Worksheet;

- **Step 4.** Determine the **Ephemeroptera Taxa** (mayflies), **Plecoptera Taxa** (stoneflies) and **Trichoptera Taxa** (caddisflies) by counting the total number of families listed for each of these orders. Record the number for each order on the front side of the Laboratory Worksheet;

- **Step 5.** Determine the **EPT Taxa** by counting the number of taxa in all three orders - Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) - together. Record that value on the front side of the Laboratory Worksheet;

- **Step 6.** Calculate the **EPT Index** by adding the number of organisms in the caddisfly, mayfly and stonefly orders and divide it by the total number of organisms and multiply by 100%. Record that value on the front side of the Laboratory Worksheet;

- **Step 7.** Calculate the **Sensitive EPT Index** by adding the number of organisms in the caddisfly, mayfly and stonefly orders that have a t-value of 0 through 3 and divide it by the total number of organisms and multiply by 100%. Record that value on the front side of the Laboratory Worksheet;

- **Step 8.** Calculate the **Percent Hydropsychidae** by dividing the number of organisms in the caddisfly family Hydropsychidae by the total number of organisms and multiply by 100%. Record that value on the front side of the Laboratory Worksheet;

- **Step 9.** Calculate the **Percent Baetidae** by dividing the number of organisms in the mayfly family Baetidae by the total number of organisms and multiply by 100%. Record that value on the front side of the Laboratory Worksheet;

- **Step 10.** Calculate the **Tolerance Value** by multiplying the t-value (0-10) for each taxon by the number of organisms in that taxon. T-values are listed in Laboratory Worksheet next to each taxon. Add these values together for all taxa and divide it by the total number of organisms (**Note: it is important to subtract from the total number of organisms, those which do not have a t-value**). Record that value on the front side of the Laboratory Worksheet;

- **Step 11.** Calculate the **Percent Intolerant Organisms** by dividing the number of organisms with t-values of 0, 1 or 2 by the total number of organisms and multiply by 100%. T-values are listed in the Laboratory Worksheet next to each taxon. (**Note: it is important to subtract from the total number of organisms, those which do not have a t-value**). Record that value on the front side of the Laboratory Worksheet;

- **Step 12.** Calculate the **Percent Tolerant Organisms** by dividing the number of organisms with t-values of 8, 9 or 10 by the total number of organisms and multiply by 100%. T-values are listed in the Laboratory Worksheet next to each taxon. (**Note: it is important to subtract from the total number of organisms, those which do not have a t-value**) Record that value on the front side of the Laboratory Worksheet;

- **Step 13.** Calculate the **Percent Dominant Taxa** by dividing the number of organisms for the most abundant taxa by the total number of organisms and multiply by 100%. Record that value on the front side of the Laboratory Worksheet.

- **Step 14.** Calculate the **Percent Collectors (CG), Percent Filterers (FC), Percent Scrapers (SC), Percent Predators (P) and Percent Shredders (SH)** by dividing the number of organisms with f-designations corresponding to the particular functional feeding group by the total number of organisms and multiply by 100% (**Note: it is important to subtract from the total number of organisms, those which do not have a f-designations**). F-designations are listed next to each taxon in the Laboratory Worksheet. Record these values on the front side of the Laboratory Worksheet;

- **Step 15.** Calculate **Abundance** by dividing the total number of organisms in subsample grids by the number of grids used for the subsampling and multiply that number by the number of possible subsampling grids. This number can be left alone or divided by the number of square feet of substrate sampled (normally 6) to determine organism/ft^2. Record that value on the front side of the Laboratory Worksheet.

Basic Statistics Important for Sampling Strategies and Data Interpretation

Statistics are an interesting and important component of biological science. There are plenty of basic and advanced books describing statistical terms and procedures. Most common calculators, and computer-spreadsheet and database programs will calculate basic statistics. This makes it simple and easy for those people needing to use them, but can be a detriment to those who really do not understand how they should be used. We will attempt to explain some of the more basic statistical principles important in bioassessment.

There are two fundamental types of statistics which are more applicable to citizen level monitoring: they are descriptive and inferential. **Descriptive statistics** are used to summarize a set of values into a single numeric summary while **inferential statistics** tests a hypothesis based on a model which we think describes a population of values. The following list of statistical terms are the most likely encountered in citizen level monitoring:

- **Biometry** - the application of statistics to biology.
- **Population** - the total individual observations existing in a specified sampling area, limited in space and time.
- **Random Sampling** - a process where each member of a population has an equal chance of being selected.
- **Replicate Samples** - a set of samples drawn from a population using a similar methodology.
- **Sample Size (N)** - the total number of replicate samples.
- **Sample Mean (M)** - the sum of the sample values divided by the sample size.
- **Standard Deviation (SD)** - the average deviation of each value from the sample mean.
- **Coefficient of Variation (CV)** - the sample mean times 100% divided by the standard deviation.

General Statistics that Apply to Bioassessment

In Chapter 8, we discussed the point source and non-point source sampling designs. With the point source design, you collect BMI samples at 3 randomly picked transects chosen from all the possible transects within that riffle. With the non-point design, you collect one BMI sample at 3 randomly picked riffles from all the possible riffles within a reach of stream. This means that the area of interest or **population** of possible sampling units comes from a single riffle in point source design, and from a reach in the non-point source design. We are collecting samples from those populations because we do not have the time to measure it all. (This statistical reasoning also applies to the subsampling portion of the laboratory procedure.) We will use the information from our 3 or more samples to make statements about all the BMIs in that single riffle for the point source design or from BMIs in all the riffles within a stream reach for the non-point source design.

The CSBP requires the BMI samples to be taken from three or more randomly chosen locations. A practical reason to randomly sample is to prevent someone from accusing you of sampling either the worst or best area. The statistical reason to collect several random samples is to allow us to produce an unbiased estimate of the population mean. When the data is presented, we want to estimate the biological conditions with some degree of confidence that it represents the real condition of the riffle or the riffle environment in the stream reach. We estimate measures of the BMI community by determining **mean** values based on all the samples and then we determine the **standard deviation** which is the average amount that all the sample values differ from the mean. We prefer presenting the standard deviation as the **coefficient of variation (CV)**. This statistical term normalizes all types of measures by dividing the standard deviation by the sample mean value and expresses it as a percentage. CV values less than 25% are generally regarded as an acceptable level of confidence in biological communities.

Random sampling also enables us to test whether one riffle or stream reach is significantly different from another. For example, if we sampled two riffles and found that one had a total of 14 different types of BMIs (Taxa Richness) and the other had 10, could we say one was different from the other? Is this difference of 4 taxa significant or could it happen by chance alone? To answer this question we need to compare the difference in the number of taxa along with our degree of confidence to a reference set of possible values from a large set of riffles. We would have to measure the number of

BMI taxa in all the riffles in the area of interest or **statistical universe** to determine the reference distribution of the possible number of taxa values. Fortunately, we do not have to go through all that trouble due to the work of a couple of guys who use to drink beer and work on statistics problems at the Guinness brewery in Dublin, Ireland.

William S. Gosset (better known as "Student") and Sir Ronald Fisher developed tables of standard normal differences you could expect by chance alone, given a certain sample size. Gosset developed the **Student's t distribution** which is used for testing two sets of samples and Fisher developed the **f distribution** used in **Analysis of Variance or ANOVA** for testing more than two sets of samples. They also calculated different reference tables of values for different probability levels so you could, for example, try to be 95% or 99% confident that the difference was not by chance alone. Both the t-test and ANOVA are models designed to test hypotheses about the data sets. There are certain assumptions associated with them, one of which is that every sample had an equal chance at being chosen or randomly sampled. The other assumptions are that the standard deviations are relatively similar for each set of samples and that the sets of samples are independent. Independent means that there is no relationship between the sample sets. For example, the standard deviation does not increase or decrease with increasing or decreasing sample means. These assumptions must be met to use these inferential models.

Significance testing is primarily used to prove that there was an effect from a pollutant spill or a toxic discharge. It is used with the results of a point-source sampling design. We usually try to avoid inferential statistics because it is too "nit-picky" to say that one riffle is statistically different from another, based on a single value representing the BMI community. But some cases demand detailed statistical analysis. It would be best to consult a biostatistician if inferential statistics are necessary.

Examining Biological Metrics

Having introduced the various biological metrics used to described BMI communities and the basic statistics needed to summarize them, we will now examine a fictitious data set to learn how to explore and interpret what the samples are saying about the condition of your stream. The following table of data is similar to a data set that would be produced during our bioassessment training workshop. We go to a local stream and sample two different riffles using the point source sampling design. Usually we will locate riffles upstream and downstream of a potential human disturbance. This data set is based on one of the workshops we conducted in a central California foothill community. The stream flowed through a city park and then through a residential area where the sewage was discharged into individual septic tanks. The community members in the workshop believed there was considerable leachate from the septic tanks entering the stream.

Table 10-1 lists the raw data for the three samples collected from the two different riffles. The BMIs were identified using the Level 2 Taxonomic Effort, so we have values for all 18 biological metrics and the abundance estimate. ***Table 10-2*** lists the means, standard deviation and the coefficient of variation. By examining the richness measures, we can see that the upstream site has a higher Taxa Richness than the downstream site. There were no stoneflies and one less mayfly at the downstream site which is reflected in a lower EPT Taxa value downstream.

The composition measures shed more light on the difference in the two sites by showing that although there were less EPT taxa downstream, there were considerably more EPT organisms as reflected in the higher EPT Index value downstream. Even though the upstream site had one third the number of EPT organisms, some of them (5%) were the types of EPT organism which are very sensitive to water quality degradation. The

downstream site had virtually no sensitive EPT organisms.

The high Percent Hydropsychidae and Percent Dominant Taxa indicate that the downstream site has an excessive number of this particular type of caddisfly. In general, the more EPT taxa and organisms indicates a healthy stream because most of these type of BMIs require cool, clean and highly oxygenated waters. However, Hydropsychid caddisflies and Baetid mayflies are the exception.

They will not be found in highly polluted waters, but can dominate in moderately polluted streams, especially those disturbed by excessive nutrients or sediment. Stoneflies are the one order in the EPT group that does not contain any tolerant types.

Table 10-1. Raw Data for Two Riffles in a Central California Foothill Stream.

Biological Metrics	Upstream Riffle			Downstream Riffle		
Richness Measures	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Taxa Richness	13	17	15	9	11	8
Ephemeroptera Taxa	3	3	4	3	2	1
Plecoptera Taxa	1	2	1	0	0	0
Trichoptera Taxa	1	2	1	1	1	2
EPT Taxa	5	7	6	4	3	3
EPT Index	20	25	21	55	68	58
Sensitive EPT Index	5	5	4	1	0	0
Percent Hydropsychidae	5	7	10	37	45	43
Percent Baetidae	10	13	7	13	20	22
Tolerance Value	3.5	2.9	3.6	4.8	4.4	4.5
Percent Intolerant Organisms	9	12	14	0	1	0
Percent Tolerant Organisms	0	2	5	23	16	19
Percent Dominant Taxa	22	27	18	37	45	43
Percent Collectors (CG)	24	19	12	46	55	48
Percent Filterers (FC)	20	23	25	30	24	28
Percent Scrapers (SC)	35	30	28	11	8	12
Percent Predators (P)	12	15	28	9	8	10
Percent Shredders (SH)	9	13	7	4	5	2
Abundance	308	698	480	658	1082	412

Table 10-2. Means, Standard Deviation and Coefficient of Variation (CV) for Two Riffles in a Central California Foothill Stream.

Biological Metrics	Upstream Riffle			Downstream Riffle		
Richness Measures	Mean	SD	CV	Mean	SD	CV
Taxa Richness	15	2.0	13%	9	1.5	16%
Ephemeroptera Taxa	3	0.57	17%	2	0.58	25%
Plecoptera Taxa	1	0.57	43%	0	n/a	n/a
Trichoptera Taxa	1	0.57	43%	1	0.57	43%
EPT Taxa	6	1.0	17%	3	0.57	43%
EPT Index	22	2.6	12%	60	6.8	11%
Sensitive EPT Index	5	0.58	12%	<1	n/a	n/a
Percent Hydropsychidae	7	2.5	34%	42	4.2	10%
Percent Baetidae	10	3.0	30%	18	4.7	26%
Tolerance Value	3.3	0.38	11%	4.6	0.21	5%
Percent Intolerant Organisms	12	2.5	21%	<1	n/a	n/a
Percent Tolerant Organisms	2	2.5	108%	19	3.5	18%
Percent Dominant Taxa	22	4.5	20%	42	4.2	10%
Percent Collectors (CG)	18	6.0	33%	50	4.7	10%
Percent Filterers (FC)	23	2.5	11%	27	3.1	11%
Percent Scrapers (SC)	31	3.6	12%	10	2.0	20%
Percent Predators (P)	18	8.5	46%	9	1.0	11%
Percent Shredders (SH)	10	3.1	31%	4	1.5	42%
Abundance	495	195	40%	717	339	47%

There is a slight difference in Tolerance Value between the upstream and downstream sites, but a considerable difference in the Percent Intolerant and Percent Tolerant Organism metrics. It is typical that the Tolerance Value of moderately disturbed streams will be in the mid range values and that large differences will not be obvious. That is when the Percent Intolerant and Tolerant Organism metrics can provide additional information. In this case, there are some organisms that cannot tolerate pollution in the upstream site and none in the downstream site, and more organisms that can tolerate pollution in the downstream site and very few in the upstream site. The trophic measures show a well balanced functional feeding group composition in the upstream site and an unusually high composition of Collectors and Filterers in the downstream site. The highly variable abundance values really do not say much except that there are more organisms in the downstream riffle probably as a product of the dominant pollution tolerant organisms.

This data set would confirm that the downstream riffle section of this stream was

polluted by excessive nutrients compared to the upstream riffle section. All the biological metric values measured in the downstream riffle reinforced that this moderate type of pollution decreased the species diversity, eliminated the most sensitive organisms and allowed net-spinning caddisflies in the family Hydropsychidae to take advantage of the more plentiful suspended organic material produced by the increased nutrients.

Before making such a statement about the condition of the stream, we must examine possible variability within the data set. Could things like sampling problems or substrate and velocity differences between the riffles be confounding the data? These problems are usually reflected in the CV values. However, examination of our fictitious data set indicates that the samples are fairly consistent with CV values for most measures within the 25% range. Additionally, experience in conducting bioassessment projects throughout California have shown us that these biological metrics are quite robust and not affected much by sampling errors, riffle substrate and velocity differences.

There will, on occasion, be highly variable biological metric values. These unusual data points are called **outliers** and they should be examined in more detail. First, you will notice in our fictitious data set, the highest CV values were associated with biological metrics that had the lowest values. This is quite common and they are not considered outliers. You will also notice some "n/a" terms in the SD and CV columns which means that the variance values could not be computed because there were more than one 0 value for the particular metric. These metrics are not considered outliers either. Our fictitious data set does not include any outliers. When outliers occur, they will be associated with one of the three replicates. Some or all the metric values for a particular sample will not fit. Usually, the values can be explained by going back to the CBW and looking at the field notes. Sometimes one transect was considerably different than the others or afterward you noticed unusual land-use activity at one transect (i.e. the path of a cattle crossing). As you can see, taking thorough field notes will help you to examine outliers. In other instances, a group member did a miscalculation or entered a number on the wrong line.

We think that our fictitious data set tells us that there is a human disturbance polluting the stream. All the metrics suggest a difference in the BMI community from above the disturbance to below and our statement is backed up by low variability in the data and no outliers. However, this assessment should be confirmed with other sampling events during the same year and at least one more year of data. This information should also trigger a more detailed investigation which could include expanding the monitoring area, increasing the number of sites and initiating chemical monitoring.

Examination of Data Collected Using the Non-point Source Sampling Design

The preceding example of data analysis was based on a typical data set that would be produced during a workshop session. It is an example of a point source design which we find to be the most appropriate design to demonstrate bioassessment techniques in a workshop format. However, most citizen groups involved with bioassessment will be part of a watershed effort interested in surveying a particular stream within their watershed and usually on a long-term basis. These groups may be more interested in knowing if the stream will improve over time following stream restoration work or conversely, if their particular watershed is degrading over time following increased land-use activities. These monitoring objectives are more appropriately addressed using a non-point source sampling design. Instead of examining mean biological metric values obtained from riffles immediately above and below a point source of pollution, we examine mean biological metric values

obtained from stream reaches distributed throughout a watershed or region.

Data obtained from stream reaches using the non-point source sampling design is examined using a combination of **trend analysis, control stream comparisons** or **biocriteria**. With trend analysis, the biological metric values are examined over time to observe changes in a direction that might reflect degradation or improvement in stream health. Trend analysis works well for monitoring the success of a restoration project, improvements in land-use practices or to document how stream health is changing in your watershed. A trend analysis uses **baseline data** as the starting point. Baseline can refer back to comparable monitoring data collected by the government or another entity that was interested in your stream in the past. However, more than likely, baseline will be established with the data from your first sampling event. If you are interested in monitoring change resulting from a restoration project, then baseline data should be collected as many years as possible prior to the project.

Trend analysis of stream reach data can be improved if there are also data available from reaches of similar streams in the watershed or a near-by watershed that are not affected by your project or land-use activities . These reaches are called control sites. Having a stream or reach that is as close to its natural undisturbed condition as possible, will allow you to compare the changes you observe in your stream with changes that occur naturally. Depending on your location in California, natural changes may be severe, although, in most instances, changes will be gradual and over time (geological time). Generally, you will see the result of natural disturbances level-off over the period of a long-term monitoring program. Whether you have more or less active geology in your watershed, control reaches are invaluable for short-term (less than 5 year) monitoring projects. Choosing control or reference sites is not easy and will add additional costs to your monitoring project.

Control or reference sites should be determined by the government. After examining the biological metric values from stream reaches in their watershed, a citizen group should be able to ask DFG or their RWQCB the question - "What should the biological metric values be for our stream reach?" This information would allow you to confirm that the biological metric values are lower or higher than that expected of an undisturbed, healthy stream in the area, and provide insight on how far below or above the standard your stream reach falls. Answering this question requires knowing the expected or reference values for the class of stream in your region of California. In addition to establishing good reference reaches throughout California, the best biological metrics for each region must be determined and their expected values integrated into a single scoring criteria. This is the essence of biocriteria standards which were discussed in Chapter 5.

Integrating Biological Metrics Into a Single Value

In the above example, we examined 18 biological metrics to describe the biological condition of our two monitoring sites. This form of data analysis is called the multi-metric approach and is recommended by the U.S. EPA for citizen, as well as professional, biological monitoring programs. Ultimately, a number of these metrics can be integrated into a single scoring criteria. This scoring criteria, also called an Index of Biological Integrity (IBI) requires a large data set collected from a large regional area or even an entire state. Eventually, there will probably be separate IBIs developed for northern and southern California, the Sierras, the Central Valley and the Central Coast. There will also be different IBIs for different classifications of streams and rivers, such as headwaters and middle and lower elevation streams.

Developing IBIs for California will take several years of gathering data from many bioassessment projects throughout the state.

It will be coordinated by the government and most of the data will be collected at the professional level. DFG has produced an IBI for the Russian River as a demonstration project to show how the process works. Appendix D shows the Fact Sheet for the Russian River IBI and describes how it works. The numbers are based on the Level 3 Taxonomic Effort and will be updated on a regular basis. At this time, it will not work with data generated using the Level 2 Taxonomic Effort. However, the requirement for bioassessment validation, which is built into the CSBP for citizen monitors, will provide the information that will eventually allow calibration of the IBIs to the Level 2 Taxonomic Effort (this will be explained further in Chapter 11).

Data Analysis of Physical/Habitat Quality

Physical/habitat quality is measured during each field sampling event. The method which comes directly from U.S. EPA and is used throughout the United States, integrates 10 parameters into a single value which ranges from 0 to 200. There are four categories of physical condition; Optimal (200 to 150), Suboptimal (149 to 100), Marginal (99 to 50) and Poor (40 to 0). This categorical ranking system is similar to the IBI. Regional standards will be established at the same reference streams that are used for the biological condition. Although visual ranking systems are inherently subjective, this national scoring criteria works quite well as long as it is done by trained people and has quality assurance measures built into the program (this will be explained further in Chapter 11).

The physical/habitat quality score is the measure of physical integrity and can stand alone or can accompany the biological data. Usually, there will be a relationship between the physical and biological conditions of a stream reach, but not always. Sometimes the poor biological condition of a stream can be explained by poor physical/habitat quality. Damaged stream banks and riparian cover will usually adversely alter the aquatic community. However, polluted water can flow through a stream, altering the aquatic community, but not the physical/habitat quality.

Data Analysis using the Physical/Habitat Characteristics

The CSBP requires measuring a number of physical/habitat characteristics at each riffle where BMIs are collected. The most important use of this information is to help explain outliers. Outliers, discussed earlier in this chapter, are biological metric values considerably different than the others from the same area. Outliers usually result from samples collected in a riffle or part of a riffle that has drastically different physical/habitat characteristics. Having this information during the data analysis phase can be invaluable. With larger data sets, patterns between outliers and a particular physical/habitat characteristic may lead to further investigation on the relationships between physical/habitat characteristics and biological metric values. For example, a strong relationship between decreased percent canopy cover and lower IBI values can give you direct evidence that riparian destruction impairs water quality.

Storing Data and Submitting It to DFG or other Government Agencies

The U.S. EPA has supported the development of a custom database application for use with Microsoft Access. It is called the Ecological Data Application System (EDAS) and is widely used throughout the country. As mentioned in Chapter 8, whenever a watershed group or individual applies for a DFG Scientific Collectors Permit, they will receive a copy of the program. The program includes tables for entering site identification, habitat, chemical, fish and BMI data. It is a good way to store and submit data to DFG or anyone who asks for the data. The State is just starting to use

this database and revisions will undoubtedly be made.

Developing SOPs for Data Handling and Management

Similar to field and laboratory procedures, data handling and management should be customized for each group in a Standard Operating Procedures (SOP) manual. There should be sections in the SOP on completing and reviewing field and laboratory data sheets, entering data into the database, analyzing the data, writing a summary report and distributing the data. The U.S. EPA Volunteer Stream Monitoring Manual describes how to present data in a report format. An internal policy on releasing your data should be developed.

Chapter 11
Ensuring Quality Data

Introduction to the Chapter

Quality assurance, or the process of guaranteeing that the information you collect on the biological and physical condition of streams and rivers is credible, is the topic of Chapter 11. The field and laboratory work, data analysis, and report writing procedures to assure quality control are discussed in detail.

What is Quality Assurance and Quality Control (QA/QC)

Quality assurance (QA) is the process of guaranteeing that the information you collect is credible. It usually is described in a planning document which addresses study design, field operations, laboratory activities, data analysis and reporting. **Quality control (QC)** is the actual procedures used to ensure the credibility of the data collection, processing and reporting. Together, a QA/QC program will help ensure the usefulness of bioassessment data.

The Quality Assurance Project Plan (QAPP) is a QA/QC planning document that is a requirement of any project or program receiving a U.S. EPA grant. There are specific guidelines contained in the 1996 document "The Volunteer Monitor's Guide to Quality Assurance Project Plans" (EPA 841-B-96-003) that need to be followed. Additionally, the Adopt-A-Stream Foundation's "Streamkeeper's Field Guide" has an excellent step-by-step description of the requirements of a QAPP.

Components of a QAPP

The bulk of a QAPP is contained in the Standard Operating Procedures (SOP) which must be developed for all components of bioassessment (Chapters 8 through 10). The following critical components of a QAPP should be addressed:

1. **Project Organization**: list all the participants involved with your citizen monitoring organization. Try to assign people to the following positions even if it is the same person for several of the categories: Project Advisor, Project Design Coordinator, Project QA/QC Officer, Field Sampling Leader, Laboratory Manager, Data Processing Leader, and Project Reporting Officer.

2. **Project Description**: provide a detailed narrative on what your group perceives is the problem, what your group intends to do about the problem, and to whom the information will be distributed.

3. **Training Requirements and Certification**: list all the past applicable training and certificates that members of your organization have received. Also list the training that you believe is necessary to accomplish the objectives for your program.

4. **Field Sampling Procedures**: list your field sampling SOP. You can use the CSBP, but it would be better if the procedures were personalized for your organization.

5. **Sample Handling and Custody Procedure**: explain in detail how the samples are delivered to the laboratory. Use the Chain of Custody procedures described in Chapter 8 to explain the procedures used.

6. **Laboratory Procedures**: list your laboratory procedure SOP. You can use the CSBP, but it would be better if the procedures were personalized for your organization.

7. **Quality Control Procedures**: list all the procedures used to assure the quality of the data collected. Have subsections on BMI sampling, physical/habitat quality assessment, physical/habitat characteristics, laboratory subsampling

procedures, and taxonomic identification. Discuss specifics such as data validation procedures, internal and external QA/QC checks, performance and system audits, preventive maintenance procedures, and corrective action procedures.

8. **Instrument/Equipment Testing, Inspection and Maintenance Schedule:** list all the equipment and how often it is inspected or tested to make sure it is in working condition.

9. **Instrument Calibration and Frequency:** describe calibration procedures (usually described in the equipment manual) for each piece of equipment and how often it will be calibrated. Also list the precision of the instrument and what your acceptance requirements will be.

10. **Acquisition of Non-Direct Measurement Data:** list the data or information that will be used by your organization, but that you will not be directly measuring. Discuss how the information will help fulfill the project objectives, where it will be acquired and the qualifications and quality of the data source.

11. **Data Management Procedures and Quality Assurance:** discuss how the data will be processed and stored and where it will go. Also discuss the QA/QC procedures that will be used to guarantee the data is accurate.

12. **Data Review and Validation:** discuss who or what organization will be reviewing your data to validate its accuracy.

Importance of Training

The techniques described in this manual should not be conducted without proper training. If you are not using this manual as part of the three-day bioassessment workshop offered through SLSI, visit its website (www.slsii.org) to find out about future training opportunities. There is a section of the QAPP document which requires a list of the pertinent training that each member of your group has received. Refresher training and other advanced training should be encouraged within your monitoring group.

Once a group is organized and working on a long-term monitoring program, there should be frequent internal training. Field and laboratory crews should have regular meetings with the Project Advisor where specific techniques described in the SOP and QAPP are reviewed. Most importantly, safety procedures for working with ethanol, wading in running water, hygiene in urban streams and traversing mountain terrain should be discussed often.

The California Aquatic Bioassessment Workgroup

Another form of training available to citizen monitors is the California Aquatic Bioassessment Workgroup (CABW) which meets annually. Since 1994, DFG, the U.S. EPA and the SWRCB have been using the CABW to coordinate scientific and policy-making efforts toward implementation of aquatic bioassessment in California. Members of the CABW consist of biologists from universities, consulting firms and industry, and representatives of state and federal agencies responsible for assessing, monitoring and protecting the biological integrity of surface waters. The professional and citizen level monitoring protocols mentioned in this manual were reviewed at these meetings and the training workshops for which this manual is used were suggested by the CABW Steering Committee.

The CABW is an excellent training opportunity for citizen monitors, but be prepared to digest technical information and actively participate in the workgroups. DFG and other water resource agencies in California use the annual meetings of the CABW to present the results of bioassessment demonstration projects, present strategies to implement bioassessment programs and

discuss objectives for promoting biocriteria development. Each year there is a Citizen Monitors Workgroup which meets to discuss problems, concerns and needs which will promote the development of citizen level bioassessment. The state-wide volunteer Monitoring Coordinator from the SWRCB usually leads this workgroup and uses the information to help coordinate their efforts for the year.

The California Macroinvertebrate Laboratory Network (CAMLnet)

CAMLnet consists of professional taxonomists from inside and outside California who are involved with bioassessment work. The group provides a forum where laboratory procedures are discussed and the BMI taxonomic levels are determined. It also provides taxonomic workshops and assistance with interlaboratory taxonomic verification. All individuals, private consulting firms and agency personnel using the CSBP laboratory procedures are encouraged to contact the DFG's Water Pollution Control Laboratory (WPCL) for information on participating in CAMLnet. This group can provide information on validation laboratories and taxonomic advisors to citizen monitors and resource professionals.

Specific QA/QC Procedures for Collecting BMIs

The CSBP is designed to produce consistent, random samples of BMIs. It is important to prevent bias in riffle choice and transect placement. The Project Advisor should be primarily responsible for choosing sampling locations. However, sampling crews should be well trained so they can make wise decisions in the field if sampling modification is required. In general, collecting BMIs is simple and straight forward. As a sampling crew gains experience, their efforts become consistent and reliable. The following specific QA/QC procedures will help field crews collect unbiased and consistent BMI samples:

1. When using the CSBP, most sampling reaches should contain riffles that are at least 10 meters long, one meter wide and have a homogenous gravel/cobble substrate with swift water velocity. There are approved modifications of the CSBP when these conditions do not exist. Contact DFG or visit the California Aquatic Bioassessment Web Site for methods to sample narrow or complicated streams (see **figures 8-1 and 8-2 on pages 8-2 and 8-5 respectively**), wadeable streams with muddy bottoms, and channelized streams.

2. Preferably, the Project Advisor and all crew members will receive training on the use of the CSBP for citizen monitors before collecting samples. Regardless of the extent of the field crew's previous training, the Project Advisor must review the BMI sampling SOPs with the field crews before each field season.

3. During the training, crew members should practice collecting BMI samples as described in the CSBP. The 2 ft^2 area upstream of the sampling net should be delineated using the measuring tape or a 2 ft^2 PVC frame and the collection effort should be timed. Practice repeatedly until each crew member has demonstrated sampling consistency.

4. Throughout the sampling season, the Project Advisor must assure that the BMI sampling remain consistent by timing sampling efforts and measuring sampled area for approximately 20% of the sampling events. The results should be discussed immediately and need not be reported. If possible, the Project Advisor should perform these QA/QC procedures during random and unannounced visits to the field.

Specific QA/QC Procedures for Measuring Physical/Habitat Quality

Physical/habitat parameters are assessed using a ranking system ranging from optimal to poor conditions. This rapid ranking system relies on visual evaluation and is inherently subjective. Although having experienced and consistent field crews is an advantage in sampling BMIs, it can be a problem with assessing physical/habitat quality. The subjective nature of this procedure can lead a field crew in a direction that is considerably different than the other field crews.

The following specific QA/QC procedures will help to standardize individual observations to reduce differences in scores:

- Train your Project Advisor and all crew members on the use of the CSBP for citizen monitors before collecting samples. Regardless of the extent of the field crew's previous training, the Project Advisor must review the physical/habitat assessment procedures with the field crews before each field season.

- At the beginning of each field season, have the Project Advisor and all of the crew members conduct a physical/habitat assessment at two practice stream reaches. The first stream reach should be assessed as a team and then each of the 10 physical/habitat parameters should be discussed in details. The second stream reach should then be assessed individually and when members are finished, they should discuss the 10 parameters together and resolve the discrepancies.

- Frequently change or alternate assessment responsibilities of field crew members. At the end of each field day, crew members should discuss habitat assessment results and resolve discrepancies.

- Have the Project Advisor randomly pre-select 20% of the stream reaches where each crew member will be asked to assess the physical/habitat parameters separately. After performing these individual assessments, the differences in crew member scores should be discussed and resolved with the Project Advisor.

Specific QA/QC Procedures for the Laboratory

The laboratory procedures consist of subsampling and taxonomic identification. There are other procedures such as maintaining the voucher collection, building a reference collection and storing and maintaining the integrity of the samples before and after they are processed. Chapter 10 describes the laboratory procedures. The following specific QA/QC procedures will help to assure that subsampling and taxonomic identification is accurate:

- Train all the laboratory crew, including the Project Advisor or Taxonomic Advisor, on the use of the CSBP for citizen monitors before working in the laboratory. The Project Advisor or Taxonomic Advisor is crucial to a successful BMI laboratory.

- Regardless of laboratory crew's previous taxonomic experience or interest in BMIs, the Project Advisor must review the laboratory procedures with the laboratory crews before analysis begins.

- Check subsampling accuracy in two ways:

  1) when there are multiple subsampling stations, have the subsampling teams inspect each other's processed grids immediately following completion of the subsampling procedure. The inspecting teams are allowed no more than 5 minutes to inspect each processed grid looking for and counting missed organisms. There should be no more than 10% missed organisms.

  2) put the remnant material from all the processed grids into a separate jar labeled with the sample number

followed by "remnant". The Project Advisor or the Project QA/QC Officer can examine the remnant jars for missed organisms when they have the opportunity. However, the sooner the remnant jars are examined, the sooner a problem can be discovered and discussed.

- Taxonomic accuracy is the responsibility of the Project Advisor. They must sign each laboratory worksheet guaranteeing that the BMIs were identified properly. Taxonomic validation is a tool used by the Project Advisor to validate the accuracy of the BMI identification and to pin-point problem areas for the Project Advisor to work on with the laboratory crew. Vials of identified BMIs can be randomly selected or chosen based on the knowledge that the laboratory crew are having problems with certain groups. Then the vials are examined for taxonomic and enumeration accuracy. All missed identifications must be corrected even if it means examining all vials of a particular problem group.

Bioassessment Validation

As compared to taxonomic validation which is an internal type QA/QC procedure, bioassessment validation is an external type of QA/QC and must be conducted by an independent laboratory which has no personal connection to the monitoring group. By following the CSBP described in Chapter 8 and 9, each sample collected and processed by citizen monitors will have its integrity preserved and can be reconstituted into its original condition. Reconstituting a sample requires opening the vials containing the 100 identified BMIs, pouring the BMIs into the original sample jar and gently stirring the contents. The sample is then sent to a professional bioassessment laboratory which will process it according to the professional Level 3 Taxonomic Effort.

Information from the bioassessment validation samples will contribute to the state-wide bioassessment program and will allow DFG to evaluate and demonstrate the comparability of professional and citizen level bioassessment data. The level of bioassessment validation can range from 20% to 100% and the particular samples submitted for validation can be chosen at random or selected to help verify a water quality problem detected by the monitoring group.

Specific QA/QC Procedures for Sample Handling and Custody

When samples arrive, the California Bioassessment Worksheet should be checked to make sure it is complete. Make sure that the form includes the water-body name, sampling date and time, location, transect number and sampler's name. The steps discussed in the "Using the Chain of Custody (COC)" in Chapter 8 (page 8-16) should be followed. The sample description information should be recorded in the Laboratory Sample Inventory Log and each sample given a unique identification number. A written and electronic record should be maintained to trace the samples from entry into the laboratory through the final analysis.

After samples are processed, the Laboratory Worksheet and the benchsheets should be placed in a project file, along with the CBW and the COC. The benchsheet should be an original with all the mistakes crossed out and not erased or otherwise marked out. These forms could be requested as evidence if the results are ever disputed, so they must be original and not look like they have been modified.

Specific QA/QC Procedures for Data Analysis and Storage

All the work required to collect samples and identify the BMIs will be wasted if the data produced through those procedures is not recorded and stored correctly. Data analysis and storage is discussed in Chapter 10. Each monitoring group should develop an SOP for data handling and management that includes sections on completing and reviewing field and laboratory data sheets, entering data into

the database, analyzing the data, writing a summary report and distributing the data. The U.S. EPA's custom database, Ecological Data Application System (EDAS) should be the primary program used for data analysis and storage. The following specific QA/QC procedures will help to assure that your bioassessment data is accurate:

- Assign the position of Project QA/QC Officer and Data Processing Leader to members of your group that have an affinity for numbers and who are detail oriented. These attributes are necessary to ensure that the data is recorded and stored correctly.
- Organize and cross-check the accuracy of the data recorded on the California Bioassessment Worksheet, Laboratory Worksheet, benchsheets and COC.
- Enter the data into the EDAS database.
- Print out the forms in the EDAS database for each sample and cross-check the data.
- Examine the summary reports for outliers and unusually high coefficient of variation (CV) values. Make sure that data entry errors are not responsible for the biological metric values that we want to attribute to natural variability or human-induced impacts.

Corrective Action for the QA/QC Procedures

QA/QC procedures are meant to be more instructive than punitive. Although you should strive for no more than 10% error with most QA/QC procedures, occasions of observed error should be viewed as opportunities to identify problems and to solve them. Regardless of the severity, observed error should be examined for cause and corrective action taken immediately. Look for a pattern in the mistakes. For example, a particular type of BMI is being missed in the subsampling procedure or a particular taxa is being misidentified. Also, factors such as boredom, too much talking, and lack of concentration or personal problems should be examined as possible causes of error. Corrective action should be first discussed personally with the crew member and then, if appropriate, discussed with the entire crew. If subsampling or taxonomic error exceeds 10%, it might be necessary to examine other samples for similar problems. Field, laboratory, and data entry errors can be minimized when the Project Advisors pay attention to the crew members performance, communicate concerns frequently and assign the right person to the right job.

Chapter 12
Taxonomic Identification of Aquatic Organisms Common to Western Streams and Rivers

The Science of Taxonomic Classification

When you first look through the microscope into a dish of BMIs, you might think they all look alike. You might even have difficulty differentiating the organisms from the various types of debris that comes with each sample of excavated stream substrate. However, they are not all alike; they can look as different as cats and dogs once you know their unique characteristics and gain experience with taxonomic identification. **Taxonomy**, also referred to as systematics, is the science of classifying or arranging animals and plants into groups based on their natural relationship to each other. The basic unit of classification is the **species** and closely related species are grouped into a **genus**. When referring to an individual species, such as the stonefly commonly called the salmonfly, you use both the genus and species name, *Pteronarcys californica*, with the first letter of the genus name always capitalized and the species name always lowercase. This **scientific name** is always italicized or underlined. It is much better to refer to a BMI by its scientific name than its common name because common names can be numerous and confusing whereas the scientific name is unique and its use universal.

The scientific name of an organism is not always permanent. Advancements in science bring changes in systematics and on many occasions, changes in scientific names. The International Commission on Zoological Nomenclature has the final word on changing the scientific names of animals. Citizen monitors will not have to worry about remembering species names unless they develop a personal relationship with a particular bug. The taxonomy described in this manual deals with broader groups of organisms such as family, order, class, phylum and kingdom. Related genera are grouped into a **family**, related families into an **order**, related orders into a **class**, related classes into a **phylum** and related phyla into a **kingdom**. There can also be subdivisions added to these groups, such as suborders or tribes. The complete hierarchical classification from the broadest to the most specific group would look like the following for the salmonfly:

Kingdom: Animalia
  Phylum: Arthropoda
    Class: Insecta
      Order: Plecoptera
        Family: Pteronarcidae
          Genus: *Pteronarcys*
            Species: *californica*

Introduction to the Taxonomic Keys for Citizen Monitors

A **taxonomic key** is a written or pictorial aid to the taxonomic identification of animals or plants. Taxonomic keys can help you to separate individual species or broader categories or **taxa** (**taxon** for singular). This manual uses two types of taxonomic keys; formal dichotomous and flow-pictorial. A **dichotomous key** presents statements of contrasting characteristics. The formal dichotomous key, which is most frequently encountered in the formal literature, relies heavily on paired written statements and referrals to supporting taxonomic illustrations. The flow-pictorial keys present taxonomic illustrations with supporting brief written statements.

This manual uses both types of taxonomic keys. The formal dichotomous key will be used to separate the major taxa of BMIs because we feel it is important for the student to get some practice using a formal key. In the training workshop, we tell the student not to look at the illustrations listed at the end of each couplet. Forcing the student to read and concentrate on written descriptions of the organism, is the best way to gain confidence with taxonomy. After gaining experience with a formal dichotomous key, you should

find the flow-pictorial keys much less challenging. Having morphological features and full portraits of BMIs readily available with written descriptions, does make taxonomic identification easier and because of that, flow-pictorial keys are used extensively in later chapters for identifying the families of insects.

Taxonomic keys use statements of contrasting characteristics based on the **morphology** or structure and form of BMIs. All the keys in this manual are original and based on the organisms most commonly found in streams and rivers of the western United States. We have included familiar terms when describing morphological characteristics. However, there are some terms which could not or should not be translated. Chapter 13 deals with the terms used to describe the general body parts (head, thorax and abdomen) and the body orientation (dorsal, ventral, lateral and terminal) used to describe where the body parts are located on the specimen. There are more specific morphological terms used in Chapters 14 through 18 which deal with the identification of the various families of aquatic insects. It is important to understand these morphological characteristics when using dichotomous keys.

How to Use A Dichotomous Key

There are some general rules about dichotomous keys which you need to understand before using them. Start with the organism that you want to identify. Observe its predominant characteristics; is it hard or soft; flat or cylindrical; with or without jointed legs; how many pairs of legs? Then place your specimen under the microscope, usually using the lowest power, and start at the top of the key. The numbered descriptive statements are called **couplets** and each one is further designated with an "a" or "b". First read the 1a statement and then the 1b statement and decide which one best describes your specimen. At the end of each statement is a number designating which couplet to go to next. Proceed to that numbered couplet and again start by reading the "a" statement and then the "b" and determine which best describes your specimen. Keep following this pattern until you cannot go any further; the statement will end with the taxonomic name of your specimen.

The number in the parentheses following the statement number designates the couplet you just came from. If you become lost in the key, or the taxonomic description seems totally off, or the couplets and their numbering become too confusing, then sometimes it helps to backtrack to preceding couplets. You can do this by moving back up the key, following the couplet numbers in parentheses.

There is a strong tendency for anyone using a dichotomous key, especially the formal type, to not put enough time into reading all the couplets and to rely on the pictures instead. Good quality taxonomic illustrations are an important aid for identifying BMIs. However, in the beginning, it is important to read the entire key and to try not to rely on pictures. Only when you have read all the required couplets and are confident of your identification, should you try to verify it by looking at the figures listed for that taxon.

Helpful Hints for Using the Keys Effectively

Taxonomic identification of BMIs is not for everyone. It can be interesting and fun or tedious and frustrating depending on your abilities and attitude. The person who ends up enjoying taxonomy generally has an investigative nature. They enjoy a good puzzle and have the tenacity to not quit until they solve it. Those who have taxonomy in their blood, will enjoy sitting back, listening to some good music and working the microscope for 4 or 5 hours straight. Before long you will be able to recognize most taxa without the aid of the keys. In fact, there will come a time when you look forward to finding a specimen that you have not identified before. However, taxonomic identification of BMIs is not the easiest science and trained taxonomist do not grow on trees. The following tips will help you to become more competent with taxonomic identification:

Group organisms by morphological similarity

Before you look at the taxonomic keys, examine all the organisms under your microscope. Whether you are sorting or doing the final taxonomic identification, look for the organisms similar in appearance. Cluster organisms in different areas of the petri dish. When you are finished separating the different types, give them another look to see if any should be rearranged.

Besides helping you to become familiar with your organisms, you will have several specimens to look at when you use the keys. This is important since there will be many organisms in poor shape and harder to identify.

Use both hands, enough alcohol and good forceps and lighting

Use of taxonomic keys requires that the morphologic characteristics be properly examined. You will need to manipulate the specimen to see some obvious, but also some hard to recognize features.

Moving a specimen in the petri dish requires two hands. One hand should hold good quality, fine-tipped forceps and the other either another pair of forceps or a probing needle. It will not take long before you will become a "forceps snob" as you realize the tips of your forceps are not even or sharp enough.

It is also important to keep the alcohol in the petri dish at a level that covers all of your specimens. If a portion of the specimen breaks the surface of the alcohol, there will be glare that will obscure morphologic characteristics.

Finally, good directional lighting from either a high intensity incandescent bulb, high quality fluorescent or preferably, a fiber optic source will make all the difference in the world.

Do not read too much into the keys

The taxonomic keys developed for this manual were made to be as simple as possible. Some people, especially those with some limited taxonomic experience, have a problem by reading too much into them. Just keep it simple.

When necessary, go down both branches of the key

The dichotomous key is a series of statements of contrasting characteristics based on the morphology of BMIs. Sometimes, there is not an exact match for either statement. In this case, go down both branches of the key looking for corresponding characteristics. It usually does not take long before it becomes obvious that you are going the wrong way. The extra reading of the key also helps you learn the morphological characteristics faster.

Put specimens in poor condition aside until the end

Do not waste time on specimens that are missing too many body parts. Put them aside and look at other organisms that are in better shape. Sometimes, the organisms that are very small and nondescript can be young instars that cannot be identified. It is not the end of the world to have a few specimens that are labeled "unknowns", although, it is important to try to put unknowns in a group. Most often, as you are working the rest of the sample, you will run into an organism that reminds you of one of the unknowns.

Place the unknown next to the better quality specimen and try to match it. Sometimes you will see that this is the same organism.

At the end of identifying the sample, go through a process of "intelligent guessing" to put the remaining unknowns into a taxonomic group. However, there are strict rules to follow to be confident with guessing.

Follow the cardinal rule of intelligent guessing

There should be considerable caution used in guessing on some of your identifications. In general, you should always be confident with assigning organisms to a taxa, and Chapter 11 discusses the quality assurance procedure of taxonomic validation to verify that your identifications are correct.

However, there will be some specimens missing body parts or too young to identify with total confidence. The cardinal rule of intelligent guessing is to never create a new taxon unless you are extremely confident that you have a unique organism. If there is a questionable organism you know is a mayfly and it has the general size and shape of a common mayfly you have already identified, then put it in that group.

Taxonomic Keys for The Three Levels of Benthic Macroinvertebrate (BMI) Identification

As discussed in Chapter 9, there are three levels of BMI identification. Level 1 Taxonomic Effort requires subsampling 100 BMIs from the sample, sorting those 100 BMIs into the major taxonomic groups and then separating the mayflies, stoneflies and caddisflies into their different morphologic forms. The key to the major groups contained in Chapter 13 will be the only one necessary for identifying the BMI from your sample. There are one-page visual aids contained in Chapters 14, 15 and 16 for separating the mayflies, stoneflies and caddisflies, respectively, based on their morphologic forms. Level 2 Taxonomic Effort requires subsampling 100 BMIs from the sample, sorting those 100 BMIs into the major taxonomic groups and then identifying those groups to the family level of taxonomy. The key to major groups (Chapter 13) and the keys contained in Chapters 14 through 18 are required to complete this level of identification. Level 3 Taxonomic Effort, which is the professional level equivalent, requires subsampling 300 BMIs from the sample, sorting those 300 BMIs into the major groups and then identifying those groups to the lowest possible taxon, usually to genera and/or species level. The taxonomic keys required for this level of identification are not contained in this manual. However, the list of taxonomic references listed at the end of this chapter will be useful if you ever decide to pursue a career in professional taxonomy.

List of Taxa Which Can Be Identified Using the Keys in this Manual

As previously mentioned, all the keys in this manual are original and based on several years of development and numerous modifications. There are 89 distinct taxa possible when identifying BMIs for the Level 2 Taxonomic Effort. Although there might be other types of organisms in the aquatic world, these are the types that will be found most commonly in riffles of streams and rivers of the western United States. The following list shows all 89 taxa. All of the insects are identified to the family level of taxonomy and the non-insects to the phylum, class or subclass level. We only took the taxonomy as far down as necessary. We made the judgment decision that flatworms, for example, all have the same habit and occupy the same habitat and the taxonomy would be much too difficult for the citizen monitor to make further identification worthwhile. In many cases, even professional taxonomy goes no further than what we listed for the non-insects. The hierarchical classification for the 89 taxa could be slightly different in other taxonomic textbooks, but we are confident that what we present here is closest to what most experts agree on. Finally, remember that taxonomy can change, so make sure you have the most recent copy of the manual and visit the CSBP's Website (www.dfg.ca.gov/cabw/cabwhome.html) for confirmation. Those considering professional taxonomy should stay in touch with the California Aquatic Macroinvertebrate Laboratory Network (CAMLnet) for up-to-date taxonomy for BMIs.

Kingdom: Animalia
Phylum: Platyhelminthes
Class: Turbellaria (flatworms)
Phylum: Nematoda (roundworms)
Phylum: Nematomorpha (horsehair worms)
Phylum: Annelida
Class: Clitellata
Subclass: Oligochaeta (aquatic worms)
Subclass: Hirundinea (leeches)
Phylum: Mollusca
Class: Gastropoda (snails and limpets)
Class: Pelecypoda (mussels and clams)
Phylum: Arthropoda
Class: Insecta
Order: Ephemeroptera (mayflies)
Family: Ameletidae
Family: Baetidae
Family: Caenidae
Family: Ephemerellidae
Family: Ephemeridae
Family: Heptageniidae
Family: Isonychiidae
Family: Leptohyphidae
Family: Leptophlebiidae
Family: Siphlonuridae
Order: Odonata
Suborder: Anisoptera (dragonflies)
Family: Aeshnidae
Family: Cordulegastridae
Family: Corduliidae
Family: Gomphidae
Family: Libellulidae
Suborder: Zygoptera (damselflies)
Family: Calopterygidae
Family: Coenagrionidae
Family: Lestidae
Order: Plecoptera (stoneflies)
Family: Capniidae
Family: Chloroperlidae
Family: Leuctridae
Family: Nemouridae
Family: Peltoperlidae
Family: Perlidae
Family: Perlodidae
Family: Pteronarcyidae
Family: Taeniopterygidae
Order: Hemiptera **(true bugs)**
Family: Belostomatidae
Family: Corixidae
Family: Naucoridae
Order: Megaloptera (hellgrammites and alderflies)
Family: Corydalidae
Family: Sialidae
Order: Lepidoptera (aquatic moths)
Family: Pyralidae
Order: Trichoptera (caddisflies)
Family: Arctopsychinae
Family: Brachycentridae
Family: Calamoceratidae
Family: Glossosomatidae
Family: Goeridae
Family: Helicopsychidae
Family: Hydropsychidae
Family: Hydroptilidae
Family: Lepidostomatidae
Family: Leptoceridae
Family: Limnephilidae
Family: Odontoceridae
Family: Philopotamidae
Family: Phryganeidae
Family: Polycentropodidae
Family: Psychomyiidae
Family: Rhyacophilidae
Family: Sericostomatidae
Family: Uenoidae
Order: Coleoptera (aquatic beetles)
Family: Amphizoidae
Family: Dryopidae (found only as an adult)
Family: Dytiscidae (found as an adult and larvae)
Family: Elmidae (found as an adult and larvae)
Family: Gyrinidae (found only as a larvae)
Family: Haliplidae (found as an adult and larvae)
Family: Helophoridae (found only as an adult)
Family: Hydraenidae (found only as an adult)

Family: Hydrophilidae (found as an adult and larvae)
Family: Psephenidae (found only as a larvae)
Order: Diptera (aquatic flies)
Family: Athericidae
Family: Blephariceridae
Family: Ceratopogonidae
Family: Chironomidae
Family: Deuterophlebiidae
Family: Dixidae
Family: Empididae
Family: Ephydridae
Family: Psychodidae
Family: Simuliidae
Family: Stratiomyidae
Family: Tabanidae
Family: Tipulidae
Class: Arachnida
Subclass: Acari (water mites)
Class: Crustacea
Order: Amphipoda (scuds)
Order: Cladocera (water fleas)
Order: Copepoda (copepods)
Order: Decapoda (crayfish)
Order: Isopoda (aquatic sow bugs)
Order: Ostracoda (seed shrimp)

Important Flyfishing Entomology Books

The flyfishing literature contains many informative books on trout stream entomology, and mayflies are well represented. These books are worth reading to learn more about aquatic insect taxonomy and gain more insight on their life history.

Mayflies, the Angler and the Trout. Fred Arbona. 1980. Winchester Press. New Jersey. Very useful angler's guide to the identification and natural history of mayflies. This book has since been surpassed by Knopp and Cormier's *Mayflies* but remains a wealth of information found nowhere else in the general literature.

Aquatic Entomology. Patrick McCafferty. 1981. Science Books International. Massachusetts.
The best flyfishing entomology book ever written. In need of an update but still outstanding.

Western Hatches. Rick Hafele and Dave Hughes. 1981. Amato Publications, Oregon.
A general reference regarding the common Western aquatic insects and their flyfishing imitations.

Caddisflies. Gary LaFontaine. 1981. Nick Lyons Winchester Press. New York.
A classic. The first and still the best non-technical reference to the Caddisflies.

Dave Whitlock's Guide to Aquatic Trout Foods. 1982. Nick Lyons Winchester Press. New York.
A comprehensive guide to simple taxonomic identification, life history and habits of aquatic organisms.

Instant Mayfly Identification Guide. Al Caucci and Bob Nastasi. 1984. Comparahatch Ltd., Pennsylvania.
A field guide that quickly keys the mayfly. Many errors at the species level but still quite useful.

Sierra Trout Guide. Ralph Cutter. 1991. Frank Amato Publications. Oregon.
The most concise and complete aquatic entomology reference available for the California flyfisher.

An Illustrated Guide to the Mountain Stream Insects of Colorado. 1992 J.V. Ward and B.C. Kondratieff. University Press of Colorado.
Although this guide was written for Colorado streams, it has excellent illustrations, keys and descriptions of stream insects.

An Angler's Guide to Aquatic Insects and Their Imitations for all North America. Rick Hafele and Scott Roederer. 1995. Johnson Books, Colorado.
A unique taxonomic key to the types of aquatic insects important to flyfisherman.

Mayflies: An Angler's Study of Trout Water Ephemeroptera. Malcom Knopp and Robert Cormier. 1997. Greycliff Publishing. Montana.
An extraordinary compendium of all the North American mayflies and their relationship to flyfishing.

Caddis Super Hatches. Carl Richards and Bob Braendle. 1997. Frank Amato Publications. Oregon.
A field guide and key to the common North American caddisflies. The best key to adult caddis in the general literature.

Literature Used by Professional Taxonomists

The following list of scientific literature are among some of the more important references for the groups of non-insects, insects and all invertebrates. It is by no means complete and new literature becomes available regularly. Again, those considering professional taxonomy should stay in touch with the California Aquatic Macroinvertebrate Laboratory Network (CAMLnet) for up-to-date taxonomy for BMIs.

Non- Insects

A Guide to the Freshwater Annelida (Polychaeta, Naidid and Tubidicid Oligochaeta, and Hineninea of North America. Klemm, D.J. 1985. Kendall/Hunt Publishing Co., Dubuque, Iowa.

Freshwater Invertebrates of the United States, 3rd Ed. Pennak, R.W. 1989. John Wiley and Sons, Inc., New York.

Insects

The Stoneflies (Plecoptera) of the Rocky Mountains. Baumann, R.W., A.R. Gaufin and R.R. Surdick. 1977. American Entomological Society, Philadelphia, PA.

Aquatic Dryopoid Beetles (Coleoptera) of the United States. Brown, H.P. 1972. U.S. Environmental Protection Agency Project, # 18050 ELD. Washington, D.C.

The Mayflies of North and Central America. Edmunds, G.G., S.L. Jensen and B. Lewis. 1976. University of Minnesota. Press, Minneapolis, Mn.

An Introduction to the Aquatic Insects of North America., 2nd Ed. Merritt, R.W. and K.W. Cummins. 1995. Dendall/Hunt Publishing Co., Dubuque, Iowa

Nymphs of North American Stonefly Genera (Plecoptera). Stewart, K.W. and B.P.Stark. 1993. University of North Texas Press, Denton, TX.

Nearctic Genera of Chloroperlinae (Plecoptera: Chloroperlidae). Surdick, R.F. 1985. University of Illinois Press. Chicago, IL.

Aquatic Insects of California. Usinger, R.L. University of California Press. Berkeley, Ca. 1956

Chironomidae of the Holarctic Region - Part 1. Larvae. Wiederholm, T. 1983. Entomologica Scandinavica, Supplement No. 19. Sandby, Sweden.

Chironomidae of the Holarctic region - Part 2. Pupae. Wiederholm, T. 1986. Entomologica Scandinavica, Supplement No.28. Sandby, Sweden.

Larvae of the North American Caddisfly Genera (Trichoptera). Wiggins, G.B. 1977. University of Toronto Press, Toronto, Canada.

Systematics of the Genus Rhyacophila (Trichoptera: Rhyacophilidae) in Western North America with Special Reference to the Immature Stages. Wold, J.L. 1974. Masters of Science Thesis. Oregon State University, Corvallis, OR.

All Invertebrates

Aquatic Invertebrates of Alberta. Clifford, H.F. 1991. The University of Alberta, Calgary, Alberta.

Ecology and Classification of North American Freshwater Invertebrates. Thorp, J.H. and A.P. Covich. 1991. Academic Press. San Diego, CA.

Chapter 13
Description of the Groups of Non-Insects and Taxonomic Keys to the Major Groups of Aquatic Macroinvertebrates Common to Western Streams and Rivers

Introduction to the Non-Insects

Chapter 12 lists 89 taxa of the most common aquatic macroinvertebrates found in streams and rivers of the western United States. It is important to emphasize the words common and streams and rivers. We believe that all the taxa of aquatic invertebrates are represented in the keys, but you may find a rare organism that cannot be identified using the keys in this manual. Those unidentifiable specimens should be verified by a professional taxonomist. There are several groups of aquatic invertebrates, such as several families of beetles and dragonflies, that occur only in still water environments or are semi-aquatic, such as the springtail (Order: Collembola), so they are not included in the taxonomic keys. Additionally, with the exception of adult beetles, these keys are for larval forms and will not work to identify adults and pupal forms that can occur in some groups of insects.

Of the 89 different taxa, there are six phyla including Platyhelminthes, Nematoda, Nematomorpha, Annelida, Mollusca and Arthropoda. The first four phyla are all worms. They are soft-bodied, either flat or cylindrical, and of various sizes. Although any of these four groups of worms can be found in a riffle sample, the annelids are most common. They can also be extremely abundant, especially in samples collected in areas affected by wastewater discharge. The fifth phylum is the molluscs which consist of snails and clams. These groups all have hard shells enclosing their soft bodies. The sixth phylum is the arthropods which are invertebrates having exoskeletons. There are three major classes of arthropods, insects, arachnids and crustaceans. The insects are by far the most significant and they are discussed in Chapters 14 through 18.

This chapter deals with the non-insects, and each of the groups are discussed in detail in a later section. Many of the non-insects do not occur in running water environments and some of the taxa could be drifting through the riffle and not really be part of the resident population. This could occur especially if the collection site is located just below a lake or reservoir or has adjoining ponds or marshes. On the other hand, in low gradient streams and rivers that have warm, nutrient enriched waters, the riffles can contain several still water organisms, especially when the water is running over sand or mud instead of rock substrate. The non-insects comprise an important group of stream organisms and should not be overlooked. They are also relatively easy to identify.

Morphological Characteristics

The morphological characteristics of the non-insects can be divided into the worms which have soft flat or cylindrical shaped bodies, the snails and clams which have hard shells covering their bodies and the mites and crustaceans which have an exoskeleton. At the end of this chapter is the taxonomic key used to identify the non-insects and separate the orders of aquatic insects. The insects will need further identification using taxonomic keys found in chapters 14 through 18. Review the basic morphologic characteristics of the insects (*Figures 14-1, 15-1* and *16-1* found at the end of their respective chapters) before using the key in this chapter. The way the key is written, knowing insect morphology will help you to identify the non-insects.

The following terms are used in all of the manual's taxonomic keys to describe the orientation of the body for both insects and non-insects:

Dorsal - top side of the body

Ventral - bottom side of the body

Lateral - sides of the body

Terminal - end of the body

The following morphologic characteristics are also important to understand before using the keys in this chapter:

Filaments -fleshy appendages protruding from the body; usually lateral or terminal (Figures *14-1, 15-1* and *16-1* found at the end of their respective chapters).

Labium - the lowermost mouth part of an insect; lower lip. (*Figures 14-1, 15-1* and *16-1* found at the end of their respective chapters).

Prolegs - fleshy appendage protruding from various parts of the body. Non-segmented; not a true leg (*Figures 14-1, 15-1* and *16-1* found at the end of their respective chapters).

Segmented - repetition of body parts such as in aquatic worms or separately movable jointed sections such as legs in insect (*Figures 14-1, 15-1* and *16-1* found at the end of their respective chapters).

Wing pads - developing wings located on the dorsal surface of the thorax. Wing pads are identifying characteristics for mayflies and stoneflies and are visible in more mature larvae (*Figures 14-1, 15-1* and *16-1* found at the end of their respective chapters).

Life Histories

Non-insects have varied life histories which range from several weeks to six or seven years which is the case for some species of crayfish (Order: Decapoda). Unlike the aquatic insects which live primarily in the water as larvae and emerge into the terrestrial world as adults, most aquatic non-insects spend their entire life cycle in the water. There are some very complex life histories in some groups of non-insects. For example, mites (Subclass: Acari) have a parasitic stage before becoming a nymph and an adult, and cladocerans have bust and boom population growths where at times virtually all individuals are female. The specific life histories for the groups of non-insects is discussed in the "Non-Insects Common to Western Riffles" section.

Importance as Biological Indicators

As a whole, the non-insects are tolerant of water pollution. They are not very specialized and can live in the mud and sometimes in water where the dissolved oxygen level is low. The most sensitive groups have tolerance values of 4 or 5, but most are in the higher ranges of tolerance. The only group shown through research as being an important pollution indicator group are the mites (Subclass: Acari). Although, the taxonomy and life histories of these organisms are relatively unknown, the species that have been studied have shown specific environmental requirements that would make them good environmental indicators.

Tolerance Value and Functional Feeding Group Designation for the Major Groups of Non-Insects Common Riffle Species

	Tolerance Value	Functional Feeding Group
Cladocera	8	Collector Filterer (FC)
Ostracoda	8	Collector Gatherer (CG)
Gastropoda	7	Scraper (SC)
Pelecypoda	8	Collector Filterer (FC)
Oligochaeta	8	Collector Gatherer (CG)
Nematoda	5	Collector Gatherer (CG)
Nematomorpha	-	-
Turbellaria	4	Predator (P)
Hirundinea	10	Predator (P)
Acari	5	Predator (P)
Decapoda	6	Collector Gatherer (CG)
Isopoda	8	Shredder (SH)
Amphipoda	4	Collector Gatherer (CG)
Copepoda	8	Collector Gatherer (CG)

Non-Insects Common to Western Riffles

Most entomology books report about 24 taxa of non-insects found in North America. The taxa not addressed in this chapter were eliminated because they are not commonly found in running waters or because they are too small to be collected using the sampling technique described in this manual. The keys in this manual include the following 14 taxa which are commonly encountered when sampling riffle environments in western streams:

WATER FLEAS (Phylum: Arthropoda, Class: Crustacea, Order: Cladocera) - There are about 400 species of cladocerans in North America, but by far the most well-known of all is *Daphnia magna*. Daphnia is among the most easily cultured freshwater invertebrates and is used as aquarium fish food and most importantly, as a laboratory "guinea pig" for testing chemical pollutants. In the wild, cladocerans are found in almost all freshwater environments, except for swift moving streams and rivers. They predominantly live in still waters such as ponds and lakes. They swim in the water column with a jerky motion and this, combined with their general appearance, gives rise to their common name of "water flea". They have a short life cycle of approximately 30 to 60 days. Their populations can be phenomenally large, fluctuating in abundance with cycling algal populations, which are their primary food source.

Cladocerans are round, transparent animals that are very small, ranging from one-half to 3 mm long. At times they can be orange colored and when conditions are right for a population explosion, the surface of the water can turn solid orange. They have an obvious head with a compound eye and conspicuous protruding antennae (***Figure 13-1***). Most Cladocerans are tolerant of water pollution and are commonly found in wastewater oxidation ponds. They are given a tolerance value of 8. They will not be found in most riffle samples except if the site is located below an impoundment such as a warm water reservoir, below the discharge from a wastewater treatment plant with oxidation ponds, or deep water sites.

SEED SHRIMP (Phylum: Arthropoda, Class: Crustacea, Order: Ostracoda) - Seed shrimp are one of the oldest known microorganisms, but as a group, have not received as much attention from stream

ecologists and taxonomists as other crustacean taxa. The number of described species in North America increased from 60 to 420 in the past 50 years. There probably are many more left to be discovered. Ostracods can inhabit all types of substrates in both still and running waters. There are swimming and non-swimming varieties, but they are all benthic and rarely found suspended in the plankton. Seed shrimp live in vegetation, rocks or on muddy bottoms where they eat bacteria, molds, algae and other fine particulate organic matter. Ostracod eggs have been known to stay viable in dried up ponds for 20 years and more, but their entire life cycle from egg to adult lasts from several weeks to 6 months.

Seed shrimp look like seeds or very small clams with a few legs sticking out between the shells (***Figure 13-2***). They rarely exceed 3 mm and are usually less than 1 mm long. Small transparent plant seeds are usually common in BMI samples. You may often mistake them for stream organisms when you first start looking at BMI samples. Eventually, you will learn to ignore them, but do not forget seed shrimp. You must pay attention to very small plant seeds to make sure they are not seed shrimp. Ostracods are generally pollution tolerant with a tolerance value of 8. Although they will not be in grossly polluted waters, they can be found in waters with pH values as low (acidic) as 4.0 and very low oxygen levels.

SNAILS and LIMPETS (Phylum: Mollusca, Class: Gastropoda) - Snails and limpets make up three-quarters of all the known species of molluscs in the world. There are more than 500 species of freshwater snails and limpets in North America. A 1981 taxonomic survey reported 67 species of snails and limpets in California. Recent work associated with the 1991 Cantara Loop Spill on the Upper Sacramento River described 10 new species and there are probably many more undescribed species remaining to be discovered. Snails and limpets can be found in all aquatic environments including running water. They are most common in springs, temporary ponds and streams, lakes, and slow moving streams and rivers. Most snails and limpets are found in the shallow littoral area of lakes and streams where they feed by scraping periphyton from rocks. The species living in temporary waters will burrow in the bottom muds or even crawl out of the stream and aestivate in leaf litter when the water dries up. Most species of gastropods live from 9 to 15 months.

Everyone should be familiar with the general shapes of snails and limpets. The hard shell is always present in freshwater snails and limpets. The shell can be conical in shape (***Figure 13-3***), whorled all in one plane (***Figure 13-4***) or whorls elevating into a spire (***Figure 13-5***). Gastropods range in size from 2 to 70 mm with the bigger species being found in lakes. They cannot be confused with any other organism. Snails and limpets are fairly tolerant of pollution so they are given a tolerance number of 7. There are gilled and ungilled snails, but their tolerance still seems to be similar. Gastropod distribution is most dependent on calcium levels which they need to build their shells and pH which affects how much calcium is dissolved in the water. Snails and limpets are most abundant in hard water and are never common when the pH is more acidic than 6.2.

MUSSELS and CLAMS (Phylum: Mollusca, Class: Pelecypoda) - Mussels and clams are all aquatic and can occur in all types of freshwater habitats. They are most common in larger rivers, especially in the eastern states. For example, out of the 230 species of mussels in the 48 contiguous states, 50 species are found in the upper Mississippi River drainage and only 24 in all of California. They can be quite abundant in their ideal environment which is stable gravel, sand and substrates composed of sand or gravel mixed with other materials. They prefer being in water that is not much deeper than 6 feet and in moving water that is not very turbid. They bury themselves, either completely or partially, in the substrate exposing a siphon which they use

to filter primarily fine particulate organic matter (FPOM). Most mussels and clams live for 1 to 2 years, but some species are known to live 10 to 15 years.

Everyone should be familiar with the general shapes of mussels and clams. The hard shell is always present in two "valves" attached to each other dorsally by an elastic hinge ligament (***Figure 13-6***). Mussels and clams can be as small as 2 mm and as large as 10 inches. They cannot be confused with any other organism. Most of the mussels and clams remaining in California's streams and rivers are relatively pollution tolerant and tend to be concentrated in warm waters with high nutrient loads. The numbers and diversity of native species are being threatened by heavy pollution, silting in of rivers, construction of dams and by the introduction of exotic species. The Asiatic clam, *Corbicula fluminea*, has spread throughout streams and rivers of the United States in a phenomenal fashion, displacing native species.

AQUATIC WORMS (Phylum: Annelida, Class: Clitellata, Subclass: Oligochaeta) - Ten families of freshwater Oligochaetes occur in North America. The three most important families are Lumbriculidae, Naididae and Tubificidae. Members of the family Lumbriculidae are the typical aquatic worms. In fact, their ecologic role is similar to terrestrial worms: they burrow in mud or fine sediment by eating it, digesting the organic material and excreting the rest. Just like terrestrial earthworms, they mix the benthic soil or substrate. Members of the families Lumbriculidae and Naididae occur in highest numbers and diversity in the bottom of lakes, ponds and wetlands. However, they can also be found in running waters from high mountain streams to larger rivers as long as there is some silt or mud in the substrate. Some members of the family Tubificidae live in mud bottom streams and ponds, but can also live where there is little or no dissolved oxygen. They are called sludge worms because they can be found in large colonies where organic sludge is present.

Members of the families Lumbriculidae are usually greater than 25 mm and look exactly like a terrestrial earthworm (***Figure 13-7***). Members of the Naididae and Tubificidae families are never more than 25 mm long and usually much smaller. Although size differences exist, oligochaetes are difficult to identify. For this reason, the three families are counted as one group. Oligochaetes are cylindrical and segmented and can only be confused with the nematodes and nematomorphs which are cylindrical, but not segmented. Oligochaetes are given a tolerance value of 5 because of their wide distribution, but when found in large numbers can indicate excessive sedimentation. Tubificids have been recognized as an indicator of organic pollution since the time of Aristotle. In very polluted waters, they can be present in such large colonies that sampling nets can be covered with small (10 mm), slender red worms.

ROUNDWORMS (Phylum: Nematoda) - Most of the interest in nematodes has been with the large group of parasitic and predatory ones which can be extremely important to human economics and health. The group of free-living, freshwater nematodes have not been studied much since the 1930's, primarily because they are small and hard to identify. There are not much more than 1500 free-living nematodes reported in the world with 500 being described in Europe. This probably is only a fraction of the species that exist and maybe someday someone will find the time and interest to explore the world of the free-living nematodes of North America.

Free-living round worms are quite common and can be found in almost any freshwater habitat including the benthos of streams and rivers. They are small (less than 10 mm), cylindrical and not segmented (***Figure 13-8***). They can be separated from other worm-type invertebrates such as oligochaets (aquatic worms) and nematomorphs (horsehair worms) by the size difference alone. Aquatic worms are usually more than 25 mm and segmented while horsehair

worms are longer than 100 mm. Because they are found almost everywhere, including polluted and unpolluted water, and since very little is known about them, they are given a tolerance value of 5.

HORSEHAIR WORMS (Phylum: Nematomorpha) - Another poorly studied group of aquatic invertebrates are the horsehair worms. There are less than 20 genera in the common taxonomic references and not all are restricted to North America. Larval nematomorphs are parasites of terrestrial arthropods, especially grasshoppers and crickets. The adults are free-living and can be found in streams and rivers, but not commonly. They are called horsehair worms because they resemble a long curled horse hair and until the late 1800's they were thought to come from horse hairs that fell in the water.

Adult horsehair worms are very long (100 to 700 mm) and slender (***Figure 13-9***). They can be separated from other worm-type invertebrates such as oligochaetes (aquatic worms) and nematodes (roundworms) by their unique size and shape. They are most often entangled in a large mass and sometimes with other worms or around a twig. They are rarely encountered and never in large numbers. They can be found in a stream one year and not the next which can probably be attributed to the abundance of the terrestrial host organisms. There is no tolerance value for this group because so little is known about them. The same species can be found on the shore, in the benthos of running water, and in lakes.

FLATWORMS (Phylum: Platyhelminthes, Class: Turbellaria) - There are more than 200 species of turbellarians in North America and some species can be common and often abundant in freshwater environments, including the benthos of running waters. Flatworms are not one of the most glamorous of the BMIs and they do not preserve well, so they have not been well studied. There could be many undescribed species and genera in North America and the west. From what we do know, flatworms seem to be more diverse in running water environments than in ponds and lakes and have been associated with distinct habitat such as springs, headwaters, and larger rivers. The most studied group of turbellarians are in the order Tricladida, also known as planarians. There are approximately 43 described species in North America, but the number will probably increase in the future

The most commonly encountered flatworms are the planarians which are free-living predators ranging in size from 5-20 mm. They have a flat, elongated body which is soft and usually tapered at both ends (***Figure 13-10***). Preserved specimens can be shriveled, sometimes resembling a piece of leather. They can only be confused with leeches because they both preserve in a similar manner, but with leeches resembling leather even more. However, there should be no problem separating well preserved planarians from leeches, since leeches usually have suckers, are segmented and are not quite as flat. Because of the lack of adequate studies, there is not enough information to fully understand their environmental requirement and relationships. They are given a tolerance value of 4 since they can be found in many waters, including pristine areas.

LEECHES (Phylum: Annelida, Class: Clitellata, Subclass: Hirundinea) - The leeches are predominantly a freshwater group with about 70 species in North America. They inhabit all types of aquatic environments including running waters, but are most prevalent in ponds, lakes, and wetland areas. Leeches can live for up to one year and most die after reproducing. Many people think of leeches as "bloodsuckers". A few species do feed on blood and tissue of warm-blooded animals, but most are predators and scavengers feeding on either fish, birds, or small invertebrates. In some ponds, leeches can be the top predator and in larger lakes they can be a major component of fish diets. Leeches are used as bait and every fly angler who

fishes still waters will have a leech pattern in their fly box.

Leeches can be as long as 450 mm while swimming fully extended in lakes of some northern states. Most leeches, however, especially those found in running water will be from 10 to 60 mm when fully extended. Quite often though, preserved leeches will be shriveled, resembling a piece of leather and will not be their full length (***Figure 13-11***). Leeches are related to the aquatic worms and both are segmented. Aquatic worms smashed in the sampling process can be flattened and resemble leeches. With close examination, it should be obvious that leeches are morphologically flat and sometimes oval in shape. Platyhelminthes which are the only worm-like BMI which are flat, usually are smaller and not segmented. Leeches also have suckers at each or one end of their body. Leeches are given a tolerance value of 10 because they can withstand a wide range of environmental conditions. They are found in waters with very low salt content and in waters saltier than the ocean. They can live in water devoid of dissolved oxygen and can survive out of water.

WATER MITES (Phylum: Arthropoda, Class: Arachnida, Subclass: Acari) - Water mite experts estimate that more than 1500 species of water mites occur in North America. However, many of the species have not been adequately described and more than half the species are still waiting to be named. Species richness is highest in littoral lake habitats and in depositional pools in streams, ponds and sheltered bays in lakes. There are 25 described taxa that can be found in stream riffles. Although water mites can be one of the most abundant and diverse groups of organisms in stream riffles, they are relatively unknown to many stream ecologists. Water mites have a larval stage that parasitizes other aquatic invertebrates before becoming a nymph and adult. This general life history is only completely known for a few species and little is known about the longevity of most species. However, it is believed that most do not live longer than one year. Water mites swim or crawl on the substrate and are strictly predators of other aquatic invertebrates.

Water mites are related to spiders and have four pairs of legs. Their round body looks just like a spider or tick (***Figure 13-12***) so most people have no problem identifying them. They cannot be confused with any other organism. They are quite small, rarely exceeding 4 mm. As a group, water mites are given a pollution tolerance value of 5, right in the middle. However, recent research has indicated that on a species level, water mites are quite specialized and are found in narrow ranges of physical and chemical regimes and they are particular about which organism they parasitize. This has lead some researchers to believe that this group of BMIs can be excellent indicators of water pollution and habitat destruction. The only problem is the lack of knowledge about their taxonomy and ecology.

AQUATIC SOW BUGS (Phylum: Arthropoda, Class: Crustacea, Order: Isopoda) - Almost everyone is familiar with terrestrial pill bugs. Of the 2600 species of isopods in North America, only 130 are known to occur in freshwater. Most species live in springs, streams, springs and subterranean waters. Unlike most of the other crustaceans, very few isopods are found in ponds and lakes. Similar to the sow bugs in your garden, stream isopods are rarely in the open, preferring to be under rocks or hidden in vegetation or debris. They crawl around on the bottom of the stream scavenging whatever they can get, including dead animals and vegetation. They are thought to live less than a year.

Aquatic sow bugs are strongly flattened dorsoventrally with the head and thorax fused, and seven remaining body segments each containing a pair of legs (***Figure 13-13***). They really cannot be confused with any other organism. Their size ranges from 5 to 20 mm. Isopods are generally pollution tolerant having a tolerance value of 8.

CRAYFISH (Phylum: Arthropoda, Class: Crustacea, Order: Decapoda) - Everyone is familiar with crayfish, primarily as a high-priced food item. There are over 10,000 species of decapods, most of which are marine. There are 350 species of freshwater decapods which can be found in lakes, ponds, sloughs, swamps, underground waters and even in wet meadows where there is no open water. Unlike most of the other freshwater crustaceans, they are also found in swift running water. Crayfish usually walk or climb with ease on rocks, vegetation and muddy bottoms, but can also quickly dart backward to escape from predators. Some species dig extensive burrows where they hide from predators and stay moist during dry periods. Crayfish are omnivores and their normal life span is 2 years, but some species can live up to 6 to 7 years.

It would be hard to confuse a crayfish with any other stream organisms, even when they are small. They have the typical lobster-like appearance with 2 long antennae, a fused head and thorax, 4 pairs of large legs, smaller swimming appendages on the abdomen and usually a pair of large claws. They can be drab blue, red or brown in color and can be quite large. However, when sampling riffles, the larger crayfish usually escape and only the smaller (one-half to 3-inch) specimens are captured in the net. Crayfish are slightly less tolerant than the other crustaceans and are given a tolerance value of 6.

SCUDS (Phylum: Arthropoda, Class: Crustacea, Order: Amphipoda) - Amphipods are crustaceans which include the familiar saltwater shrimp. Amphipods look somewhat like shrimp and some people refer to them as freshwater shrimp which they are not. They are only distantly related to saltwater shrimp. However, most amphipods are marine with only 150 species found in freshwater. Amphipods are usually more active at night than during the day. They inhabit the substrate of a variety of lakes, ponds, streams, springs, and subterranean waters where they crawl, walk or swim on their side or back. The young and adults look the same and most species complete a life cycle in a year or less. Scuds are voracious eaters of all kinds of plant and animal material and can be quite abundant, especially in vegetation mats of small streams and lakes.

The body of a scud is laterally compressed with 7 pairs of thoracic legs. They have two sets of antennae which can be short or long (***Figure 13-14***). They are usually in a curled up position when preserved in alcohol and do have the general appearance of a tiny shrimp ranging from 5 to 20 mm. They are difficult to confuse with any other organism. They are found in unpolluted waters and are given a tolerance value of 4. Scuds are found in both warm and cold water environments and usually where high oxygen levels are present.

COPEPODS (Phylum: Arthropoda, Class: Crustacea, Order: Copepoda) - Copepods are a large and important group of crustaceans. There are over 5500 species of copepods in the world with only about 1500 found in freshwater. They can be the single most abundant organism in marine zooplankton and are an important component of the ocean food chain. There are a few species of parasitic copepods in the freshwater environment, but most copepods are free-living. They can be found in the water column, littoral zone, and in the benthos of, primarily, still water environments such as lakes, ponds, and wetlands. Copepods swim in the water column or crawl on the bottom sediments and vegetation, eating almost anything they can get, but primarily algae. The life cycle of the copepods is highly variable ranging from 7 to 180 days. One species is known to have a one-year life cycle.

Copepods can be a drab grey color or sometimes a brilliant orange, purple or red. They are very small, ranging from less than one-half to 3 mm. Copepods have a distinct head with a compound eye and long antennae, a segmented tapering body and a terminal appendage (***Figure 13-15***). They

are difficult to confuse with any other organism. Copepods have the same tolerance value as cladocerans (8) and are somewhat more tolerant of low dissolved oxygen levels. As with cladocerans, they are usually not found in riffle environments. However, it is not uncommon to find them in riffle sample, especially in slower moving urban streams.

Taxonomic Keys to the Major Groups of Aquatic Macroinvertebrates

1a		Organism very small (<3mm) and body encased by a transparent shell or organism of various sizes and body enclosed by hard shell.....2
1b		Organism not enclosed within a shell; most body parts visible.....5
2a	(1a)	Organism very small (<3mm) and body encased by a transparent shell; small head or legs may be visible.....3
2b		Body totally covered by a hard shell.....4
3a	(2a)	Head with eye spot visible; water fleas.....**Order: Cladocera (Figure 13-1)**
3b		Seed-like shell over body; 3 pairs of legs usually visible; seed shrimp.....**Class: Ostracoda (Figure 13-2)**
4a	(2b)	Body enclosed in a single shell; usually with spiraling coils; snails and limpets.....**Class: Gastropoda (Figures 13-3, 13-4 and 13-5)**
4b		Body enclosed in two hinged shells; mussels and clams.....**Class: Pelecypoda (Figure 13-6)**
5a	(1b)	Jointed legs absent; sometimes worm-like in appearance.....6
5b		Jointed legs present.....11
6a	(5a)	Body cylindrical.....7
6b		Body flat.....10
7a	(6a)	Body with head (may not be easily seen); fleshy prolegs may be present; aquatic flies.....**Order: Diptera (Chapter 17)**
7b		Body without head and/or prolegs.....8
8a	(7b)	Body segmented; aquatic worm.....**Subclass: Oligochaeta (Figure 13-7)**
8b		Body not segmented.....9
9a	(8b)	Body cylindrical and tapered at both ends; often crescent shaped; length 10 mm or less; roundworms.....**Phylum: Nematoda (Figure 13-8)**
9b		Body cylindrical and very long (10-1000 mm); often entangled in a large mass; horse-hair worms.....**Phylum: Nematomorpha (Figure 13-9)**
10a	(6b)	Flattened body tappered at both ends; eye spots may be present at one end; usually shriveled and leather-like when preserved; flatworms.....**Class: Turbellaria (Figure 13-10)**
10b		Flattened body with sucker at one or each end; usually shriveled and leather-like when preserved; leeches.....**Subclass: Hirudinea (Figure 13-11)**
11a	(5b)	Four or more pairs of jointed legs.....12
11b		Only three pairs of jointed legs.....16
12a	(11a)	Body small and round and with four pairs of jointed legs; spider-like; water mite.....**Subclass: Acari (Figure 13-12)**
12b		Five or more pairs of jointed legs.....13
13a	(12b)	Very large; characteristic lobster-shape; crayfish.....**Order: Decapoda**
13b		Not crayfish-like; much smaller.....14

14a (13b) Eyes not apparent; body dorso-ventrally flattened; aquatic sowbugs..... **Order: Isopoda (Figure 13-13)**

14b Eyes usually apparent.....15

15a (14b) Body laterally flattened; resembles small shrimp; scuds..... **Order: Amphipoda (Figure 13-14)**

15b Body not compressed and with two tails; copepods..... **Order: Copepoda (Figure 13-15)**

16a (11b) Wings hard, shell-like or leather-like covering entire body except legs.....17

16b Wingless or with wing pads.....18

17a (16a) Wings hard, shell-like; characteristic beetle-shape; aquatic beetles..... **Order: Coleoptera (adult) (Chapter 18)**

17b Wing leather-like; sucking mouthpart in form of a beak; true bugs..... **Order: Hemiptera (Chapter 18)**

18a (16b) End of body with two or three long and slim tails.....19

18b End of body without slim tails; sometimes leaf-like gills at end of body.....20

19a (18a) Dorsal or lateral gills present on abdomen; one claw at tip of legs; one pair of wing pad on thorax; three or sometimes two tails; mayflies..... **Order: Ephemeroptera (Chapter 14)**

19b Dorsal or lateral gills not present on abdomen; two claws at tip of legs; two pairs of wing pads on thorax; two tails; stoneflies..... **Order: Plecoptera (Chapter 15)**

20a (18b) Mouth covered with a mask-like labium; end of body with leaf-like terminal gills or three short triangular structures; damselflies and dragonflies ..... **Order: Odonata (Chapter 18)**

20b Mouth without a mask-like labium.....21

21a (20b) Ventral prolegs on middle four abdominal segments; jointed legs short and stubby; aquatic moths..... **Order Lepidoptera (Chapter 18)**

21b Ventral prolegs absent; prolegs, if present, at end of body and usually with distinct hooks.....22

22a (21b) Abdomen with long lateral filaments.....23

22b Abdomen without long lateral filaments.....24

23a (22a) End of body with single long tapering filament or with two hooked prolegs; larvae usually large; hellgrammites and Alderflies..... **Order Megaloptera (Chapter 18)**

23b End of body with four small hooks; larvae usually smaller; aquatic beetles (in part)..... **Order Coleoptera (larvae) (Chapter 18)**

24a (22b) End of body with two visible hooked claws, some at end of long prolegs; antennae short; larvae may be in case; caddisflies..... **Order Trichoptera (Chapter 16)**

24b End of body without two hooked claws; larvae never in case; body sometimes oval and flat; or body sometimes elongate and hard; aquatic beetles (in part)..... **Order Coleoptera (larvae) (Chapter 18)**

Other organisms which may not keyed- out using the preceding key could be:

Collembola

Chironomidae pupae (**Figure 17-1**)

Simuliidae pupae (**Figure 17-2**)

Trichoptera pupae

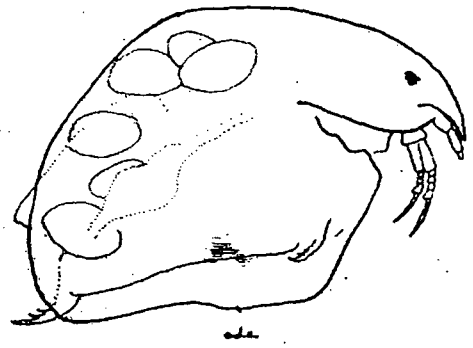


Fig. 13-1 Cladocera (water fleas)

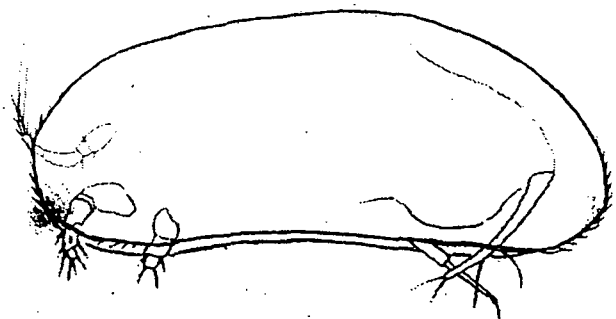


Fig. 13-2. Ostracoda (seed shrimps)

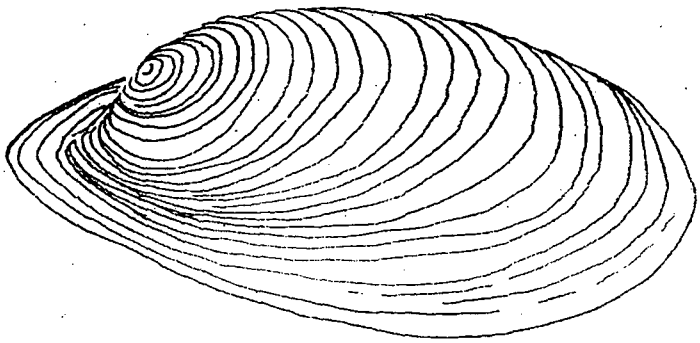


Fig. 13-3. Gastropoda (limpets)

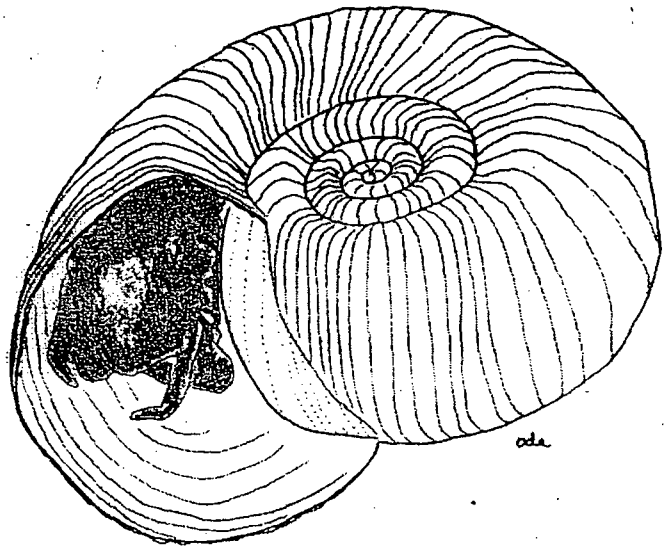


Fig. 13-4. Gastropoda (snails)

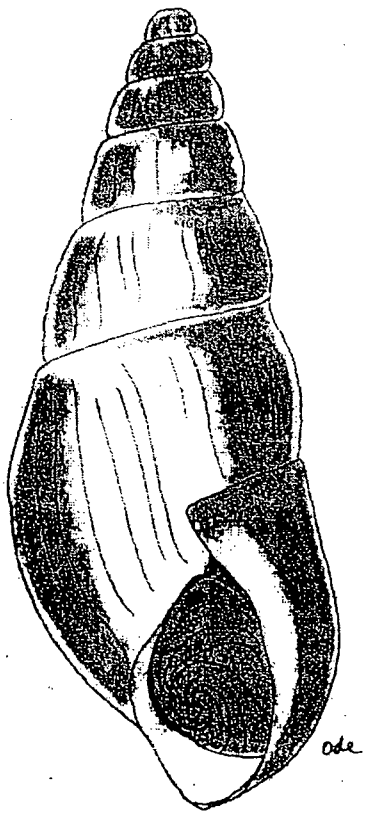


Fig. 13-5 Gastropoda (snails)

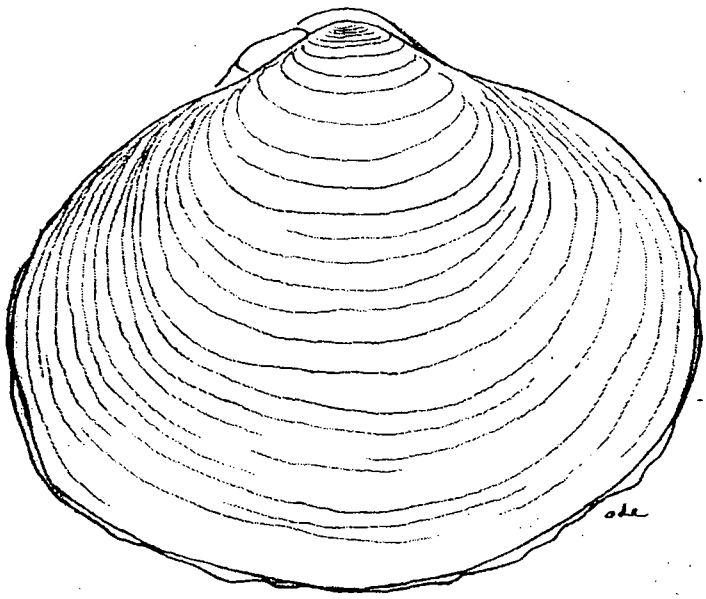


Fig. 13-6 Pelecypoda (clams)

MAJOR GROUPS OF NON-INSECTS

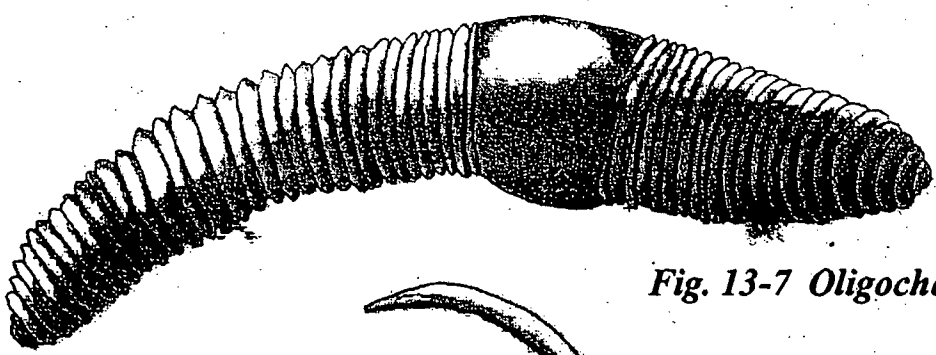


*Fig. 13-7 **Oligochaeta*** (aquatic worms)

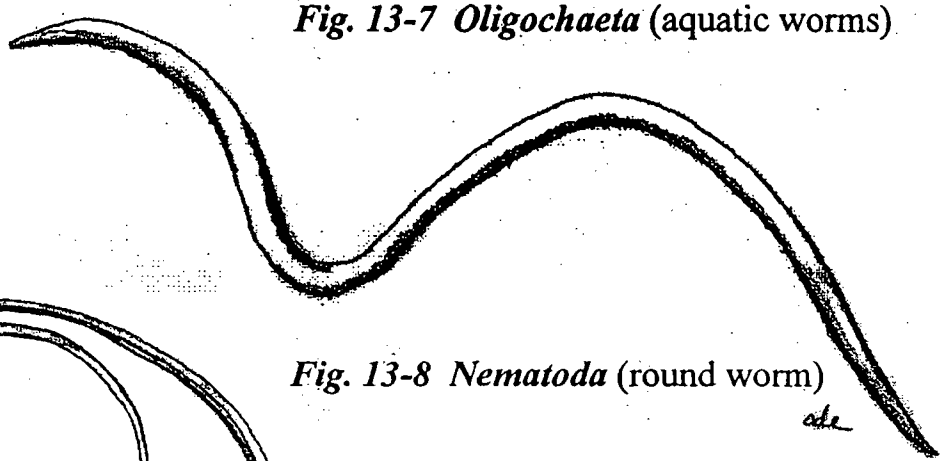


*Fig. 13-8 **Nematoda*** (round worm)

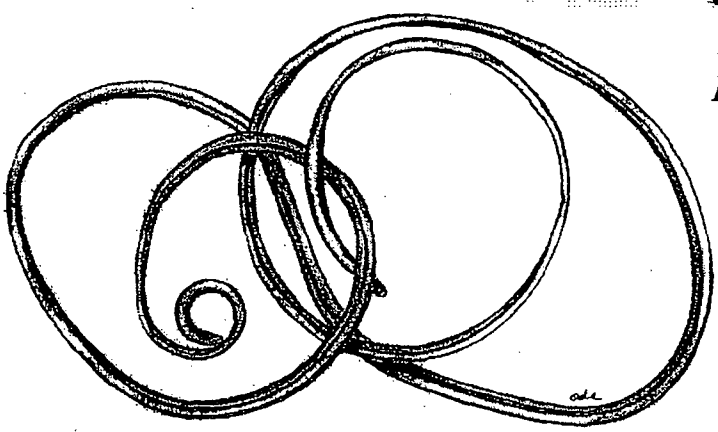


*Fig. 13-9 **Nematomorpha*** (horse-hair worms)

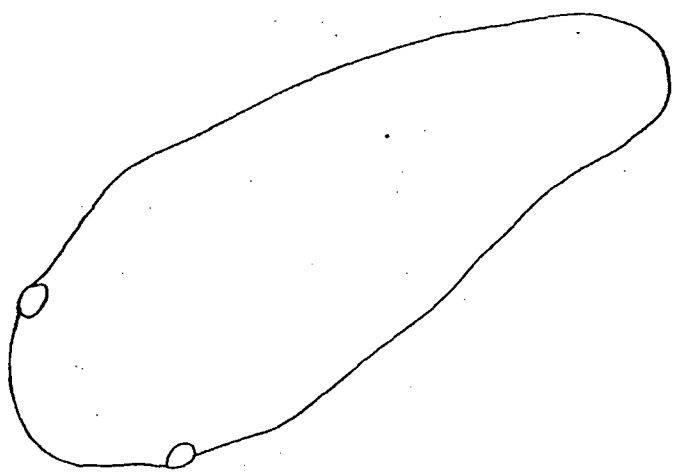


*Fig. 13-10 **Turbellaria*** (flat worm)

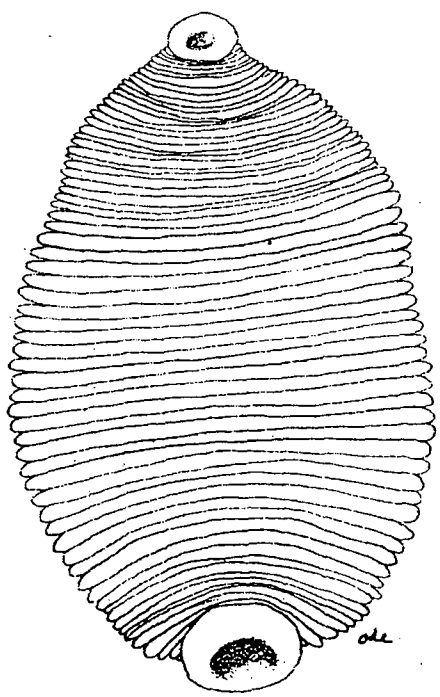


*Fig. 13-11 **Hirundinea*** (leeches)

MAJOR GROUPS OF NON-INSECTS

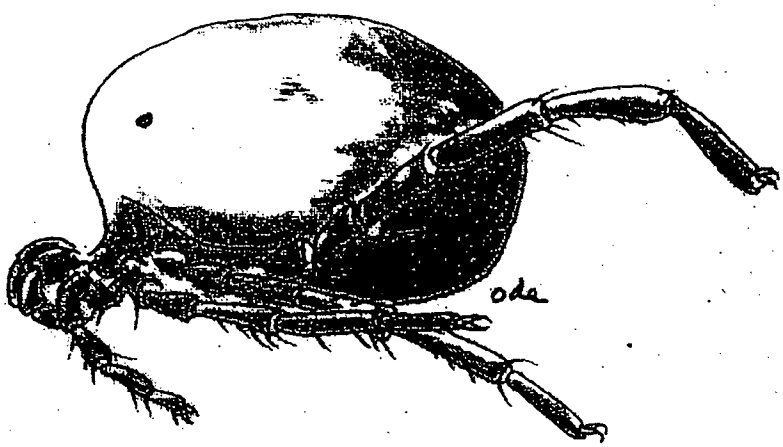


Fig. 13-12 Acari (water mites)

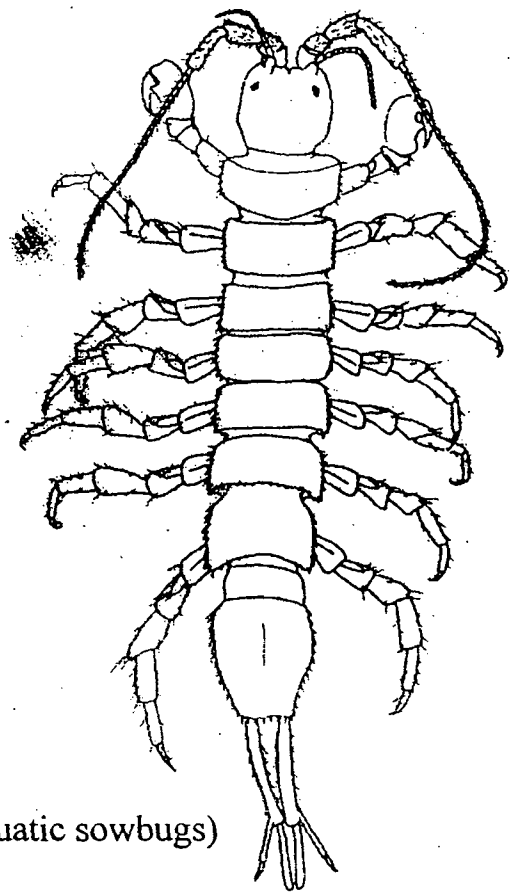


Fig. 13-13 Isopoda (aquatic sowbugs)

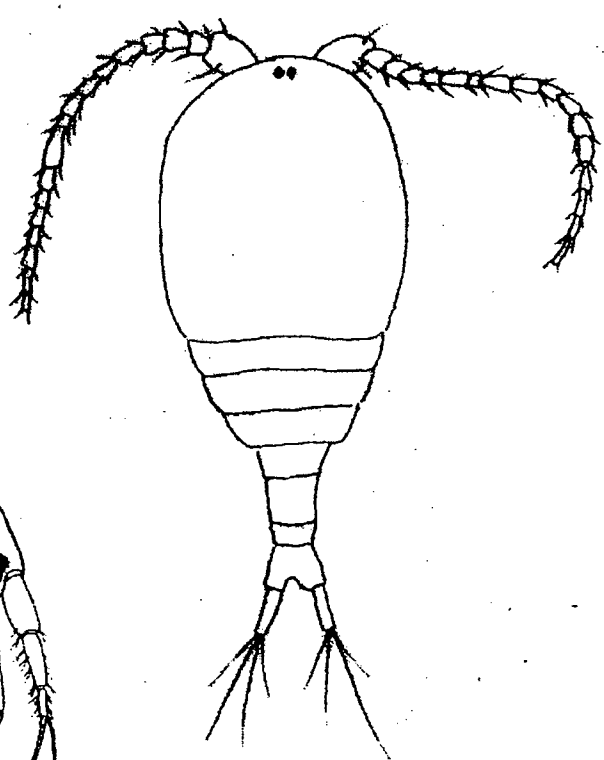


Fig. 13-15 Copepoda (copepods)

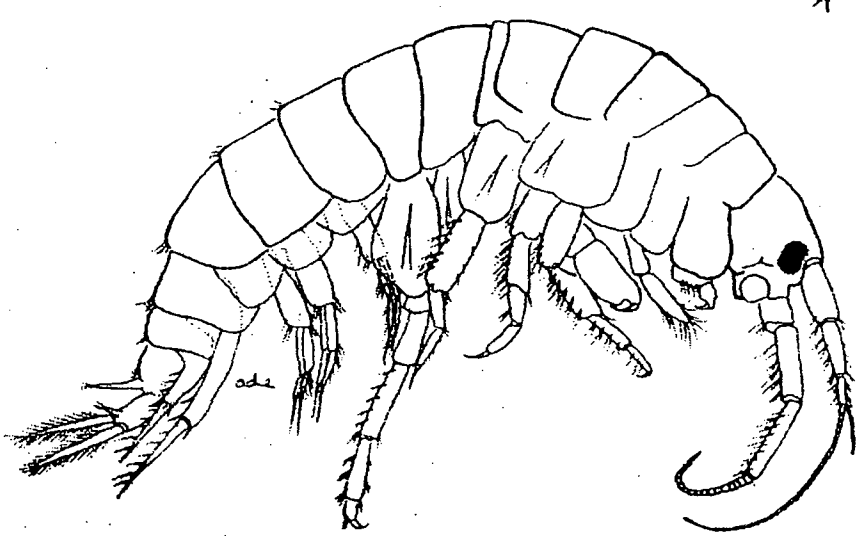


Fig. 13-14Amphipoda (scuds)

Chapter 14
Description and Taxonomic Keys to the Families of Mayflies (Order: Ephemeroptera) Common to Western Streams and Rivers

Introduction to the Mayflies

Mayflies are probably the most well known and important macroinvertebrates in the aquatic environment. Although there are many species that live in lakes, ponds, and large rivers, they reach their highest diversity in streams and can be the most common insect in riffle environments. The delicate and graceful adults produce some of the most spectacular hatches found around the stream side environment. Because of their abundance and availability, mayflies are an important food source for fish and as a result are very important to the fly anglers. Even the smallest of mayflies, when they emerge, are so numerous that trout will key in on a particular species, and eat nothing else. Any fly box should contain several imitations of nymph and adult mayflies.

Morphological Characteristics

Mayfly nymphs are usually small (3 - 20 mm) with one visible wing pad, one tarsal claw, and sometimes two, but usually three tails or cerci. They all have gills on the abdomen but in various shapes and placement which help to distinguish one family from another. ***Figure 14-1*** shows the body parts of a typical mayfly.

Mayflies have four basic body shapes: clingers, swimmers, crawlers and burrowers. **Recognizing these body shapes will help in taxonomic identification and understanding the habits and habitats of mayflies.** Clingers are flat and shaped to resist fast currents while clinging to the top of rocks. Swimmers are minnow-like with sleek, fusiform shaped bodies. They get around by swimming and can swim against fast moving water sometimes deliberately moving into such areas. Crawlers are neither flat nor fusiform. They live between rocks or in detritus where they crawl around out of the influence of strong currents. Burrowers are usually large with fringed gills. They are found in soft substrate where they can build burrows for shelter. ***Table 14-1*** lists which families of mayflies have these basic body shapes.

Table 14-1. Basic body shapes for the families of mayflies

Clingers:
- Heptageniidae

Burrowers:
- Ephemeridae

Swimmers:
- Ameletidae
- Baetidae
- Siphlonuridae
- Isonychiidae

Crawlers:
- Caenidae
- Ephemerellidae
- Leptohyphidae
- Leptophlebiidae

Life History

All species of mayflies have aquatic larval forms usually referred to as nymphs. While a few species of mayfly can require two years to complete a life cycles or some can complete three life cycles in one year, it takes one year for a typical mayfly to complete a life cycle. Mayflies go through incomplete metamorphosis. When the nymph is ready to hatch, it either drifts to the surface or crawls out of the margin of the water. As it floats on the surface of the water or becomes attached to a rock or stream side vegetation, it sheds its nymphal shuck and crawls out to dry its wing and fly away. Unlike all other insects, mayflies go through a pre-adult stage called

the subimago or dun before it goes through another molting to become the imago or adult. The scientific name Ephemeroptera means ephemeral winged and comes from the fact that the winged adult is very short lived. The adult stage of most mayfly species lives no longer than three days. Its sole purpose is to reproduce. In fact, having non-functional mouth parts, mayflies never even eat or drink as adults. Mating occurs within a frenzy of swarming males dancing up and down in the air column enticing females to fly into the swarm to mate. They mate in the air and then the females usually drops eggs onto the water, dip at the water surface releasing eggs or sometimes swim into the water to attach eggs to some object. Both the male and female die shortly after mating.

Importance as Biological Indicators

Mayfly nymphs are important biological indicators because of their diversity and abundance in the aquatic environment. Tolerance values for mayfly families range from 0 to 7. On the low tolerance extremes are members of the families Ameletidae, Isonychiidae, Ephemerellidae and Leptophlebiidae which are found in cool, clean and highly oxygenated water. On the high end of tolerance extreme are members of the families Siphlonuridae and Caenidae which can survive in lower oxygenated, sometimes stagnant waters and prefer silty substrates. Members of the other families are capable of withstanding temperature and oxygen fluctuations, but in general are associated with unpolluted environments. However, some families can be deceiving. Baetids, for example, are some of the first organisms to inhabit disturbed areas and can be quite tolerant of sedimentation and nutrient enrichment. In addition, their abundance in riffles can influence and sometime bias biological metrics such as the EPT index and percent dominance.

Tolerance Value and Functional Feeding Group Designation for Mayfly Families with Common Riffle Species

Taxa	Tolerance Value	Functional Feeding Group
Ameletidae	0	Collector Gatherer (CG)
Baetidae	4	Collector Gatherer (CG)
Caenidae	7	Collector Gatherer (CG)
Ephemerellidae	1	Scraper (SC)
Ephemeridae	4	Collector Gatherer (CG)
Heptageniidae	4	Scraper (SC)
Isonychiidae	2	Filterer Collector (FC)
Leptohyphidae	4	Collector Gatherer (CG)
Leptophlebiidae	2	Scraper (SC)
Siphlonuridae	7	Collector Gatherer (CG)

Mayfly Families Common to Western Riffles

Most entomology books report 17 North American families of mayflies, but recent reorganization of the Ephemeroptera resulted in new families, bringing the total to 21. The keys in this manual include the following 10 families which can be encountered when sampling riffle environments in western streams:

Family: Ameletidae - The family Ameletidae is represented by only one genus, *Ameletus*. However, there are many species in this genus and probably several that are undescribed. *Ameletus* used to belong to the family Siphlonuridae and was just recently placed into its own family. Be aware that many entomology books, especially flyfishing books may still include this genus in the family Siphlonuridae. Members of this family have a large streamlined body (6-20 mm) with plate-like abdominal gills on segments 1-7 and three tails. *Ameletus* is similar in body shape and size to the other swimmer-type mayfly families Siphlonuridae and Isonychiidae, but usually much larger than baetids. *Ameletus* can be distinguished from the other swimmer-type mayflies by its conspicuous crown of comb-like spines on the maxillae (***Figure 14-2***).

Nymphs of the family Ameletidae usually live for one year in the stream and can hatch anywhere between April and October. Ameletus are good swimmers that usually live in quiet water habitats in unpolluted streams and rivers. They can be picked up in riffle samples.

Family: Baetidae - The family Baetidae is represented by 19 North American and six common western genera with the genus *Baetis* being by far, the most common. Members of this family have a streamlined body (3-12 mm) with plate-like gills on abdominal segments and either two or three tails. Baetids are similar in body shape to the other swimmer-type mayfly families Ameletidae, Siphlonuridae and Isonychiidae, but much smaller in size. It can also be distinguished from the other swimmer-type mayflies by its long antenna which can be more than three times the width of the head.

Nymphs of the family Baetidae usually produce two to three generations per year and can hatch anywhere between April and October. Baetids are excellent swimmers, negotiating the swiftest of flows and can maneuver in fast current to avoid predation or competition. Baetids will often be the first organisms to recolonize disturbed areas and can be quite tolerant of sedimentation and nutrient enrichment.

Family: Caenidae - The family Caenidae is represented by four North American genera and one common western genus, *Caenis*. Members of this family have a small crawler-shaped body (2-8 mm) with unique nearly square operculate gills and three tails (***Figure 14-3***). Caenids are quite similar in body shape to Leptohyphid mayflies which have triangular operculate gills rather than square. The other two mayfly families with crawler-shaped nymphs (Ephemerellidae and Leptophlebiidae) are usually larger and have much different shaped gills.

Nymphs of the family Caenidae usually live for one year in the stream, but in warmer waters may have two life cycles per year with hatches primarily in June, lasting sporadically through August. Caenids inhabit silty and debris-laden sections of lakes, ponds and slow moving areas of stream. They tend to be secretive and are often found partially covered by silt. Caenids can tolerate low levels of oxygen and are quite tolerant of sedimentation and other types of pollution.

Family: Ephemerellidae - The family Ephemerellidae is represented by eight North American and six common western genera. Members of this family have a medium sized crawler-shaped body (5-15 mm) with plate-like gills on top of abdominal segments 3-7 or 4-7 and three tails (***Figure 14-4***). Ephemerellids are similar in body shape to other mayfly families with crawler-shaped nymphs (Caenidae, Leptohyphidae and

Leptophlebiidae) but can be distinguished from other crawlers by the shape and placement of the gills and their tendency to have blunt to sharp spines on the head, thorax and abdomen.

Nymphs of the family Ephemerellidae usually live for one year in the stream, hatching either in the spring or fall. Ephemerellids can be found in a variety of habitat but are most commonly found in swift flowing riffles of cold, clean streams. They are generally intolerant of pollution and habitat destruction. **(Note: tolerance varies greatly within genus/species of this family)**

Family: Ephemeridae - The family Ephemeridae is represented by four North American and two common western genera. Members of this family have a typical burrowing-form body and are quite large (12-32 mm). They have tusks that curve upward and outward from the head (***Figure 14-5***), filamentous gills (***Figure 14-6***) that extend upward on top of the abdomen and three tails. Ephemerids are the only burrowing mayflies found in the west and because of their unique size and shape, really cannot be confused with members of other mayfly families.

Nymphs of the family Ephemeridae usually live for one year in the stream (sometimes two years in northern states) and hatch during the summer months. They inhabit pockets of sand and silt in stream riffles or silty bottoms of lakes and large rivers. In large river systems like the Sacramento, ephemerids can be so abundant that hatches can be quite spectacular, sometimes becoming a nuisance. Although not as pollution intolerant as other mayfly families, because of their size and abundance, ephemerids have been historically used as severe water pollution indicators and for toxicity testing in laboratory experiments. They are only occasionally picked up in riffle samples, especially from lower valley and silty bottomed slow moving streams.

Family: Heptageniidae - The family Heptageniidae is represented by 14 North American and nine common western genera. Members of this family have a medium-sized (5-20 mm) uniquely-flattened body adapted for clinging to substrate in swiftly flowing riffles. They have a large flat head with large eyes, wide spread legs, gills on abdominal segments 1 through 6 or 7 and two or three tails (***Figure 14-7***). Heptageniids are the only clinger type mayflies and because of their unique shape, really cannot be confused with members of other mayfly families.

Nymphs of the family Heptageniidae usually live for one year in the stream and hatch between April and August. Although some rare species inhabit lakes and slow moving rivers, heptageniids are usually found on substrate in swiftly flowing riffles of small to medium sized streams. Members of the family Heptageniidae range in pollution tolerance from very sensitive to moderately sensitive. As a group they tolerate temperature fluctuations but are sensitive to metals and intolerant of habitat disturbance and scour events.

Family: Isonychiidae - The family is represented by one genus, *Isonychia*. *Isonychia* used to belong to the family Oligoneuriidae and was just recently reclassified as its own family. Be aware that many entomology books, especially flyfishing books may still include this genus in the family Oligoneuriidae. Members of this family have a large streamlined body (8-17 mm) with plate-like abdominal gills on segments 1-7 and three tails (***Figure 14-8***). *Isonychia* is similar in body shape and size to the other swimmer-type mayfly families Ameletidae and Siphlonuridae, but usually much larger than baetids. *Isonychia* can be distinguished from the other similar sized swimmer-type mayflies by its rows of long hairs on the front legs (***Figure 14-9***).

Nymphs of the family Isonychiidae usually live for one year in the stream and can hatch anywhere between April and October. *Isonychia* is an excellent swimmer that is found in swift unpolluted waters of medium sized streams and larger rivers.

Family: Leptohyphidae - The family Leptohyphidae is represented by two North American genera and one common western genus, *Tricorythodes*. *Tricorythodes* used to belong to the family Tricorythidae and was just recently placed into this family. Be aware that many entomology books, especially flyfishing books may still include this genera in the family Tricorythidae. Members of this family have a small crawler-shaped body (3-7 mm) with unique triangular operculate gills and three tails (***Figure 14-10***). Leptohyphids are quite similar in body shape to Caenid mayflies which have nearly square operculate gills rather than triangular. The other two mayfly families with crawler-shaped nymphs (Ephemerellidae and Leptophlebiidae) are usually larger and have much different shaped gills.

Nymphs of this family usually live for one year in the stream, but in warmer waters may have two life cycles per year with hatches in spring and summer. Leptohyphids are widespread, inhabiting silt, detritus, and gravel of small streams and lakes. Leptohyphids are more sensitive to pollution than the closely related caenids, but can tolerate low levels of oxygen and are quite tolerant of sedimentation and other types of pollution.

Family: Leptophlebiidae - The family Leptophlebiidae is represented by 10 North American and four common western genera. Members of this family have a medium-sized, crawler-shaped body (4-15 mm) with double or forked gills on abdominal segments 1 to 6 or 7 and three tails (***Figure 14-11***). Leptophlebiids are similar in body shape to other mayfly families with crawler-shaped nymphs (Caenidae, Ephemerellidae and Leptohyphidae), but can be distinguished from other crawlers by the shape and placement of the gills.

Nymphs of the family Leptophlebiidae usually live for one year in the stream hatching either in the spring or fall. Leptophlebiids can be found in a variety of habitats but are most commonly found in swift flowing riffles of cold, clean streams. They are intolerant of pollution and habitat destruction.

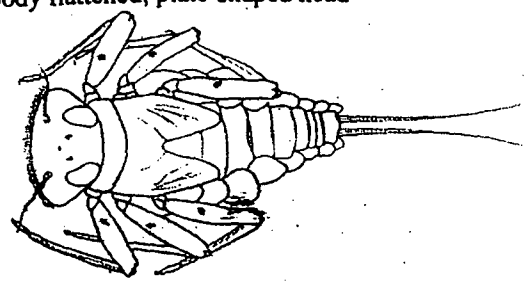
Family: Siphlonuridae - The family Siphlonuridae is represented by four North American genera and one common western genus, *Siphlonurus*. Members of this family have a large streamlined body (6-20 mm) with plate-like abdominal gills on segments 1-7 and three tails. *Siphlonurus* is similar in body shape and size to the other swimmer-type mayfly families Ameletidae and Isonychiidae, but usually much larger than baetids. *Siphlonurus* can be distinguished from the other similar sized swimmer-type mayflies since it lacks the conspicuous crown of comb-like spines that *Ameletus* has on its maxillae (mouth part) and the rows of long hairs that *Isonychia* has on its front legs.

Nymphs of the family Siphlonuridae usually live for one year in the stream and can hatch anywhere between April and October. Siphlonurids are good swimmers that can be found in many different habitats such as lakes, large rivers, and quiet water areas of streams. They are quite tolerant of low oxygen and can be found in stagnant pools separated from the flow of the river. They are more likely to be picked up in riffle samples if the sample came from a slower moving, silty bottom side water.

Taxonomic Keys to the Families of Mayflies (Order: Ephemeroptera)

EPHEMEROPTERA LARVAE

body flattened; plate-shaped head

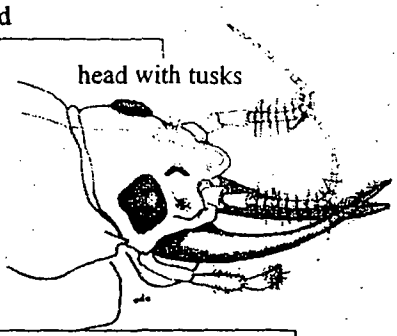


Heptageniidae

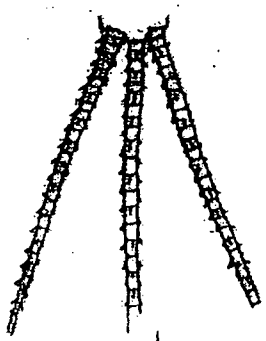
body not flattened

head without tusks

head with tusks



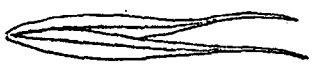
tails rigid; whirls of short setae on each segment



tails not rigid;
no whirls of short setae;
body streamlined,
minnow-shaped

abdominal gills fringed

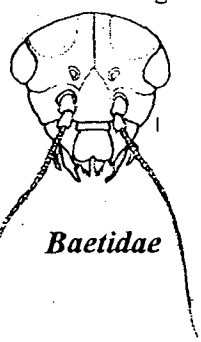
abdominal gills forked



(in part)
Leptophlebiidae

Ephemeridae

antennae long



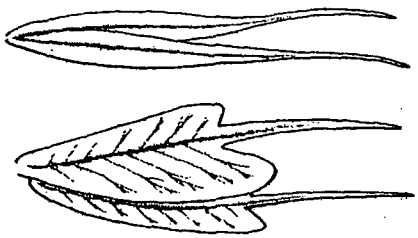
Baetidae

antennae short

front legs with rows of long hairs

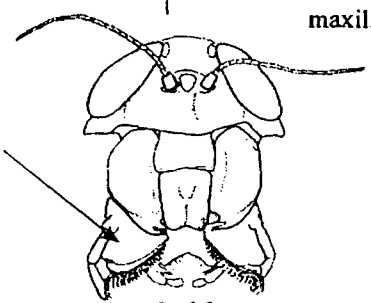
Isonychiidae

abdominal gills forked



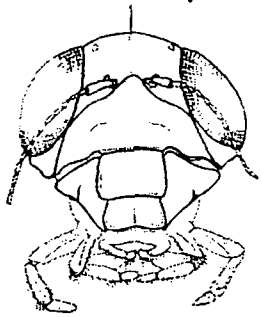
Leptophlebiidae

maxillae with comb-like spines



Ameletidae

maxillae without comb-like spines

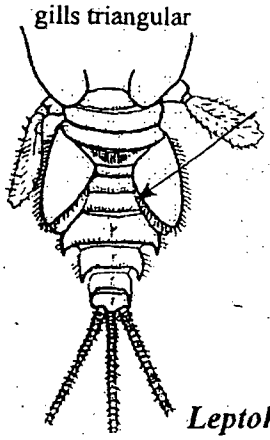


Siphlonuridae

abdominal gills not forked

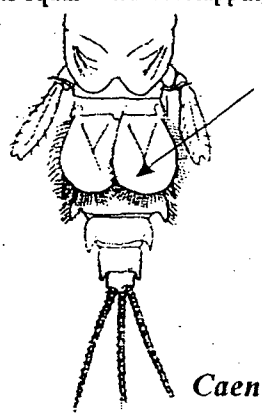
2 large gills covering abdominal segments 2-6

gills triangular



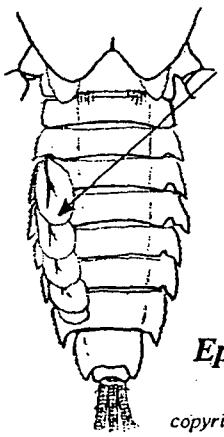
Leptohyphidae

gills square and overlapping



Caenidae

smaller dorsal gills on abdomen;
usually with dorsal abdominal spines



Ephemerellidae

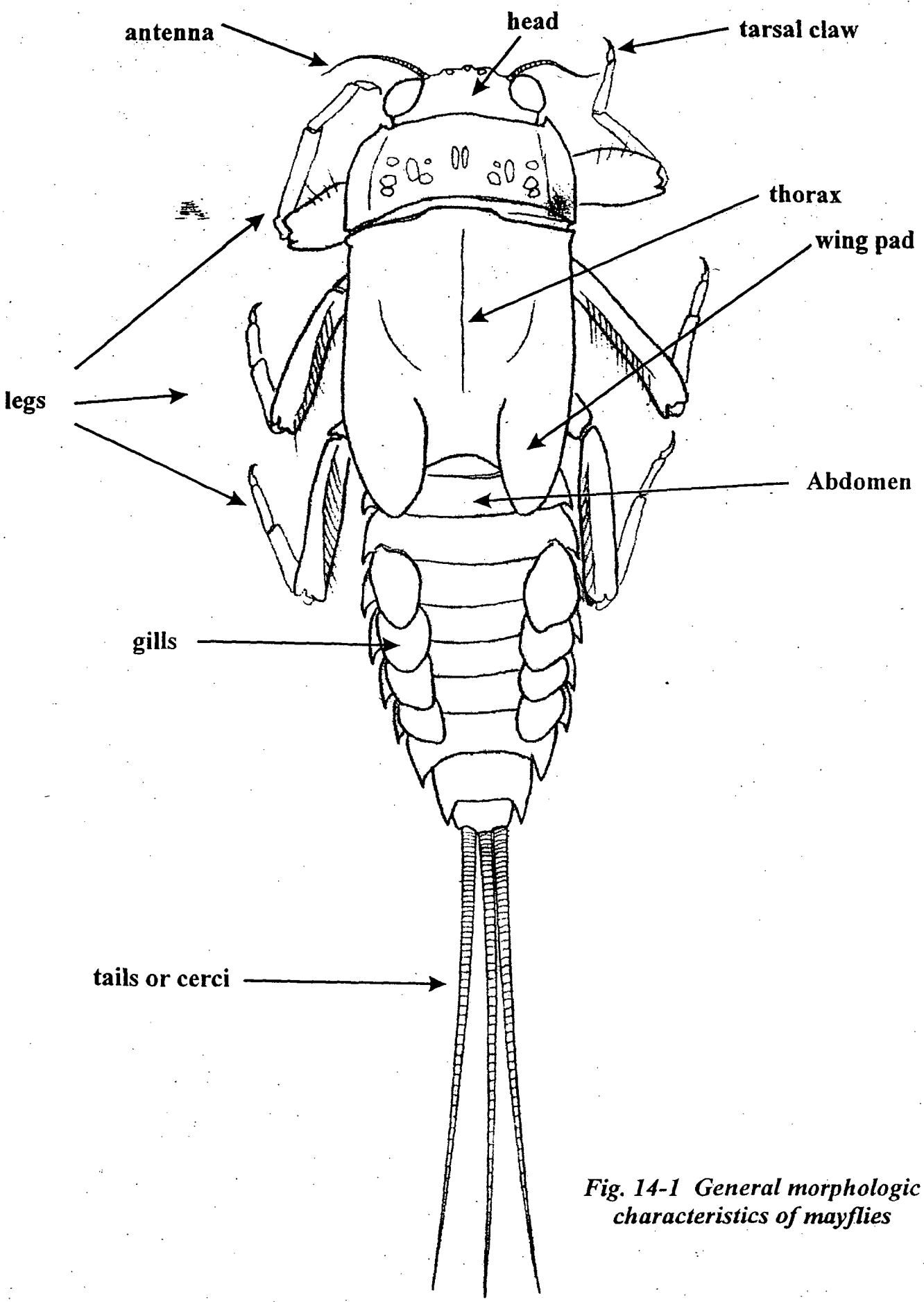


Fig. 14-1 General morphologic characteristics of mayflies

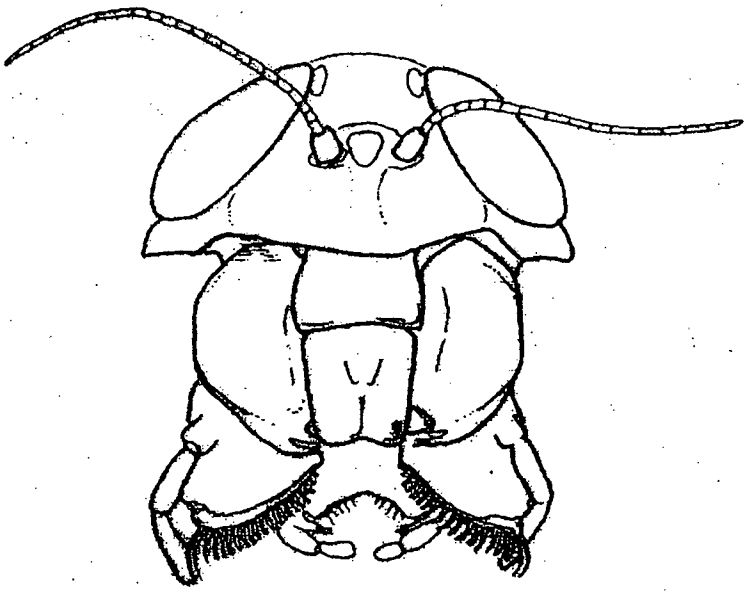


Fig. 14-2 Ameletidae maxillae with comb-like spines

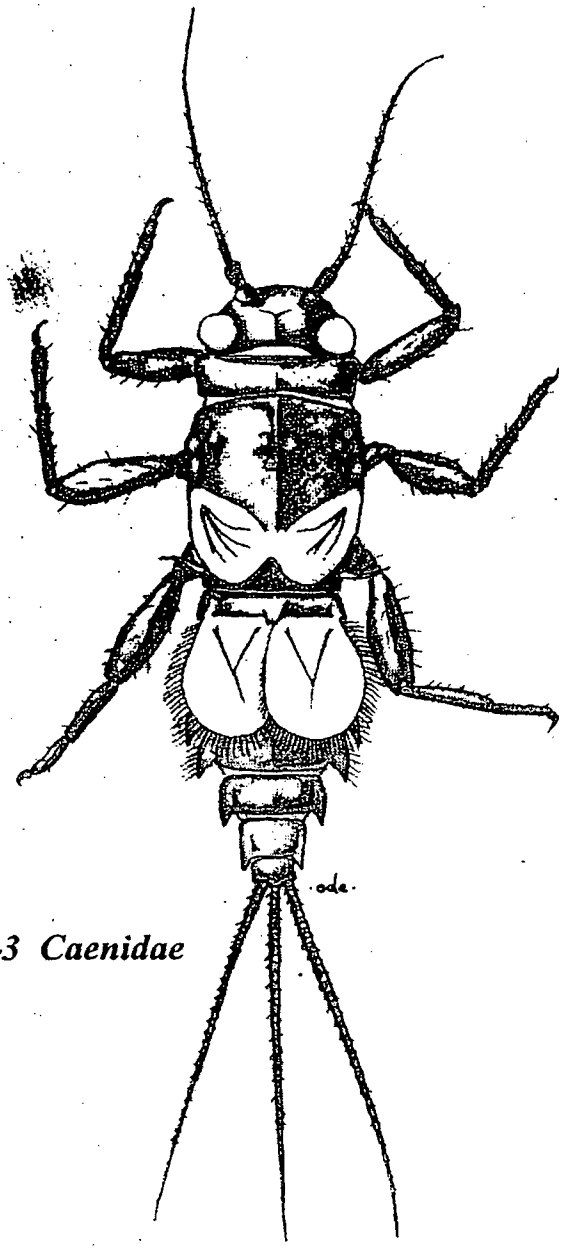


Fig. 14-3 Caenidae

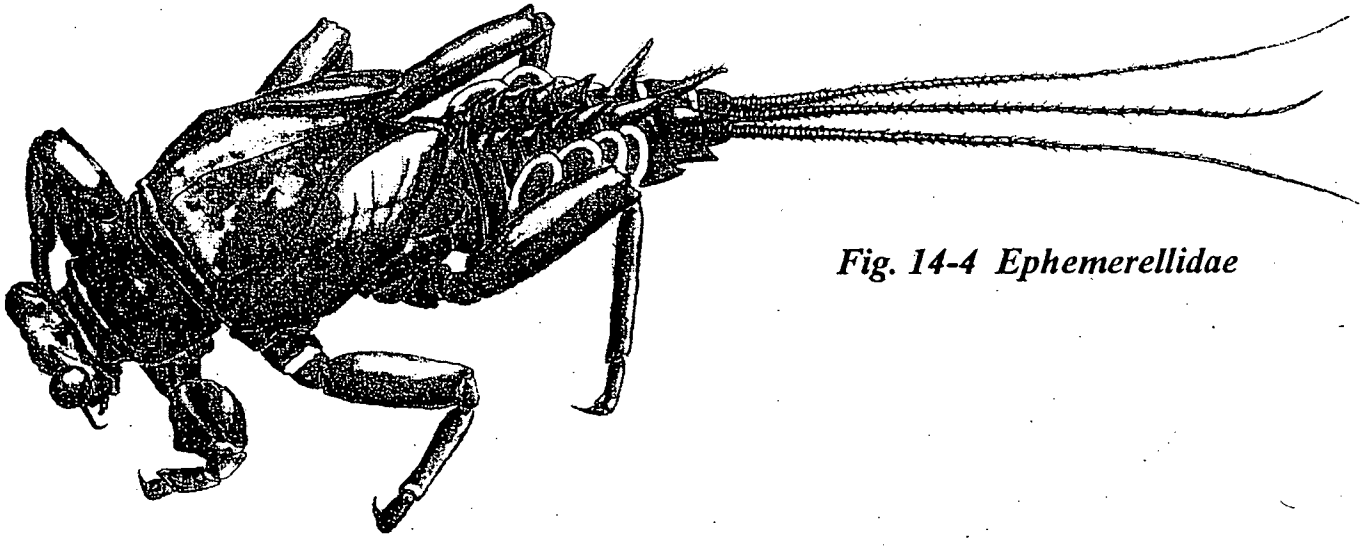


Fig. 14-4 Ephemerellidae

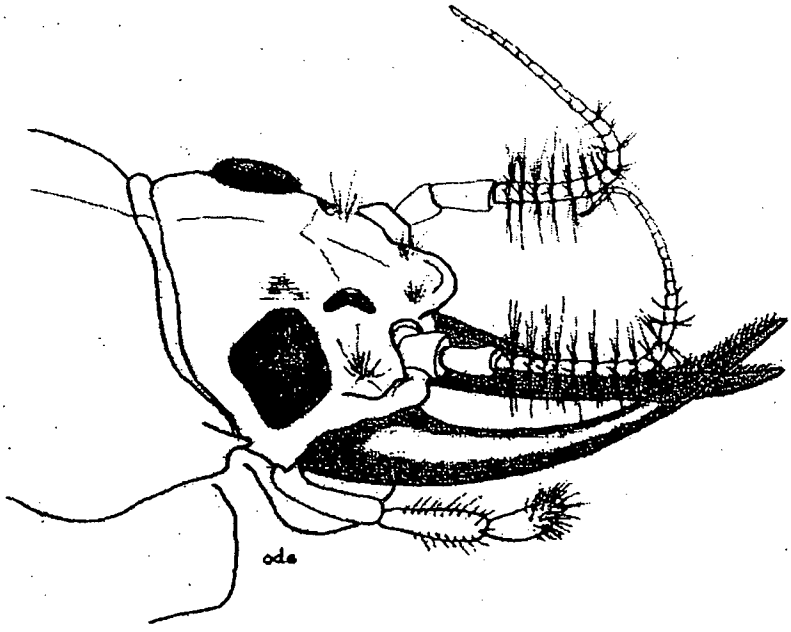


Fig. 14-5 Ephemeridae head with tusks

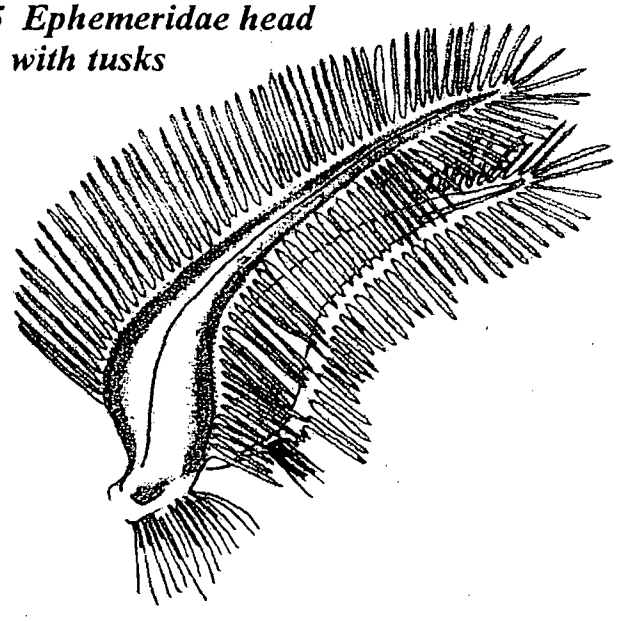


Fig. 14-6 Ephemeridae filamentous gills

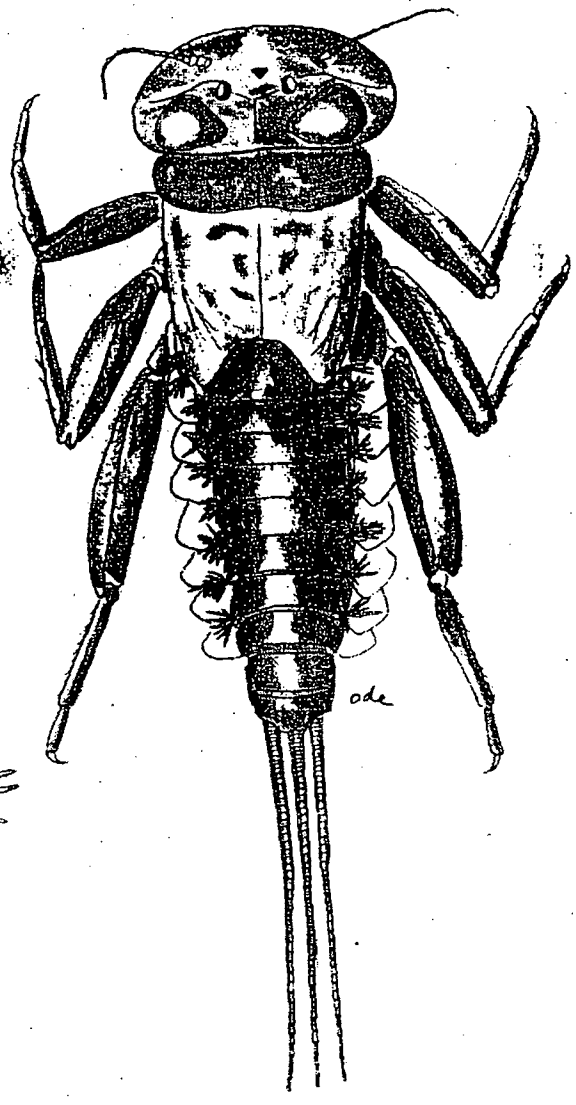


Fig. 14-7 Heptageniidae

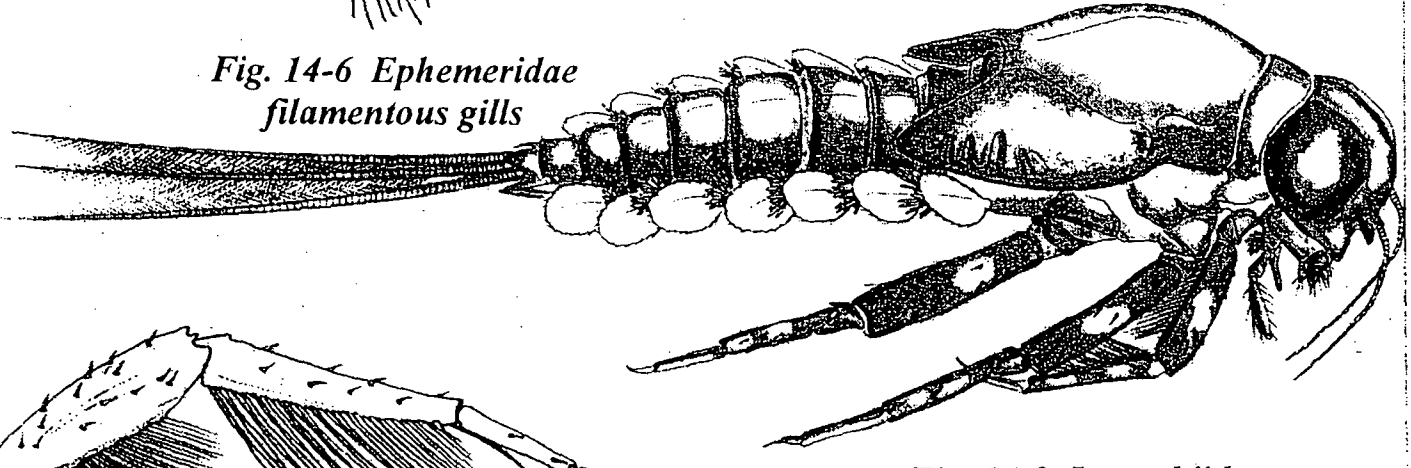


Fig. 14-8 Isonychiidae

Fig. 14-9 Isonychiidae front legs with rows of long hairs

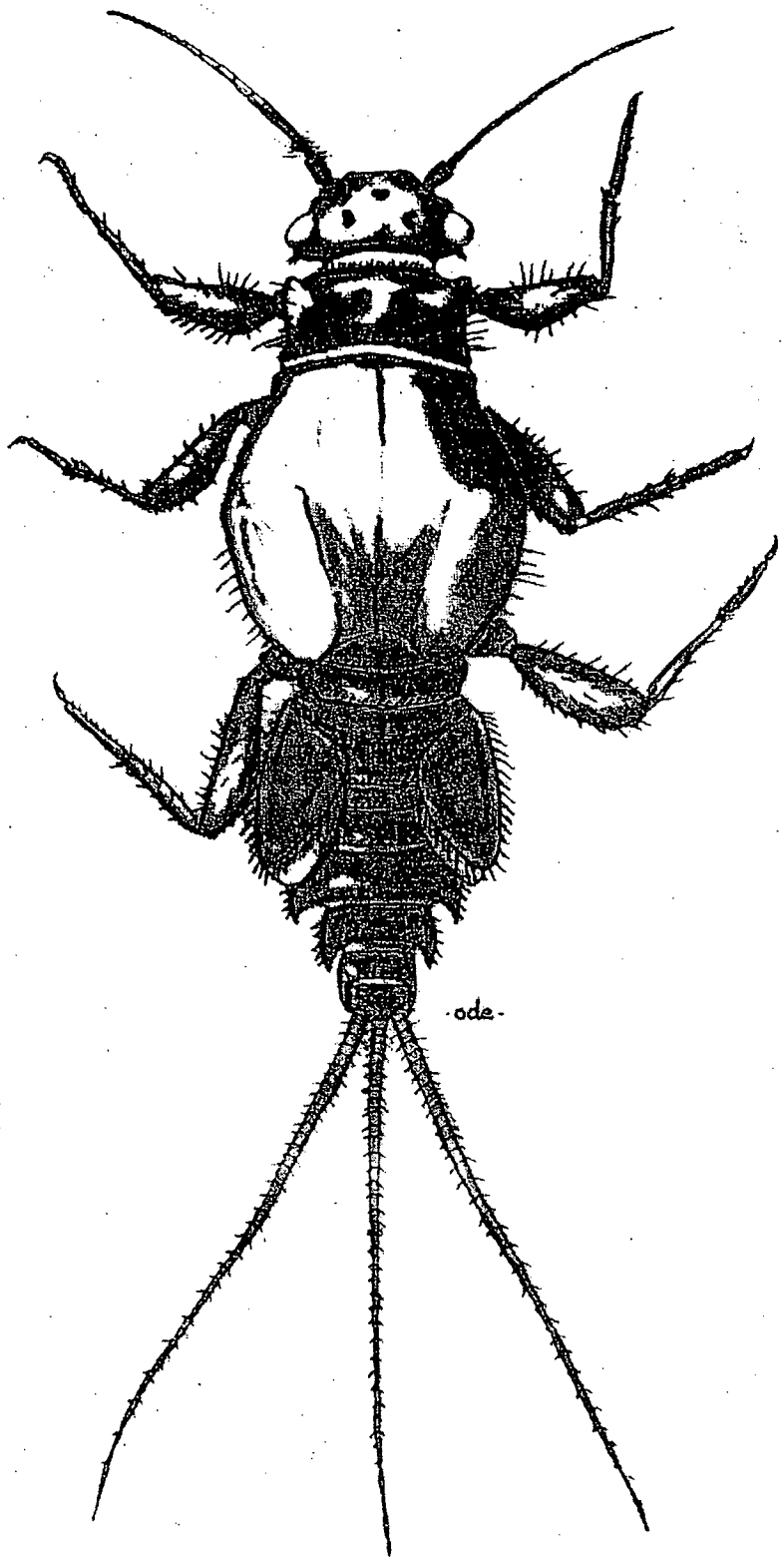


Fig. 14-10 Leptohyphdae

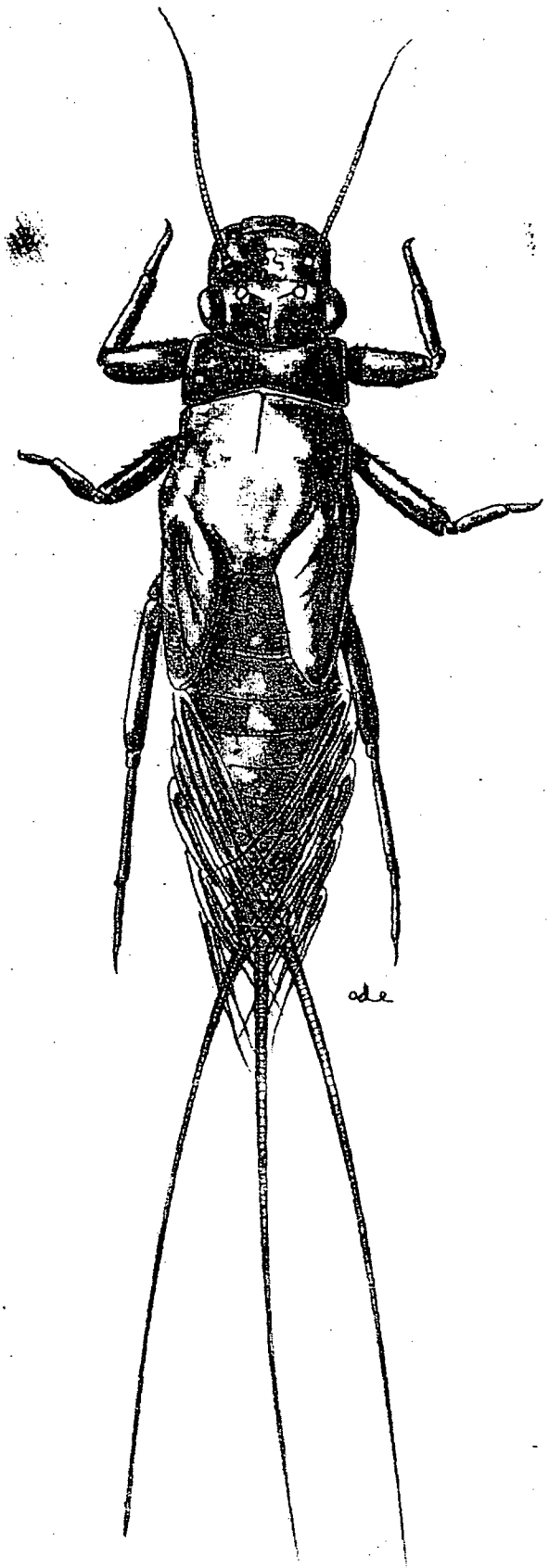


Fig. 14-11 Leptophlebiidae

Chapter 15
Description and Taxonomic Keys to the Families of Stoneflies (Order: Plecoptera) Common to Western Streams and Rivers

Introduction to the Stoneflies

Stoneflies are another important group of aquatic macroinvertebrates for fly anglers and stream ecologists. Except for a few species living in highly oxygenated areas of cold lakes, all stonefly nymphs inhabit stream environments, reaching their highest diversity in mountain streams. Stoneflies make up an essential part of the stream food web by providing a significant food source for fish and other vertebrates and are the top predator in the insect food web. Stoneflies do not produce the spectacular hatches that mayflies do, but the large size of the adults of some species and the fact that there is a hatch going on each season, even winter, makes them a very popular insect to imitate. In fact, the first artificial fly described almost 500 years ago was patterned after a stonefly, and today, spring hatches of the salmonfly (Pteronarcyidae) represent a multi-million dollar event for the flyfishing industry.

Morphological Characteristics

Stonefly nymphs are usually 5 to 35 mm but some species can reach 60 mm when mature. They have two visible wing pads, two tarsal claws and two tails. Some stoneflies do not have gills. Those possessing gills can have simple or branched gills on the head, thorax, base of legs or first few abdomen segments. ***Figure 15-1*** shows the body parts of a typical stonefly.

Unlike mayflies, stoneflies do not have a number of unique body shapes which will help in taxonomic identification. They are all elongate, somewhat flat to cylindrical in shape. There are three important morphological characteristics of stoneflies which once recognized, do make identification of stoneflies less frustrating. They are:

1) the shape of a mouth part called the labium (***Figure 15-2***);
2) the way the hind wing pads are oriented to the plane of the body (***Figure 15-3***); and
3) the length of the lateral fold of the abdomen (***Figure 15-4***).

You will run into these characteristics in the taxonomic keys soon enough. Just remember to practice and be patient.

Life History

All species of stoneflies have aquatic larval forms usually referred to as nymphs. Typical life cycles require one year, but nymphs of the families Perlidae, Pteronarcyidae, Nemouridae and Perlodidae can live for two to three years before emerging as adults. Stoneflies go through incomplete metamorphosis. When the nymph is ready to emerge, it crawls out of the margin of the water, attaches to an object like a stone (thus the name stonefly), splits its nymphal shuck and crawls out to dry its wing and fly, or more than likely, crawls away. Some stonefly adults have reduced or no wings and therefore, crawl everywhere. Adult stoneflies have a life span ranging from a few days to a few months. Mating occurs in vegetation or on the ground, never in flight. Most stoneflies visually locate each other for mating. Another popular means of attracting a mate is for the male to beat its abdomen on a hard surface making a significant drumming noise, which is returned by the female.

Importance as Biological Indicators

Stoneflies are a primitive group of animals which either lack gills, or have limited gill structure. In addition, the nymphs can have specific water temperature, substrate type, and stream size requirements. These attributes contribute in giving stoneflies, more than any other group, the reputation of being clean

water organisms. Tolerance values for stonefly families only range from 0 to 2. They are intolerant of toxic substances and require clean, cool, highly oxygenated water. Some stonefly groups will be found only on large rocks or in small streams, even streams where the riffles dry up seasonally. Most families of stoneflies are sensitive to excessive disturbance and loss of habitat complexity.

Contrary to the generalized reputation of stoneflies being found only in cool and clean water, some species in the families Perlidae and Pteronarcyidae having branched gills, can be found in warmer water with moderate habitat disturbance and sedimentation.

Family: Capniidae - The family Capniidae is represented by 10 North American and eight common western genera. Genus level identification of capniids is difficult, although professional laboratories in California must identify Capniidae to the lowest possible taxon. Members of this family are small (3-6 mm), slender and cylindrical (the hind legs never extends to the tip of the abdomen). The body of the labium has shallow notches, the hind wing pads are parallel to the body plane and the lateral fold is present on all 9 abdominal segments. There are no branching gills present. Capniids closely resemble nymphs of the family Leuctridae. The following characteristics can help identify and separate capniids from leuctrids:

Tolerance Value and Functional Feeding Group designation for Stonefly Families with Common Riffle Species

Family	Tolerance Value	Functional Feeding Group
Capniidae	1	Shredders (SH)
Chloroperlidae	1	Predators (P)
Leuctridae	0	Shredders (SH)
Nemouridae	2	Shredders (SH)
Peltoperlidae	0	Shredders (SH)
Perlidae	1	Predators (P)
Perlodidae	2	Predators (P)
Pteronarcyidae	0	Shredders (SH)
Taeniopterygidae	2	Shredders (SH)

Stonefly Families Common to Western Riffles

Unlike the mayflies, there have not been any major recent changes in the higher classification of stonefly orders. There are nine North American families of stoneflies and all can be found in the west. The keys in this manual include all nine families which can be encountered when sampling riffle environments in western streams:

1) hind wing pads of capniids can be shorter and broader than leuctrids;
2) the abdomen is cylindrical (cross-section round) with capniids and arch-like with leuctrids;
3) the posterior end of the abdomen usually appears slightly swollen in capniids, but not with leuctrids ; and
4) viewed from above, the lateral margins of the abdomen appear zig-zagged in capniids and smooth in leuctrids.

Nymphs of the family Capniidae usually live for one year in the stream and hatch in winter or early spring. The small dark colored adults can often be seen crawling on the snow. The nymphs are found in streams of all sizes but are especially abundant in smaller streams. They can also be found inhabiting spring seeps, intermittent streams and cold lakes.

Although it might be extinct, a species of the genus *Capnia* spends its entire life cycle in the depths of Lake Tahoe. All the members of the family Capniidae are intolerant of pollution and habitat deterioration.

Family: Chloroperlidae - The family Chloroperlidae is represented by 13 North American and 10 common western genera. Although difficult, professional laboratories in California must identify chloroperlids to the lowest possible taxon. Members of this family are medium sized (5-12 mm), elongate and cylindrical (cross-section of abdomen round). The body of the labium has one deep notch, the hind wing pads are parallel to the body plane and they usually have no gills. Without the aid of a microscope to see the different notching of the labium, chloroperlids look similar to stoneflies in the families Capniidae and Leuctridae. Chloroperlids have the same deep-notched labium as perlodids, but the following characteristics can help identify and separate chloroperlids from perlodids:

1) perlodids have hind wing pads that diverge from the plane of the body;
2) the cerci of chloroperlids are shorter than 3/4 the length of the abdomen where perlodids are as long or longer than the abdomen; and
3) the head and thorax of chloroperlids are not patterned where perlodids have distinct patterns.

Nymphs of the family Chloroperlidae usually live from one to two years in the stream and hatch in late spring or early summer. The nymphs are usually found in small to medium sized permanent streams with moderate to fast flowing water. Members of the family Chloroperlidae can inhabit the hyporheic zone which is the area below the water flow, and can extend beyond the stream margin. Some species have been found at considerable depths and distances from the stream. All the members of the family Chloroperlidae are intolerant of pollution and habitat deterioration.

Family: Leuctridae - The family Leuctridae is represented by seven North America and five common western genera. Although difficult, professional laboratories in California must identify leuctrids to the lowest possible taxon. Members of this family are small (3-6 mm) and slender (the hind legs never extends to the tip of the abdomen). The body of the labium has shallow notches, the hind wing pads are parallel to the body plane and the lateral fold is present on no more than the first 7 abdominal segments. There are no branching gills present. Leuctrids closely resemble nymphs of the family Capniidae. The following characteristics can help identify and separate leuctrids from capniids:

1) hind wing pads of capniids can be shorter and broader than leuctrids;
2) the abdomen is cylindrical (cross-section round) with capniids and arch-like with leuctrids;
3) the posterior end of the abdomen usually appears slightly swollen in capniids, but not with leuctrids; and
4) viewed from above, the lateral margins of the abdomen appear zig-zagged in capniids and smooth in leuctrids.

Nymphs of the family Leuctridae usually live from one to two years in the stream and hatch anytime between spring and fall. The nymphs are primarily found in small, cool, permanent streams, but at least one genus can be found in intermittent streams. All the members of the family Leuctridae are intolerant of pollution and habitat deterioration.

Family: Nemouridae - The family Nemouridae is represented by 12 North American and 10 common western genera. Members of this family are small (3-8 mm), broad and short-bodied (hind legs extend beyond the tip of the abdomen). The body of the labium has shallow notches, the hind wing pads diverge from the body plane and they either have no gills or gills ranging from simple to highly branched at the base of the neck (cervical gills.) Branching gills are never present at the base of the legs. Nemourids can have a "dirty look" because debris always seems to cling to their characteristically hairy bodies. Taeniopterygids closely resemble nymphs of the family Nemouridae, but taeniopterygids will never have cervical gills.

Nymphs of the family Nemouridae usually live from one to two years in the stream and hatch anytime between spring and fall. The nymphs can be found in small rivers, streams and springs. All the members of the family Nemouridae are intolerant of pollution and habitat deterioration.

Family: Peltoperlidae - The family Peltoperlidae is represented by six North American and three common western genera. Members of this family are medium-sized (8-15 mm), broad, flattened and roach-like in appearance (***Figure 15-5***). The body of the labium has shallow notches, both the top and bottom of the thoracic segments have overlapping plates and simple gills are present at the base of the legs. Peltoperlids are distinctively roach-like and their unique shape is difficult to confuse with members of other stonefly families.

Nymphs of the family Peltoperlidae live from one to two years in the stream and hatch in late spring or early summer. The nymphs are usually found in smaller streams where they can be quite abundant, especially in cold, mountain streams. All peltoperlids are intolerant of pollution, habitat deterioration, and sedimentation.

Family: Perlidae - The family Perlidae is represented by 15 North American and five common western genera. Members of this family are large (8 - 35 mm) with a stocky, flattened appearance. The body of the labium has one deep notch and heavily branched gills at base of the legs. Perlids are large stoneflies but not as large as pteronarcyids which are the only other stonefly family possessing branching gills. The gills of the perlids, however, are only found at the base of the legs, never on the abdominal segments as with pteronarcyid stoneflies. Additionally, perlids are usually light brown in color with golden markings and aggressive when observed alive.

Nymphs of the family Perlidae live from one to three years in the stream and hatch throughout the summer. The nymphs can be found in permanent streams of all sizes, usually in moderate to fast flowing water. Perlids are aggressive, territorial and usually the top predator of the insect food web. In general, perlids are intolerant of pollution and habitat deterioration. However, they can be found sometimes in warmer water with moderate habitat disturbances and sedimentation.

Family: Perlodidae - The family Perlodidae is represented by 29 North American and 17 common western genera. Members of this family are medium sized (8-16 mm), with a stocky, flattened appearance (***Figure 15-6***). The body of the labium has one deep notch, the hind wing pads diverge from the body plane and they usually have no gills. Perlodids can have a similar size, shape and patterning as perlids, but do not possess the branched gills that are characteristics of the perlids. Perlodids have the same deep-notched labium as chloroperlids, but the following characteristics can help identify and separate perlodids from chloroperlids:
1) chloroperlids have hind wing pads that are parallel to the long axis of the body;
2) the cerci of chloroperlids are shorter than 3/4 the length of the abdomen where perlodids are as long or longer than the abdomen; and
3) the head and thorax of chloroperlids lack the distinct patterns common with the perlodids.

Nymphs of the family Perlodidae usually live for one year in the stream and hatch in spring or fall. The habits and habitat requirements of the perlodids are similar to the perlids. The primarily predacious nymphs can be found in permanent streams of all sizes usually in moderate to fast flowing water. All the members of the family Perlodidae are intolerant of pollution and habitat deterioration.

Family: Pteronarcyidae - The family Pteronarcyidae is represented by two North American genera which are both common in the west. Members of this family are large (15 - 60 mm) with elongated, cylindrical abdomens (***Figure 15-7***). The body of the labium has shallow notches and the thorax has heavily branched gills at base of the legs and the first two or three abdominal segments. Pteronarcyids are the largest stoneflies and

can only be confused with members of the family Perlidae which are also large stoneflies with branching gills. The gills of the perlids, however, are only found at the base of the legs, never from the abdominal segments. Additionally, pteronarcyids are dark in color and slow moving when observed alive.

Nymphs of the family Pteronarcyidae live from one or four years in the stream and hatch in spring or early summer. The nymphs are usually found in small to medium sized permanent streams with moderate to fast flowing water. In general, all pteronarcyids are intolerant of pollution and habitat deterioration. However, they can be found sometimes in warmer water with moderate habitat disturbances and sedimentation.

Family: Taeniopterygidae - The family Taeniopterygidae is represented by 6 North American and four common western genera. Members of this family are small (3-12 mm), broad and short bodied (***Figure 15-8***). The hind legs extend beyond the tip of the abdomen. The body of the labium has shallow notches, the hind wing pads diverge from the body plane and they sometimes have simple gills at the base of the legs, branching gills are never present. Taeniopterygids closely resemble nymphs of the family Nemouridae, but never possess gills at the base of the neck (cervical gills) which can be present on nemourids.

Nymphs of the family Taeniopterygidae usually live for one year in the stream and hatch in winter or early spring. Taeniopterygids are referred to as "winter stones" because where they occur, it is common to see the small dark colored adults crawling on the snow. The nymphs are found in streams of all sizes but are especially abundant in smaller streams. In general, the members of the family Taeniopterygidae are intolerant of pollution and habitat deterioration. There is one common genus, *Taeniopteryx*, which can be found in larger rivers and is more tolerant of warmer water, moderate habitat disturbances and sedimentation.

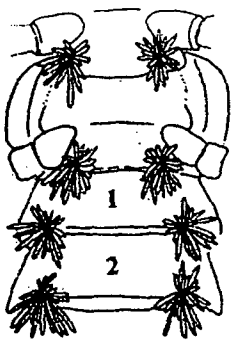
Taxonomic Keys to the Families of Stoneflies (Order: Plecoptera)

PLECOPTERA LARVAE

distinctive branching gills present

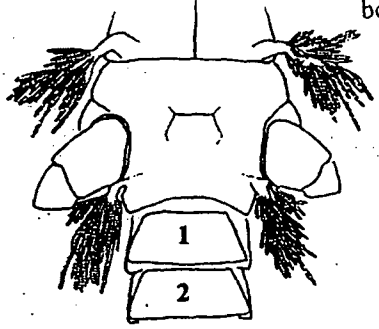
gills absent or simple; branching gills, if present, sometimes at base of neck

gills from near base of legs and from abdominal segments 1-2 or 3



Pteronarcyidae

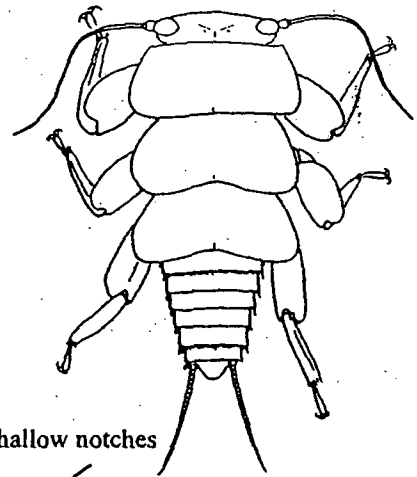
gills from base of legs but not from first 2 or 3 abdominal segments



Perlidae

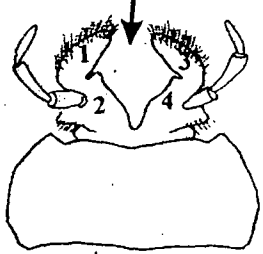
body not roach-like

body roach-like



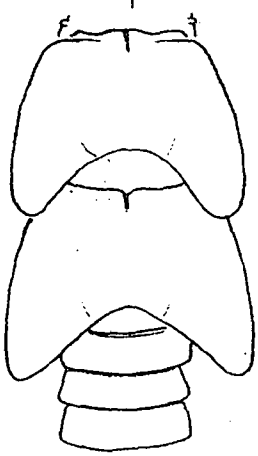
Peltoperlidae

body of labium with one deep notch



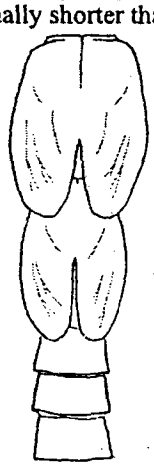
body of labium with shallow notches

wing pads divergent; tails as long or longer than abdomen



Perlodidae

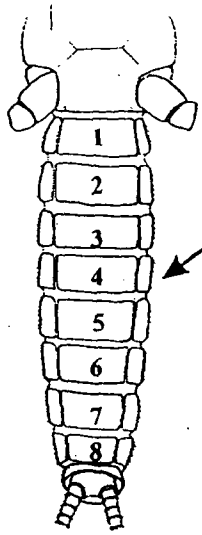
wing pads parallel; tails usually shorter than abdomen



Chloroperlidae

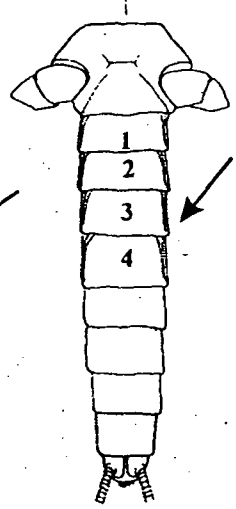
wing pads parallel; hind legs not extending to tip of abdomen

first 8 abdominal segments divided laterally



Capniidae

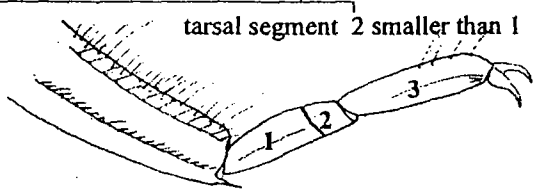
never more than 7 (usually 4) abdominal segments divided laterally



Leuctridae

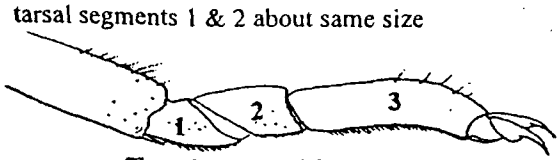
wing pads divergent; hind legs extending to or beyond tip of abdomen

tarsal segment 2 smaller than 1



Nemouridae

tarsal segments 1 & 2 about same size



Taeniopterygidae

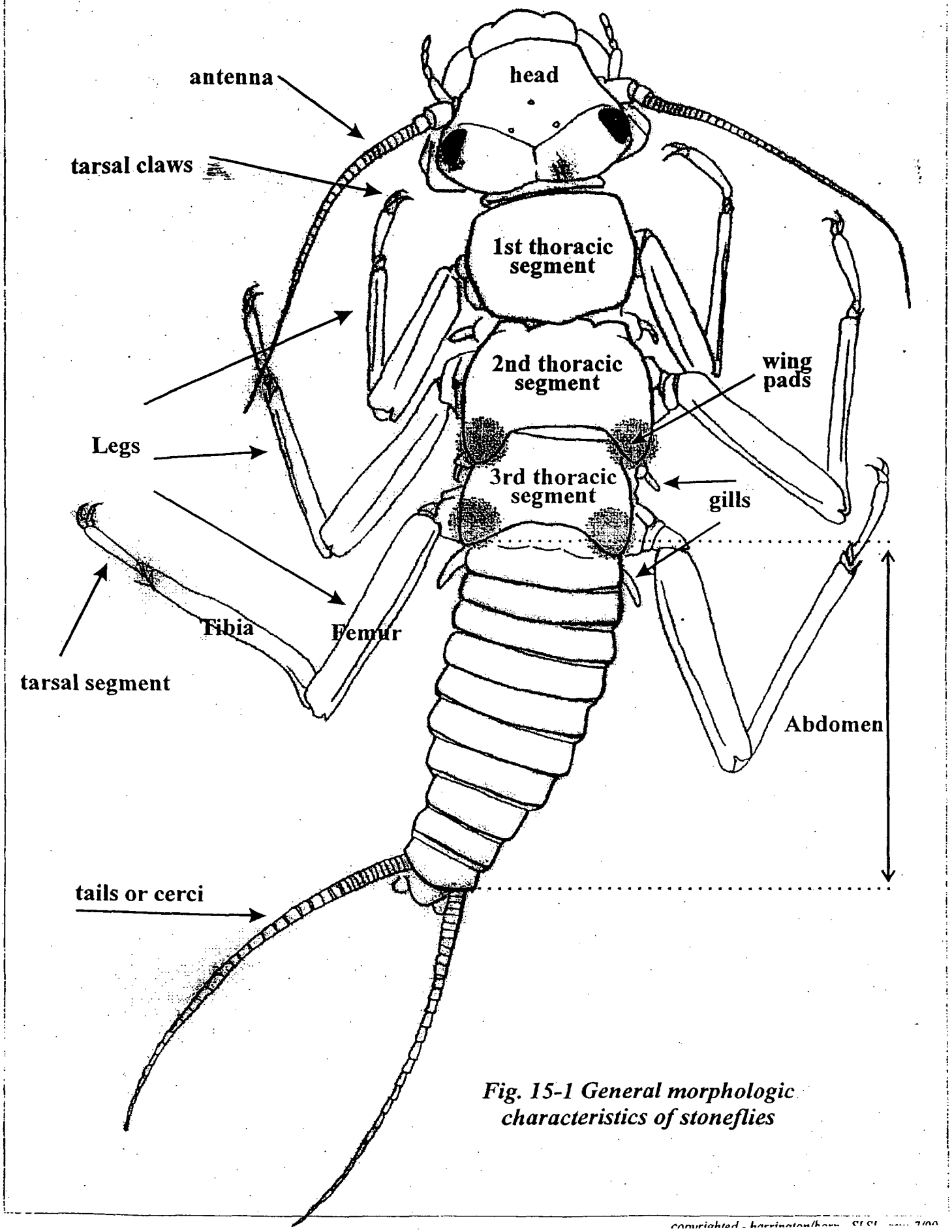


Fig. 15-1 General morphologic characteristics of stoneflies

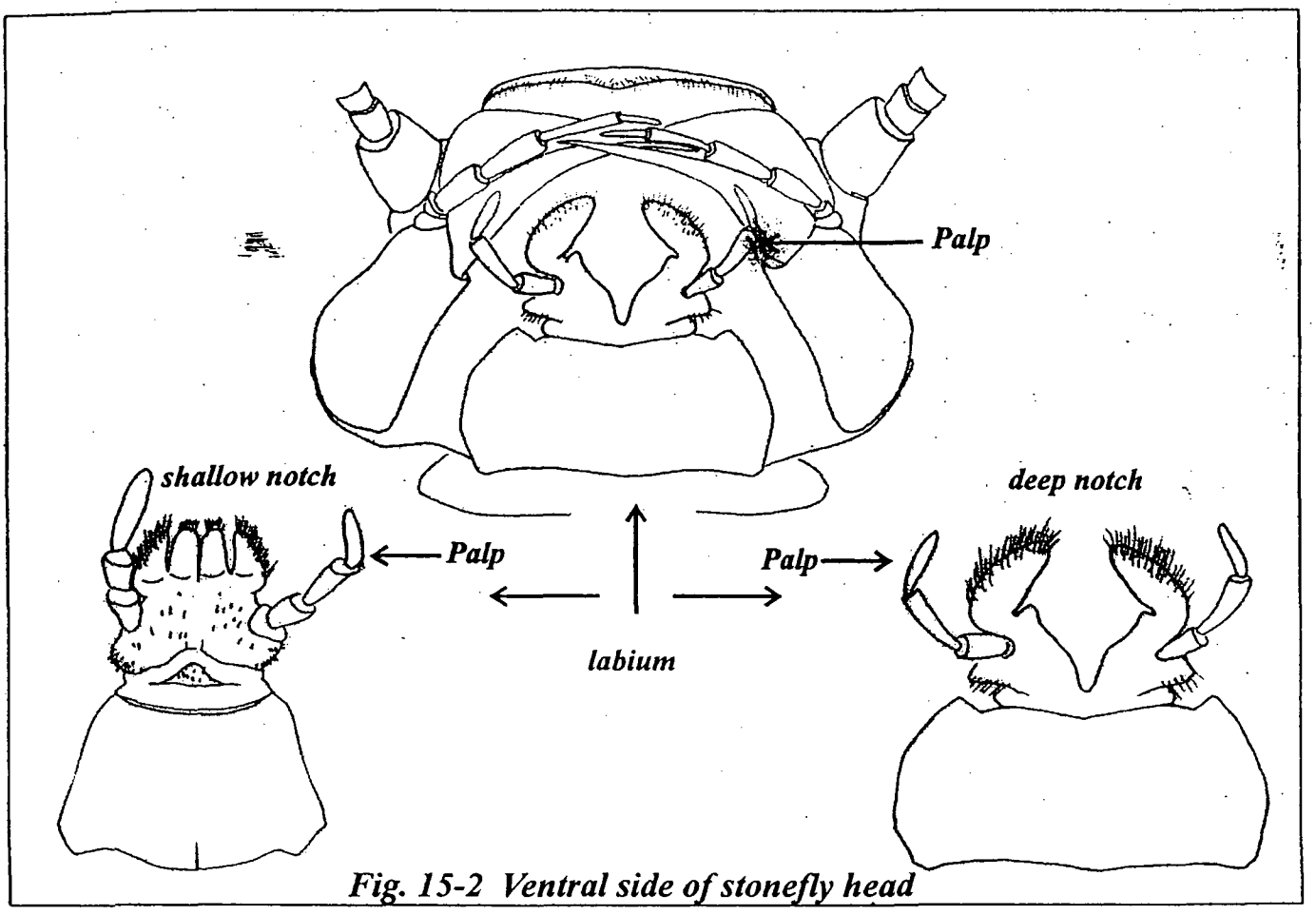


Fig. 15-2 Ventral side of stonefly head

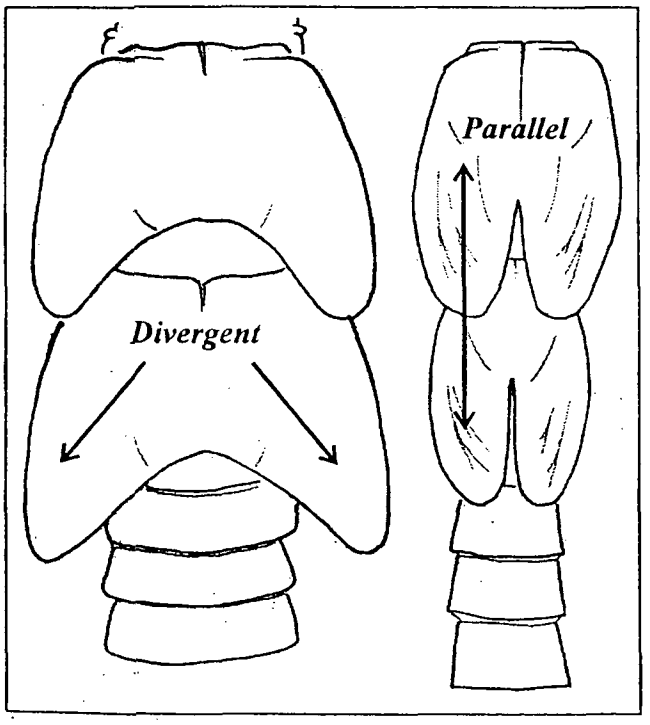


Fig. 15 -3 Wingpad orientation of stoneflies

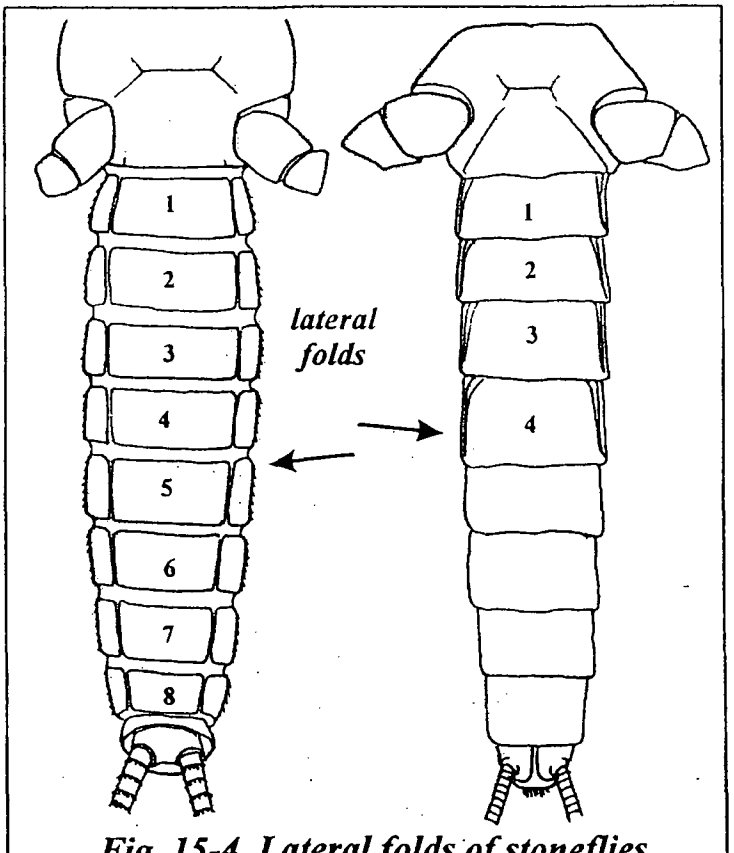


Fig. 15-4 Lateral folds of stoneflies

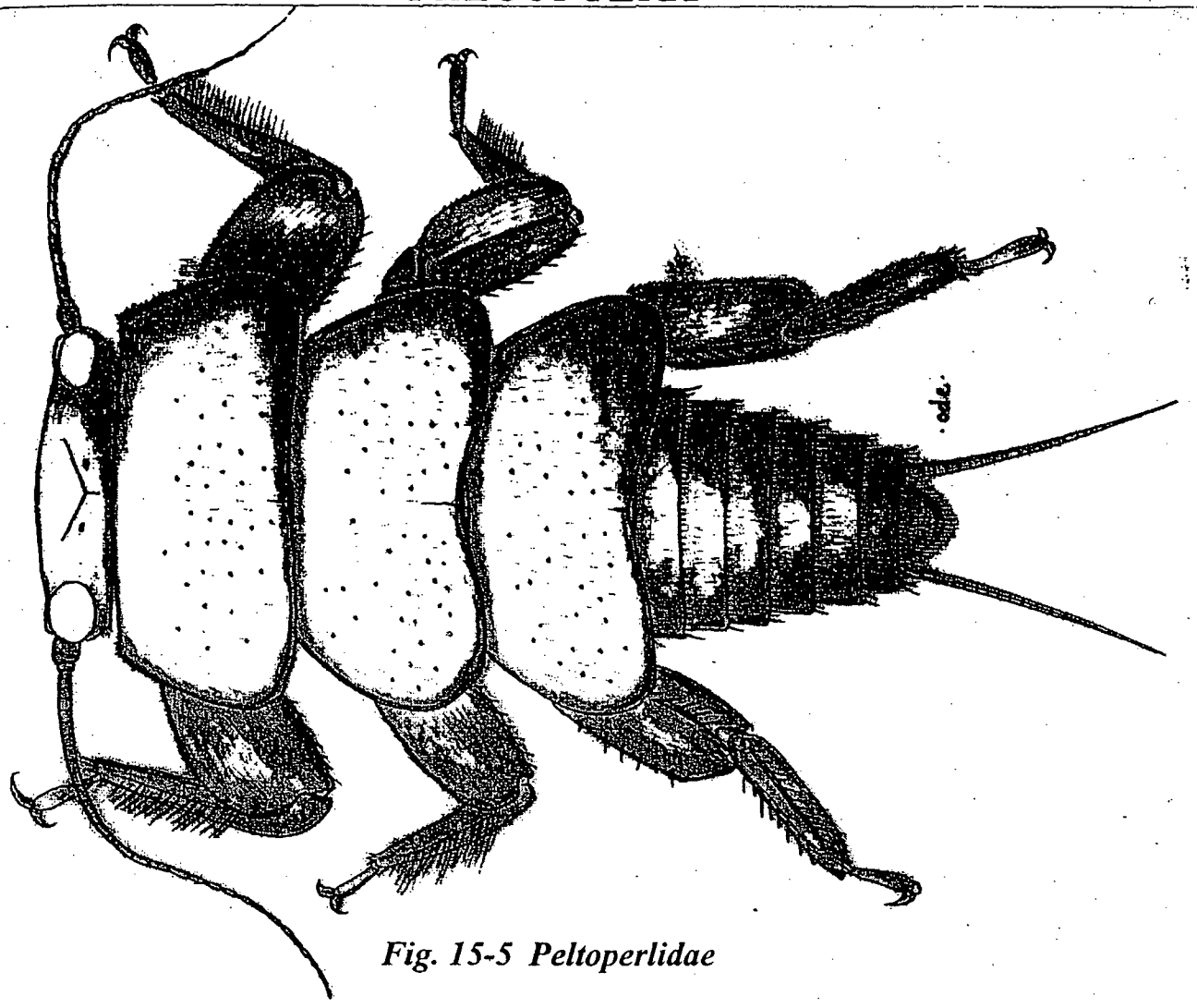


Fig. 15-5 Peltoperlidae

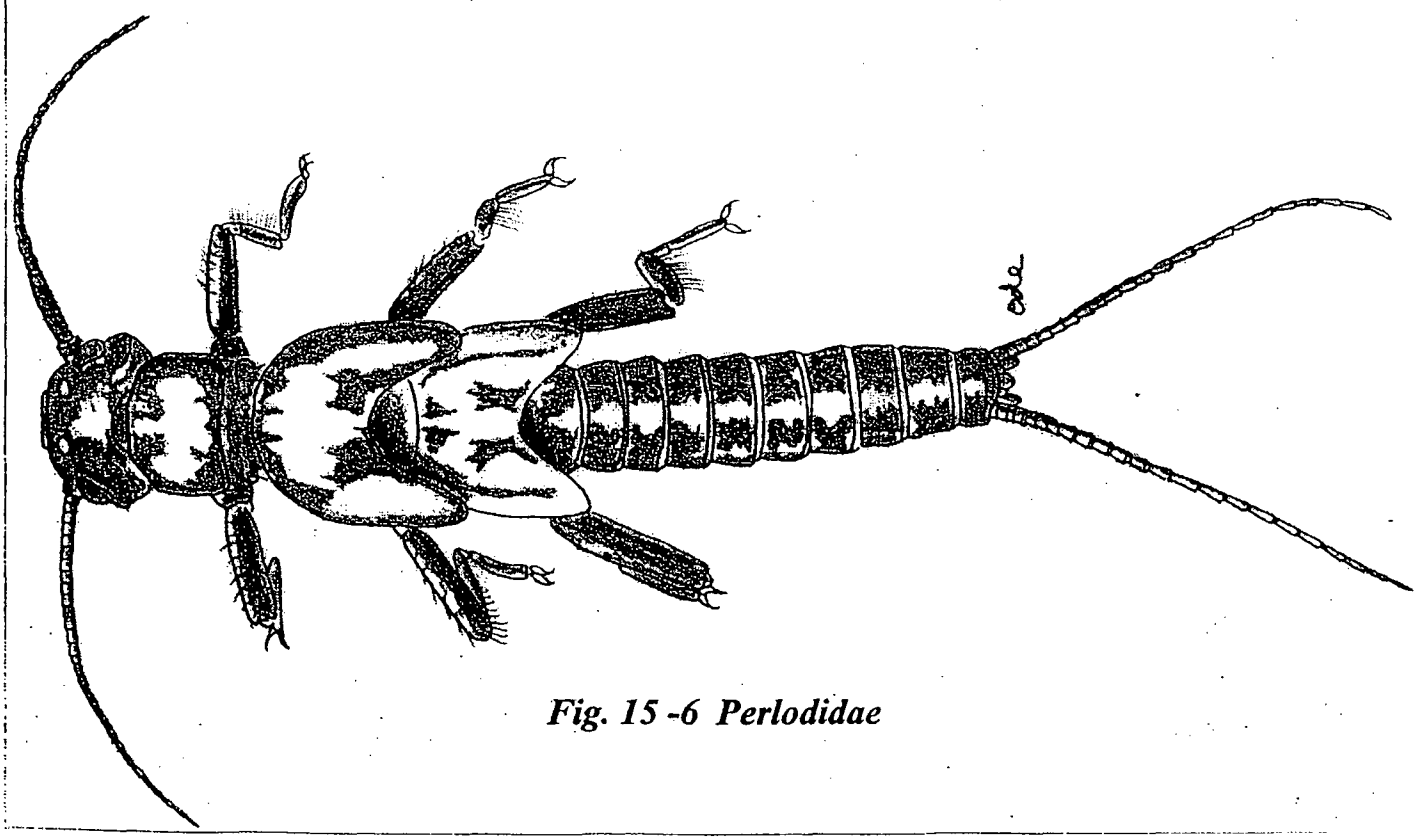


Fig. 15 -6 Perlodidae

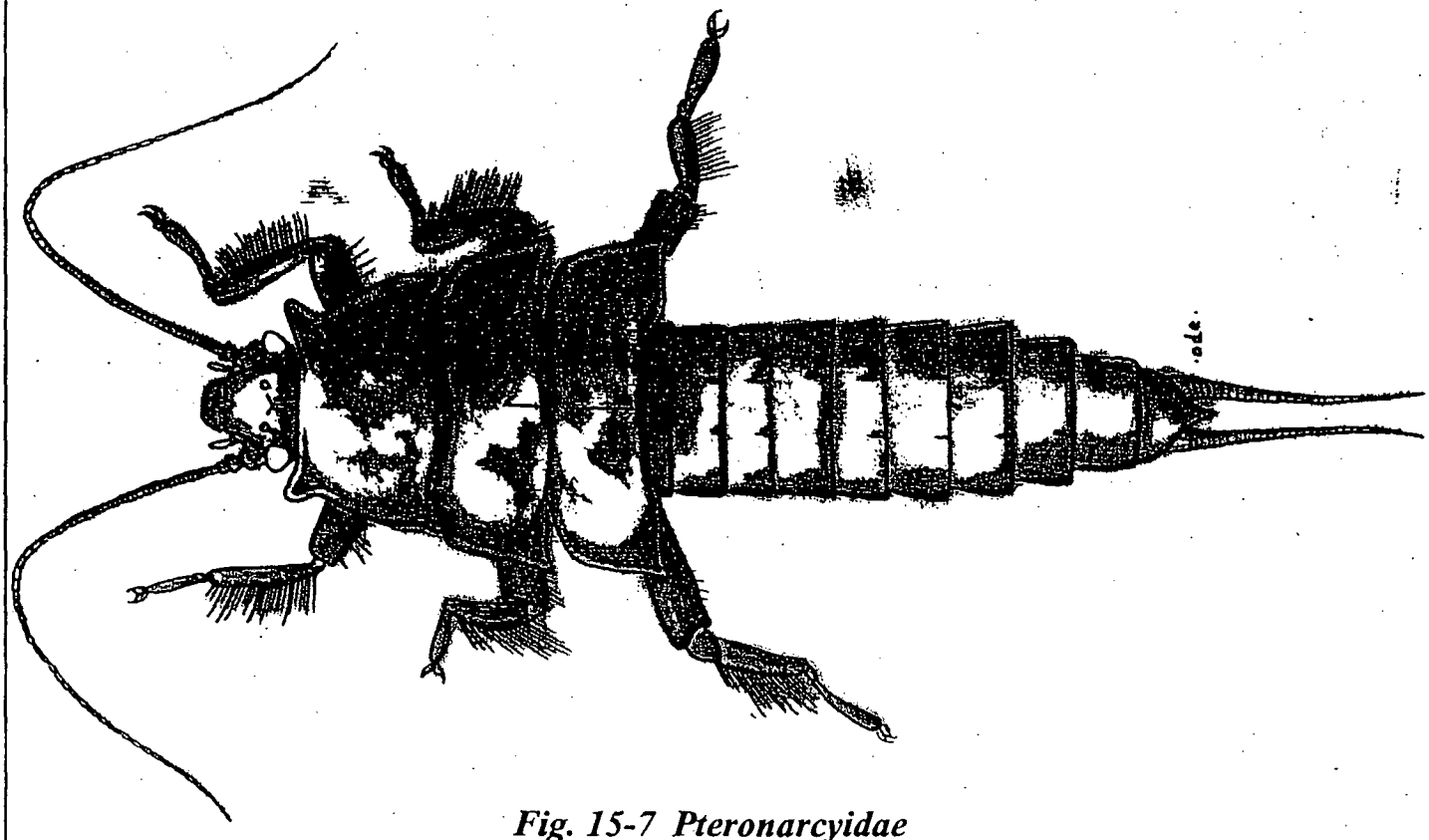


Fig. 15-7 Pteronarcyidae

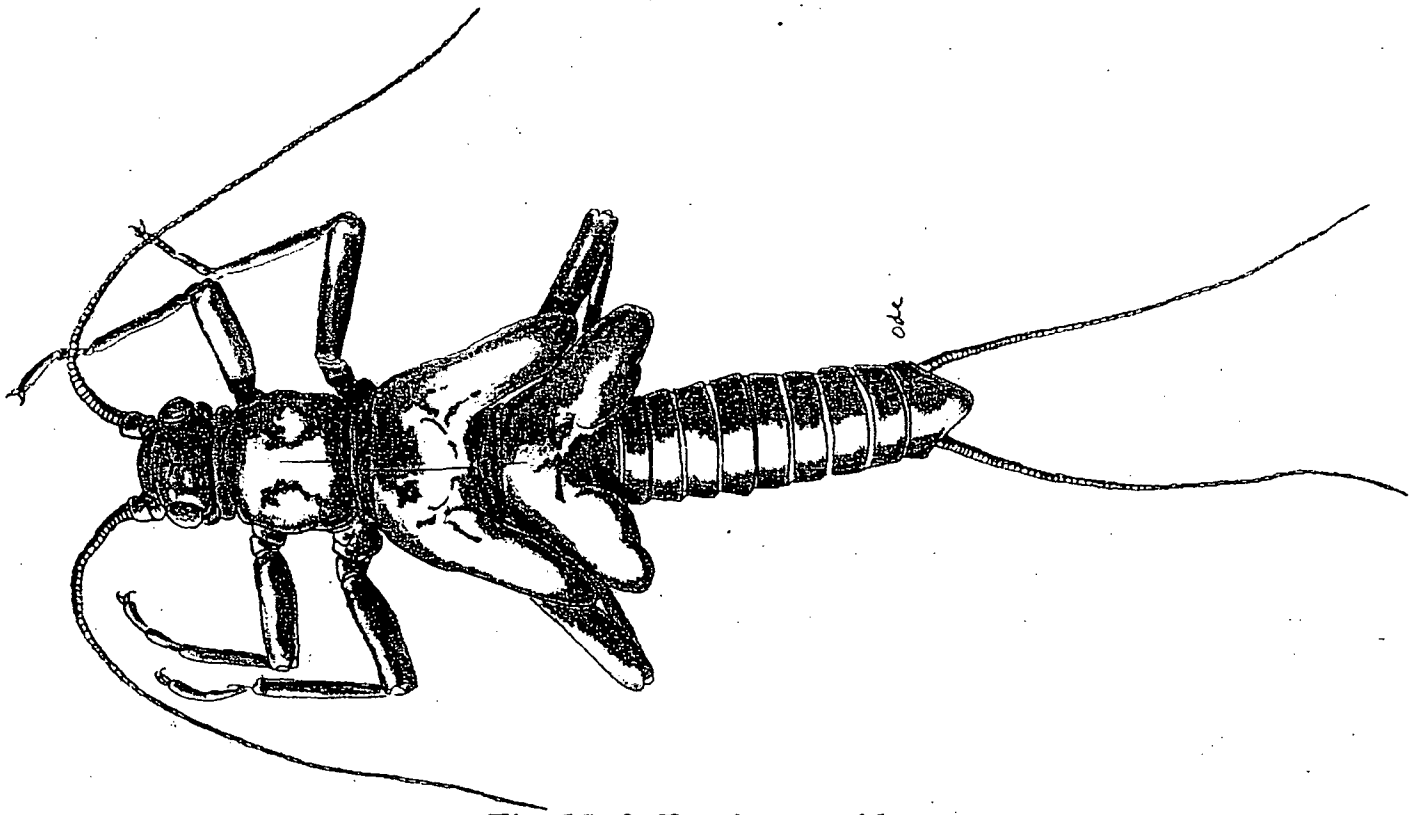


Fig. 15 -8 Taeniopterygidae

Chapter 16
Description and Taxonomic Keys to the Families of Caddisflies (Order: Trichoptera) Common to Western Streams and Rivers

Introduction to the Caddisflies

Caddisflies are one of the largest groups of aquatic insects, and one the most interesting. They are widely distributed in virtually all types of aquatic habitats throughout the world. There are more than 10,000 species world-wide with at least 1,350 species found in North America. Members of this order are close relatives of moths and butterflies. The name Trichoptera is derived from Greek and means hairy wing. It refers to the adult caddis which are small, drab, moth-like creatures with hairy tent shaped wings. Most people who explore streams and lakes know the caddisflies as the aquatic insects that build cases of rocks, twigs, and almost any debris found in water. Because of this, larval caddisflies are sometimes called rock worms or periwinkles. However, not all caddisflies build tube-case structures; there are also free-living forms, saddle-case makers, snail-case makers, purse-case makers, net-spinners and retreat-makers. ***Table 16-1*** lists which families of caddisflies have these basic life styles. The ability of caddisflies to construct cases and build nets comes from their ability to produce silk. The utilization of silk contributes to the vast diversity of caddisfly species. For example, some members of the family Limnephilidae have overcome their need to live in highly oxygenated riffle environment by using their cases as a ventilation chamber.

The cases have an opening in the front where the head is located and a smaller opening at the end. Many caddis undulates its body inside the case producing a current. This current of oxygen-laden water moves over their abdominal gills enabling them to exist in pools of streams and rivers and in lakes and ponds. Members of the family of net-spinning caddisflies (Hydropsychidae) build nets between rocks where they strain food particles from the water current. Each genus has a different-sized mesh so they can distribute themselves in different parts of the riffle based on individual water velocity requirements. On the other hand, members of the family of free-living caddis (Rhyacophilidae) do not use silk in any way. Considered a more primitive group of caddisflies, they grapple around in riffles looking for prey.

Table 16-1 Life styles for the families of caddisflies.

Free-living caddis:
- Rhyacophilidae

Net-spinners:
- Hydropsychidae
  - Arctopsychinae (subfamily)

Retreat-makers:
- Philopotamidae
- Polycentropodidae
- Psychomyiidae

Saddle-case makers:
- Glossosomatidae

Snail-case makers:
- Helicopsychidae

Purse-case makers:
- Hydroptilidae

Tube-case Makers:
- Brachycentridae
- Calamoceratidae
- Goeridae
- Lepidostomatidae
- Leptoceridae
- Limnephilidae
- Odontoceridae
- Phryganeidae
- Sericostomatidae
- Uenoidae

Morphological Characteristics

Caddisfly larvae range in size from 1 mm in some members of the microcaddis (Family Hydroptilidae) to 30 mm for the "Giant Orange Sedge", a large tube-case maker (Family Limnephilidae). Caddisfly larvae have distinctive heads with small peg-like antennae and thoraces with varying arrangements of sclerotized plates. Each thoracic segment has a pair of segmented legs. The abdomen is soft and worm-like and all caddisflies have a pair of anal claws. The size of these claws and the general body shape relates to the different behavioral forms. ***Figure 16-1*** shows the body parts of a typical caddisfly. The net-spinners and free-living forms have larger claws usually at the base of large prolegs (***Figure 16-2***) which they use to grapple around in the riffles. The caddis that live in cases have smaller claws (***Figure 16-3***) which they use only to secure themselves to the inner silk lining. The length of the legs are progressively longer with the case-makers and relatively even in length with the non-case-makers. Case-makers can also have humps on either the sides or top of the first abdominal segment.

Life History

All caddisflies have aquatic larval forms usually referred to as larvae instead of nymphs which stonefly and mayfly larval forms are called. Most caddisflies complete their life cycle in one year, but some require two and some less than a year. Caddisflies go through complete metamorphosis which means at the end of their larval phase, they form a cocoon, attach themselves to a solid object and metaphorphose into a "pharate" adult. After two or three weeks, they escape the pupal case and swim to the surface, sometimes exploding out of the water. This is the phase that excites fish and brings out the fly angler at sunset to catch surface feeding fish. The adult lives for about a month, laying eggs on the surface of the water or with some species, dives under the water to lay eggs on rocks. This behavior also attracts fish and persistent fly anglers.

Importance as Biological Indicators

Caddisflies are important indicators of water pollution and habitat destruction. The tolerance values for the 19 families found in western streams and rivers range from 0 to 6. As a whole, caddisflies are generally considered a clean water group. However, because of their diversity and abundance, there is usually a caddisfly genera or two that will be present in polluted waters. One family tolerant of organic pollution is the hydropsychids. They build nets to capture food material drifting in the water currents. When water is overly enriched from sewage, producing excessive algae, detritus and other suspended material, the numbers of hydropsychids can explode. On the other hand, when riffles are filled in with sediment and the area between rocks (interstitial spaces) are missing, many caddisflies including the hydropsychids, and especially members of the family Glossosomatidae, disappear.

Caddisfly Families Common to Western Riffles

Most entomology books report 22 to 24 North American families of caddisflies, but recent reorganization of the Trichoptera resulted in new families bringing the total to 25. We have included the new taxa, eliminated the taxa with only eastern or lentic species, and divided one taxa into two for bioassessment reasons. The keys in this manual include the following 19 families which can be encountered when sampling riffle environments in western streams:

Tolerance Values and Functional Feeding Group Designations for Caddisfly Families with Common Riffle Species

Family	Tolerance Value	Functional Feeding Group
Brachycentridae	3	Collector Gatherer (CG)
Calamoceratidae	2	Shredder (SH)
Glossosomatidae	0	Scraper (SC)
Goeridae	1	Scraper (SC)
Helicopsychidae	3	Scraper (SC)
Hydropsychidae	4	Filterer Collector (FC)
Arctopsychinae	2	Filterer Collector (FC)
Hydroptilidae	4	-
Lepidostomatidae	1	Shredder (SH)
Leptoceridae	4	Collector Gatherer (CG)
Limnephilidae	4	Shredder (SH)
Odontoceridae	0	Shredder (SH)
Philopotamidae	3	Filterer Collector (FC)
Phryganeidae	4	Shredder (SH)
Polycentropodidae	6	Filterer Collector (FC)
Psychomyiidae	2	Collector Gatherer (CG)
Rhyacophilidae	0	Predator (P)
Sericostomatidae	3	Shredder (SH)
Uenoidae	0	Scraper (SC)

Sub-family: Arctopsychinae - see familly Hydropsychidae

Family: Brachycentridae - The family Brachycentridae is represented by five North American and four common western genera. Brachycentrids are a medium-sized (6-12 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment, and several well-developed plates on top of the second and usually third thoracic segments. Brachycentrids can be separated from other tube-case makers by their lack of both dorsal and lateral humps. Gills are either single or lacking.

Larvae of the family Brachycentridae live for one year in the stream and hatch between April and May or July and August. Brachycentrids are always found in running waters from cold headwater streams to larger slow moving rivers. Some genera hide in moss and others are exposed on substrate where they have been observed using their silken threads to propel themselves downstream in search of new habitat, as do hydropsychids. Brachycentrids build round or rectangular cases of plant material or sand.

Family: Calamoceratidae - The family Calamoceratidae is represented by three North American genera with only one species, *Heteroplectron californicum*, occurring in the west. *Heteroplectron* is a large-sized (20-25 mm) tube-case maker (***Figure 16-4***). As is typical of other tube-case makers, they have small anal claws fused to the last abdominal segments, one large plate on top of the first thoracic segment, and several well-developed plates on top of the second and usually third thoracic segment. *Heteroplectron* has dorsal and lateral humps, but the lateral humps are more ventral than other tube-case makers. *Heteroplectron* can be separated from other tube-case makers by the presence of 16 long bristles on their labium. Gills are branched or single.

Heteroplectron lives for two years in the stream and the hatching time is unknown.

Heteroplectron is a shredder and is usually found in the slower moving sections of cool streams where leaf material accumulates. However, it can also be collected in riffle environments. It cannot tolerate pollution and usually prefers forested streams. Instead of building a case like the other case-makers, *Heteroplectron* quite often uses hollowed-out twigs as a case. This makes it necessary to inspect twigs when processing samples collected in areas where this caddisfly is known to occur.

Family: Glossosomatidae - The family Glossosomatidae is represented by six North American and five common western genera. Glossosomatids are relatively small (3-8 mm) with a plate on top of the first thoracic segment and either three, two, or no plates on the second thoracic segment. The anal prolegs are fused to the last abdominal segment which also has a dorsal plate. There are no abdominal gills. These saddle-case makers share characteristics of both the free-living caddis and other case-makers. They can be distinguished by their anal proleg which is well developed, but not as large as the net-spinners and free-living caddis. They also possess a unique tortoise-shaped case of small rocks with openings on the bottom of both ends. Unfortunately, the cases are loosely assembled and usually are smashed during collection.

Larvae of the family Glossosomatidae usually live for one year in riffles of streams and hatch in the spring and fall. Glossosomatids are the most primitive case makers. The larva must re-build a new case whenever it grows too large for it. On the other hand, the case does provide good protection since the larva can eat without being exposed. The larva can turn itself around inside the case, sticking its head out of either opening to feed while it secures itself to the substrate with its anal claw. Glossosomatids require cool, highly oxygenated water and are found exclusively in riffles where they can feed on periphyton. They can be quite abundant in some riffles and are susceptible to habitat destruction and particularly sedimentation.

Family: Goeridae - The family Goeridae is represented by four North American and two common western genera. Goerids are a medium- sized (6-10 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well-developed plates on top of the second and usually third thoracic segments (***Figure 16-5***). Goerids can be separated from other tube-case makers by the forward projecting sclerites on the second thoracic segment. They have both dorsal and lateral humps and the gills are either single or branched.

Goerids probably live for one year in the stream and the hatching time is unknown. Goerids are scrapers, eating periphyton from rocks in riffles of small streams and larger rivers. They cannot tolerate pollution and usually prefer cool temperature streams. Goerids build straight rock cases with larger rocks glued to each side to act as ballast as they walk.

Family: Helicopsychidae - The family Helicopsychidae is represented by only one North American genera which is common in the west. Helicopsychids have a medium-sized (10-15 mm) body which is slightly spiraled. It is unique among the caddisflies in that it builds a snail-shaped case of fine rock or sand particles (***Figure 16-6***). The unique shape is the only characteristic necessary to distinguish this caddisfly from the others and since the larva's spiraling body fits snugly into the case, it is always collected in the case.

Larvae of the family Helicopsychidae live for one year and can hatch continuously from the spring through the fall. Helicopsychids are normally associated with running water, but can also be found in lakes and in thermal streams where water temperatures can reach more than 30° C. Although they are generally a clean water indicator, their temperature tolerance enables them to live in many different environments.

Family: Hydropsychidae - The family Hydropsychidae is represented by six North American and two common western genera. Hydropsychids have medium-sized (8-15 mm) body with plates on top of all three thoracic segments and well-developed anal prolegs. They have branched gills on the bottom of the abdomen and the anal prolegs can have a tuft of long hairs (***Figure 16-7***). Members of the families Hydropsychidae and Hydroptilidae, and sub-family Arctopsychinae are the only caddisfly larvae to have a large single plate on top of all three thoracic segments. Hydroptilids are much smaller than the hydropsychids and arctopsychids and build a purse-shaped case with a conforming body shape. Hydropsychids can be separated from arctopsychids by the absence of a middle plate on the bottom of the head.

Larvae of the family Hydropsychidae usually live for one year in the stream and hatch between April and July. In warmer water, they may have two life cycles per year. Members of this family are referred to as common netspinners. They can be found in streams of all sizes, currents, and temperatures and can be the most abundant insect in riffle environments. They are one of the more pollution tolerant families of caddisflies and are often associated with organic enrichment. They can be extremely abundant below dams where their nets can catch the plentiful planktonic organisms suspended in the flow coming out of the reservoir.

Sub-family: Arctopsychinae - The subfamily Arctopsychinae is represented by two North American genera both of which can be found in the west. In most entomology books, arctopsychines are grouped in the family Hydropsychidae. Although the subfamily Arctopsychinae has been recognized as a separate family in Europe for some time, it is not so recognized in North America. It is listed as a separate taxa in this manual primarily because arctopsychids are more sensitive than the other members of the family Hydropsychidae. Be aware of this ambiguous taxonomy in other entomology and flyfishing books.

Arctopsychines are relatively large (10-30 mm) and have plates on top of all three thoracic segments and well-developed anal prolegs. They have branched gills on the bottom of the abdomen and the anal prolegs can have a tuft of long hairs. Members of the families Arctopsychinae, Hydropsychidae and Hydroptilidae are the only caddisfly larvae to have a large single plate on top of all three thoracic segments. Hydroptilids are much smaller than the arctopsychids and hydropsychids, and build a purse-shaped case with a conforming body shape. Arctopsychids can be separated from the hydropsychids by the presence of a middle plate on the bottom of the head.

Larvae of the sub-family Arctopsychinae live from one to two years in the stream and hatch between June and July. Members of this sub-family are referred to as common netspinners. Arctopsychids are usually found in moderate to high gradient sections of cold, forested streams of all sizes. They are excellent indicators of biological and habitat integrity since they are sensitive to sedimentation and cannot tolerate embedded substrate.

Family: Hydroptilidae - The family Hydroptilidae is represented by 16 North American and ten common western genera. Hydroptilids are small (2-6 mm), have plates on top of all three thoracic segments and small anal claws (***Figure 16-8***). They usually do not have gills. Members of the families Hydropsychidae and Hydroptilidae, and sub-family Arctopsychinae, are the only caddisfly larvae to have a large single plate on top of all three thoracic segments. Hydroptilids which are referred to as microcaddis because they are so small, can be separated from the arctopsychids and hydropsychids simply on size alone. The only other caddisflies approaching their small size are members of the families Glossosomatidae and Psychomyiidae. Hydroptilids are free-living until their last growth stage when they build a purse-shaped case. At this time their

abdomens can become uniquely enlarged, filling their laterally flattened case.

Larvae of the family Hydroptilidae live for one year in the stream and hatch between June and September. As a group, hydroptilids are called piercers because they feed on algae by piercing the cell wall and eating the contents. However, they are not given a feeding group designation in this manual and in the CSBP because piercers are such a rare group. Some genera however, are collectors and grazers. Members of this family can be found in riffles, slower-moving sections of rivers, and in lakes. They are tolerant of high temperature, sedimentation, and some genera are found in eutrophic waters.

Family: Lepidostomatidae - The family Lepidostomatidae is represented by two North American genera with only one common to the west. Lepidostomatids are a medium-sized (7-15 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well- developed plates on top of the second and usually third thoracic segments. Lepidostomatids can be separated from other tube-case makers by their lack of a dorsal hump. Gills are single.

Larvae of the family Lepidostomatidae live for one year in the stream and hatch between June and September. Lepidostomatids are shredders so they are usually found in the slower moving sections of streams and rivers where leaf material accumulates. However, they can also be collected in riffle environments. They cannot tolerate pollution and usually prefer cool temperature streams. Lepidostomatids build different types of cases as they grow. Early life stages build cylindrical sand grain cases and later life stages build four-sided cases of bark and leaves.

Family: Leptoceridae - The family Leptoceridae is represented by eight North American and five common western genera. Leptocerids are a medium-sized (10-15 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well developed plates on top of the second and usually third thoracic segments. They have both lateral and dorsal humps. Leptocerids can be separated from other tube-case makers by their relatively long antennae (6X longer than wide). Most caddisflies have very small antennae, usually impossible to see. Gills are single or lacking.

Larvae of the family Leptoceridae live for one year in the stream and hatch between May and September. Leptocerids are omnivores eating primarily detritus, but some genera are predators. They inhabit lakes, ponds, streams, and rivers. Some have very long hind legs which they use for swimming, even when in their case. They are intolerant of pollution, but are usually found in warmer slow-flowing rivers and streams. Leptocerid cases are highly variable and include hooded sand cases, cylindrical tubes of silk, rock cases, and some made of twigs or pine needles.

Family: Limnephilidae - The family Limnephilidae is the largest of the caddisfly families. They are represented by 41 North American and 28 common western genera. Limnephilids vary in size from small to large (6-30 mm). As typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well developed plates on top of the second and usually third thoracic segments. They have both lateral and dorsal humps. Limnephilids are the quintessential case-maker and are what all the other case-makers are compared to. Their gills can be either branched, single, or lacking.

Larvae of the family Limnephilidae live from one to two years in the stream and hatch between July and November. Limnephilids, as a group are called shredders, but some genera are omnivores or scrapers. They can inhabit almost all environments from lakes to high mountain streams, but they are never found in large numbers. Although as a group they are intolerant of pollution, genera can

range from highly to moderately intolerant. Limnephilid cases are highly variable and can include any material found in the aquatic environment. We have collected the Limnephilid genera *Dicosmoecus* which had glued live snails to their case.

Family: Odontoceridae - The family Odontoceridae is represented by six North American and four common western genera. Odontocerids are a large sized (15-20 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well developed plates on top of the second and usually third thoracic segment (***Figure 16-9***). They have both lateral and dorsal humps. Odontocerids can be separated from the group of tube-case makers which possess dorsal humps by the absence of a horn on its neck (prosternal horn). Gills are branched.

Larvae of the family Odontoceridae live for one to two years in the stream and hatch between April and June. Odontocerids are omnivores. They inhabit small spring-fed streams or small rivers where they either hide in vegetation or burrow into sand, gravel, or soft substrates. They are intolerant of pollution. Odontocerids build cases of rock or sand, but unlike other case-building caddisflies, they do not line the case with silk.

Family: Philopotamidae - The family Philopotamidae is represented by three North American genera all three of which can be found in the west. Philopotamids have a medium-sized (8-12 mm) body with a plate on top of only the first thoracic segment and well-developed anal prolegs. They do not have gills. All larvae of the net spinning families Polycentropodidae, Psychomyiidae and Philopotamidae have a plate on top of just the first thoracic segment. Philopotamids can be separated from members of these other families by the T-shaped fleshy labrum.

Larvae of the family Philopotamidae usually live for one year in the stream and can hatch throughout the year. Members of this netspinning family are referred to as fingernet caddis because they build specialized tunnel-like nets beneath rocks in which they live and gather food. They live in cold to warm streams of all sizes. In general, all philopotamids are intolerant of pollution and habitat deterioration.

Family: Phryganeidae - The family Phryganeidae is represented by ten North American and probably three western genera. Phryganeids are a large-sized (20-40 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment and one large plate on top of the first and second thoracic segments. They have a prosternal horn and both lateral and dorsal humps. Phryganeids can be separated from the group of tube-case makers which possess dorsal humps and prosternal horns by the absence of dorsal plates on the third thoracic segment.

Larvae of the family Phryganeidae live for one to two years in the stream and hatch between April and June. Phryganeids are omnivores becoming shredders during their final aquatic life stage. They primarily inhabit marshes, backwaters, and slow moving areas of stream and rivers. They can also live in ponds and lakes. They are moderately tolerant of pollution. Phryganeids build cases from bits of wood and leaves. They are more active than other tube-case makers and have a tendency to leave their cases.

Family: Polycentropodidae - The family Polycentropodidae is represented by six North American and four common western genera. Polycentropodids have a medium-sized (10-12 mm) body with a plate on top of only the first thoracic segment and well-developed anal prolegs. They do not have gills, but can have a fringe of short hairs on the sides of the abdomen. All larvae of the net spinning families Polycentropodidae, Psychomyiidae and Philopotamidae have a plate on top of just the first thoracic segment. Polycentropodids can be separated from members of these other families by the pointed shape of the shoulder of the front legs (trochantin) and the presence of light or dark spots on the head.

Larvae of the family Polycentropodidae usually live for one year in the stream and hatch between June and August. Members of this netspinning family are referred to as trumpetnet and tubemaking caddis because they build specialized tube-shaped nets that sometimes flair at one or both end. They can be found in lakes, temporary ponds, and streams with moderate to slow current. They can produce a current in their tube by undulating their bodies, which allows them to live in waters with lower dissolved oxygen levels. The family Polycentropodidae is the most pollution tolerant family of caddisflies and are often associated with organic enrichment. Similar to members of the family Hydropsychidae, polycentropodids can be extremely abundant below dams where their nets can catch the plentiful planktonic organisms suspended in the flow coming out of the reservoir.

Family: Psychomyiidae - The family Psychomyiidae is represented by four North American and two common western genera. Psychomyiids have a medium-sized (5-10 mm) body with a plate on top of only the first thoracic segment and well developed anal prolegs. They do not have gills. All larvae of the net spinning families Polycentropodidae, Psychomyiidae and Philopotamidae have a plate on top of just the first thoracic segment. Psychomyiids can be separated from members of these other families by the hatchet shape of the shoulder of the front legs (trochantin).

Larvae of the family Psychomyiidae usually live for one year in the stream and hatch between June and August. Members of this netspinning family are referred to as nettube caddis because they build specialized tube-like retreats in which they live, but unlike other net spinners, do not use them for collecting food. They live in streams with moderate currents where they construct their tube nets under and between rock and wood. In general, all psychomyiids are intolerant of pollution and habitat deterioration.

Family: Rhyacophilidae - The family Rhyacophilidae is represented by two North American genera both of which are found in the west. Rhyacophilids have a medium-sized (11-18 mm) body with a plate on top of only the first thoracic segment and well-developed anal prolegs (***Figure 16-10***). Gills can be either absent or present in small clusters of single filaments. Similar to the netspinning families Polycentropodidae, Psychomyiidae, and Philopotamidae, Rhyacophilid larvae have a plate on top of just the first thoracic segment. Rhyacophilids can be separated from the netspinners by the plate which is on top of abdominal segment 9.

Larvae of the family Rhyacophilidae live from one to two years in the stream and hatch in the spring and fall. They do not build a net to live in or collect food. They are totally free-living, roaming through the substrate of riffle environments hunting for prey. There are many species of rhyacophilids and some will be found in lower elevation, warmer streams, but usually they are only found in cool or cold mountain streams. They are always associated with clean streams and are excellent indicators of biological and habitat integrity.

Family: Sericostomatidae - The family Sericostomatidae is represented by three North American genera with only one common in the west. Sericostomatids are a large-sized (15-19 mm) tube-case maker. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well developed plates on top of the second and usually third thoracic segments. They have both lateral and dorsal humps. Sericostomatids can be separated from the group of tube-case makers which possess dorsal humps by the presence of distinctive clusters of 30 or more on the dorsal side of the last abdominal segment where the anal claws are located. Gills are single.

Larvae of the family Sericostomatidae probably live for one to two years in the stream and hatching time is unknown. Sericostomatids are shredders. They inhabit the flowing portions of cold springs and

riffles of warmer streams. They are moderately tolerant of pollution. Sericostomatids build curved cases of small rocks or sand.

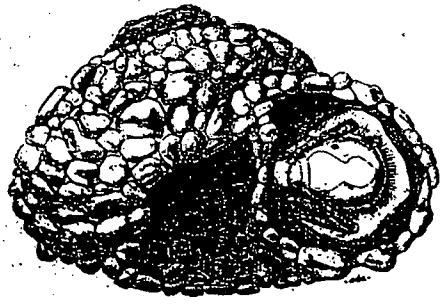
Family: Uenoidae - The family Uenoidae is represented by five North American and 4 common western genera. Uenoids are medium- sized (6-15 mm) tube-case makers. Typical of other tube-case makers, they have small anal claws fused to the last abdominal segment, one large plate on top of the first thoracic segment and several well-developed plates on top of the second and usually third thoracic segment (***Figure 16-11***). They have a prosternal horn and both lateral and dorsal humps. Uenoids can be separated from the group of tube-case makers which possess dorsal humps by their first thoracic segment which is longer than wide. (Note: This characteristic can sometimes be difficult to see). The uenoids have two different body types; one is long and slender while the other is shorter and wider. The wider type does not always have a longer than wide first thoracic segment and can easily be confused for a limnephilid caddisfly. Gills are single or lacking.

Larvae of the family Uenoidae live for one to two years in the stream and hatch between April and June or August and September. Uenoids are scrapers, eating periphyton on rocks. They inhabit small, cool headwater streams and slightly warmer medium-sized streams. They are intolerant of pollution. Uenoids either build cases of rock or long, slender and curved sand cases which can be mistaken for pine needles.

Taxonomic Keys to the Families of Caddisflies (Order: Trichoptera)

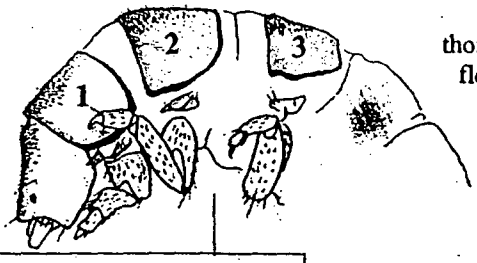
TRICHOPTERA LARVAE

Larvae always in shell-like case



Helicopsychidae

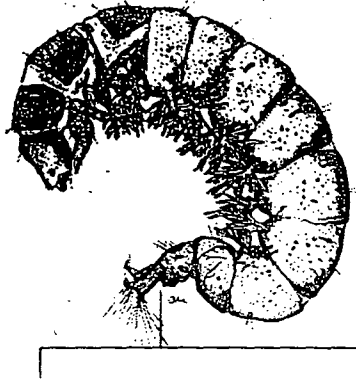
All 3 thoracic segments covered with dorsal plates



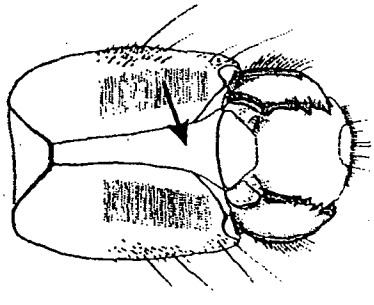
thoracic segment 2 fleshy or with 2 small plates

thoracic segment 2 with well developed plates (use tubecase maker key)

abdomen with branched gills

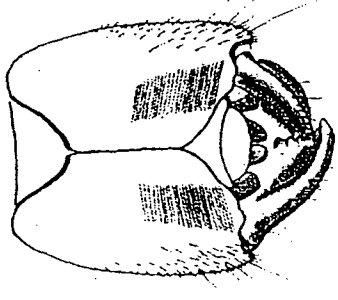


ventral side of head with a middle plate



Arctopsychinae

ventral side of head without a middle plate

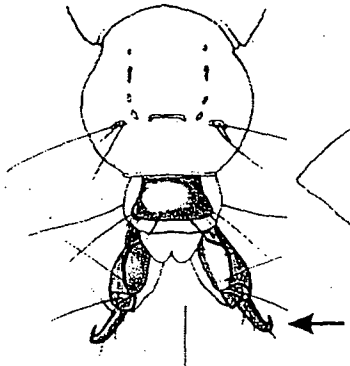


Hydropsychidae

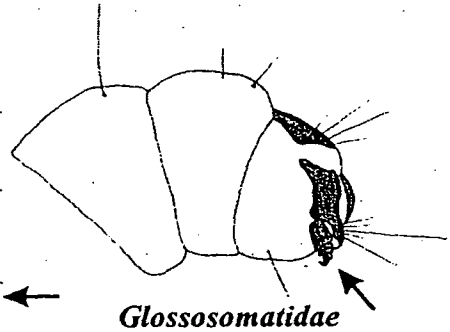
no gills; larvae very small

Hydroptilidae

well developed anal prolegs



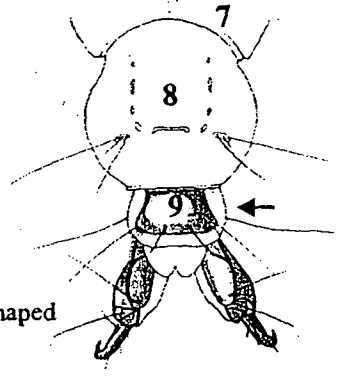
small anal prolegs



Glossosomatidae

abdomen segment 9 without top plate

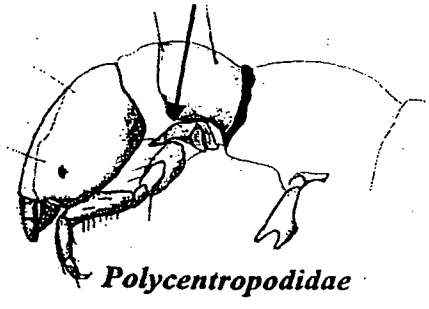
abdomen segment 9 with dorsal plate



Rhyacophilidae

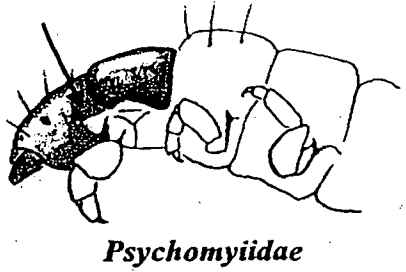
labrum not T-shaped

shoulder of front leg pointed



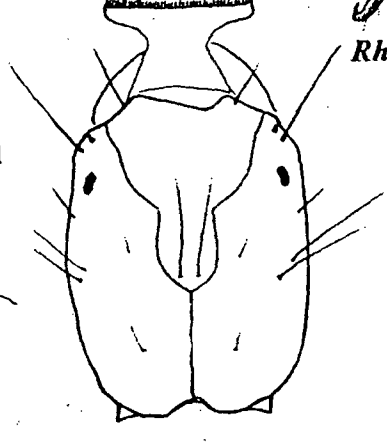
Polycentropodidae

shoulder of front leg hatchet-shaped



Psychomyiidae

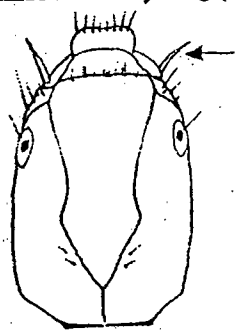
labrum fleshy and T-shaped



Philopotamidae

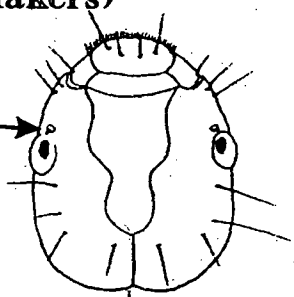
TRICHOPTERA LARVAE (tube-case makers)

antennae relatively long (6x longer than wide)

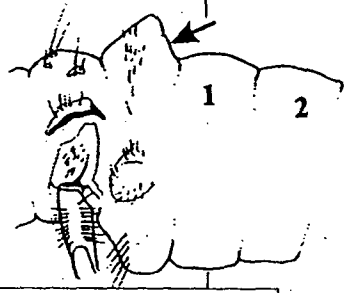


Leptoceridae

antennae relatively short (< 3x longer than wide)

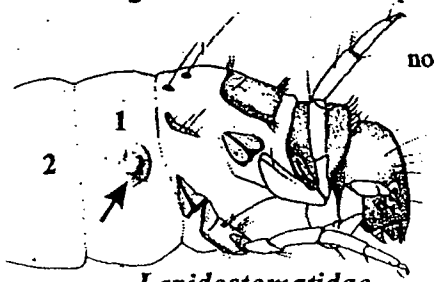


abdominal segment 1 with dorsal hump



abdominal segment 1 without dorsal hump

abdominal segment 1 with lateral humps

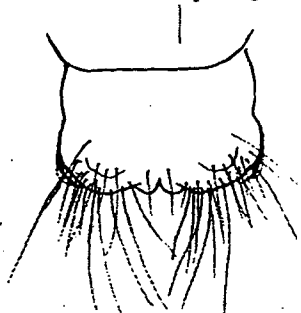


Lepidostomatidae

no hump on abdominal segment 1

Brachycentridae

many (~30) long hairs on anal proleg

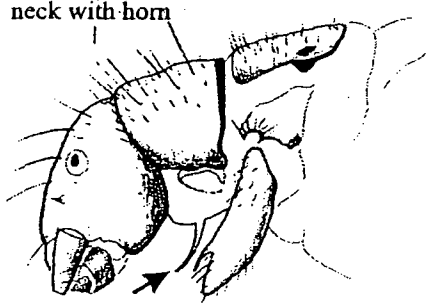


Sericostomatidae

few (<10) long hairs on anal proleg

labrum with fewer bristle

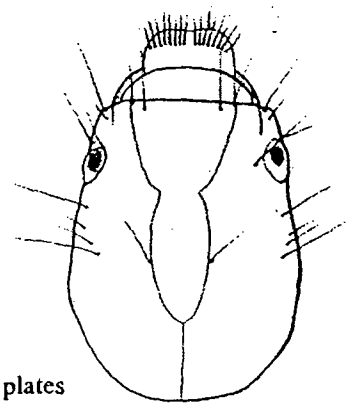
neck with horn



neck without horn

Odontoceridae

labrum with ~ 16 bristles

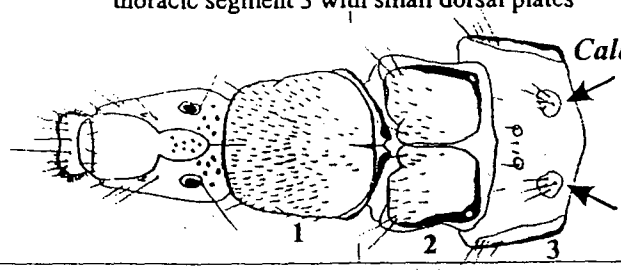


Calamoceratidae

thoracic segment 3 without small dorsal plates

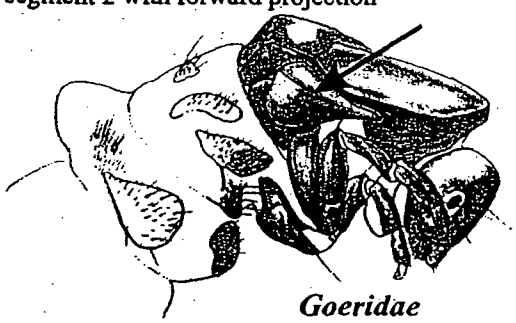
Phryganeidae

thoracic segment 3 with small dorsal plates



thoracic segment 1 wider than long

thoracic segment 2 with forward projection

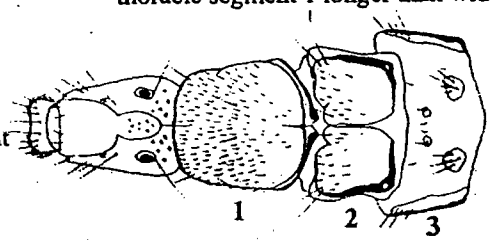


Goeridae

thoracic segment 2 without forward projection

Limnephilidae

thoracic segment 1 longer than wide



Uenoidae

TRICHOPTERA

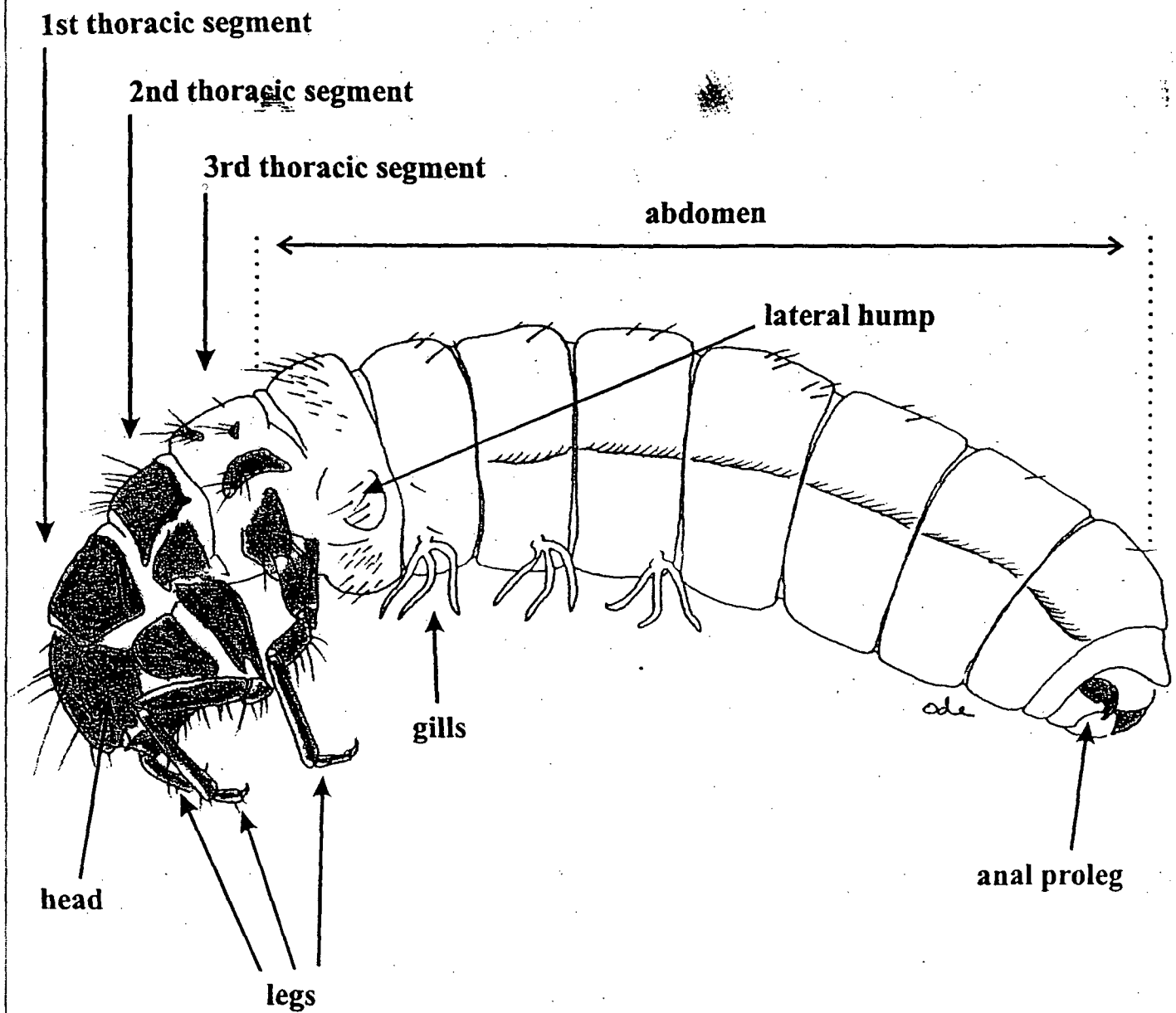


Fig. 16-1 General morphologic characteristics of caddisflies

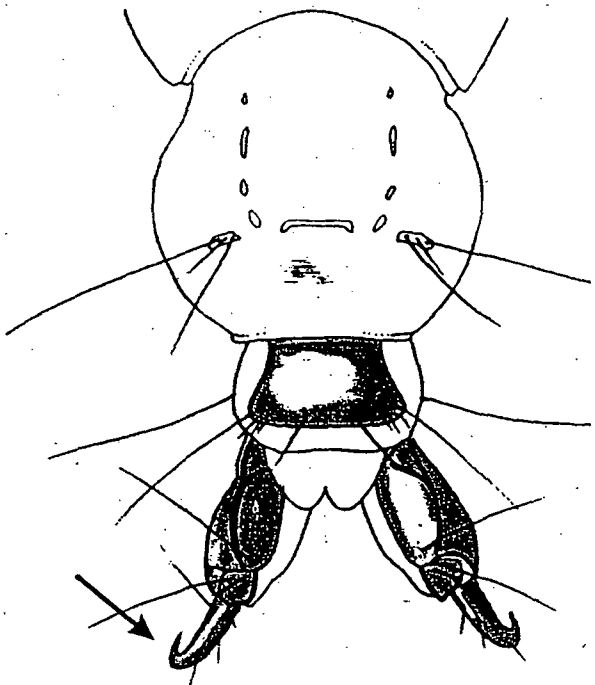


Fig. 16-2 Anal proleg of caddisfly

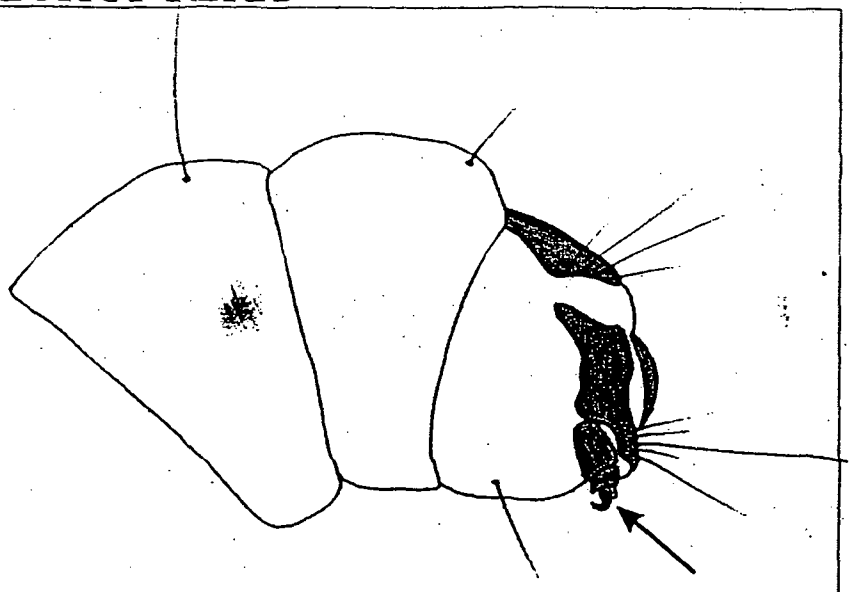


Fig. 16-3 Anal proleg of caddisfly

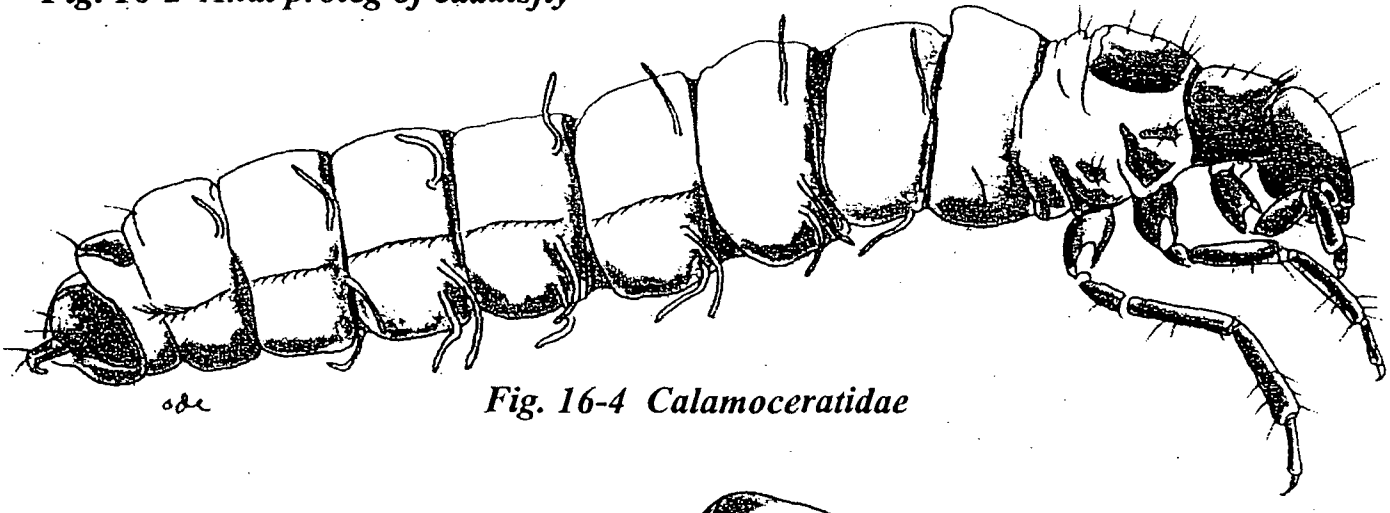


Fig. 16-4 Calamoceratidae

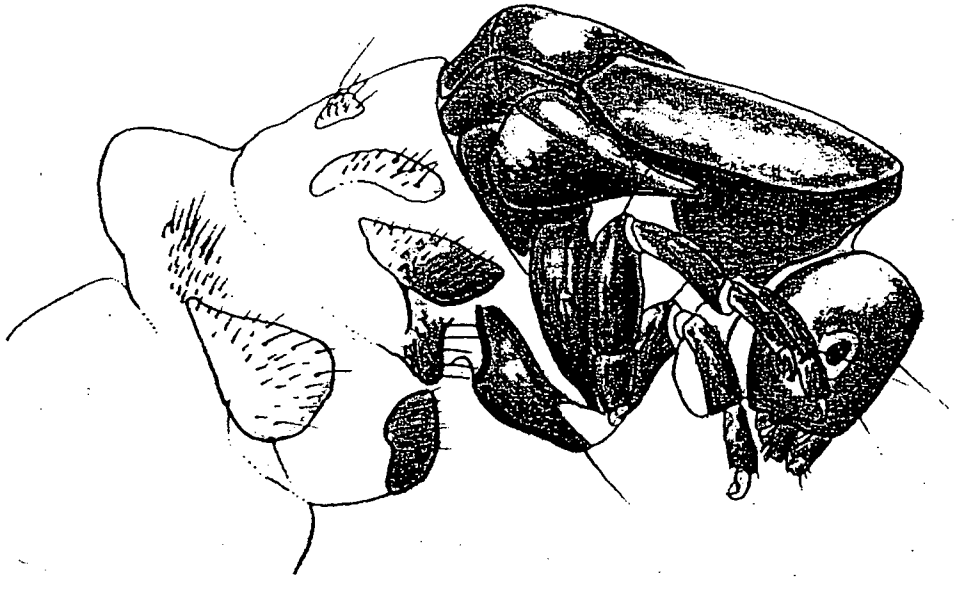


Fig. 16-5 Goeridae

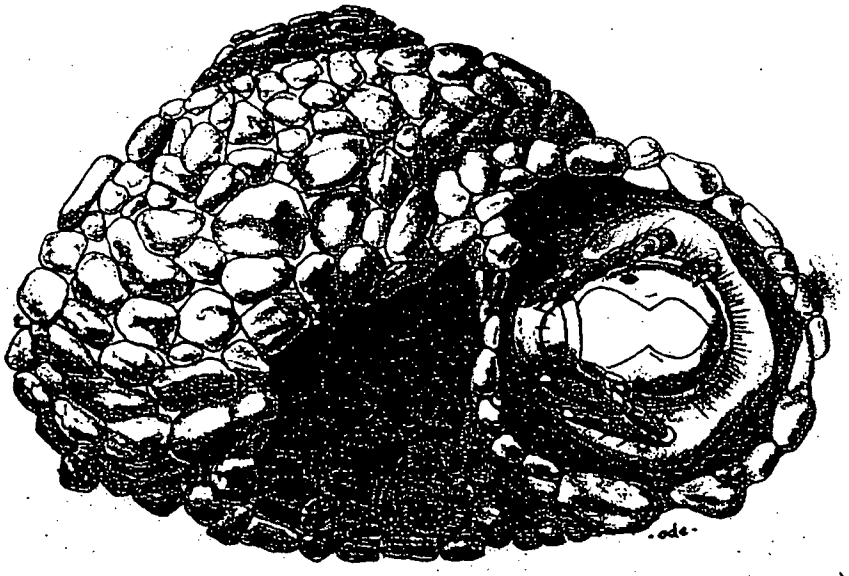


Fig. 16-6 Helicopsychidae

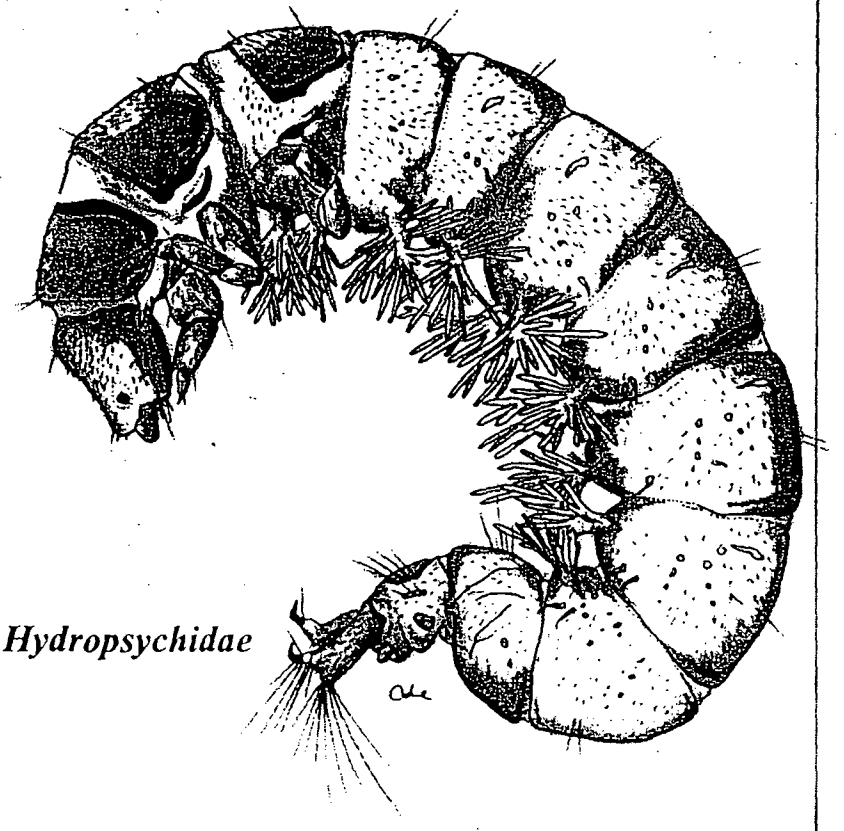


Fig. 16-7 Hydropsychidae

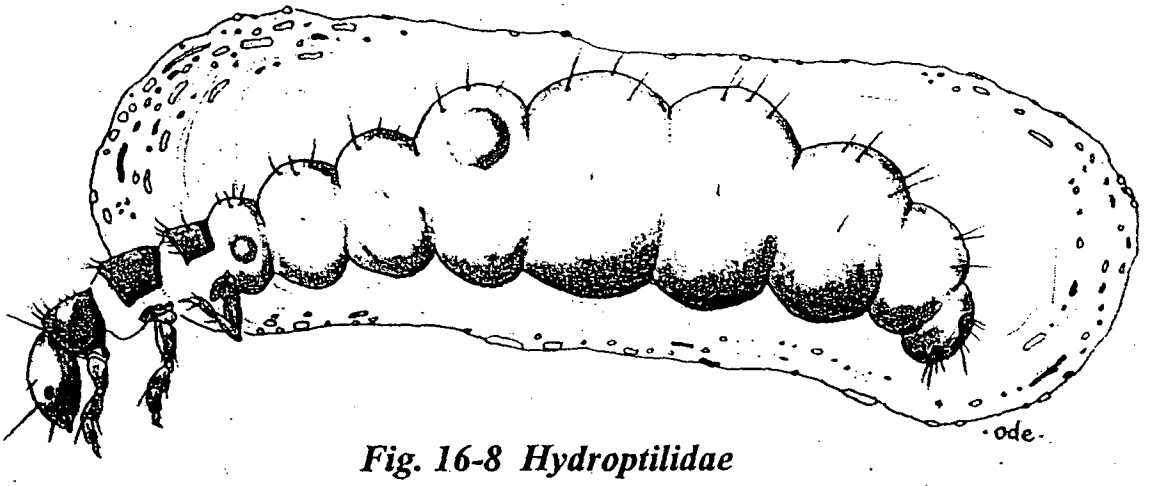


Fig. 16-8 Hydroptilidae

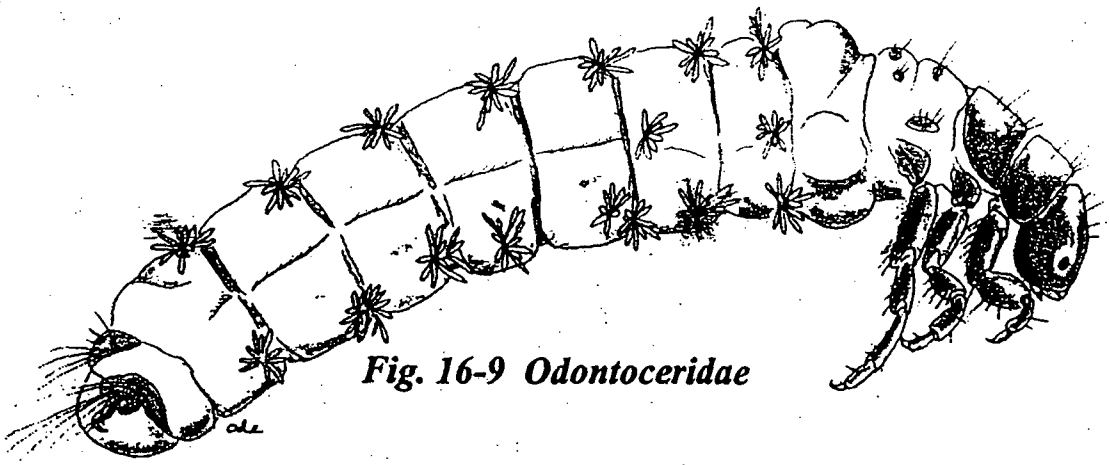


Fig. 16-9 Odontoceridae

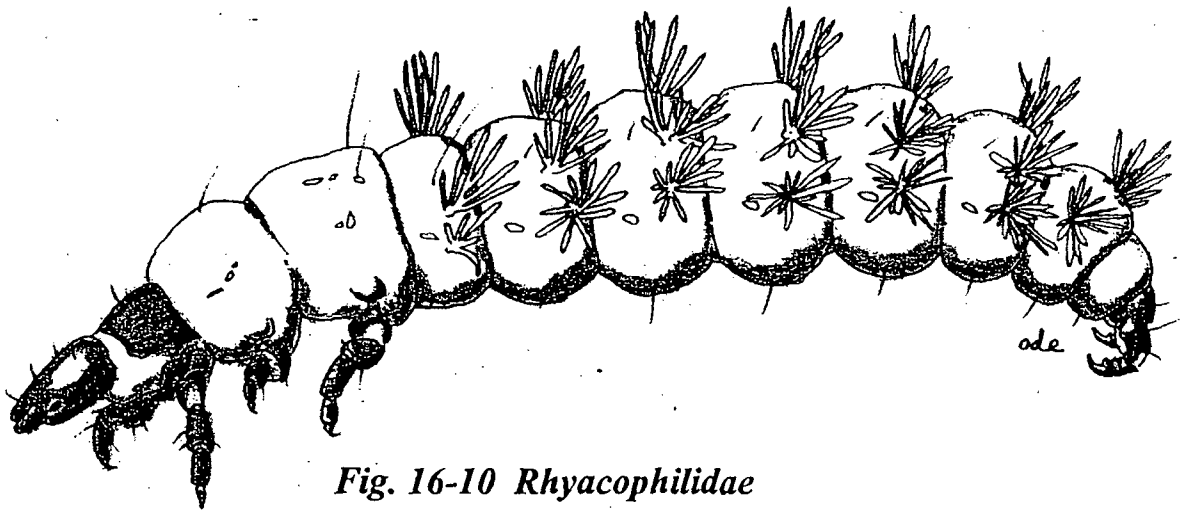


Fig. 16-10 Rhyacophilidae

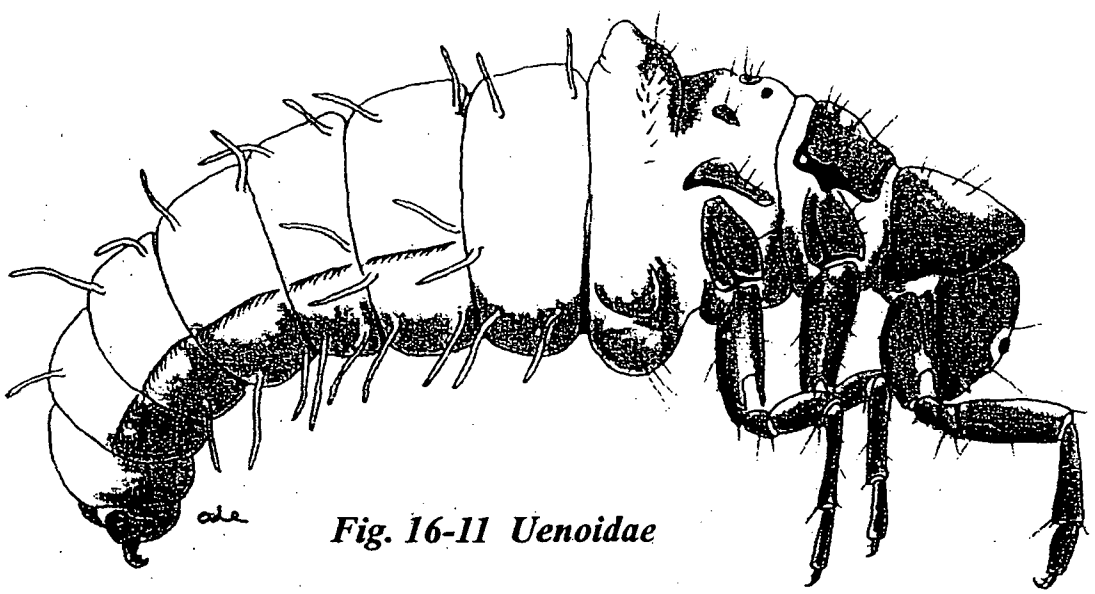


Fig. 16-11 Uenoidae

Chapter 17
Description and Taxonomic Keys to the Families of True Flies (Order: Diptera) Common to Western Streams and Rivers

Introduction to the True Flies

The order Diptera, or true flies, is a large, primarily terrestrial group that should be familiar to everyone. The order is also an important group in the aquatic environment and is by far the largest group of aquatic insects. Almost half of all the species of aquatic insects belong to this order. Dipterans can be found in every type of aquatic environment from stagnant puddles and intermittent streams, to mountain springs and fast running rivers. Some species of the family Ephydridae can also tolerate saltwater lakes and thermal springs.

Although there is little information on the taxonomy and life history of most aquatic dipterans, some families are well known and the subject of much research. Adults of the family Culicidae (mosquitoes) seem to bother everyone and can transmit human diseases such as malaria, filariasis and yellow fever. Mosquitoes are never found in running water environments and will not be covered in this manual. However, there are other running water dipterans with unpopular adults including the families Tabanidae (horse flies and deer flies), Simuliidae (black flies) and Ceratopogonidae (biting midges). Another important group of aquatic dipterans is the family Chironomidae which are referred to as non-biting midges. This family is the largest, comprising more than a third of all aquatic Diptera species, and can be so abundant in some areas that they can be a nuisance when they hatch. This is also the most important family of aquatic flies to the flyfisherman, especially when fishing in lakes.

Morphological Characteristics

Dipteran larvae have elongated and soft bodies with no segmented legs. They come in many different shapes and sizes ranging in length from 1 to 100 mm. Dipterans are separated in two groups: one with conspicuous, scleroterized heads and one with very small or undeveloped heads usually withdrawn into the body. The taxonomic keys in this manual for families of dipterans are divided into families with apparent heads and those without. Dipteran families can also be separated into those with prolegs and those without. Prolegs are non-segmented and not a true leg; they are fleshy appendages protruding from various parts of the body. The only other group of invertebrates that can be confused with dipterans are caddisflies (Order: Trichoptera) and aquatic worms (Subclass: Oligochaeta) because of the similar soft worm-like body shape. The presence of segmented legs in caddisflies separate them from dipterans, and aquatic worms look usually like typical earthworms and will never have heads or prolegs.

Life History

Dipterans go through complete metamorphosis having larval, pupal and adult stages. The larvae of true flies live for just a few weeks to one or two years. Pupation in dipterans usually occurs in the water but some larvae leave the water and pupate in mats of vegetation, and in mud or sand near the shoreline. Those that pupate in the water can have cocoons or pupal cases and some are free-living. There are two dipteran families that are commonly found in riffle samples and are quite often present in the pupal form. The pupae of Chironomidae (***Figure 17-1***) and Simuliidae (***Figure 17-2***) cannot be identified in the taxonomic keys so you need to just be

familiar with their unique appearance. The adults look totally different from the larvae and pupae. They can live for a few hours or several months. Mating occurs in flight or on vegetation and the eggs are either deposited on the water surface or placed on vegetation near the water.

Importance as Biological Indicators

Dipterans are important biological indicators of water pollution. Although many people think of water maggots as indicators of poor water quality, they actually vary in tolerance from extremely sensitive to extremely tolerant. Larvae of the families Blephariceridae and Deuterophlebiidae are only found in clean, cool waters, where psychodids and some chironomids can be found in waters polluted with organic waste or chemical contamination. In general, when dipterans dominate a riffle sample, it usually means that there is a water quality impairment. Most often the impairment will be organic enrichment and the dominant dipteran families will be Chironomidae and Simuliidae as they are collector organisms that can take advantage of the excessive fine particulate organic matter.

True Fly Families Common to Western Riffles

Most entomology books report 23 North American families of true flies. The keys in this manual include the following 13 families which can be commonly encountered when sampling riffle environments in western streams:

Family: Athericidae - The family Athericidae is represented by only one North American genus, *Atherix*, which can be found in western streams and rivers. There is one other genus, but it is only found in southwest Texas and Mexico. Species of the genus *Atherix* have a small, indistinguishable head, pairs of prolegs on the ventral side of the first seven abdominal segments, and a single ventral proleg with a pair of fringed projections on the last abdominal segment (***Figure 17-3***). They are medium-sized at 12-18 mm in length. There are two other dipteran families (Empididae and Ephydridae,) with small indistinguishable heads, well-developed prolegs and terminal projections. *Atherix* can be distinguished from the other two dipteran families by its

Tolerance Values and Functional Feeding Group Designations for Dipteran Families with Common Riffle Species

Family	Tolerance Value	Functional Feeding Group
Athericidae	2	Predator (P)
Blephariceridae	0	Scraper (SC)
Ceratopogonidae	6	Predator (P)
Chironomidae	6	Collector Gatherer (CG)
Deuterophlebiidae	0	Scraper (SC)
Dixidae	2	Collector Gatherer (CG)
Empididae	6	Predator (P)
Ephydridae	6	Collector Gatherer (CG)
Psychodidae	10	Collector Gatherer (CG)
Simuliidae	6	Filterer Collector (FC)
Stratiomyidae	8	Collector Gatherer (CG)
Tabanidae	8	Predator (P)
Tipulidae	3	Shredder (SH)

terminal projections which are longer than the others and fringed.

Larvae of the family Athericidae occur in riffles or among stream vegetation. The larvae leave the stream to pupate in moist soil along the edge of the stream. The adults lay their eggs on vegetation above the stream so that when the larvae emerge they fall into the water. The entire life cycle takes about one year. The larvae are predacious, eating other aquatic insects. Athericids require highly oxygenated waters and are relatively intolerant of water pollution.

Family: Blephariceridae - The family Blephariceridae is represented by five North American genera, which can all be found in western streams and rivers. Blepharicerids are quite distinctive having a flattened body with a distinguishable head, and seven body segments with sucker discs on the ventral side of the first six segments (***Figure 17-4***). They are small to medium with a length of 4-12 mm. The only other dipterans that can be confused with Blepharicerids are members of the family Deuterophlebiidae which have a similar lateral constriction of the body segments, but do not have the sucker discs, and members of the family Ceratopogonidae which have similar looking pairs of lateral tubercles, but no sucker discs.

Larvae of the family Blephariceridae occur in very fast waters of mountain streams where they use their sucker discs to keep themselves attached to the substrate. The larvae move to the edge of the streams and pupate in cracks and depressions of the rocks. The adults lay their eggs just above the water line on rocks where flooding waters wash the hatching larvae into the water. The entire life cycle takes about one year. The larvae scrape the rocks they are attached to and eat diatoms and other algae. Blepharicerids require cold, highly oxygenated waters and are highly intolerant of water pollution.

Family: Ceratopogonidae - The family Ceratopogonidae is represented by 20 North American genera and all but two can be found in western streams and rivers. Ceratopogonids have a visible head and two distinctive body types; one that is small, elongated and without prolegs (***Figure 17-5***,) and one that has one proleg on the first abdominal segment and well-developed bristles or spines on each of the other segments (***Figure 17-6***). Their size ranges from 2 to 15 mm. The only other dipteran that can be confused with Ceratopogonids are members of the family Psychodidae which have a similar body shape but with dorsal plates on all body segments.

Larvae of the family Ceratopogonidae can be found in riparian or moist terrestrial habitats and even in tree holes, marshes, and swamps. They also live in lakes and streams where they get around by swimming in a serpentine-like motion. The larvae do not pupate in a cocoon but hang in the surface film where they emerge to become adults. The adults of some species can be quite nasty. They are swarming, biting midges that feed on warm-blooded animals including humans. The entire life cycle takes about one year. The larvae are predators of other aquatic insects. Ceratopogonids are moderately pollution tolerant.

Family: Chironomidae - The family Chironomidae is by far the largest family of aquatic insects consisting of more than 150 North American genera, many of which can be found in western streams and rivers. Although chironomids have a variety of shapes, sizes and colors, they have distinctive body characteristics. They are slender, usually cylindrical and slightly curved with a pair of prolegs near the head and on the terminal end (***Figure 17-7***). They range in size from 2 to 20 mm. The only other dipteran that can be confused with chironomids are members of the family Dixidae which have a similar body shape but have paired prolegs on the first two abdominal segments. Chironomid pupae are often collected in riffle samples and cannot be identified using the keys in this manual. However, they are distinct, having the same size as the larvae, but with visible developing wings. The wings have been described as

having the look of puppy dog ears (*Figure 17-1*).

Larvae of the family Chironomidae occur in a variety of permanent and temporary aquatic habitats. They can be very abundant in lakes and will be found in almost all riffle samples. The larvae usually live in the substrate where they build cases of sand or mud. They can also move around by swimming. The larvae either pupate in the case or in a free-living state where they can be found in the surface water film. Their emergence as adults can be spectacular because of their incredible abundance. The adult are very short-lived, but their numbers can be quite a nuisance in some areas.

The life cycle of chironomids can range from several per year to a 2-year cycle in some northern species. The usual life cycle takes about one year. The larvae food habits are also variable with most being either predators or collector-gatherers of detritus and other fine particulate matter. Chironomids can have a variety of tolerances to water pollution ranging from highly sensitive to extremely pollution tolerant. Red-colored chironomids which are called blood worms and found in sewage treatment ponds can tolerate close to zero dissolved oxygen levels. In general, they are moderately tolerant to pollution and their dominance at a site can indicate nutrient enrichment.

Family: Deuterophlebiidae - The family Deuterophlebiidae is represented by only one rare North American genus, Deuterophlebia, which can be found in western streams and rivers. Deuterophlebia has a visible head with distinctive branched antennae and lateral constriction of the body segments which are actually prolegs (**Figure 17-8**). They are very small and usually do not exceed 6 mm in length. Members of the families Blephariceridae and Ceratopogonidae can be confused with Deuterophlebia because they have similar lateral constrictions of the body segments. The most obvious difference are the branched antennae on Deuterophlebia.

Larvae of the family Deuterophlebiidae are found in rapid currents of western mountain streams. They inhabit the upper surface of light-colored, smooth rocks that have cracks or depressions, or in mossy vegetation near the margin of the stream. They live near the surface of the water and pupate in the same habitat. The adults live only one to two hours. They live about a year in higher elevations and can have more than one generation in a year at lower elevations. They occupy similar habitat as the Blephariceridae and also eat diatoms and other algae by scraping the rocks on which they graze. Deuterophlebias require cold, highly oxygenated waters and are highly intolerant to water pollution.

Family: Dixidae - The family Dixidae is represented by 3 North American genera, all of which can be found in western streams and rivers. Dixids have a visible head, and an elongated, cylindrical body with paired prolegs on the first two abdominal segments (*Figure 17-9*). They are small, ranging in size from 3 to 7 mm. The only other dipteran that can be confused with Dixids are members of the family Chironomidae which have the same elongated, slender shape, but have paired prolegs on the first abdominal segment and at the terminal end.

Larvae of the family Dixidae are related to mosquitoes and like mosquitoes, breathe atmospheric air through breathing syphons. This means that they are found at or just below the water surface in still water habitats, and in vegetation near the stream shore. They move around by bowing their body into a U-shape and then straightening out. The larvae pupate out of the water in vegetation and the adults are short-lived, but unlike mosquitoes, do not bite. They are believed to have multiple life cycles in a year. The larvae feed on microorganisms and detritus in the surface film. Although Dixids breathe atmospheric air, they are not found in polluted waters and are considered sensitive.

Family: Empididae - The family Empididae is represented by 16 North American genera, five of which can be found in western streams

and rivers. Empidids have a small indistinguishable head, pairs of prolegs on the ventral side of seven or eight abdominal segments, and a simple terminal process which is not fringed (***Figure 17-10***). They are small, usually not exceeding a length of 7 mm. There are two other dipteran families (Athericidae and Ephydiridae) that also have small indistinguishable heads, well-developed prolegs and terminal projections. Empidids can be distinguished from the other two dipteran families by their terminal projections which are simple and not fringed.

Larvae of the family Empididae live in rocky substrates of riffle habitat or in vegetation in fast moving sections of streams. The larvae pupate in the water and the adults are known to swarm in a dance-like pattern above the stream before laying their eggs. The larvae are predators of other aquatic insects. The life history of empidids is not well-known and although they live in swift water, they are considered moderately pollution tolerant.

Family: Ephydridae - The family Ephydridae is represented by 65 North American genera, but only a few can be found in western streams and rivers. Most ephydrids are semiaquatic and many live in alkaline lakes, hot geyser pools, and ponds containing oil. They have a small indistinguishable head, usually have prolegs on the abdominal segments and two terminal breathing tubes (***Figure 17-11***). They are small, ranging from 2 to 12 mm in length. There are two other dipteran families, (Athericidae and Empididae,) with small indistinguishable heads, well developed prolegs and terminal projections. Ephydrids can be distinguished from the other two dipteran families by their terminal breathing tubes.

Stream-dwelling larvae of the family Ephydridae are found on the stream margins, sometimes in vegetative mats. The larvae pupate on the surface of the water and the adults can be found walking on the shore or skating on the surface of the water. They are known as shore flies and lay their eggs singularly on the surface of the water. The larvae either feed on diatoms and other algae or on detritus. The life history of stream dwelling ephydrids is not well-known and they are considered moderately pollution tolerant.

Family: Psychodidae - The family Psychodidae is represented by 6 North American genera, three of which can be found in western streams and rivers. Psychodids have a slender, cylindrical body with a visible head, no prolegs and dorsal plates on some or all the body segments (***Figure 17-12***). They are small, usually not exceeding 5 mm in length. The only other dipteran that can be confused with psychodids are some members of the family Ceratopogonidae which can have a similar body shape but with no dorsal plates on the body segments. Members of the families Chironomidae and Dixidae can also be confused with psychodids because they have the same general body shape. However, members of both families Chironomidae and Dixidae have prolegs which are absent in Psychodids.

Larvae of the family Psychodidae can be found in shallow, still water environments and along margins of streams. The larvae feed near the surface of the water on microorganisms and detritus. The larvae do not pupate in a cocoon; they attach themselves to substrate where they emerge to become adults. Psychodids can have several life cycles a year, especially in warm waters. The larvae feed on microorganisms and detritus. Psychodids are associated with very polluted waters and can be found in sewage settling ponds and tickling filters. Some species can even be found in sinks and drains and can tolerate hot water, detergents and harsh chemicals.

Family: Simuliidae - The family Simuliidae is represented by 11 North American genera, two of which can be found in western streams and rivers. Simulids have a cylindrical body with a swollen abdomen, visible head and one ventral proleg on the thorax (**Figure 17-13**). They also have fan-like appendages on the head and a circular sucking disk on the terminal end which are hard to see because of

their small size (3 to 8 mm). The only other dipteran that can be confused with simulids are members of the family Chironomidae which are much more slender and have paired prolegs. Simulid pupae are often collected in riffle samples and cannot be identified using the keys in this manual. However, they are distinct, having a pair of highly branched spiracular gills on the thorax (**Figure17-2**) that make them look like something from Mars.

Larvae of the family Simuliidae are found in fast moving water in streams where they attach to rock surfaces using their terminal sucking disk. They orientate themselves upright facing the flow of water so they can use their labral fans to filter diatoms and other food floating in the water column. The larvae pupate by attaching themselves to the rock in a slipper-shaped cocoon. The adults are black flies that are a nuisance to humans, especially in the northwest where they can be extremely abundant. Simulids usually have one life cycle a year, but some species have several. Simulids are moderately tolerant to pollution and similar to Chironomids, their dominance at a site can indicate nutrient enrichment.

Family: Stratiomyidae - The family Stratiomyidae is represented by 11 North American genera, all but one can be found in western streams and rivers. Stratiomyids have a somewhat flattened and broad body with a visible head, no prolegs and a rosette of hairs or few stout setae at the terminal end (***Figure 17-14***). The body is also hardened and thickened with deposits of calcium carbonate. They can be small to medium-sized, ranging from 7 to 30 mm in length. They are fairly distinct, but they could be confused with some members of the family Ceratopogonidae or Blephariceridae because of the general body characteristics. However, ceratopogonids have a proleg and blephariceridae have ventral sucking disks.

Larvae of the family Stratiomyidae can be semiaquatic, found in shallow, still water environments and in benthos or along margins of streams. The larvae usually feed near the surface of the water on microorganisms and detritus. The pupae float on the water surface before emerging as adults. The adults lay egg masses on stream's overhanging vegetation. Stratiomyid life history is not well- known, but they are considered pollution tolerant.

Family: Tabanidae - The family Tabanidae is represented by 14 North American genera, all but six can be found in western streams and rivers. Tabanids have an elongated, cylindrical body with a small indistinguishable head and welt-like rings on the abdomen (***Figure 17-15***). There is only one other dipteran family, Tipulidae, that is similar in size, shape, and without prolegs. However, Tipulids do not have the welt-like rings and usually have a bulbous terminal end.

Larvae of the family Tabanidae can be found in still water environments and in the benthos of streams. The larvae pupate in semiaquatic environment and are rarely found in the water. The adults, known as deer or horse flies, can inflict a serious bite to humans and can harm other animals. The larvae are predators of other aquatic insects. The life cycle of tabanids can take one year or they can have several cycles each year. They are considered moderately pollution tolerant.

Family: Tipulidae - The family Tipulidae is represented by 35 aquatic North American genera, 10 of which can be found in western streams and rivers. Tipulids have an elongated, cylindrical body with a small indistinguishable head and either no prolegs or poorly developed prolegs (**Figure 17-16**). They can have terminal end processes consisting of variously-shaped fleshy lobed spiracle disks or the terminal end can be bulbous. The only other dipterans that can be confused with tipulids are the tabanids which can be separated by the welt-like rings on their body segments.

Larvae of the family Tipulidae are primarily found in running water environments where they live in the substrate. They prefer clean, loose sediment where they move around like a worm, shredding woody debris and other vegetative material. The larvae pupate in

marginal stream areas or semiaquatic environments. The adults, known as crane flies, are short lived but a common sight to most people. Although many larvae shred woody debris, they are considered omnivores since they ingest the bacteria and fungi or whatever is on the material they ingest. Some species have gut bacteria that help to digest cellulose. The life cycle of tipulids can take from one to two years or they can have several each year. They are considered relatively intolerant to water pollution.

Taxonomic Keys to the Families of True Flies (Order: Diptera)

DIPTERA LARVAE

head apparent

no apparent head or very small in relation to body (use other diptera key)

no proleg

prolegs present

ventral sucking disks present on 6 body segments

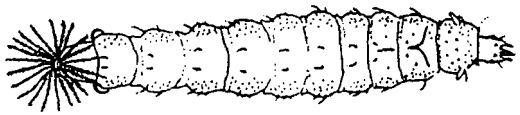
ventral sucking disks not present

much less than 7 prolegs

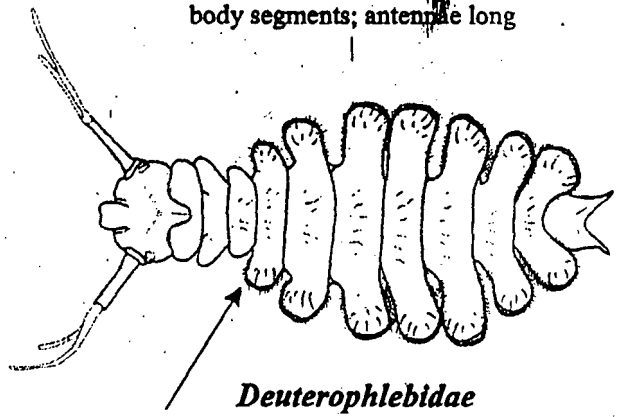
7 pairs of stout prolegs on sides of body segments; antennae long

body cylindrical

body somewhat flat & broad



Stratiomyidae

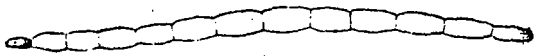


Deuterophlebidae

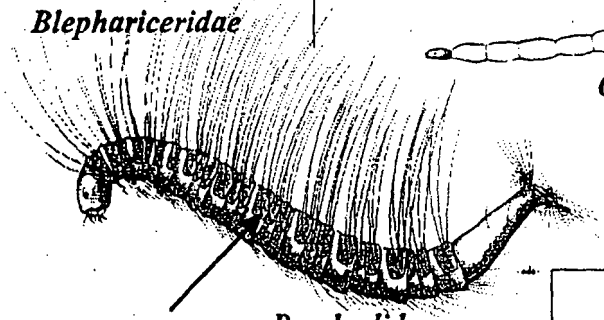
Blephariceridae

short terminal siphon; dorsal plates

needle-shaped body; no dorsal plates



Ceratopogonidae (in part)



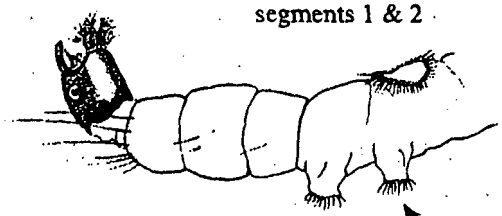
Psychodidae

paired prolegs

single anterior proleg

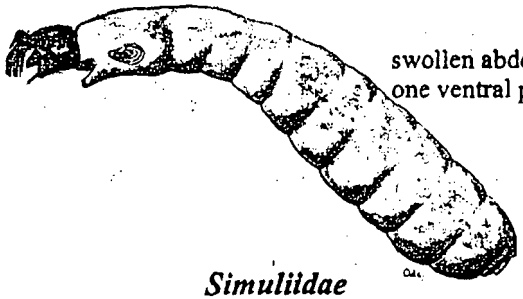
anterior & terminal paired prolegs

paired prolegs on abdominal segments 1 & 2



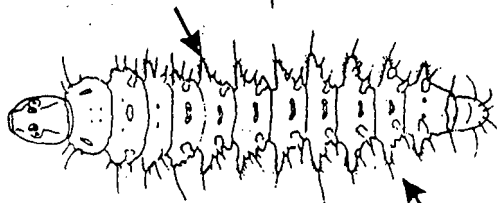
Dixidae

pairs of long lateral tubercles on all body segments

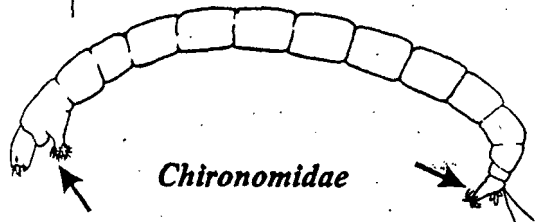


swollen abdomen; one ventral proleg

Simuliidae



Ceratopogonidae (in part)



Chironomidae

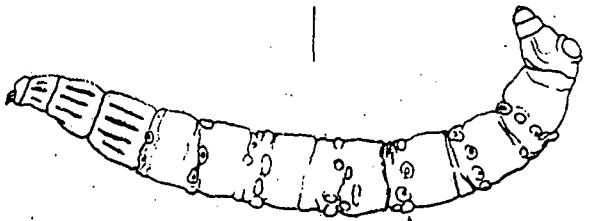
DIPTERA LARVAE

no apparent head or very small in relation to body

no apparent proleg

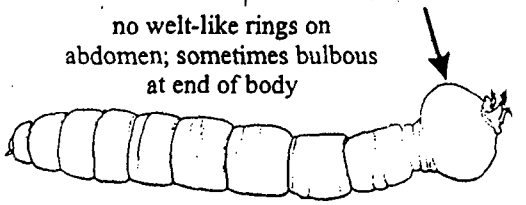
apparent prolegs

welt-like rings on abdomen



Tabanidae

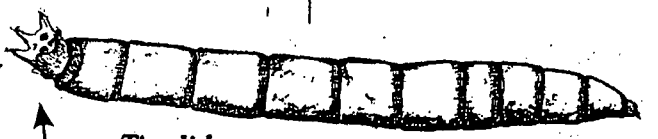
no welt-like rings on abdomen; sometimes bulbous at end of body



Tipulidae
(in part)

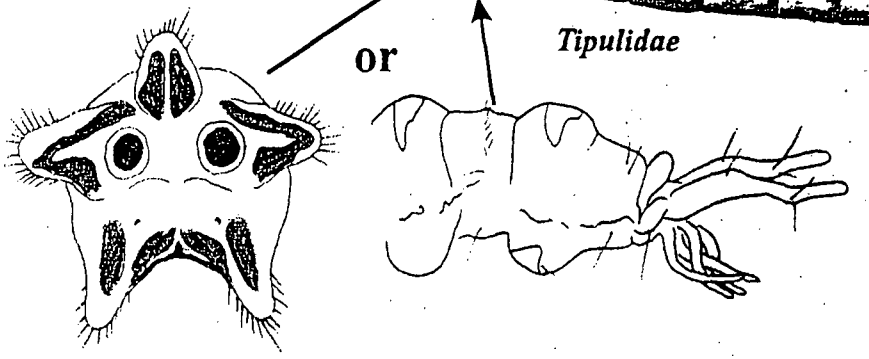
prolegs poorly developed

prolegs paired and well developed



Tipulidae

or

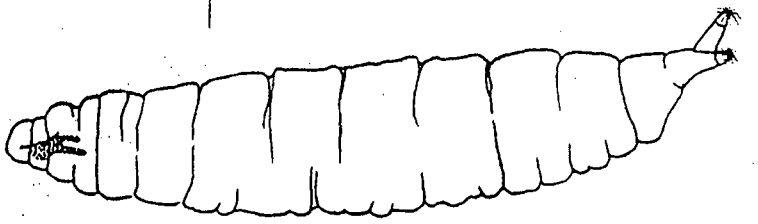


fringed & divergent terminal process

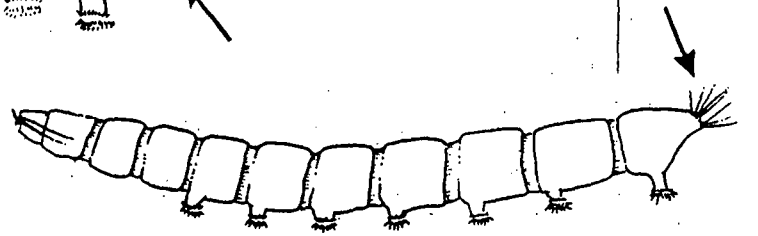
terminal process not fringed; small

end of body with 2 tubes

Athericidae



Ephydridae



Empididae
(in part)

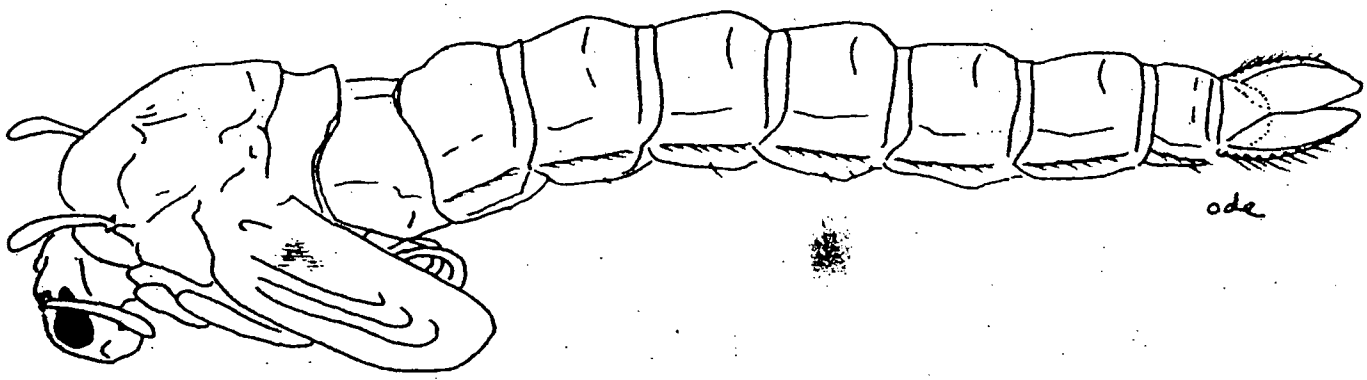


Fig. 17-1 Chironomidae pupa

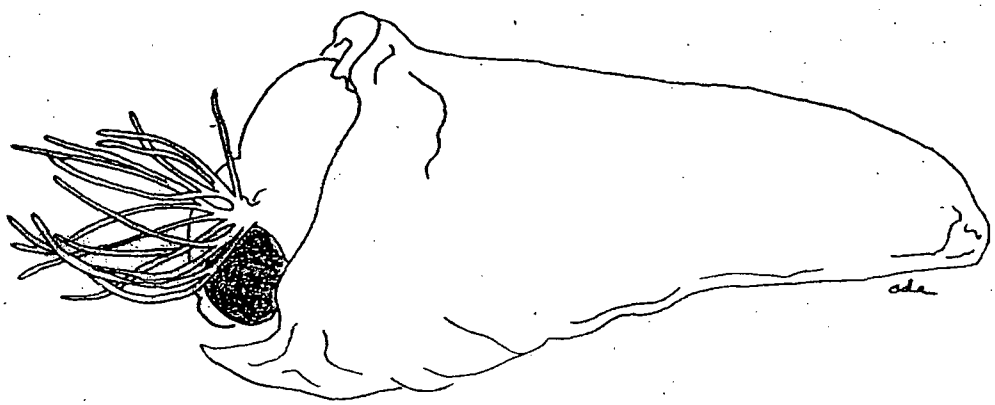


Fig. 17-2 Simuliidae pupa

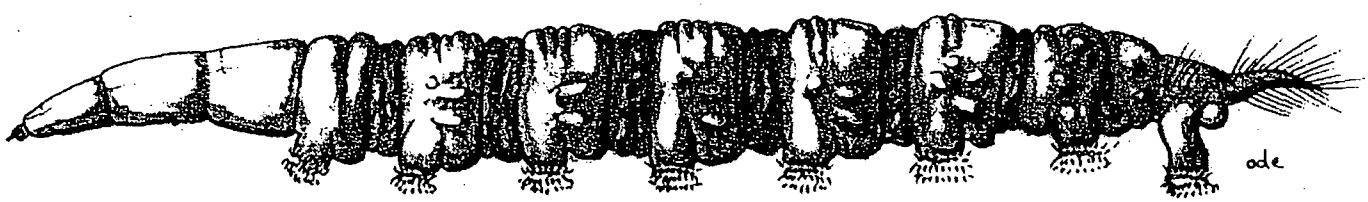


Fig. 17-3 Athericidae

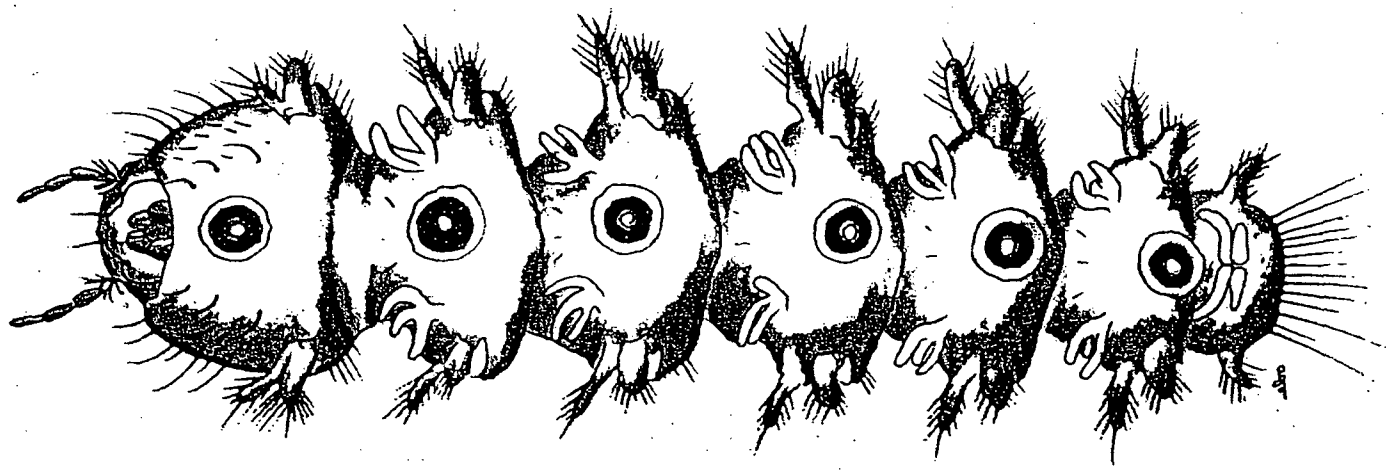


Fig. 17-4 Blephariceridae

Fig. 17-5 Ceratopogonidae

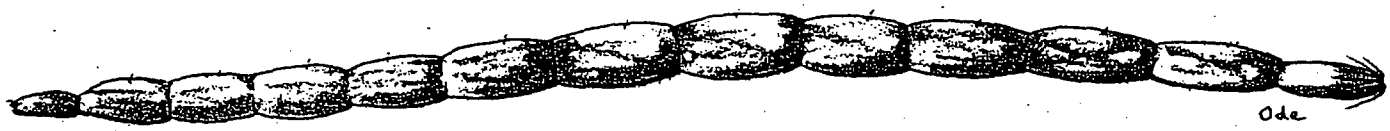


Fig. 17-6 Ceratopogonidae

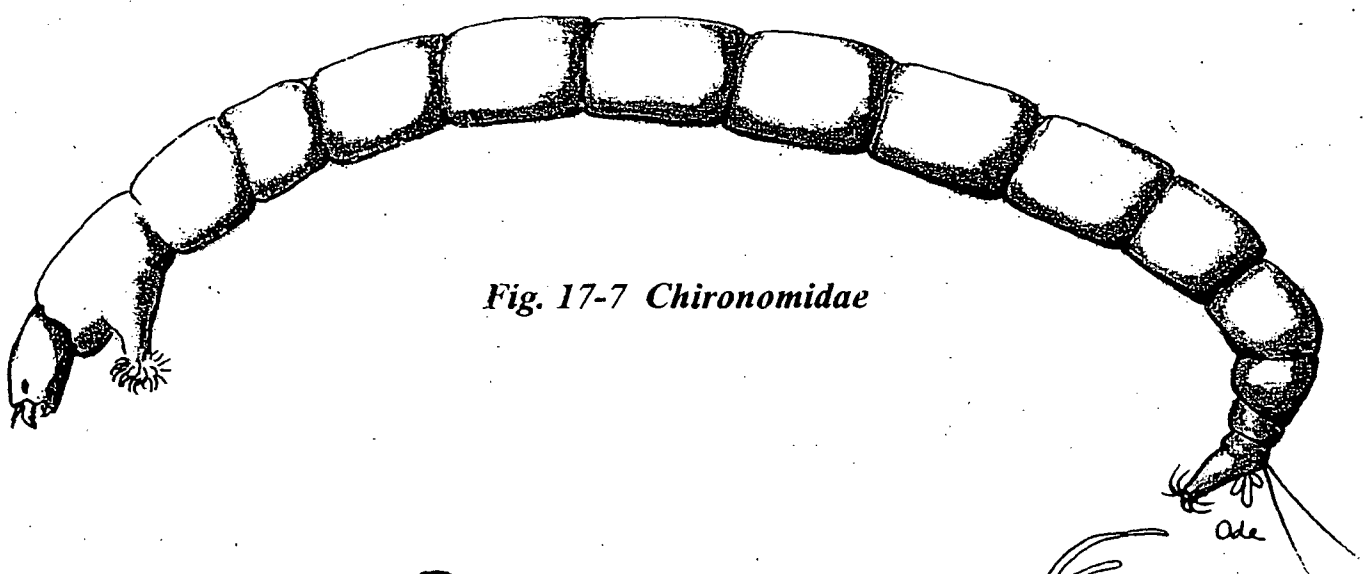


Fig. 17-7 Chironomidae

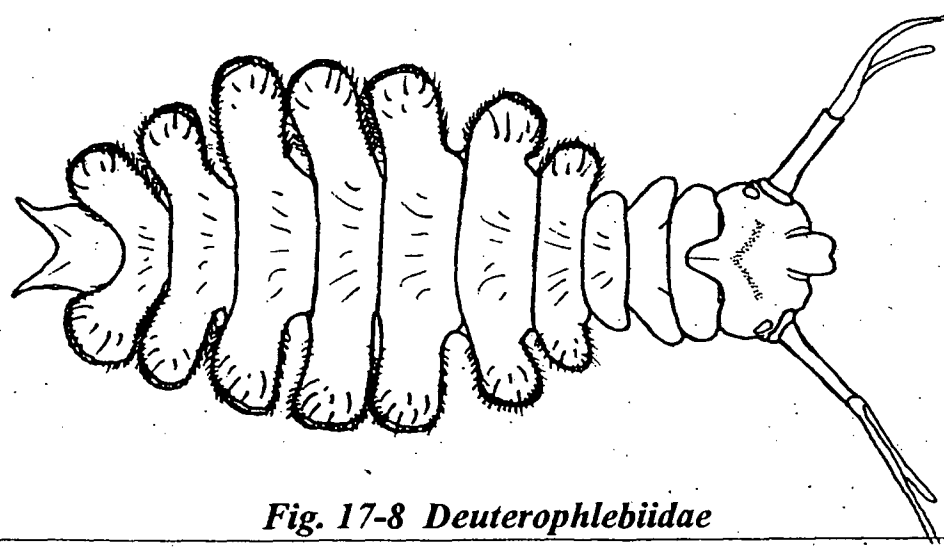


Fig. 17-8 Deuterophlebiidae

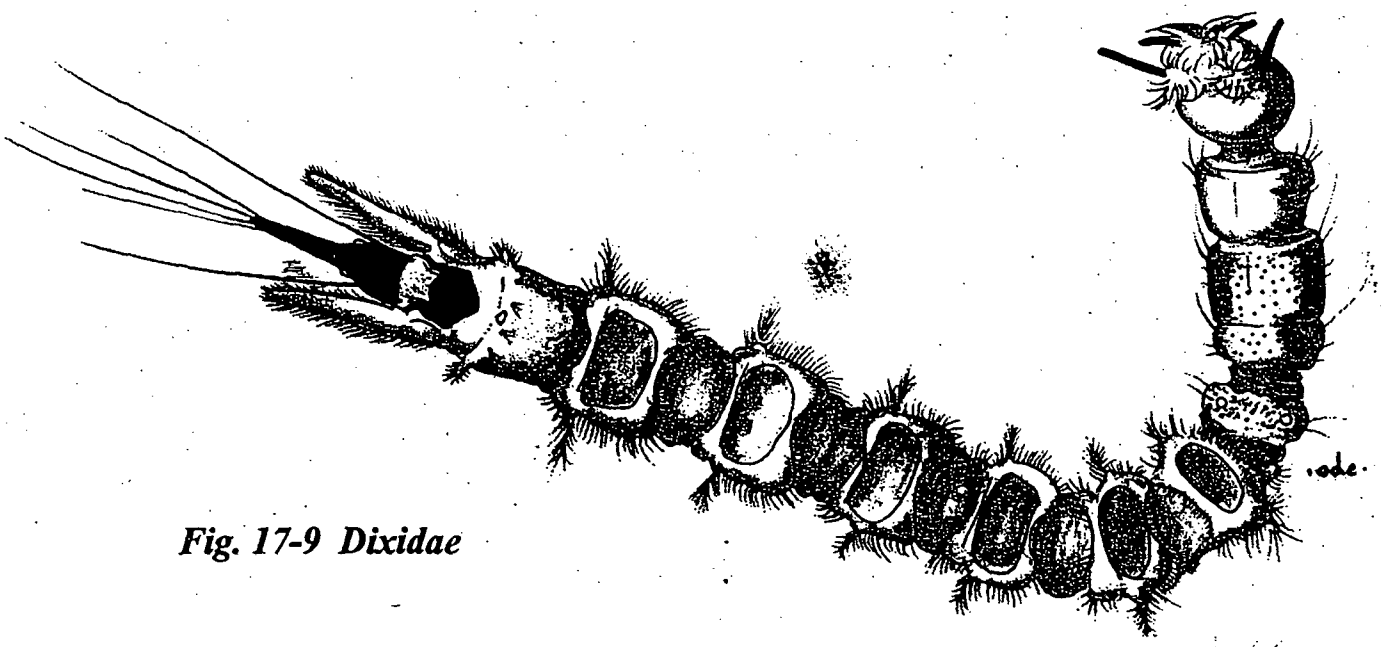


Fig. 17-9 Dixidae

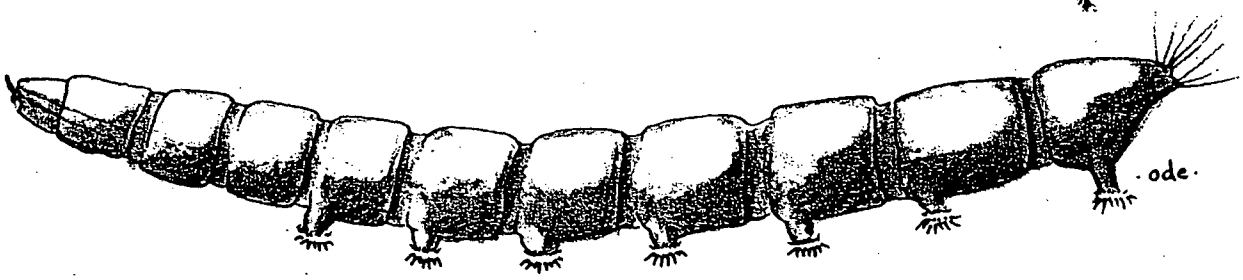


Fig. 17-10 Empididae

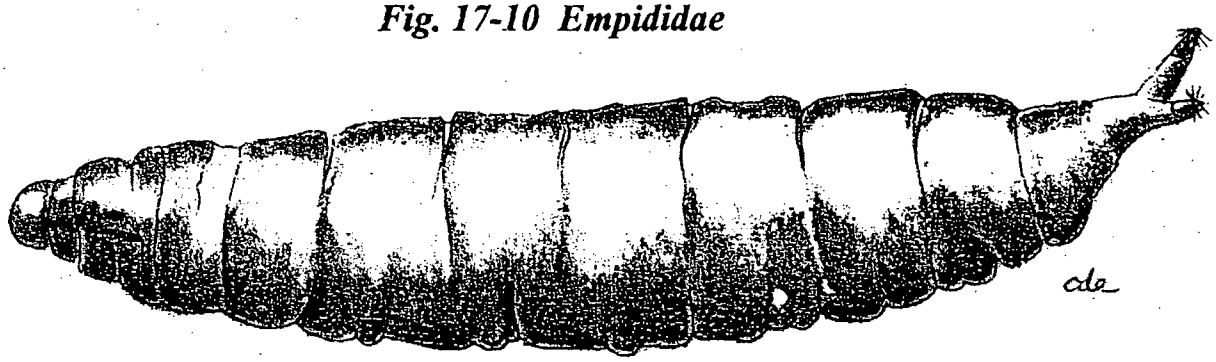


Fig. 17-11 Ephydridae

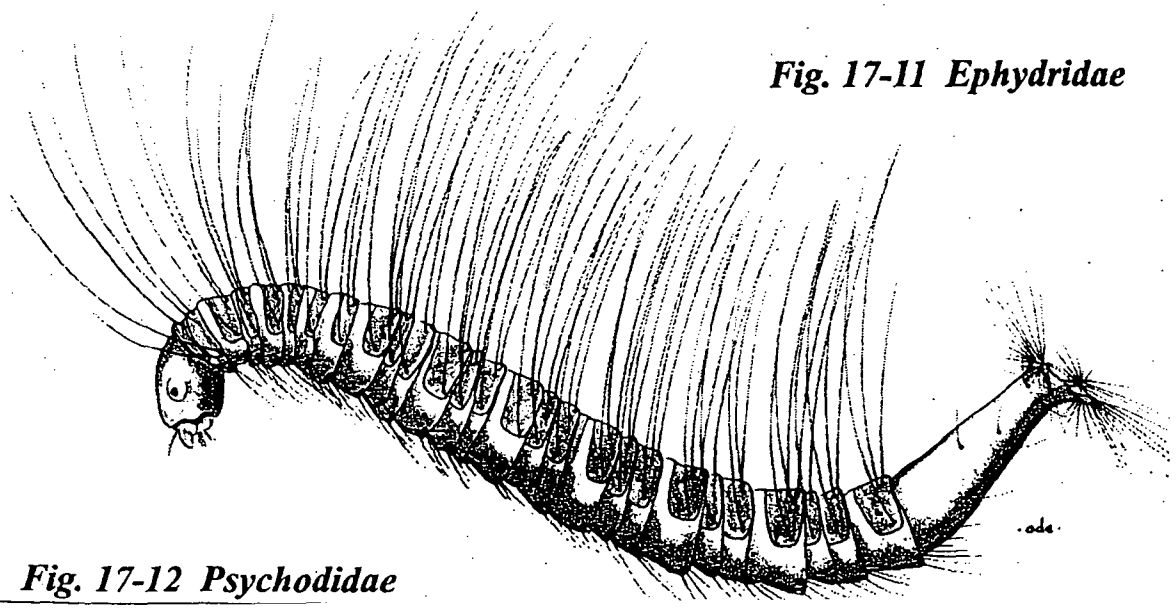


Fig. 17-12 Psychodidae

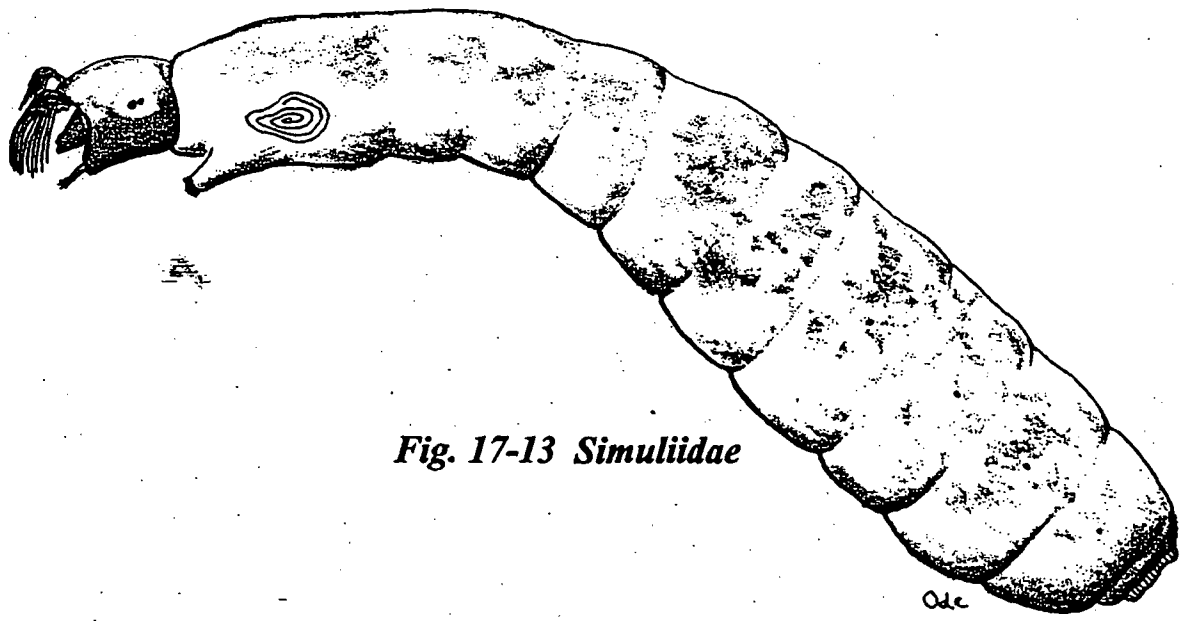


Fig. 17-13 Simuliidae

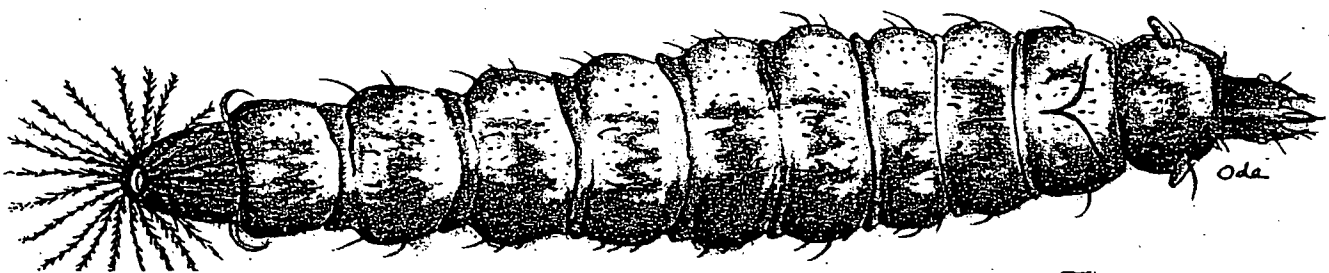


Fig. 17-14 Stratiomyidae

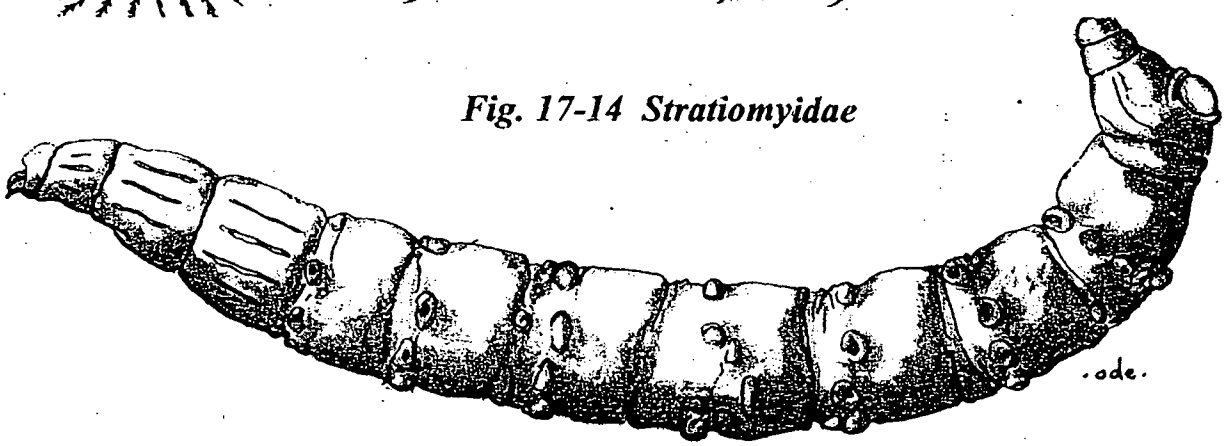


Fig. 17-15 Tabanidae

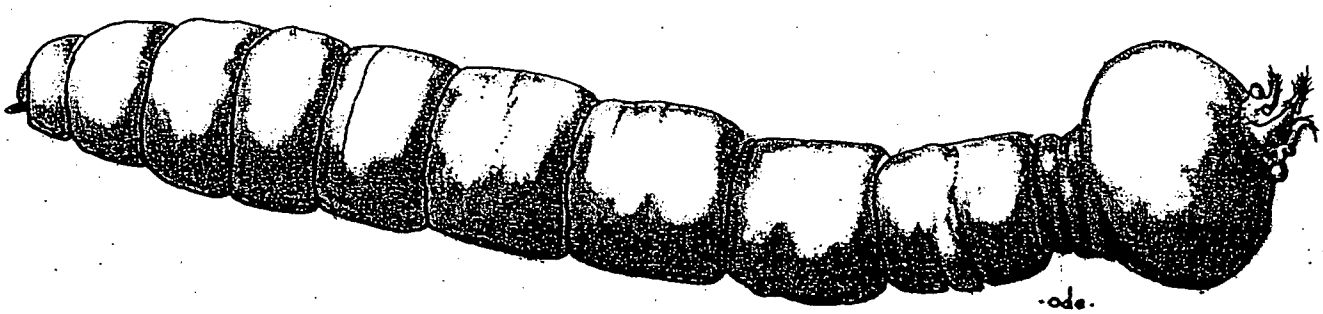


Fig. 17-16 Tipulidae

Chapter 18
Description and Taxonomic Keys to the Families of Other Aquatic Insects (Orders: Coleoptera, Odonata, Hemiptera, Megaloptera, and Lepidoptera) Common to Western Streams and Rivers

Aquatic Beetles (Order: Coleoptera)

Introduction to the Aquatic Beetles

The beetles (Order: Coleoptera) are the most species-rich insects with more than 30,000 species in North America. Only 3% or about 1,100 of those species spend all or part of their life in the aquatic environment. Beetles are a recently evolved group of insects and as a result, have evolved and adapted to many different aquatic situations. Some families are all aquatic, some are aquatic as either adults or larvae, and some families of beetles are semiaquatic. Adult beetle taxonomy was identified many years ago and with some recent revisions, most species can be identified. On the other hand, many larval forms are still a mystery to taxonomists. To date, many species and even genera cannot be identified with confidence. Of the 18 families of beetles in North America that have aquatic stages, 10 are commonly found in western streams and rivers. (***Table 18-1***).

Morphological Characteristics

Adult aquatic beetles have hard oval or elongated body shapes with shell-like wings covering most of it (see **Figures 18-1, 18-2 and 18-3**). They have a typical beetle shape which most people are familiar with. Adult beetles can be very small or quite large, ranging in size from 1 to 40 mm. The only other group of aquatic invertebrates that can be confused with adult aquatic beetles are the true bugs (Order: Hemiptera). They can be separated by observing the hard wing cover that meets along the midline of the body in beetles and the leathery wings that overlap in the true bugs. The antennae become an important feature in separating the adults of the various families of beetles. In examining the antennae, you have to be careful not to confuse them with the maxillary palps. The palps can be long and segmented like an antenna, but the actual antennae are often tucked back on the side of the head.

Table 18-1. Families of aquatic beetles (Order: Coleoptera) found in western streams and rivers in either adult, larvae or both forms.

Amphizoidae	Adult only
Dryopidae	Adult only
Dytiscidae	Adult and Larvae
Elmidae	Adult and Larvae
Gyrinidae	Larvae only
Haliplidae	Adult and Larvae
Helophoridae	Adult only
Hydraenidae	Adult only
Hydrophilidae	Adult and Larvae
Psephenidae	Larvae only

Larval aquatic beetles have a variety of sizes and shapes. They all have a unique look that is nothing like the adults. The most difficult part of the taxonomic keys involves counting the number of segments in the legs which can be small and hard to see. Fortunately, there are not that many larval beetles that will be found in streams. The two most common are the water penny (Family: Psephenidae) and the riffle beetle (Family: Elmidae) which look totally different from each other. The most common confusion people have with larval

aquatic beetles and other groups of aquatic invertebrates is mistaking riffle beetles for caddisfly larvae (Order: Trichoptera). The best way to tell the difference is to recognize the hard body of the elmids compared to the softer body of the caddisfly.

Life History

Beetles go through complete metamorphosis, having larval, pupal and adult stages. The larvae of aquatic beetles live for one to two years and put on most of their growth during the summer. Some need to visit the surface of the water for air and others have gills and remain in the benthos. You will almost never find a beetle pupa in the water because, with very few exceptions, pupation occurs totally in the terrestrial environment. When the adults emerge, they disperse by flying to different streams or different parts of the same stream. Some adult beetles will leave the stream to fly to new areas, but most will remain in the water until they mate and lay eggs, most often in the water as well.

Importance as Biological Indicators

As a group, aquatic beetles are one of least important environmental indicators. Except for the family Amphizoidae, which has a tolerance value of 1, beetle families are all given a value of 4 or 5. The beetles that are given a tolerance value of 4 are the ones commonly found in stream riffles and are more dependent on high levels of dissolved oxygen. The amphizoids are sensitive to levels of dissolved oxygen and temperature and are only found in high mountain streams.

Aquatic Beetle Families Common to Western Riffles

Most entomology books report 18 North American families of beetles. The keys in this manual include 10 families which can be encountered when sampling riffle environments in western streams and rivers. There are two sets of keys; one for larvae and one for adults. Do not separate larvae and adults when assigning them to a family.

Family: Amphizoidae - The family Amphizoidae is represented by only one North American genus, *Amphizoa*, which can be found in western streams and rivers, most commonly in the adult form. Adults of the genus *Amphizoa* are relatively large (12 to 14 mm) and broad, with a narrow thorax and no swimming hairs on their legs (***Figure 18-1***). The only other larger adult beetles which *Amphizoa* could be confused with are members of the families Hydrophilidae and Dytiscidae. Members of both these families can be separated from *Amphizoa sp.* by the presence of swimming legs that are usually flat and hairy.

Members of the family Amphizoidae are known as "trout-stream beetles" because they are found only in mountain streams. Both larvae and adults live primarily in the margin of the stream where they crawl around on the substrate. The larvae cannot swim and the adults swim poorly, but will venture into the riffles looking for stoneflies which are their primary food source. The larvae also prey on stoneflies, but rarely leave the stream margins. The life cycle of *Amphizoa* is about one year. Since *Amphizoa.* are restricted to mountain streams with cool, highly oxygenated water, they are considered intolerant of water pollution.

Family: Dryopidae - The family Dryopidae is represented by five North American genera, only one of which can be found in western streams and rivers, most commonly in the adult form. Dryopid adults are relatively small (4 to 10 mm) with a somewhat elongated shape. They are similar to adult members of the families Elmidae, Hydrophilidae and Hydraenidae which are best separated by the shape of their antennae. Dryopids are somewhat larger than elmids and have antennae with comb-like clubs. (***Figure 18-4***)

Adult members of the family Dryopidae are found in streams and rivers where they crawl in the substrate and woody debris. The larvae

are restricted to the terrestrial environment so you will not see them in riffle samples. Dryopids shred coarse particulate organic matter and are considered herbivores. Little is known of their life cycle, but they probably have one generation a year. They are considered moderately tolerant of water pollution.

found in the same streams. They can be separated by the large sickle-shaped, toothless mandibles of the dytiscids and the toothed mandibles of the hydrophilids.

Adult and larvae of the family Dytiscidae are referred to as "predacious diving beetles" because they are adept predators with good

Tolerance Value and Functional Feeding Group Designation for Aquatic Beetle Families with Common Riffle Species

Family	Tolerance Value	Functional Feeding Group
Amphizoidae	1	Predator (P)
Dryopidae	5	Shredder (SH)
Dytiscidae	5	Predator (P)
Elmidae	4	Collector Gatherer (CG)
Gyrinidae	5	Predator (P)
Haliplidae	5	Shredder (SH)
Helophoridae	5	Shredder (SH)
Hydraenidae larva	-	-
Hydraenidae adult	-	Herbivore (H)
Hydrophilidae	5	Predator (P)
Psephenidae	4	Scraper (SC)

Family: Dytiscidae - The family Dytiscidae is the largest family of aquatic beetles with more than 500 North American species in 44 genera. However, only 11 genera can be found in western streams and rivers as both larvae and adults. Dytiscid adults can range in length from 2 to 40 mm. They have an oval, streamlined body with flat, hairy hind swimming legs. The larvae can range in length from 3 to 60 mm. They have an elongated body with long legs and two tails or terminal processes (***Figure 18-5***). Dytiscid adults could be confused with members of the family Haliplidae which also have hairy swimming hind legs. They can be separated by the large plates that cover most of the hind legs of haliplids, but are not present in dytiscids. The larvae could be confused with stonefly larvae which have two tails at the end of the body. Fortunately, the two insects are rarely found in the same areas. Dytiscid larvae could also look similar to members of the beetle family Hydrophilidae which are more commonly

swimming abilities. They can be found in all types of aquatic habitats, but are most common in still water environments. The few species found in streams and rivers are usually associated with marginal slack-water areas. However, there are a couple of genera commonly found in riffles. The dytiscid life cycle lasts between one and two years, and like most beetles is moderately tolerant of water pollution.

Family: Elmidae - The family Elmidae is represented by 26 North American genera, 12 of which can be found in the western streams and rivers as both larvae and adults. Elmid adults are relatively small (1 to 8 mm) with a typical oval shape (***Figure 18-2***). The larvae are about the same size, and have an elongated, hard body with a ventral operculate opening at the terminal end of the body (***Figure 18-6***). They usually have small hooks and filamentous gills coming from the terminal opening. Elmid adults are similar to adult members of the families

Dryopidae, Hydrophilidae and Hydraenidae and are best separated by the shape of their antennae. Elmid adults are smaller than dryopids and have slender antennae which are sometimes clubbed (***Figure 18-4***), but never have a comb-like club like the dryopids. Elmid larvae are most often mistaken for caddisfly larvae because of their similar shape. They are distinguished by having a hard body compared to the soft abdomen of the caddisflies.

Adults and larvae of the family Elmidae are referred to as "riffle beetles" because they are found in the riffles of both small cold water streams and larger warm water rivers. They crawl over the rock and gravel substrate eating algae, decaying wood and detritus. They are by far the most abundant type of beetle found in riffle samples. The larvae can live in the stream for up to two years, but most complete the cycle in less than a year. As with all beetles they pupate in the terrestrial environment. When the adults emerge, they can fly considerable distances to find water, but once they enter the stream, they never fly again. The adults normally live for another one or two years. They are considered moderately tolerant of water pollution.

Family: Gyrinidae - The family Gyrinidae is represented by four North American genera, two of which can be found in the west. Although adults and larvae are aquatic, we only concern ourselves with the larval form. The larvae are elongated with lateral filaments on the abdominal segments and four terminals hooks. Gyrinid larvae can be confused with other beetle larvae with lateral filaments such as members of the family Hydrophilidae. They can be separated by the terminal hooks found only on the gyrinids.

Adults and larvae of the family Gyrinidae can be found in the same habitat including streams and rivers, but the adults are only found in the surface water. The adults are adapted to live on the water surface having two pairs of eyes for seeing above and below the surface. They can swim underwater, but are not part of the benthos. The larvae are found in the riffle substrate where they prey on other insects. Most species have a one year life cycle with the adults overwintering and the larvae growing during the summer. They are considered moderately tolerant of water pollution.

Family: Haliplidae - The family Haliplidae is represented by four North American genera, three of which can be found in the western streams and rivers as both larvae and adults. Haliplid adults (***Figure 18-3***) are small (2-6 mm,) with an oval body shape and lightly hairy swimming hind legs which are partly covered by large plates. The larvae are elongated with 9 to 10 abdominal segments. The larvae can have lateral filaments or terminal processes. The adults can be confused with other small beetle adults, but haliplids are the only ones with large plates covering the hind legs. The larvae can be confused with the family Gyrinidae because they both can have lateral filaments on long abdomens. They can be separated by the legs with two claws present on Gyrinidae and one claw on Haliplidae. Additionally, haliplids do not have have terminal hooks.

Adults and larvae of the family Haliplidae can be found on rocky bottoms of streams and rivers and crawling and swimming near vegetation. They are herbivores which feed on algae and aquatic plants. They typically have a one-year life cycle. The adults usually overwinter in the water, but have been known to crawl out and stay in moist vegetation for most of the winter. They are considered moderately tolerant of water pollution.

Family: Helophoridae - The family Helophoridae is represented by one North American genus, *Helophorus* which can be found in western streams and rivers, most commonly as adults. This family used to be a subfamily within the family Hydrophilidae. The *Helophorus* adults are similar to the hydrophilids and can be separated by the unique structure of the

pronotum which has five longitudinal grooves.

Helophorus sp. adults are found in the riffles and margins of streams and rivers where they crawl around debris, filamentous algae or aquatic vegetation. They are shredders and typically have a one year life cycle. They are considered moderately tolerant of water pollution.

Family: Hydraenidae - The family Hydraenidae is represented by four North American genera, three of which can be found in western streams and rivers, most commonly as adults. Hydraenid adults are minute (usually <2 mm,) with a typical oval shape. They are similar to adult members of the families Elmidae, Hydrophilidae and Dryopidae which are best separated by the shape of their antennae. Hydraenids are smaller than the dryopids and elmids and have a five-clubbed segment at the end of the antennae (*Figure 18-4*).

Adult members of the family Hydraenidae are found along the margins of streams and rivers where they crawl around tangled roots, debris, filamentous algae or vegetation such as moss. They cannot swim and are probably more semi-aquatic than truly aquatic. When they are disturbed from the substrate, they float upside-down on the water surface. They can be found in riffle samples, especially in streams with a lot of marginal vegetation. Because of their minute size, they are not well-studied and as a result, there is virtually no information on their life history and feeding habits.

Family: Hydrophilidae - The family Hydrophilidae is the second largest family of aquatic beetles with more than 250 North American species in 26 genera. However, only 11 genera occur in the west with just one common genera, Berosus, commonly found in streams and river as both larvae and adults. Hydrophilid adults can range in length from 1 to 40 mm with a typical oval shape. The larvae are elongated ranging in length from 4 to 60 mm. The eight-segment abdomen is soft, sometimes appearing wrinkled and usually with lateral filaments (*Figure 18-7*). Hydrophilid adults are similar to adult members of the families Dryopidae, Elmidae and Hydraenidae which are best separated by the shape of their antennae. Hydrophilid adults are usually larger than the other three and have antennae with five clubbed segments (*Figure 18-4*). Hydrophilid larvae can be similar to members of the family Dytiscidae which are more commonly found in the same streams. They can be separated by the large sickle-shaped, toothless mandibles of the dytiscids and the toothed mandibles of the hydrophilids.

Adult and larvae of the family Hydrophilidae are predominantly still water organisms, but some will be found in streams and rivers. The adults of some species are good swimmers and frequently fly, sometimes in mass. They are attracted to light and can be found swarming around light fixtures on a warm summer night. Larvae and some adults not adapted to swimming crawl around on rocks and vegetation. The larvae and most adults are predators. They typically have a one-year life cycle. The larvae grow during the summer and the adults overwinter, usually in the water. Individuals have been observed crawling out and staying in moist vegetation for most of the winter. They are considered moderately tolerant of water pollution.

Family: Psephenidae - The family Psephenidae is represented by five North American genera, four of which can be found in western streams and rives, most commonly in the larval form (*Figure 18-8*). The larvae are referred to as "water pennies" because of their somewhat flattened and oval shape. The head, legs, and gills (when present) of the larvae cannot be seen from the top side (*Figure 18-8*). They are unique and cannot be confused with any other beetle or any other aquatic invertebrate.

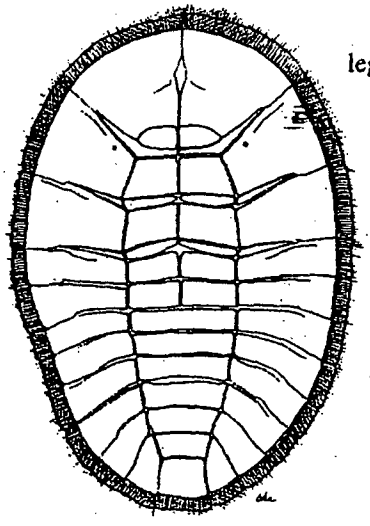
Larvae of the family Psephenidae can be found primarily in the riffle areas of streams and rivers. Next to riffle beetles (Family: Elmidae), the water pennies are the most

common beetles in stream riffles. They attach themselves to the rocks and crawl around scraping off the periphyton as a food source. Larvae pupate just above the waterline and the adults are strictly terrestrial, living in the stream's riparian zone. Most species have a one to two-year life cycle. They have the same pollution tolerance value as the elmids because they are associated with the highly oxygenated riffles and are more dependent on dissolved oxygen uptake through gills. They are considered slightly less tolerant of water pollution than most of the other beetle families.

Taxonomic Keys to the Families of Beetles (Order: Coleoptera)

COLEOPTERA LARVAE

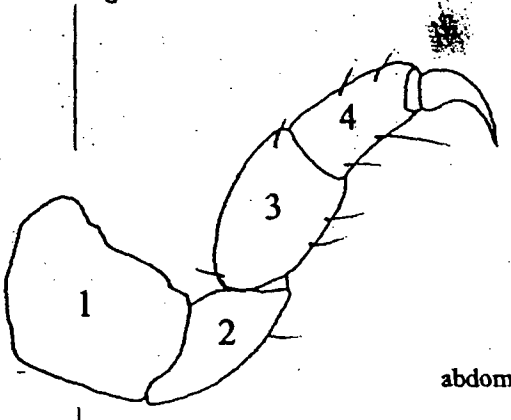
body oval and flat; head not visible from top side.



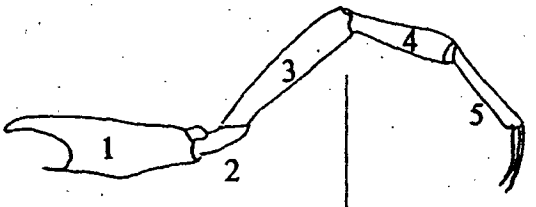
Psephenidae

body not oval and flat

legs with 4 segments



legs with 5 segments.



abdomen with 9-10 segments

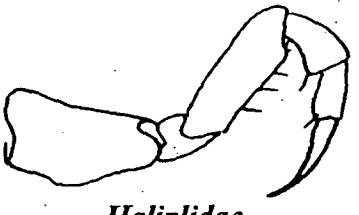
abdomen with 8 segments

Dytiscidae

2 claws; lateral filaments on abdominal segments; 4 terminal hooks

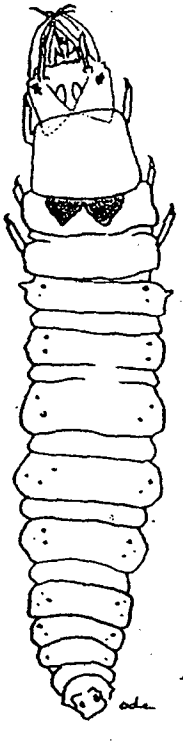
Gyrinidae

1 claw; abdomen with or without filaments; no terminal hooks



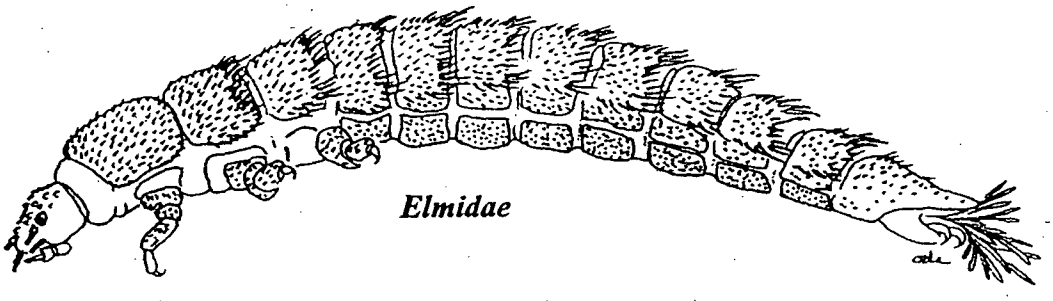
Haliplidae

abdomen with 8 segments; body usually soft



Hydrophilidae

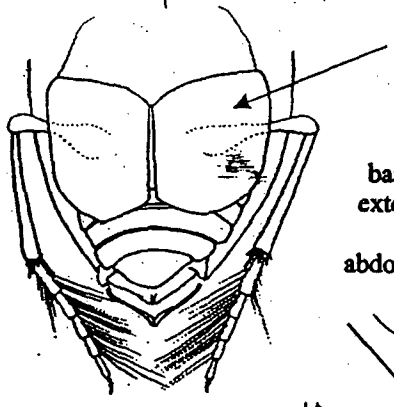
abdomen with 9 segments; body hard



Elmidae

COLEOPTERA ADULTS

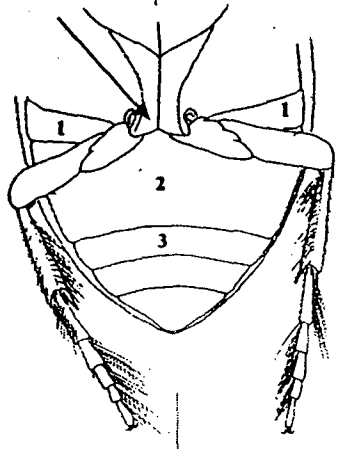
large plates covering much of hind legs



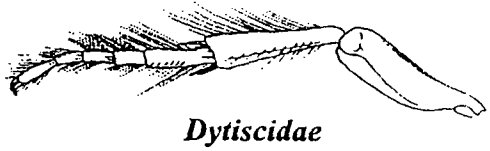
Haliplidae

no plate covering hind legs

base of hind legs extend posteriorly dividing abdominal segment 1

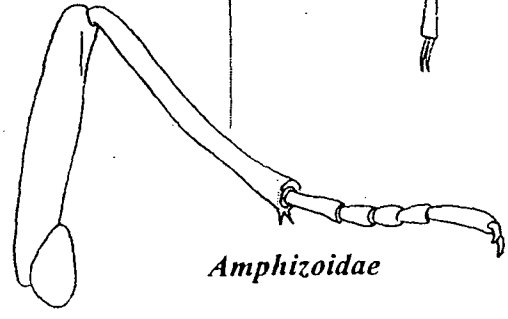


hind legs flattened and with long hairs



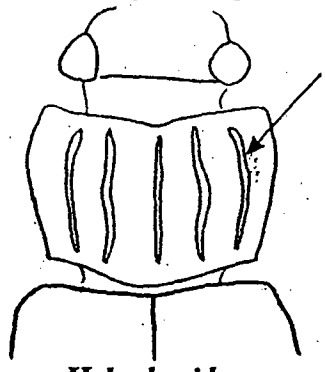
Dytiscidae

hind legs not flattened and without long hairs



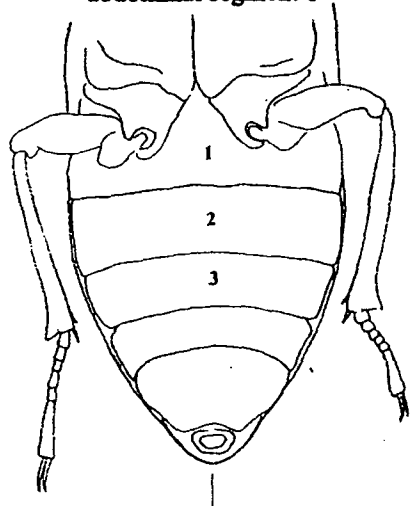
Amphizoidae

pronotum with 5 longitudinal grooves

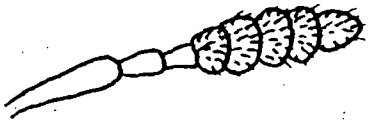


Helophoridae

base of hind legs do not divide abdominal segment 1

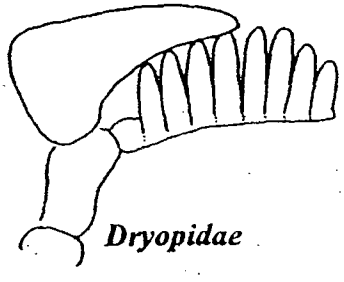


antennae with 5 clubbed segments



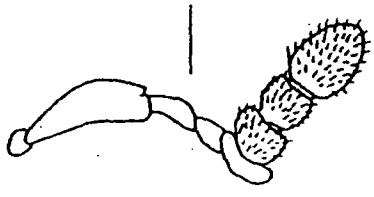
Hydraenidae

antennae with comb-like club



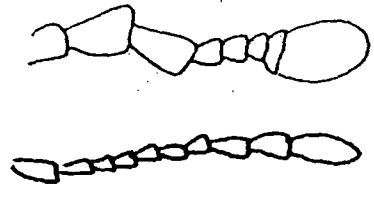
Dryopidae

antennae with 3 clubbed segments



Hydrophilidae

slender antennae; with or without clubbed segments



Elmidae

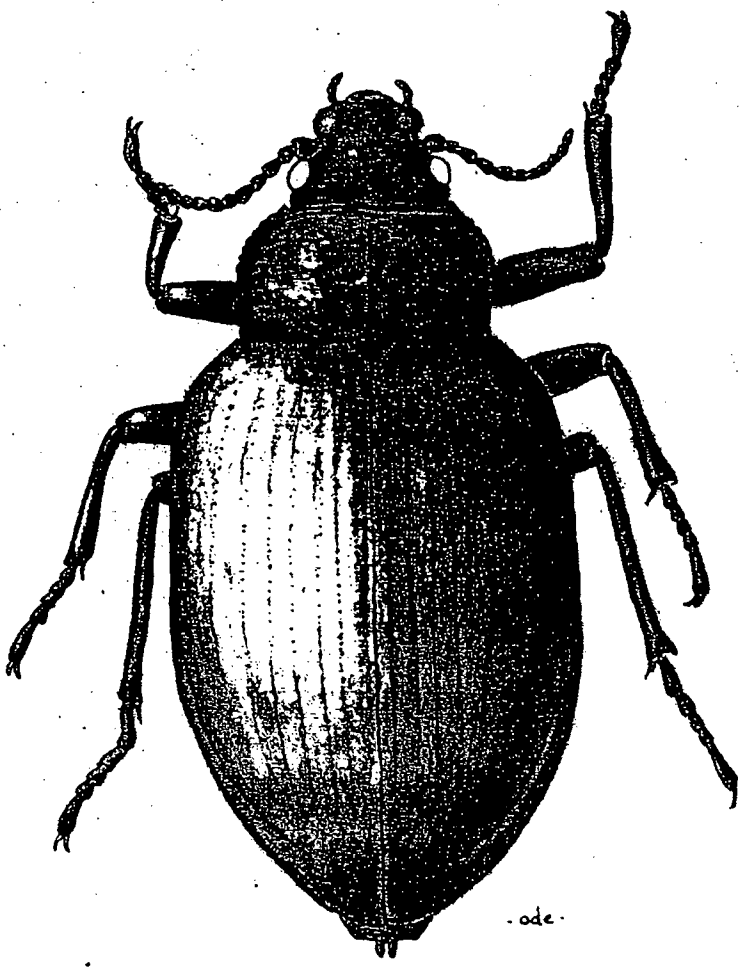


Fig. 18-1 Amphizoidae

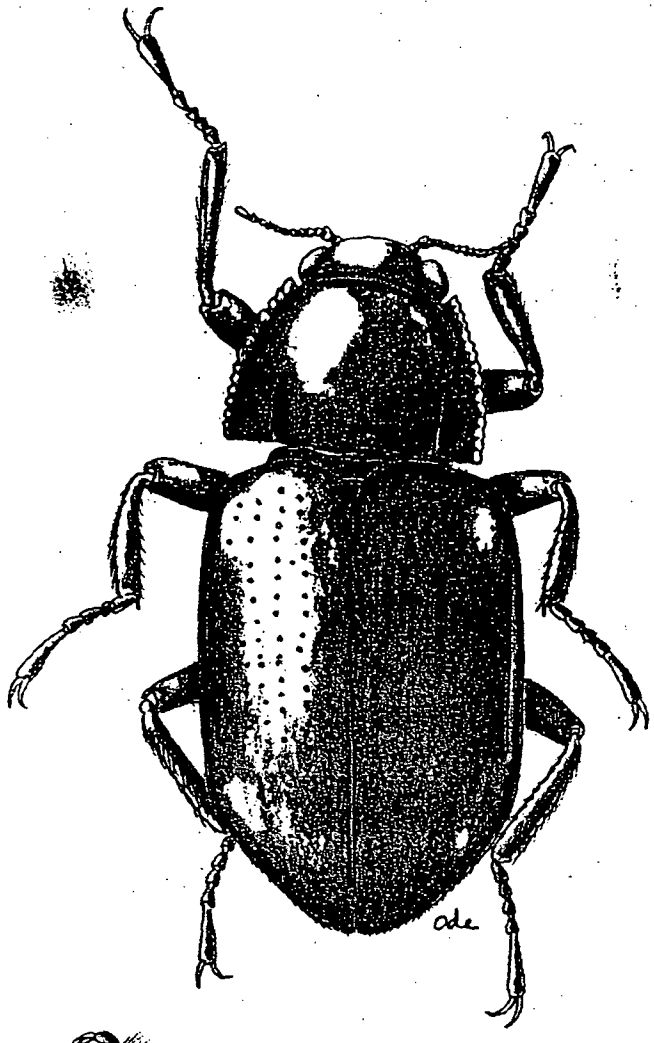


Fig. 18-2 Elmidae

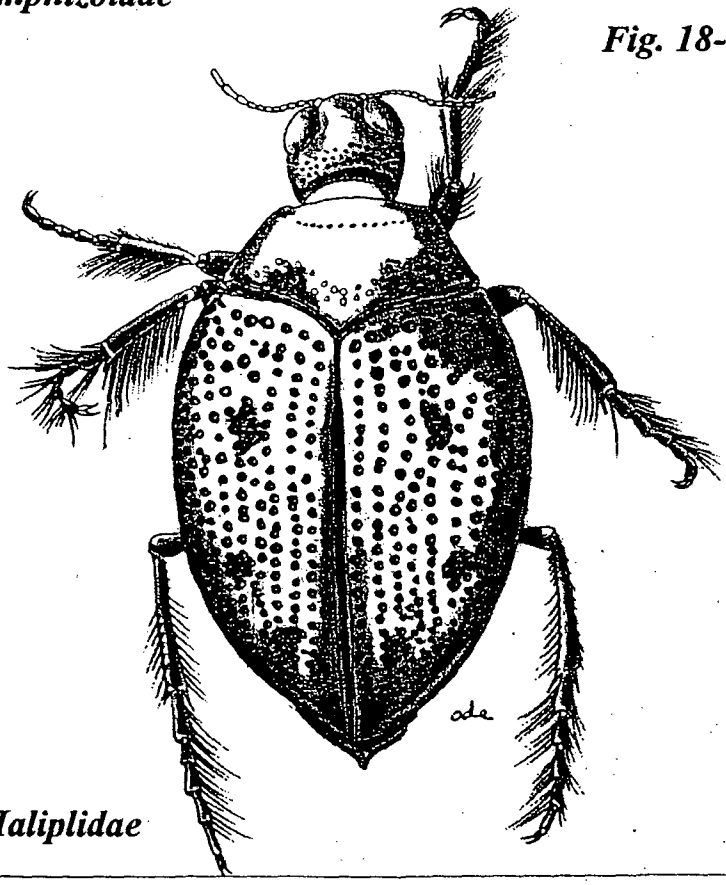


Fig. 18-3 Haliplidae

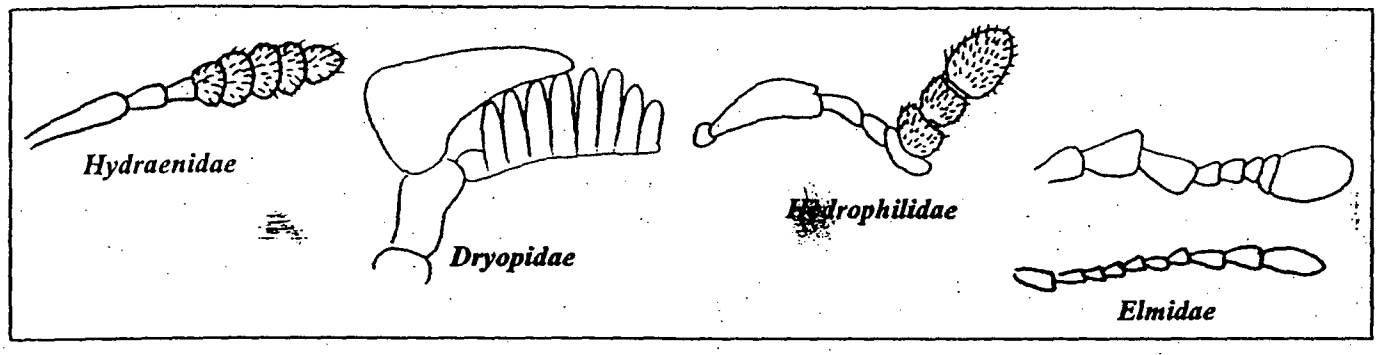


Fig. 18-4 Variously shaped antennae

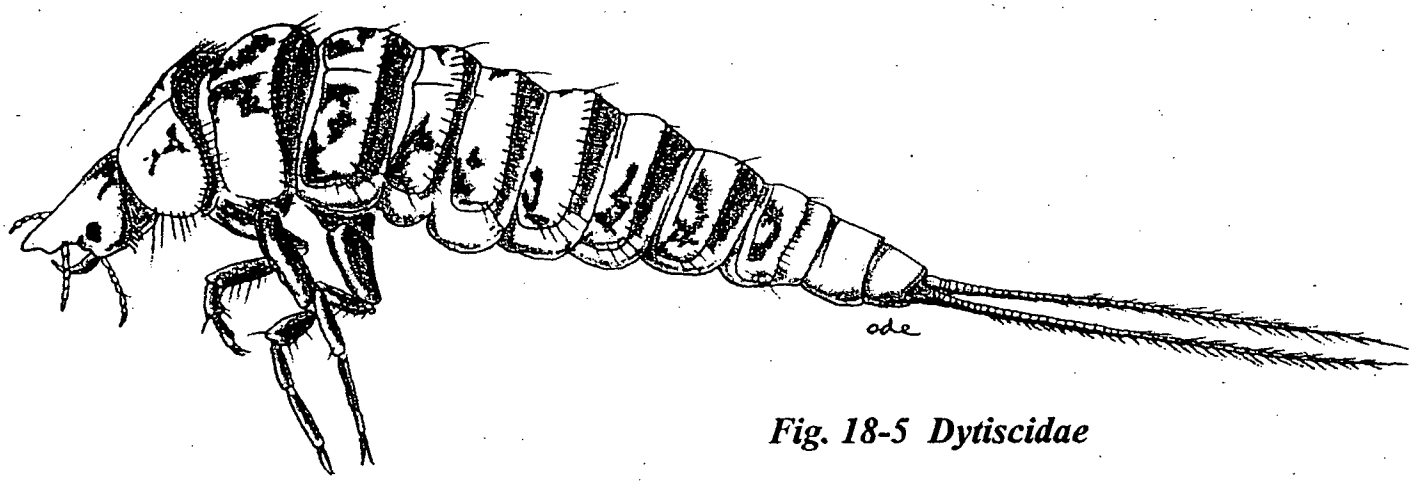


Fig. 18-5 Dytiscidae

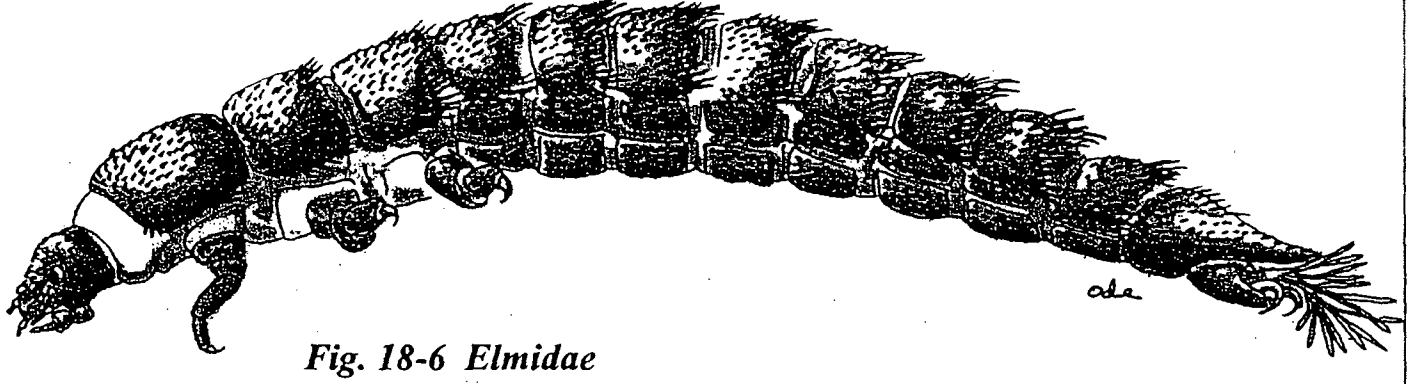


Fig. 18-6 Elmidae

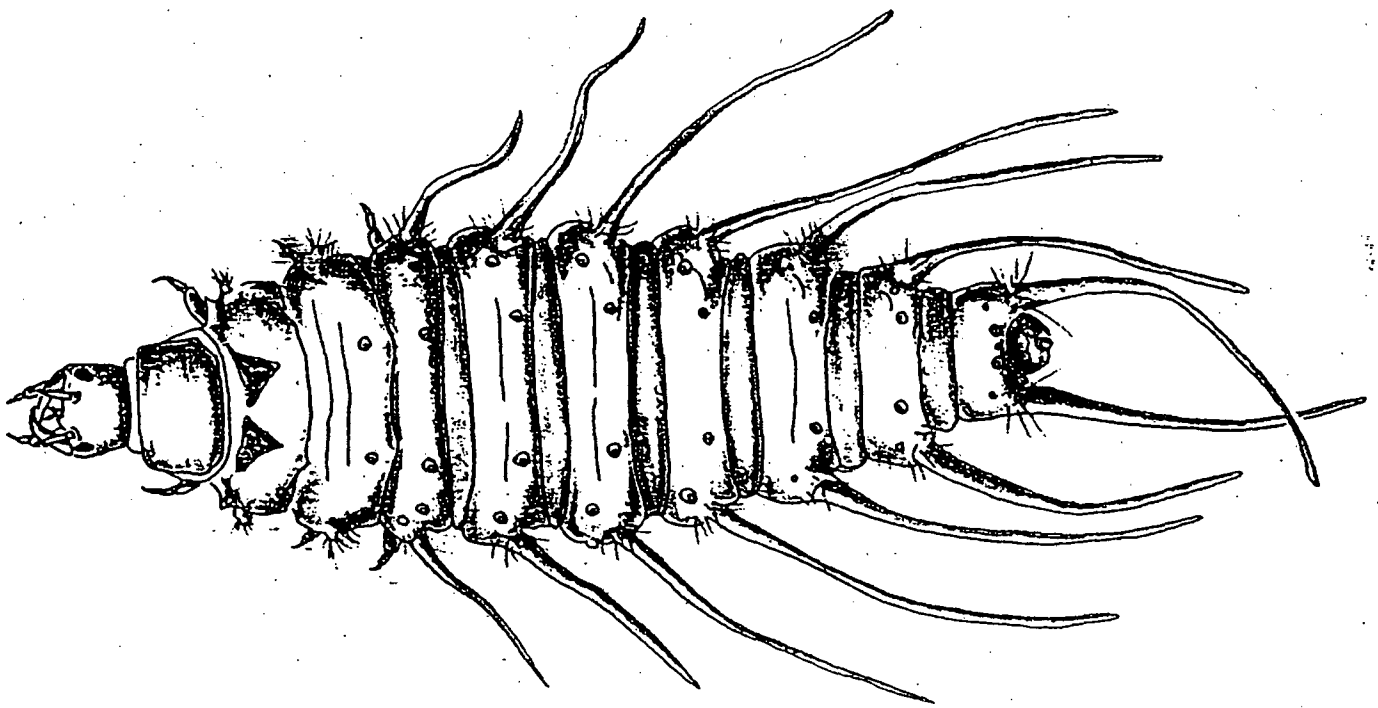


Fig. 18-7 Hydrophilidae

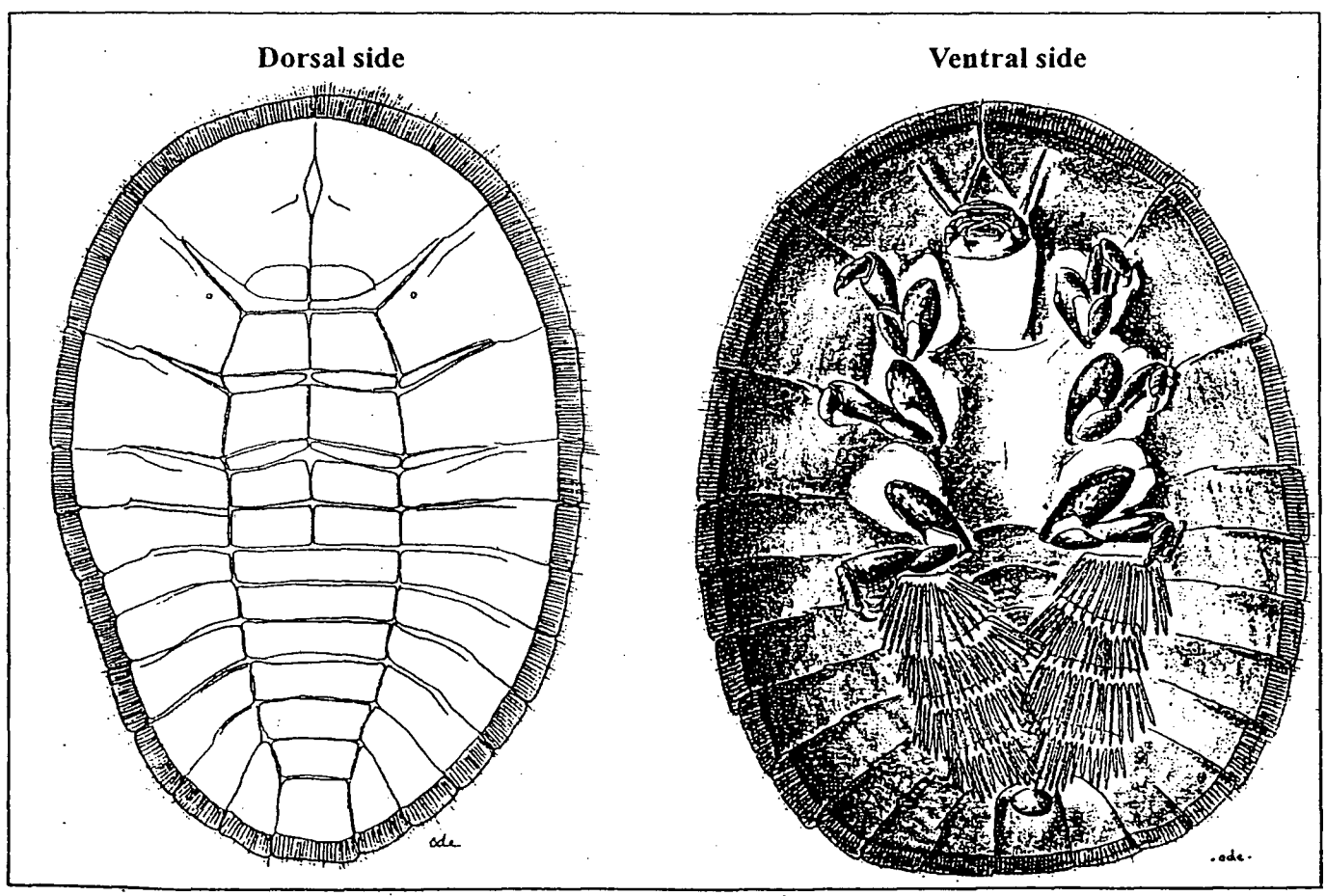


Fig. 18-8 Psephenidae

Dragonflies and Damselflies (Order: Odonata)

Introduction to the Dragonflies and Damselflies

Dragonflies and damselflies (Order: Odonata) are a very primitive group of insects that, at least in the adult form, are familiar to most people. There are 415 North American species in two distinct suborders: Anisoptera (dragonflies) and Zygoptera (damselflies). The larvae of all species of odonates are aquatic with roughly two-thirds of the species being found in still water environments and one-third in running water environments. Larvae are more commonly referred to as nymphs or naiads. Adult odonates can live for several weeks or months, flying considerable distances from the water. They are excellent flyers and voracious predators that capture their prey in flight. They can consume a significant number of pest insects, including mosquitos, which makes them beneficial to humans.

Morphological Characteristics

Most odonate nymphs have elongated bodies that can range from 10 to 60 mm. Dragonflies (Suborder: Anisoptera) are more robust than the damselflies (Suborder: Zygoptera) which tend to be slender. Another difference between the dragonflies and damselflies is in the terminal end which has three leaf-like gills on damselflies and three short triangular shaped structures on dragonflies. All odonates have visible wingpads and a modified mouth part (labium) that is used to capture prey. The labium is either flat or scoop-shaped with a hinged stock (**Figure 18-9**). When not in use, and usually always in preserved specimens, it covers the ventral side of the head and is described as mask-like. Odonates can be confused with other insects only in the very small early life stages. On closer examination, even with the smaller specimens, the mask-like labium is distinctive and unlike any other invertebrate.

Life History

Odonates go through incomplete metamorphosis, having only a nymph and adult form. The nymphs of dragonflies and damselflies live for one to four years and only a very few species have more than one generation per year. All odonate nymphs are predators, crawling around on the substrate searching for prey. The nymphs crawl out of the water onto a vertical object to emerge as adults. The adults usually live for several weeks or months, feeding on other insects and traveling great distances from the water before mating. They can have elaborate mating habits during which females choose the best territories for egg-laying around the edges of water, and males fight to control the best territories.

Importance as Biological Indicators

Odonates vary greatly in their tolerance of pollution. Although none are considered intolerant, some of the dragonflies are slightly sensitive, being given a tolerance value of 3. Damselflies tend to be more tolerant of polluted waters than dragonflies, and because of the terminal gills can live in waters with low levels of dissolved oxygen. In California, the damselfly *Argia* (Family: Coenagrionidae) is often found in some of the most polluted water where very little else can survive.

Tolerance Value and Functional Feeding Group Designation for Dragonfly and Damselfly Families with Common Riffle Species

	Tolerance Value	Functional Feeding Group
Suborder: Anisoptera		
Aeshnidae	3	Predator (P)
Cordulegastridae	3	Predator (P)
Corduliidae	5	Predator (P)
Gomphidae	4	Predator (P)
Libellulidae	9	Predator (P)
Suborder: Zygoptera		
Calopterygidae	5	Predator (P)
Coenagrionidae	9	Predator (P)
Lestidae	9	Predator (P)

Dragonfly and Damselfly Families Common to Western Streams

Most entomology books report 11 North American families of dragonflies and damselflies. The keys in this manual include the following 8 families which can be encountered when sampling riffle environments in western streams and rivers.

Dragonflies (Suborder: Anisoptera)

Family: Aeshnidae - The family Aeshnidae is represented by 11 North American genera, only two of which can be found in western streams and rivers. Aeshnid nymphs are large (20 to 40 mm) with elongated tapered abdomens (***Figure 18-10***). They have a flat labium (***Figure 18-9***) and thin, 6 or 7-segment antennae. The only other dragonfly nymphs that can be confused with the aeshnids are members of the family Gomphidae which also have a flat-shaped labium. They can be separated by the antennae which have 4 segments and are much larger than the gomphids.

Nymphs of the family Aeshnidae burrow into sand, mud, gravel, or the debris on the bottom of streams and rivers. They prefer slower moving water, but can be found in riffles. The life cycle of the aeshnids can be two to four years, especially in colder areas. They are considered fairly sensitive to water pollution.

Family: Cordulegastridae - The family Cordulegastridae is represented by only one North American genus, *Cordulegaster*, which can be found in western streams and rivers. *Cordulegaster* nymphs have a large (30 to 35 mm) elongated and hairy body. They have a spoon- shaped labium (***Figure 18-9***) with large and jagged labial teeth. There are two other families of dragonflies, Corduliidae and Libellulidae, with a spoon-shaped labium. They can be separated from *Cordulegaster* by the labial teeth which are moderate and even (Family: Corduliidae) or small or absent (Family: Libellulidae).

Cordulegaster nymphs usually live in small, forested streams where they sit on the bottom of pools or slack water waiting to ambush their prey. Instead of hiding in burrows, they camouflage themselves by squirming into the silt until they are covered. Although they prefer slack water, they are often picked up in riffle samples. The life cycle of *Cordulegaster* can be three to four years. They are considered fairly sensitive to water pollution and are quite often restricted to mountain streams.

Family: Corduliidae - The family Corduliidae is represented by nine North American genera, two of which can be found in western streams and rivers. Corduliids are

medium-sized (30 to 35 mm) nymphs with a broad and hairy body. They have a spoon-shaped labium (***Figure 18-9***) with moderate and even-sized labial teeth. There are two other families of dragonflies, Cordulegastridae and Libellulidae, with a spoon-shaped labium. They can be separated from corduliids by the labial teeth which are large and jagged in the family Cordulegastridae or small or nearly absent in the family Libellulidae. It can be difficult to recognize the difference between the shape of the labial teeth in corduliids and libellulids and these characteristics should not be used to differentiate families.

Most members of the family Corduliidae live in still water environments, but there are a few species that can be found in streams and rivers of all sizes. They live in vegetation and debris where they prey on other insects. The life cycle of corduliids can be two to four years. They are considered moderately sensitive to water pollution.

Family: Gomphidae - The family Gomphidae is represented by 13 North American genera, seven of which can be found in western streams and rivers. Many gomphid nymphs are large (20 to 40 mm) with short and broad abdomens (***Figure 18-11***). They have a flat labium (***Figure 18-9***) and large, 4-segment antennae. The only other dragonfly nymph that can be confused with the gomphids are members of the family Aeshnidae which also have a flat labium. They can be separated by observing the antennae, which have 6 to 7 segments and are slender in the aeshnids.

Nymphs of the family Gomphidae partially burrow into sand, mud, gravel, or debris on the bottom of streams and rivers. They prefer slower moving water, but can be found in riffles. The life cycle of the gomphids can be two to four years, especially in colder areas. They are considered moderately sensitive to water pollution.

Family: Libellulidae - The family Libellulidae is represented by 26 North American genera of which only one or two can be found in western streams and rivers. Libellulids are small to medium-sized (8 to 28 mm) sized nymphs with a short and broad body. They have a spoon shaped labium (***Figure 18-9***) with small or no labial teeth. There are two other families of dragonflies, Cordulegastridae and Coruliidae, with a spoon-shaped labium. They can be separated from libellulids by observing the labial teeth which are large and jagged in the family Cordulegastridae, or moderate and even in the family Corduliidae. It can be difficult to recognize the difference between the shape of the labial teeth in libellulids and corduliids.

Most members of the family Libellulidae live in still water environments, but there are a few species which can be found in streams and rivers, usually in the slack water areas. They live in vegetation and debris where they prey on other insects. Except for some pond species that can have more than one generation a year, the typical life cycle of libellulids is two or more years. They are considered tolerant of water pollution.

Damselflies (Suborder: Zygoptera)

Family: Calopterygidae - The family Calopterygidae is represented by two North American genera, *Calopteryx* and *Hetaerina*, both of which can be found in western streams and rivers. Calopterygid nymphs have elongated (25 to 50 mm) slender bodies with long stilt-like legs (***Figure 18-12***). Their three terminal gills are long and slender with the middle gill shorter than the other two. They are distinguished from the other two damselfly families by their antennae. The first segment of the antenna is considerably longer than the other segments, sometimes longer than all the other segments combined (***Figure 18-13***).

Nymphs of the family Calopterygidae live exclusively in streams and rivers of all sizes. They crawl around on the vegetation near the banks and in accumulated debris preying on other insects and small fish. The life cycle of the calopterygids is one to two years. They are considered moderately sensitive to water pollution.

Family: Coenagrionidae - The family Coenagrionidae is represented by 13 North American genera, four of which can be found in western streams and rivers. Coenagrionid nymphs are relatively small (10 to 25 mm) and slender (***Figure 18-14***). Their three terminal gills are usually broad, leaf-like and pointed. They are distinguished from the calopterygids which have short, slender antennae and from lestids which have a labium with a long, narrow stalk (***Figure 18-15***).

Most members of the family Coenagrionidae live in still-water environments, but of the four genera which can be found in streams and rivers, the genus *Argia* is most common. They live on vegetation, rocks and debris where they prey on other insects. The life cycle of coenagrionids is one to two years. They are considered water pollution tolerant. *Argia* is often found in some of the most polluted water where very little else can survive.

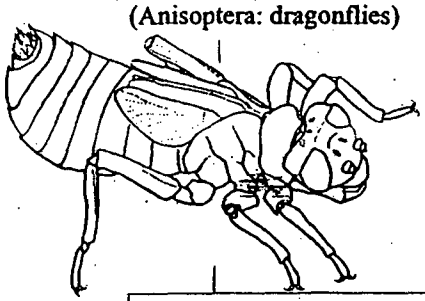
Family: Lestidae - The family Lestidae is represented by two North American genera, one found only in still water environments and the other, *Archilestes,* which can be found in western streams and rivers. *Archilestes* nymphs are long (20 to 30 mm) and slender. Their three terminal gills are usually slim and somewhat leaf-like. They are distinguished from the calopterygids by the antennae which are slender and have equal-sized segments. *Archilestes* can be separated from the members of the family Lestidae because they have a unique labium with a long and narrow stalk (***Figure 18-15***).

Archilestes can be found in streams and rivers, usually in the marginal areas where it moves around the vegetation and debris looking for prey. *Archilestes* has a one year life cycle. It is considered water pollution tolerant.

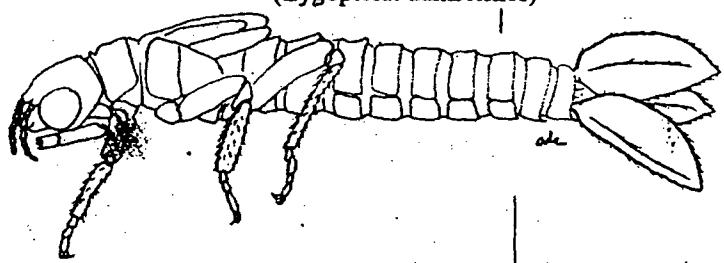
Taxonomic Keys to the Families of Dragonflies and Damselflies (Order: Odonata)

ODONATA LARVAE

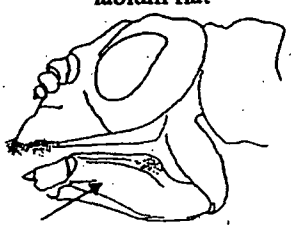
body robust; no gills at end of body
(Anisoptera: dragonflies)



body slender & long; 3 long broad gills at end of abdomen
(Zygoptera: damselflies)



labium flat

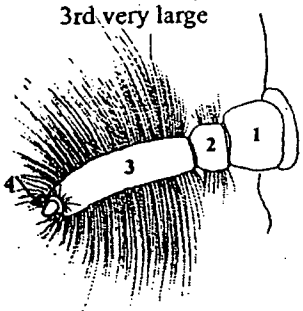


labium spoon-shaped

antennae segment 1 very long

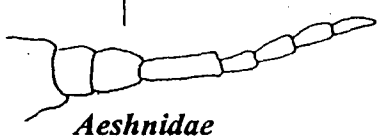
antennae segment 1 same as others

antennae with 4 segments; 3rd very large

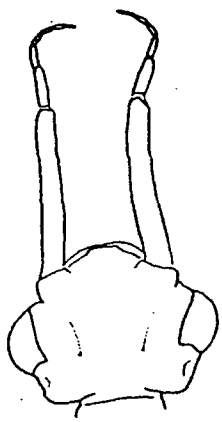


Gomphidae

antennae with 6 or 7 segments, all slender

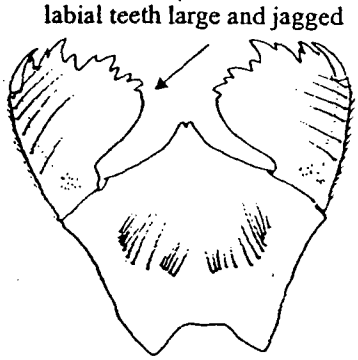


Aeshnidae



Calopterygidae

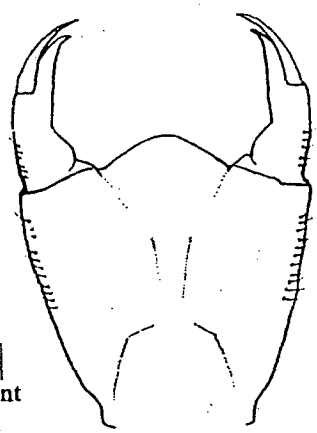
labial teeth large and jagged



Cordulegastridae

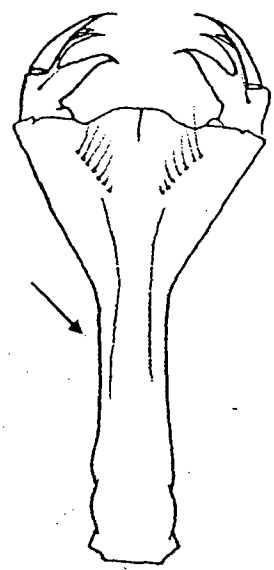
labial teeth not large and jagged

labium without narrow stalk



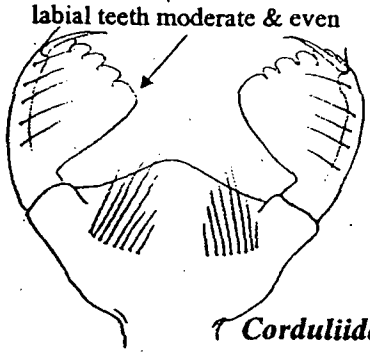
Coenagrionidae

labium with narrow stalk



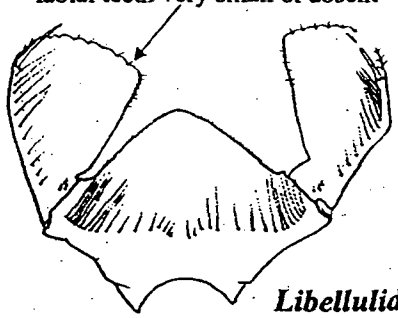
Lestidae

labial teeth moderate & even



Corduliidae

labial teeth very small or absent



Libellulidae

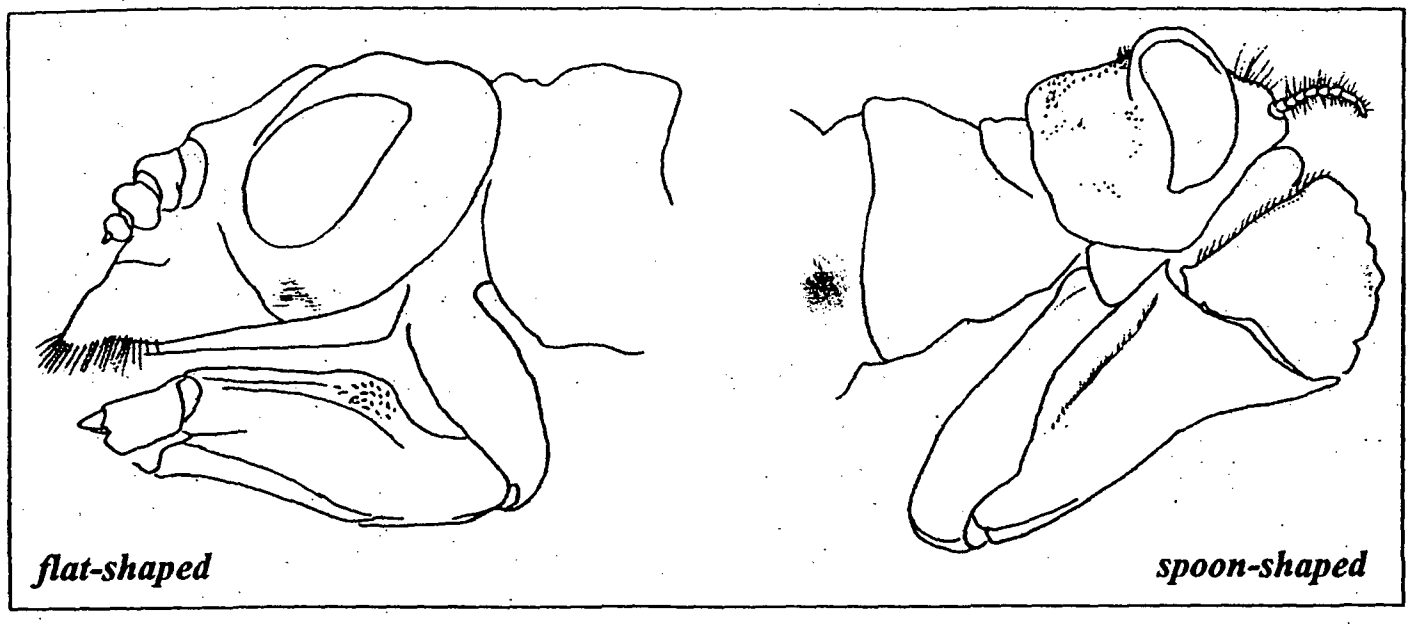


Fig. 18-9 Anisoptera labium

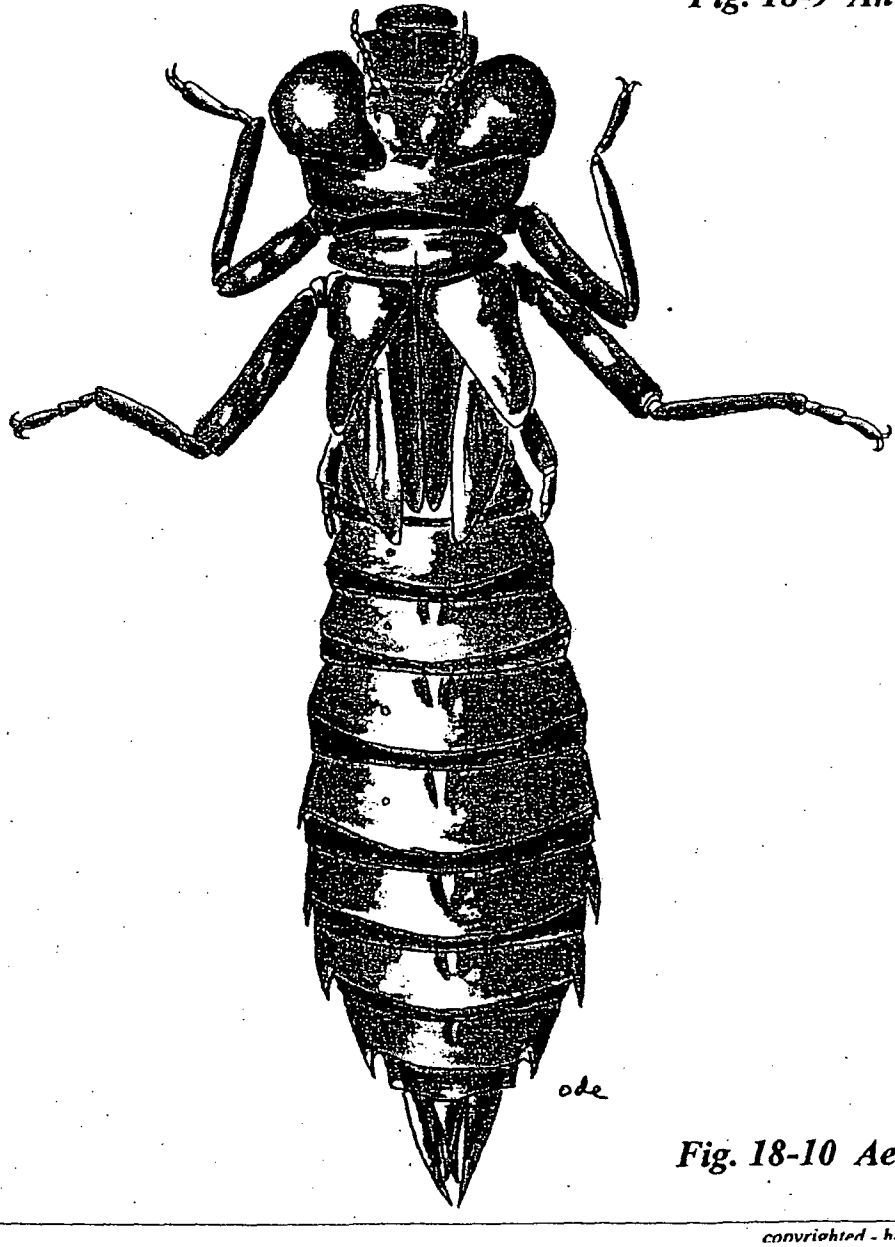


Fig. 18-10 Aeshnidae

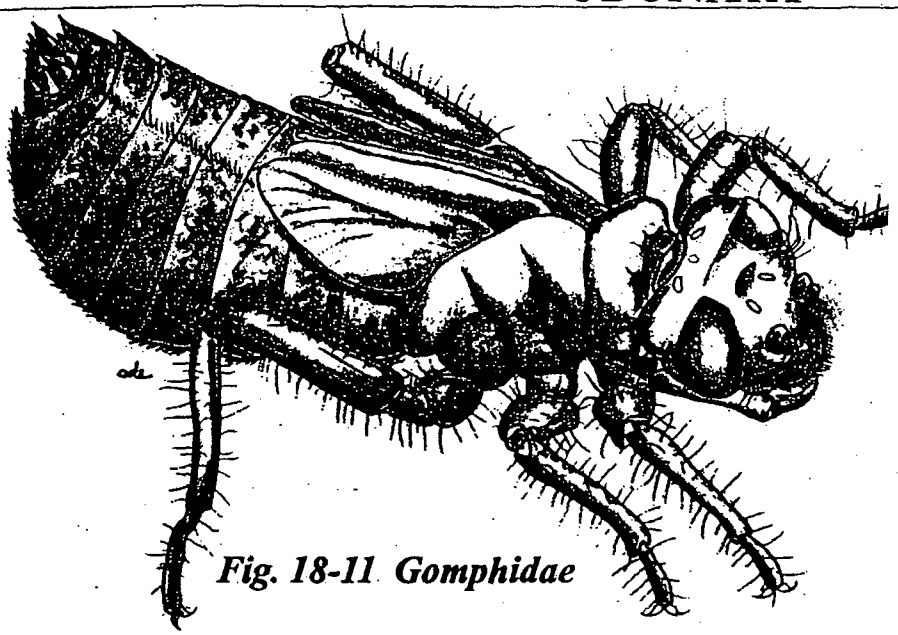


Fig. 18-11 Gomphidae

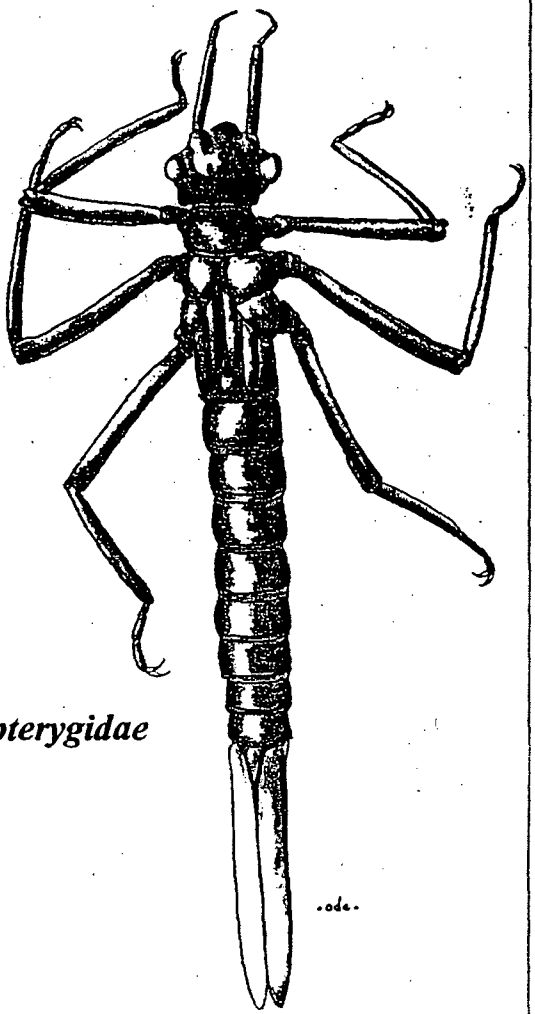


Fig. 18-12 Calopterygidae

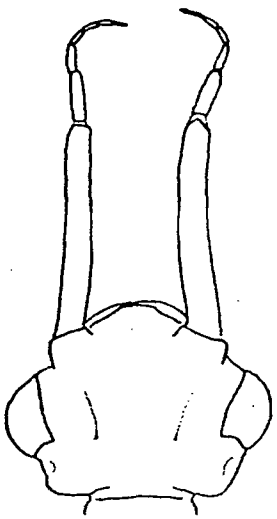


Fig. 18-13 Calopterygidae antennae

Fig. 18-14 Coenagrionidae

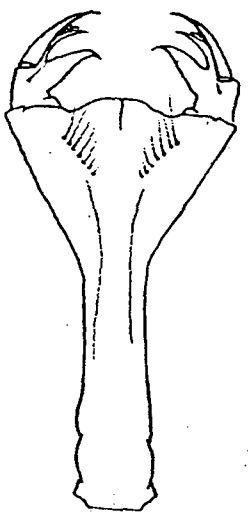


Fig. 18-9 Lestidae labium

True Bugs (Order: Hemiptera)

Introduction to the True Bugs

The order Hemiptera is referred to as "true bugs". As a group, they are primarily terrestrial insects with about 300 aquatic species in North American representing only 8% of all hemipterans. About two-thirds of aquatic bug species live in the water and the other third walk on the water surface and should be considered semi-aquatic. Most aquatic members of the order Hemiptera live in still water environments. They are all predators with a voracious appetite. They eat so much that they can have an impact on the number of organisms living in the same water body, especially small ponds. One of their morphological characteristics is their piercing-sucking mouth parts. They eat primarily other insects, but some larger specimens will target fish. The Giant Water Bug (Order: Belostomatidae) is also referred to as "toe biter" because it is known to grab hold of a human toe, mistaking it for a juicy fish.

Morphological Characteristics

Adult and larva hemipterans have similar appearance. They are oval to elongated in shape, ranging in length from 1 to 65 mm. They have well-developed heads with piercing-sucking mouthparts. They have a thorax with a pronotum, three pairs of legs and abdomen. The thorax can be wingless, have poorly developed wings, or as in most cases, have well-developed wings with a leathery wing cover. Some hemipterans have raptorial forelegs which means they are adapted to seize prey by having strong femurs and sharp tarsal claws. The only other group of aquatic invertebrates that can be confused with true bugs are the adult water beetles (Order: Coleoptera). Hemiptera means "half-wing", referring to the half-hard, half membranous first wing, in contrast to the beetles, which have "whole" wings. They can be separated by observing the leathery wings that overlaps in the true bugs and the hard wing cover that meets along the midline of the body in beetles. Both the adults and the larvae have similar morphological characteristics except for the development of the wing.

Life History

Hemipterans go through incomplete metamorphosis, and have a larval stage often referred to as a nymph. The nymphs and adults have the same environmental requirements and are often found together. The life cycle normally is one to two years. Hemipterans obtain oxygen from an air bubble stored under their wing next to their body. They must swim to the surface of the water to restore the air bubble. Aquatic bugs will mate and lay eggs in the water and usually, never leave except to disperse to new water bodies when forced.

Importance as Biological Indicators

Hemipterans breathe atmospheric air and can even escape and fly to other water bodies when necessary. For these reasons, true bugs are considered pollution tolerant. The semi-aquatic species that live on the water surface (which are not included in the keys) are not affected by water pollution except when their food supply disappears.

Tolerance Value and Functional Feeding Group Designation for Hemipteran Families with Common Riffle Species

Family	Tolerance Value	Functional Feeding Group
Belostomatidae	8	Predator (P)
Corixidae	8	Collector Gatherer (CG)
Naucoridae	8	Predator (P)

True Bugs Families with Common to Western Streams

There are 17 families of true bugs, but only three are covered in the keys in this manual.

Family: Belostomatidae - The family Belostomatidae is represented by three North American genera, each of which can be found in western streams and rivers. Belostomatid adults and nymphs are medium to large-sized (20 to 65 mm) with a somewhat flat and oval-shaped body (***Figure 18-16***). The head is distinct and does not fit into the pronotum. The forelegs are raptorial with one or two tarsal claws. The edge of the pronotum closest to the head is relatively even. Belostomatids and naucorids have the same general shape and structure of the fore legs. They can be distinguished from each other by the structure of the head. Naucorids have heads that fit perfectly into the pronotum.

Belostomatids, also known as "toe-biter", can be found in slackwater areas of rivers or in riffles of smaller streams where they swim or crawl around looking for prey. They are all voracious predators which will attack anything including small fish. The adults will frequently fly and are attracted to light. They have a one to two-year life cycle and are considered water pollution tolerant.

Family: Corixidae - The family Corixidae is represented by 18 North American genera, two of which can be found in western streams and rivers. Corixid adults and nymphs are small- sized (3 to 11 mm) with a somewhat flat and elongated body (***Figure 18-17***). The body of a corixid is built to swim. The middle and hind legs are modified to be oar-like with dense swimming hairs and the forelegs are small and scoop-shaped. They can be distinguished from the other hemipterans by their small size, shape and the structure of their legs, and shape of rostrum.

Most corixids can be found in still water environments, but some inhabit slackwater areas of rivers and streams. These species swim, sometimes in large numbers, looking for material to eat. They feed on detritus, algae, protozoans, and other small animals. The adults will frequently fly, occasionaly in extremely large numbers. Corixids are one of the first aquatic invertebrate to inhabit new ponds and temporary pools of water. They have a one-year life cycle and are considered water pollution tolerant.

Family: Naucoridae - The family Naucoridae is represented by four North American genera, of which only one, *Ambrysus*, can be found in western streams and rivers. *Ambrysus* adults and nymphs are small to medium-sized (6 to 15 mm) with a somewhat flat and oval-shaped body (***Figure 18-18.***) The shape of their head is round and fits perfectly into the pronotum. The edge of the pronotum closest to the head is concave, extending along the sides of the head. Naucorids and belostomatids have the same general shape and structure of the fore legs. They can be distinguished from each other by the structure of the head. Belostomatids have a more distinct head that does not fit into the pronotum.

Ambrysus can be found in streams and rivers, creeping and swimming on the bottom of pools and riffles looking for prey. Naucorids carry a large air bubble and usually live in oxygen rich habitats (riffles) so they rarely need to surface for air. Adults have well developed wings, but rarely fly. They have a one year life cycle and are considered water pollution tolerant.

Taxonomic Keys to the Families of True Bugs (Order: Hemiptera)

Fig. 18-16 Belostomatidae

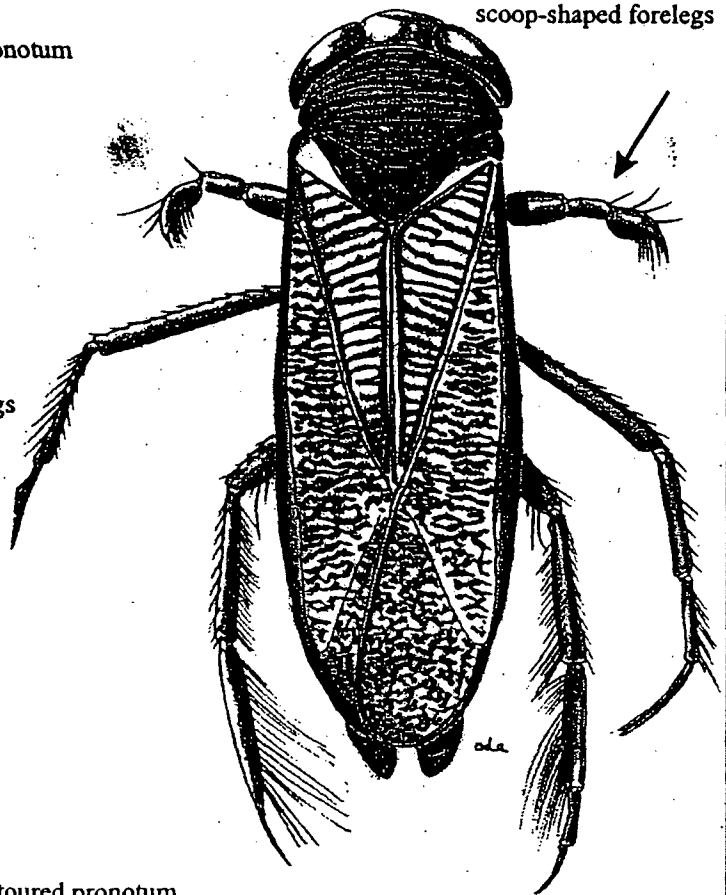


Fig. 18-17 Corixidae

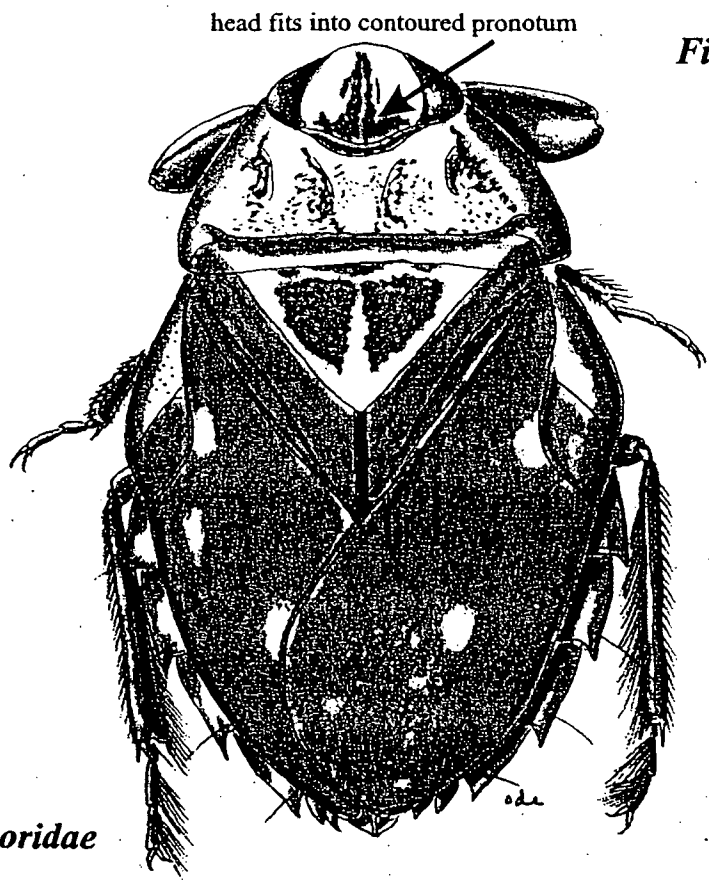


Fig. 18-18 Naucoridae

Hellgrammites and Alderflies (Order: Megaloptera)

Introduction to the Hellgrammites and Alderflies

The order Megaloptera is a small group of strictly aquatic insects consisting of only two families, eight genera and about 50 species. Larvae of the family Corydalidae, referred to as "hellgrammites", are well known to fisherman because they are large and make good bait. They are so familiar that many people call all aquatic insects big enough to be considered bait, hellgrammites. The adults of the family Sialidae, which is much less common, are referred to as alderflies. Megalopterans live primarily in streams and rivers. They are often associated with highly oxygenated waters because they uptake oxygen only through their body surface. All megalopterans have fairly long filaments which help to increase the body's surface area and spiracles (openings used to absorb oxygen) along the side of the body. This enhanced oxygen uptake ability allows some species to leave the water and live in moist areas adjacent to the stream. Using this process, some species can survive in intermittent streams (another reason to protect dry streambeds). They are predators with a voracious appetite. They eat so much that they can have an impact on the number of organisms living in the same water body.

Morphological Characteristics

Megalopteran larvae have a large (10 to 90 mm), elongated and somewhat flattened body. They have relatively large heads with well-developed chewing mouthparts, a thorax with three pairs of legs, and no wing pads. The abdomen has lateral filaments on segments 1-7 or 8 (**Figure 18-19**). The only other groups of aquatic invertebrates that can be confused with megalopterans are some larval species of beetles (Order: Coleoptera - Family: Gyrinidae) that also have lateral filaments. Fortunately, megalopterans are common in riffles and beetles usually inhabit still water environments. Other than that, comparing your specimen to the illustration should work since there is so little variation in megalopteran morphology.

Life History

Megalopterans go through complete metamorphosis including larval, pupal and adult stages. However, unlike other insects that go through complete metamorphosis, the adults and larvae of megalopterans are not distinctly different in appearance. The larval stage can take one to four years. When the larvae are ready to hatch, usually in spring or summer, they leave the water and pupate in the ground or in moist debris fairly close to the stream. The adults only live for a few days and probably do not eat. They are poor flyers, but can crawl or run on the ground quite well. They mate on the ground and lay their eggs on objects above the stream so the larvae can drop into the water when they hatch.

Importance as Biological Indicators

Megalopterans are considered highly to moderately sensitive to water pollution. Corydalids are very sensitive, primarily because they are more associated with cool mountain streams. The species that live in intermittent streams can not tolerate habitat disturbance since they oversummer just below the surface of the dried streambed, or in moist areas of the riparian zone.

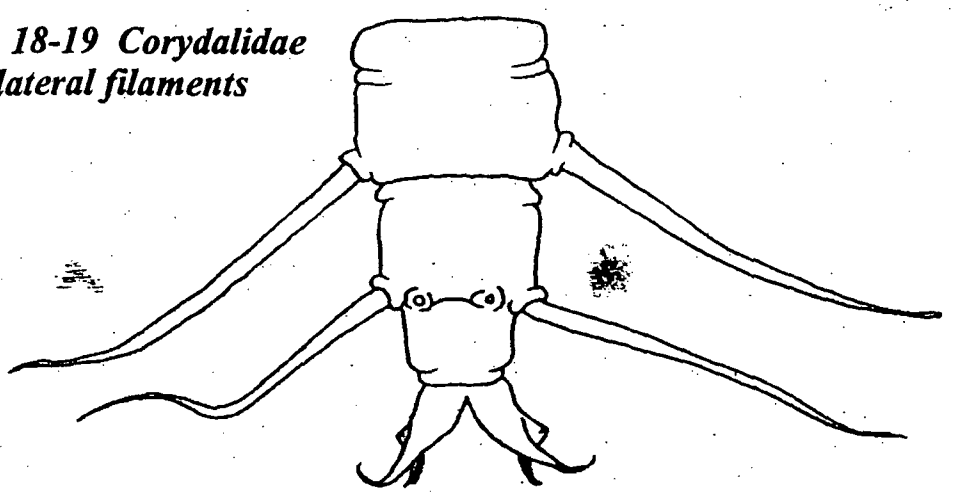


Fig. 18-19 Corydalidae lateral filaments

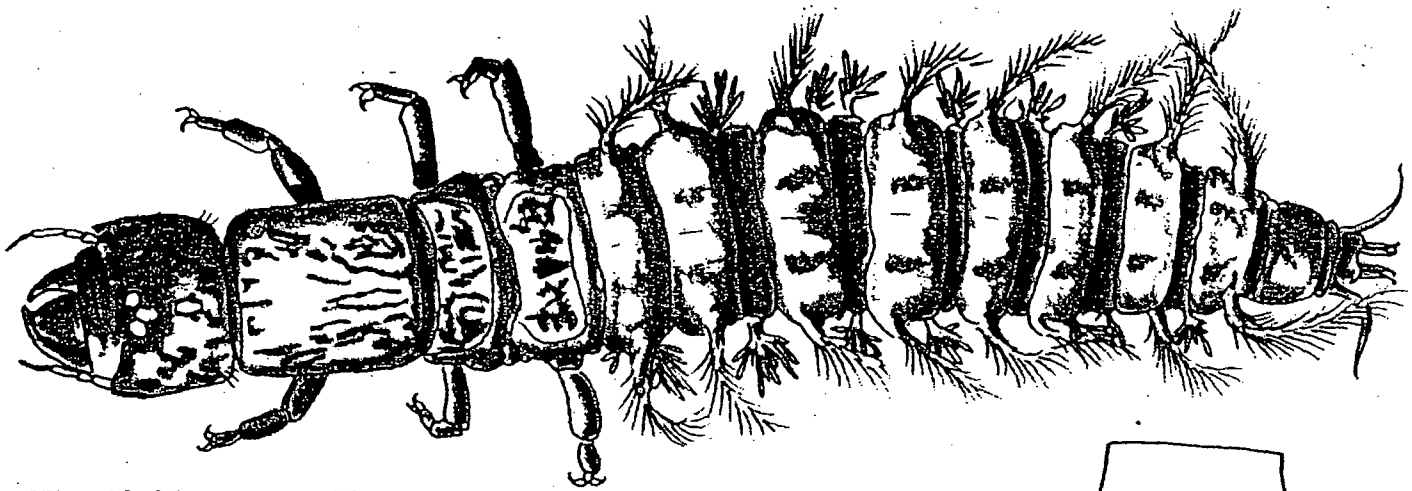


Fig. 18-20 Corydalidae

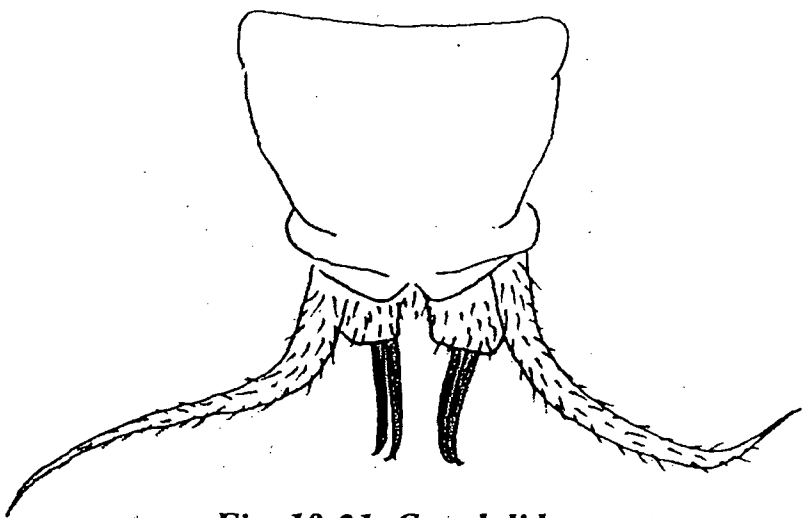


Fig. 18-21 Corydalidae terminal segments

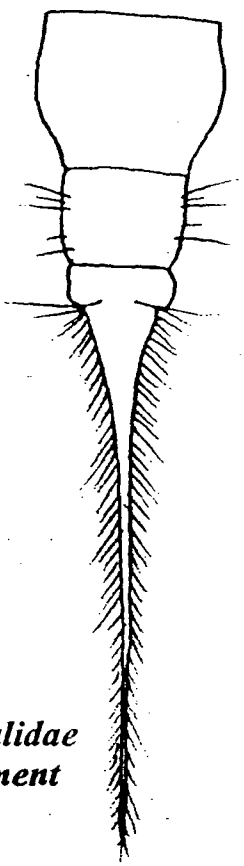


Fig. 18-22 Sialidae terminal segment

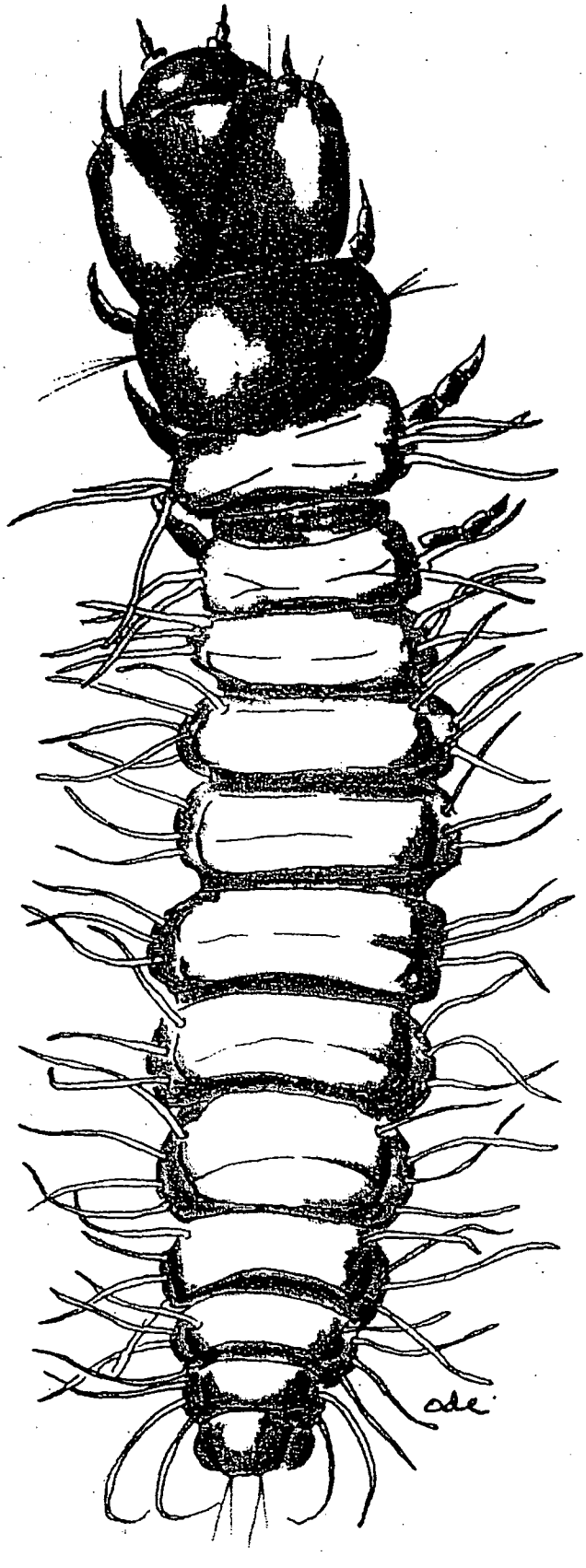


Fig. 18-23 Pyralidae

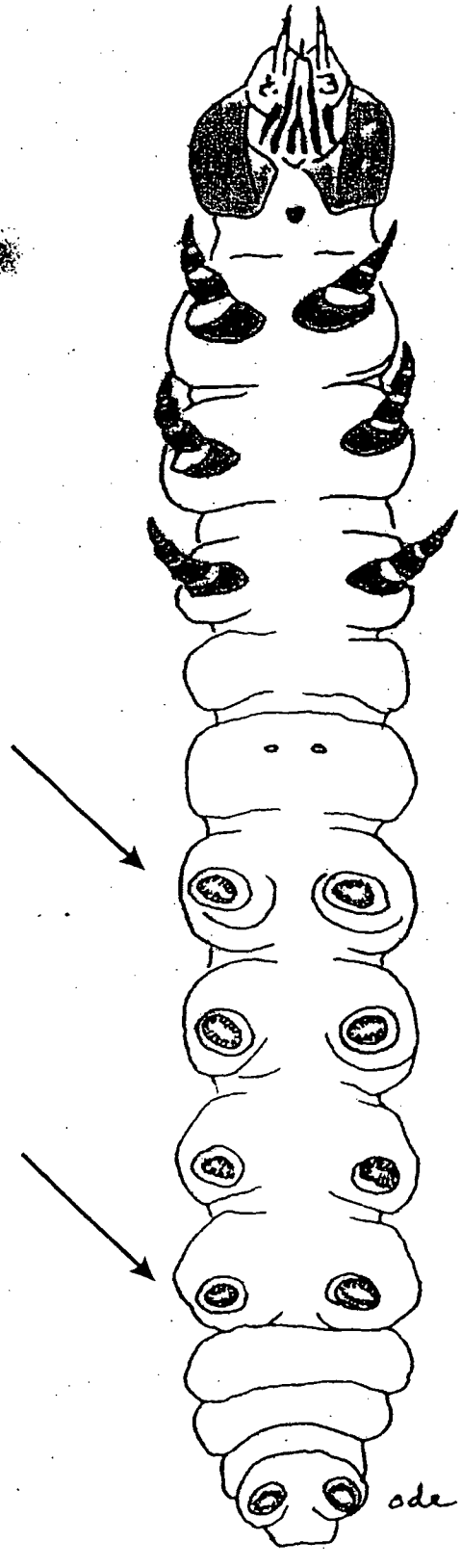


Fig. 18-24 Pyralidae ventral prolegs

APPENDIX A

References for the "Three Conceptual Models for Implementing Biological Criteria in California" Section on page 5-12, Chapter 5

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APPENDIX B

APPENDIX C

48461	14952	72619	73689	52059	37086	60050	86192	67049	64739
76534	38149	49692	31366	52093	15422	20498	33901	10319	43397
70437	25861	38504	14752	23757	59660	67844	78815	23758	86814
59584	03370	42806	11393	71722	93804	09095	07856	55589	46020
04285	58554	16085	51555	27501	73883	33427	33343	45507	50063
77340	10412	69189	85171	29082	44785	83638	02583	96483	76553
59183	62687	91778	80354	23512	97219	65921	02035	59847	91403
91800	04281	39979	03927	82564	28777	59049	97532	54540	79472
12066	24817	81099	48940	69554	55925	48379	12866	51232	21580
69907	91751	53512	23748	65906	91385	84983	27915	48491	91068
80467	04873	54053	25955	48518	13815	37707	68687	15570	08890
78057	67835	28302	45048	56761	97725	58438	91528	24645	18544
05648	39387	78191	88415	60269	94880	58812	42931	71898	61534
22304	39246	01350	99451	61862	78688	30339	60222	74052	25740
61346	50269	67005	40442	33100	16742	61640	21046	31909	72641
66793	37696	27965	30459	91011	51426	31006	77468	61029	57108
86411	46809	36698	42453	83061	43769	39948	87031	30767	13953
62098	12825	81744	28882	27369	88183	65846	92545	05065	22655
68775	06261	54265	16203	23340	94750	16317	88686	86842	00879
52679	19595	11687	74872	89181	01939	18447	10787	76246	80072
84096	87152	20719	25215	04349	54434	72344	93008	83282	31670
63964	55937	21417	49944	38356	98404	14850	17994	17161	98981
31191	75131	72306	11689	95727	05414	88727	45583	22568	77700
30545	68523	29850	67833	05622	89975	79042	27142	99257	32349
52573	91001	52315	26430	54175	30122	31796	98842	37600	26025
16586	81842	01076	99414	31574	94719	34656	80018	86988	79234
81841	88481	61191	25013	30272	23388	22463	65774	10029	58176
43563	66829	72838	08074	57080	15446	11034	98143	74989	26885
19945	84193	57581	77252	85604	45412	43556	27518	90572	00563
79374	23796	16919	99691	80276	32818	62953	78831	54395	10705
48503	26615	43980	04810	18289	66679	73799	48418	12647	40044
32049	65541	37937	41105	70106	89706	40829	40780	59547	00783
18547	71562	95493	34112	76825	46766	96395	31718	48302	45893
03180	96742	61486	43305	34183	99605	67803	13441	09241	29557
94822	24738	67749	83748	59799	25210	31053	62925	72061	69991
34330	60599	85828	19152	68499	27977	35611	96240	62747	89529
43770	81537	59527	95674	76692	86420	69930	10020	72881	12532
56908	77192	50623	41215	14311	42834	80651	93750	59957	31211
32787	07189	80539	75927	75475	73965	11796	72140	48944	74156
52441	78392	11733	57703	29133	71164	55355	31006	25526	55790
22177	54723	18227	28449	04570	18882	00023	67101	06895	08915
18376	73460	88841	39602	34049	20589	05701	08249	74213	25220
53201	28610	87957	21497	64729	64983	71551	99016	87903	63875
34919	78901	59710	27396	02593	05665	11964	44134	00273	76358
33617	92159	21971	16901	57383	34262	41744	60891	57624	06962
70010	40964	99780	72418	52571	18415	64362	90636	38034	04909
19282	68447	35665	31530	59832	49181	21914	65742	89815	19231
91429	73328	13266	54878	68795	40948	80808	63887	89939	47938
97637	78393	33021	05867	86520	45363	43066	00988	64040	09803
95150	07625	05255	83254	93943	52325	93230	62668	79529	65964

58237	81333	12573	36181	84900	39614	61303	05086	97670	07961
54789	75554	36795	42649	02971	97584	38223	52643	25027	56849
55373	14272	62729	25659	84359	02654	08409	52703	88803	31919
74251	66100	10773	71393	80972	45092	07932	83065	06585	16454
86077	90904	14779	75116	50267	52217	08539	08345	52750	22815
13506	84170	08716	28894	20133	99489	87768	55582	96081	20774
13226	41411	16074	15438	68840	17064	96917	25404	47708	17861
01642	25456	69804	29277	99473	07912	90488	73325	88266	18082
23715	70933	37381	20388	34929	96585	14146	81617	36664	25060
98436	61100	45346	94664	30677	18677	99524	70767	39521	34023
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34918	50080	97862	84932	57596	33749	78745	73377	72328	63074
47898	91359	10606	33735	46812	96239	23815	36757	17882	96143
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70750	97663	18316	16741	75016	01404	78331	76908	68[illegible]	18714
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58892	85844	04181	58470	13348	64277	43838	50362	08531	83388
79508	78596	96537	20553	41148	37805	14553	09919	11490	70231
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51863	00432	27846	54577	84476	06652	88250	40187	29735	32621
65489	54535	60256	91285	81743	48426	58351	89166	52478	23935
86119	57900	04979	16358	06281	25469	02454	20658	08869	29293
01963	62421	86788	54260	61287	69893	56446	11608	04760	85532
52164	39397	60568	88382	01561	78861	02849	31033	76875	08260
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47657	02006	33820	89370	60192	08248	10221	27754	31323	59019

CALIFORNIABIOASSESSMENTWORKSHEET

WATERSHED/STREAM:______________________

DATE/TIME:________ ______________________

COMPANY/AGENCY:______________________

SAMPLEID#:______________________

SITEDESCRIPTION:____

SAMPLINGCREW

____

____

SITEINFORMATION

GPSCoordinates:

Latitude: ______________

Longitude: ______________

Elevation: ______________

Ecoregion: ______________

COMMENTS:

____

____

____

____

CHEMICALCHARACTERISTICS

WaterTemperature: ________

SpecificConductance: ________

pH: ________

DissolvedOxygen: ________

Bioassessment Laboratory Information:

____

____

____

____

____

SENDACOPYOFTHISFORMTO:
DFG/WPCL
2005NimbusRoad
Rancho Cordova,CA95670
(916)358-2858
*website:*www.dfg.ca.gov/cabw/cabwhome.html

RIFFLE/REACHCHARACTERISTICS

PointSourceSamplingDesign

RiffleLength: ________

Transect1: ________

Transect2: ________

Transect3: ________

(recordPhysical/Habitat CharacteristicsinRiffle1column)

Non-PointSourceSamplingDesign

ReachLength: ________

PhysicalHabitatQualityScore: ________

Physical/HabitatCharacteristics

	Riffle1	Riffle2	Riffle3
RiffleLength:			
TransectLocation:			
Avg.RiffleWidth:			
Avg.RiffleDepth:			
Riffle Velocity:			
%CanopyCover:			
SubstrateComplexity:			
Embeddedness:			
SubstrateComposition:			
Fines(<0.1"):			
Gravel(0.1-2"):			
Cobble(2-10"):			
Boulder(>10"):			
Bedrock(solid):			
SubstrateConsolidation:			
PercentGradient:			

PHYSICAL/HABITAT QUALITY

California Stream Bioassessment Procedure

WATERSHED/STREAM: Malibu / Las virgenes creek DATE/TIME: _____

COMPANY/AGENCY: _____ SAMPLE ID NO.(S): _____

SITE DESCRIPTION: _____

(Circle the appropriate score for all 20 habitat parameters. Record the total score on front page of the CBW)

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 (7) 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 (11)	10 9 8 7 6	5 4 3 2 1 0
3. Velocity/Depth Regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is < 0.3 m/s, deep is > 0.5 m.)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/ depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 (11)	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 (9) 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 (7) 6	5 4 3 2 1 0

* The bridge is not part of stream reach

Parameters to be evaluated broader than sampling reach

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration past evidence of dredging for harmonic activities	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 (11)	10 9 8 7 6	5 4 3 2 1 0
7. Frequency of Riffles (or bends) fast - shallow	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 (16)	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
clear water 8. Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 (7) 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 (4) 3	2 1 0
9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 (6)	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 (4) 3	2 1 0
127 10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 (7) 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 (3)	2 1 0

Total Score

CALIFORNIA STREAM BIOASSESSMENT PROCEDURE
CHAIN-OF-CUSTODY (COC) RECORD

Project Name: _____ Date/Time: _____

Watershed Name: _____ Bioassessment Lab: _____

Sample No.	BioLab No.	Sample Date	Sample Description

Sampled by:
(sign and date)

Received by:
(sign and date)

Received by:
(sign and date)

Received by:
(sign and date)

Relinquished by:
(sign and date)

Received by:
(sign and date)

Address of Sampler:

Address of Project Advisor:

Level 1 Taxonomic Effort Worksheet for Citizen Monitors

Acari (**water mites**)	Total:_____
Amphipoda (**scuds**)	Total:_____
Cladocera (**seed fleas**)	Total:_____
Copepoda (**copepods**)	Total:_____
Decapoda (**crayfish**)	Total:_____
Gastropoda (**snails and limpets**)	Total:_____
Hirudinea (**leeches**)	Total:_____
Isopoda (**aquatic sowbugs**)	Total:_____
Nematoda (**roundworms**)	Total:_____
Nematomorpha (**horse-hair worms**)	Total:_____
Pelecypoda (**mussels and clams**)	Total:_____
Oligochaeta (**aquatic worms**)	Total:_____
Ostracoda (**seed shrimp**)	Total:_____
Turbellaria (**flatworms**)	Total:_____
Diptera (**aquatic flies**)	Total:_____
Coleoptera (**aquatic beetles**)	Total:_____
Odonata (**damsel and dragonflies**)	Total:_____
Hemiptera (**true bugs**)	Total:_____
Lepidoptera (**aquatic moths**)	Total:_____
Megaloptera (**hellgrammites and alderflies**)	Total:_____

Ephemeroptera (**mayflies**)		Plecoptera (**stoneflies**)		Trichoptera (**caddisflies**)	
Taxa 1	Total_____	Taxa 1	Total_____	Taxa 1	Total_____
Taxa 2	Total_____	Taxa 2	Total_____	Taxa 2	Total_____
Taxa 3	Total_____	Taxa 3	Total_____	Taxa 3	Total_____
Taxa 4	Total_____	Taxa 4	Total_____	Taxa 4	Total_____
Taxa 5	Total_____	Taxa 5	Total_____	Taxa 5	Total_____
Taxa 6	Total_____	Taxa 6	Total_____	Taxa 6	Total_____
Taxa 7	Total_____	Taxa 7	Total_____	Taxa 7	Total_____
Taxa 8	Total_____	Taxa 8	Total_____	Taxa 8	Total_____

Total Number of Organisms _____

Subsampling Data	**Project Advisor**
Number of Possible Subsampling Grids: _____	Name: _____
Number of Organisms in Each Grid:	Address: _____
_____ _____ _____ _____ _____ _____	_____
Total Number of Organisms in Subsample: _____	Phone/e-mail: _____

LABORATORY WORKSHEET - LEVEL 1 TAXONOMIC EFFORT

WATERSHED/STREAM: _____ DATE/TIME: _____
MONITORING GROUP: _____ SAMPLE ID NUMBER: _____
SITE DESCRIPTION: _____

Biological Metrics	Description	Sample Value
Richness Measures		
Taxa Richness	Total number of individual taxa	
Ephemeroptera Taxa	Number of mayfly taxa	
Plecoptera Taxa	Number of stonefly taxa	
Trichoptera Taxa	Number of caddisfly taxa	
EPT Taxa	Number of taxa in the Orders: Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly)	
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	
Tolerance/Intolerance Measures		
Percent Dominant Taxa	Percent composition of the single most abundant taxon	
Percent Stoneflies	Percent composition of stonefly larvae	
Abundance	Number of organisms in the total sample	

Record any problems with taxonomic identification of BMIs:

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

CALIFORNIA STREAM BIOASSESSMENT BENCHSHEET

Levels 1 and 2 Taxonomic Effort (for Citizen Monitors)

Subsampling Notes

Laboratory Number: _____

Sample Number: _____

Sample Description: _____

Number of Possible Subsampling Grids: _____ **Total Number of Organisms in Subsample:** _____

Random Grid # _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____	**Random Grid #** _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____	**Random Grid #** _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____
Random Grid # _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____	**Random Grid #** _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____	**Random Grid #** _____ _____ _____ _____ Total bugs/grid _____ Subsamplers initials _____

Level 1 Taxonomic Effort Sorting Benchsheet

Acari (**water mites**)_____ Total:_____

Amphipoda (**scuds**)_____ Total:_____

Cladocera (**water fleas**)_____ Total:_____

Copepoda (**copepods**)_____ Total:_____

Decapoda (**crayfish**)_____ Total:_____

Gastropoda (**snails and limpets**)_____ Total:_____

Hirundinea (**leaches**)_____ Total:_____

Isopoda (**aquatic sowbugs**)_____ Total:_____

Nematoda (**roundworms**)_____ Total:_____

Nematomorpha (**horse-hair worms**)_____ Total:_____

Pelecypoda (**mussels and clams**)_____ Total:_____

Oligochaeta (**aquatic worms**)_____ Total:_____

Ostracoda (**seed shrimp**)_____ Total:_____

Turbellaria (**flatworms**)_____ Total:_____

Diptera (**aquatic flies**)_____ Total:_____

Coleoptera (**aquatic beetles**)_____ Total:_____

Odonata (**damsel and dragonflies**)_____ Total:_____

Hemiptera (**true bugs**)_____ Total:_____

Megaloptera (**hellgrammites and alderflies**)_____ Total:_____

Lepidoptera (**aquatic moths**)_____ Total:_____

Ephemeroptera (**mayflies**)		Plecoptera (**stoneflies**)		Trichoptera (**caddisflies**)	
Taxa 1	Total____	Taxa 1	Total____	Taxa 1	Total____
Taxa 2	Total____	Taxa 2	Total____	Taxa 2	Total____
Taxa 3	Total____	Taxa 3	Total____	Taxa 3	Total____
Taxa 4	Total____	Taxa 4	Total____	Taxa 4	Total____
Taxa 5	Total____	Taxa 5	Total____	Taxa 5	Total____
Taxa 6	Total____	Taxa 6	Total____	Taxa 6	Total____
Taxa 7	Total____	Taxa 7	Total____	Taxa 7	Total____
Taxa 8	Total____	Taxa 8	Total____	Taxa 8	Total____

BMI Identification Crew:_____

Date:_____

Level 2 Taxonomic Effort Sorting Benchsheet

Acari (**water mites**)_____ Total:_____

Amphipoda (**scuds**)_____ Total:_____

Cladocera (**water fleas**)_____ Total:_____

Copepoda (**copepods**)_____ Total:_____

Decapoda (**crayfish**)_____ Total:_____

Gastropoda (**snails and limpets**)_____ Total:_____

Hirundinea (**leaches**)_____ Total:_____

Isopoda (**aquatic sowbugs**)_____ Total:_____

Nematoda (**roundworms**)_____ Total:_____

Nematomorpha (**horse-hair worms**)_____ Total:_____

Pelecypoda (**mussels and clams**)_____ Total:_____

Ostracoda (**seed shrimp**)_____ Total:_____

Oligochaeta (**aquatic worms**)_____ Total:_____

Turbellaria (**flatworms**)_____ Total:_____

NEEDS FURTHER TAXONOMIC IDENTIFICATION

Ephemeroptera (**mayflies**)_____ Total:_____

Plecoptera (**stoneflies**)_____ Total:_____

Trichoptera (**caddisflies**)_____ Total:_____

Diptera (**aquatic flies**)_____ Total:_____

Coleoptera (**aquatic beetles**)_____ Total:_____

Odonata (**damsel and dragonflies**)_____ Total:_____

Hemiptera (**true bugs**)_____ Total:_____

Megaloptera (**hellgrammites and alderflies**)_____ Total:_____

Lepidoptera (**aquatic moths**)_____ Total:_____

Final Count:_____

Name of Sorter(s)_____ Date:_____

CALIFORNIA STREAM BIOASSESSMENT BENCHSHEET
Level 2 Taxonomic Effort (for Citizen Monitors)

Benthic Macroinvertebrate Assemblage for Ephemeroptera (Mayflies)

Sample No. ___ Description: _____

		Total
Ameletidae	_____	_____
Baetidae	_____	_____
Caenidae	_____	_____
Ephemerellidae	_____	_____
Ephemeridae	_____	_____
Heptageniidae	_____	_____
Isonychiidae	_____	_____
Leptohyphidae	_____	_____
Leptophlebiidae	_____	_____
Siphlonuridae	_____	_____
Unknown	_____	_____
	Final Count:	_____

Name of Sorter(s) _____ Date: _____

_____ Date: _____

CALIFORNIA STREAM BIOASSESSMENT BENCHSHEET
Level 2 Taxonomic Effort (for Citizen Monitors)

Benthic Macroinvertebrate Assemblage for Plecoptera (Stoneflies)

Sample No. ___ Description: _____

		Total
Capniidae	_____	_____
Chloroperlidae	_____	_____
Leuctridae	_____	_____
Nemouridae	_____	_____
Peltoperlidae	_____	_____
Perlidae	_____	_____
Perlodidae	_____	_____
Pteronarcyidae	_____	_____
Taeniopterygidae	_____	_____
Unknown	_____	_____
	Final Count:	_____

Name of Sorter(s) _____ Date: _____

CALIFORNIA STREAM BIOASSESSMENT BENCHSHEET
Level 2 Identification (for Citizen Monitors)

Benthic Macroinvertebrate Assemblage for Trichoptera (Caddisflies)

Sample No. ___ Description: _____

		Total
Arctopsychidae	_____	_____
Brachycentridae	_____	_____
Calamoceratidae	_____	_____
Goeridae	_____	_____
Glossosomatidae	_____	_____
Helicopsychidae	_____	_____
Hydropsychidae	_____	_____
Hydroptilidae	_____	_____
Lepidostomatidae	_____	_____
Leptoceridae	_____	_____
Limnephilidae	_____	_____
Odontoceridae	_____	_____
Philopotamidae	_____	_____
Phryganeidae	_____	_____
Polycentropodidae	_____	_____
Psychomyiidae	_____	_____
Rhyacophilidae	_____	_____
Sericostomatidae	_____	_____
Uenoidae	_____	_____
Unknown	_____	_____
	Final Count:	_____

Name of Sorter(s) _____ Date: _____

_____ Date: _____

CALIFORNIA STREAM BIOASSESSMENT BENCHSHEET
Level 2 Taxonomic Effort (for Citizen Monitors)

Benthic Macroinvertebrate Assemblage for Other Orders of Insects

Sample No. ___ Description: _____

		Total
Diptera		
Athericidae	_____	_____
Blephariceridae	_____	_____
Ceratopogonidae	_____	_____
Chironomidae	_____	_____
Deuterophlebiidae	_____	_____
Dixidae	_____	_____
Empididae	_____	_____
Ephydridae	_____	_____
Psychodidae	_____	_____
Simuliidae	_____	_____
Stratiomyidae	_____	_____
Tabanidae	_____	_____
Tipulidae	_____	_____
Unknown	_____	_____
Coleoptera (Water Beetles)		
Amphizoidae	_____	_____
Dryopidae	_____	_____
Dytiscidae	_____	_____
Elmidae	_____	_____
Gyrinidae	_____	_____
Haliplidae	_____	_____
Helophoridae	_____	_____
Hydraenidae	_____	_____
Hydrophilidae	_____	_____

Psephenidae _____ _____

Odonata (Dragonflies and Damselflies)

Aeshnidae _____ _____

Calopterygidae _____ _____

Coenagrionidae _____ _____

Cordulegastridae _____ _____

Corduliidae _____ _____

Gomphidae _____ _____

Lestidae _____ _____

Libellulidae _____ _____

Unknown _____ _____

Hemiptera (dragonflies and damselflies)

Belostomatidae _____ _____

Corixidae _____ _____

Naucoridae _____ _____

Megaloptera (hellgrammites and alderflies)

Corydalidae _____ _____

Sialidae _____ _____

Lepidoptera (aquatic moths)

Pyralidae _____ _____

Final Count: _____

Name of Sorter(s) _____ Date: _____

_____ Date: _____

LABORATORY WORKSHEET - LEVEL 2 TAXONOMIC EFFORT

WATERSHED/STREAM: _____ DATE/TIME: _____
MONITORING GROUP: _____ SAMPLE ID NUMBER: _____
SITE DESCRIPTION: _____

Biological Metrics	Description	Sample Value
Richness Measures		
Taxa Richness	Total number of individual taxa	
Ephemeroptera Taxa	Number of mayfly families	
Plecoptera Taxa	Number of stonefly families	
Trichoptera Taxa	Number of caddisfly families	
EPT Taxa	Number of families in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	
Sensitive EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae with Tolerance Values of 0 through 3	
Percent Hydropsychidae	Percent of organisms in the caddisfly family Hydropsychidae	
Percent Baetidae	Percent of organisms in the mayfly family Baetidae	
Tolerance/Intolerance Measures		
Tolerance Value	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) and intolerant (lower values)	
Percent Intolerant Organisms	Percent of organisms in sample that are highly intolerant to impairment as indicated by a tolerance value of 0, 1 or 2	
Percent Tolerant Organisms	Percent of organisms in sample that are highly tolerant to impairment as indicated by a tolerance value of 8, 9 or 10	
Percent Dominant Taxa	Percent composition of the single most abundant taxon	
Functional Feeding Groups		
Percent Collectors (CG)	Percent of macrobenthos that collect or gather fine particulate matter	
Percent Filterers (FC)	Percent of macrobenthos that filter fine particulate matter	
Percent Scrapers (SC)	Percent of macrobenthos that graze upon periphyton	
Percent Predators (P)	Percent of macrobenthos that feed on other organisms	
Percent Shredders (SH)	Percent of macrobenthos that shreds coarse particulate matter	
Abundance	Number of organisms in the total sample	

LEVEL 2 TAXONOMIC EFFORT WORKSHEET (for Citizen Monitors)

Benthic Macroinvertebrate Assemblage

Organisms	t-value	f-desig	Number
Non-Insects			
Acari (water mites)	5	P	____
Amphipoda (scuds)	4	CG	____
Cladocera (water fleas)	8	FC	____
Copepoda (copepods)	8	CG	____
Decapoda (crayfish)	6	CG	____
Gastrpoda (snails)	7	SC	____
Hirudinea (leeches)	10	P	____
Isopoda (sowbug)	8	SH	____
Nematoda (roundworms)	5	CG	____
Nematomorpha (horsehair)	-	-	____
Pelecypoda (mussels & clams)	8	FC	____
Oligochaeta (aquatic worms)	8	CG	____
Ostracoda (seed shrimp)	8	CG	____
Tubellaria (flatworms)	4	P	____
Unknown			____
E= Ephemeroptera (mayflies)			
Ameletidae	0	CG	____
Baetidae	4	CG	____
Caenidae	7	CG	____
Ephemerellidae	1	SC	____
Ephemeridae	4	SC	____
Heptageniidae	4	SC	____
Isonychiidae	2	FC	____
Leptohyphidae	4	CG	____
Leptophlebiidae	2	SC	____
Siphlonuridae	7	CG	____
Unknown			____
P= Plecoptera (stoneflies)			
Capniidae	1	SH	____
Chloroperlidae	1	SH	____
Leuctridae	0	SH	____
Nemouridae	2	SH	____
Peltoperlidae	0	SH	____
Perlidae	1	P	____
Perlodidae	2	P	____
Pteronarcyidae	0	SH	____
Taeniopterygidae	2	SH	____
Unknown			____
T= Trichoptera (caddisflies)			
Arctopsychinae	2	FC	____
Brachycentridae	3	CG	____
Calamoceratidae	2	SH	____
Glossosomatidae	0	SC	____
Goeridae	1	SC	____
Helicopsychidae	3	SC	____
Hydropsychidae	4	FC	____
Hydroptilidae	4	-	____
Lepidostomatidae	1	SH	____
Leptoceridae	4	CG	____
Limnephilidae	4	SH	____
Odontoceridae	0	SH	____
Philopotamidae	3	FC	____
Phryganeidae	4	SH	____
Polycentropodidae	6	FC	____
Psychomyiidae	2	CG	____
Rhyacophilidae	0	P	____
Sericostomatidae	3	SH	____
Uenoidae	0	SC	____
Unknown			____
Diptera (aquatic flies)			
Athericidae	2	P	____
Blephariceridae	0	SC	____
Ceratopogonidae	6	P	____
Chironomidae	6	CG	____
Deuterophlebiidae	0	SC	____
Dixidae	2	CG	____
Empididae	6	P	____
Ephydridae	6	CG	____
Psychodidae	10	CG	____
Simuliidae	6	FC	____
Stratiomyidae	8	CG	____
Tabanidae	8	P	____
Tipulidae	3	SH	____
Unknown			____
Coleoptera (aquatic beetles)			
Amphizoidae (A)	1	P	____
Dryopidae (A)	5	SH	____
Dytiscidae (A,L)	5	P	____
Elmidae (A,L)	4	CG	____
Gyrinidae (L)	5	P	____
Haliplidae (A,L)	5	SH	____
Helophoridae (A)	5	SH	____
Hydraenidae (A)	-	-	____
Hydrophilidae (A,L)	5	P	____
Psephenidae (L)	4	SC	____
Unknown			____
Odonata (dragonflies and damselflies)			
Aeshnidae	3	P	____
Calopterygidae	5	P	____
Coenagrionidae	9	P	____
Cordulegastridae	3	P	____
Corduliidae	5	P	____
Gomphidae	4	P	____
Lestidae	9	P	____
Libellulidae	9	P	____
Unknown			____
Hemiptera (true bugs)			
Belostomatidae	8	P	____
Corixidae	8	CG	____
Naucoridae	8	P	____
Megaloptera (hellgrammites and alderflies)			
Corydalidae	0	P	____
Sialidae	4	P	____
Lepidoptera (aquatic moths)			
Pyralidae	5	SC	____

Total Number of Organisms ____

Subsampling Data

Number of Possible Subsampling Grids ____

Number of Organisms in Grids:

____ ____ ____ ____ ____ ____ ____

Total Number of Organisms in Subsample: ____

Project Advisor

Name: _____

Address: _____

_____

Phone/e-mail: _____

APPENDIX D

An Index of Biological Integrity for First to Third Order Russian River Tributary Streams

California Department of Fish and Game - Water Pollution Control Laboratory
2005 Nimbus Rd. Rancho Cordova, CA 95670 (916) 358-2858; jharr@sna.com
California Aquatic Bioassessment Web Site at www.dfg.ca.gov/cabw/cabwhome.html

Summary

The conceptual model described by the U.S. Environmental Protection Agency for development of biocriteria was followed to produce a first iteration of an Index of Biological Integrity for the Russian River Watershed (RRIBI). Benthic macroinvertebrate (BMI) were collected from 35 reaches within 21 tributary streams and the mainstem Russian River during the fall 1995 and spring 1996 and 1997 using the California Stream Bioassessment Procedure. A set of core biological metrics, commonly used for bioassessment of California stream were used to describe the BMI communities in the 35 reaches. Monitoring reaches within the first to third order streams classified as similar with different channel type having no influence on mean biological metric values. The biological metrics, Taxa Richness, EPT Taxa, Modified EPT Index, Shannon Diversity, Tolerance Value and Percent Dominant Taxa were chosen as the most appropriate to be included in producing the RRIBI. These six metrics were integrated into a single scoring criteria by producing a histograms of the values for each of the biological metrics and visually determining breaks in their distribution. This approach of determining scoring criteria was more intuitive and probably most appropriate given the data came from streams that could have been moderately impaired and not actually representative of pristine reference conditions. Although there was no indication of strong seasonal variability in the BMI communities, it was recommend that the index period for the Russian River tributary streams be in the spring. It was also recommended that the RRIBI be considered preliminary and that data on more Russian River tributaries and the mainstem be collected to 1) test the effectiveness of this scoring criteria on other first to third order Russian River tributaries, 2) test the appropriateness of using other biological metrics, 3) evaluate the use of the RRIBI in other north coast California streams to test its effectiveness at assessing biological integrity of streams outside the Russian River watershed, and 4) produce an IBI for fourth order and larger stream reaches.

Biological Metric	Visual Distribution Score		
	5	3	1
Taxa Richness	≥36	35-26	<26
% Dom. Taxa	≤14	15-39	>39
EPT Taxa	≥19	18-12	<12
Mod EPT Index	≥54	53-17	<17
Shannon Diversity	≥3.0	2.9-2.3	<2.3
Tolerance Value	≤3.0	3.1-4.6	>4.6

How to Use the Russian River Index of Biological Integrity

Obtain a sample of benthic macroinvertebrates following the state standard procedures (California Stream Bioassessment Procedures - May 1999 version). There must be at least three replicate samples collected at each monitoring location. The samples should be processed by a professional bioassessment laboratory using the Level 3 Taxonomic Effort. Determine the mean values for the six listed biological metrics, compare them to the values in the columns and add the scores listed in the column headings. The total score will be between a low of 6 and high of 30. Determine biotic condition of the monitoring location from the following categories:

Excellent	Good	Fair	Poor
30 - 24	23 - 18	17 - 12	11 - 6

About the Authors

Jim Harrington is not truly from Arcata, as he often claims, but he did graduate from Humboldt State University (HSU) in 1979 with a Bachelors of Science in Fisheries Management and in 1983 with a Masters of Science in Watershed Management. His graduate work emphasis was in water quality of wildland streams and for his thesis, he developed an analytical technique for monitoring changes in the benthic macroinvertebrate communities of second-order streams affected by clear-cut logging. While at HSU, Jim also had the opportunity to work on a two-year, full-time assignment with Dr. George Allen at his wastewater aquaculture facility which is now the model for a wetland wastewater treatment plant.

Jim started working as an aquatic biologist in 1980 for Redwood National Park (RNP) where he worked on inland and estuarine aquatic resource studies. While with RNP, he designed his first major watershed monitoring program which was intended to measure the effects of sediment produced from construction of the 16 mile Redwood Bypass on the aquatic resources of several north coast streams.

In 1987, Jim started working for the California Department of Fish and Game's (DFG) Environmental Services Division and is currently assigned to the Water Pollution Control Laboratory (WPCL). As Staff Water Quality Biologist for the WPCL, Jim's primary duties are to support the DFG's Regional Water Quality Biologists and to interpret the biological significance of pollutants spilled into the waters of the state. He also designs and conducts water quality monitoring programs throughout California. Since 1997, Jim has been actively promoting bioassessment for citizen monitors, and has conducted over fifty three-day workshops throughout the state.

Monique Born graduated with a Masters Degree in Communication and a Masters Degree in Environmental Science.

She is currently an Environmental Specialist III with DFG's Native Anadromous Fish and Watershed Branch in Sacramento. Over the last three years, she has conducted extensive field sampling, including rapid bioassessment and has been active in conducting and coordinating workshops to train citizen monitors in habitat and biological assessment state-wide. Her current position focuses on the coordination of training such as the Watershed Academy, and the preparation of educational materials such as the watershed assessment reference and field reference for the Watershed Academy and a three-volume set of coho salmon reference materials.
Since 1997, Monique has been actively promoting bioassessment for citizen monitors, and has conducted over twenty three-day workshops throughout the state.

Previously, she worked for five years as an information officer for DFG's Conservation Education Office. In that capacity, Monique also assisted the Office of Emergency Services during several of California's major disasters, and provided support during the Cantara spill incident, preparing many of the slide shows and visual materials used for public presentations. She has written several published articles.

Monique, a native of Switzerland, is occasionally fluent in English, and was raised speaking both French and Italian. Having spent the equivalent of several years, a few months at a time, in Central America, she has a good working knowledge of Spanish, and hopes to promote bioassessment in Latin America. She is a member of The Nature Conservancy, the Association of Environmental Professionals and Women in Natural Resources.

About the Illustrator

Peter Ode, by his own account, was raised on insects, having both an entomologist father and an entomologist brother. Growing up in the forests of western Pennsylvania, he was drawn to streams from an early age. After an undergraduate degree in biology at Allegheny College introduced him to the combination of these two interests, he traveled to Ithaca, NY, to pursue a doctoral degree in Entomology. Under the instruction of Dr. Barbara Peckarsky, he studied behavioral interactions among mayfly larvae in the beautiful East River valley in the West Elk Range of the Rocky Mountains in Colorado.

He moved to California in 1995 and has worked as a stream insect ecologist for the California Department of Fish and Game (DFG) since his arrival. As the head taxonomist of the DFG's Aquatic Bioassessment Laboratory, he is actively involved in developing taxonomic resources for bioassessment in California and developing and promoting bioassessment throughout the state.

Peter's interest in drawing has existed for nearly as long as his interest in biology. Surrounded by insects his whole life, he was able to hone his artistic skills throughout his academic and professional career. The illustrations in this manual are his first published work.