FINAL REPORT

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INVESTIGATIONS OF AN INDEX OF BIOTIC INTEGRITY IN NEW MEXICO

Federal Aid Grant F-59-R-7

Development of an Index of Biotic Integrity For Use in Water Resource and Fishery Management

Project No. 01

By

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Project Title: Investigations of an Index of Biotic Integrity Utilizing Aquatic Macrobenthic Invertebrates for Use in Water Resource and Fishery Management.

Contract Period: November 1, 1990 to February 28, 1998

Study Objective: To establish a database from selected water bodies based on species from four dominant orders of macrobenthic invertebrates (Diptera, Chironomidae; Ephemeroptera; Plecoptera; and Trichoptera) as they relate to environmental parameters and fish populations at each site.

ABSTRACT

This report presents results of research regarding the development of indicies of biotic integrity (IBI's) for perennial streams in New Mexico. To date, the focus of study has been to: (1) evaluate schemes for landscape classification with respect to chemical and physical environmental factors, (2) identify "faunal regions" and determine if they are consistent with regional strata defined by environmental factors, (3) characterize associations, or assemblages, of biota, (4) initiate identification of summary statistics for inclusion in indices of biotic integrity, and (5) develop taxonomic keys for benthic macroinvertebrates and an atlas of chironomid pupal exuviae to facilitate application of an IBI.

Major findings are presented in three appended reports. One appended report describes the results of "exploratory" statistical analysis of data from a number of sites in the upper Rio Grande drainage of New Mexico (Appendix 1).

A second appended report elucidates the fish faunal regions in New Mexico using cluster analysis of plausible presence/absence records of the late prehistoric to early historic (circa. 1550 a. d.), native fish fauna for 154 sample sites (Appendix 2). Fish faunal regions were defined on the basis of species, genus and reproductive guild. Analyses by these alternative classification schemes were conducted to reveal the strongest correlation with environmental data. We provide a description of how fish faunal assemblages are structured by underlying physical, chemical, and climatic features of their environment prior to large-scale impacts by humans. Native fish faunal regions provide a baseline from which we can assess contemporary changes in fish community structure. Definition of changes in fish assemblages will provide an important metric for inclusion in an IBI.

A third appended report delineates general boundaries for aquatic ecoregions in New Mexico (Appendix 3). The purpose of the report is to facilitate the study of fish, benthic macroinvertebrate and chironomid distributions within regions where the composition of the biotic communities might be expected to be similar. Four aquatic ecoregions have been identified that intersect major drainage boundaries and physiographic provinces. This indicates

an underlying similarity among sites that is more related to elevation and growing season length rather than to physiography, surface or subsurface geology.

In anticipation of developing fish-based IBI's, we examine the degree of spatial concordance of fish faunal regions with environmental-based aquatic ecoregions of the state. There was little correspondence between fish faunal regions and aquatic ecoregions. It remains to be determined if the aquatic ecoregion classification will provide an adequate framework, or, if one of the fish faunal region classifications will prove more useful.

Statewide analysis of data for benthic macroinvertebrates and chironomids remains to be done, although exploratory analyses of a subset of this data has been completed for the upper Rio Grande drainage of the state (Appendix 1).

To facilitate application of an IBI, taxonomic keys of invertebrates and a photographic atlas of chironomid pupal exuviae are being developed (appendices 4-8). Recommendations for future research are offered.

INTRODUCTION

This report presents results of research regarding the development of indices of biotic integrity for perennial streams in New Mexico. To date, our research efforts have focused on understanding biota-environment relationships and how such knowledge can be employed in the development of indices of biotic integrity (IBI's). Biotic integrity can be defined as the condition in which the biota of a given system have an organizing, self-correcting capability to recover from disturbance and regain an end-state that is normal and good for that system (Regier, 1993). "Normal and good" can be something other than pristine or naturally whole.

Biotic integrity and health of the environment are not new concepts (Karr, 1993). Monitoring of the environmental health of freshwater systems has progressed from the near universal measurement of BOD earlier in this century, to measurement of a broader spectrum of chemical and physical quantities, to incorporation of biota into indices that are reflective, at least to some extent, of environmental health (e.g., Karr, 1981; Hilsenhoff, 1982). In spite of this progression, and even with the acknowledgment that biota provide better interpretability than chemical parameters (Steedman and Haider, 1993), there is much to be learned. Indeed, the "agony of community ecology" (Lewontin, 1974) is that we often do not know which variables are important and we lack simple quantitative models to describe environmental variation and its effect on the biota (Keddy et al., 1993).

IBI's have important potential uses in fisheries management and in watershed protection. When properly constructed, an IBI will identify sites where single or multiple stressors begin to cause species composition to differ substantially from expectation. Complementing this, IBI's offer easily observable measures of ecosystem response to management.

JOB OBJECTIVES

1. Determine the species composition of major macrobenthic invertebrate groups (Chironomidae, Ephemeroptera, Plecoptera, Trichoptera) at selected water bodies throughout the state.

2. Apply the collection of surface floating pupal exuviae of Chironomidae (Thienemann net technique) as a semi-quantitative method of determining species richness and relative abundance of Chironomidae alone as an indicator of water quality as compared with all major groups of macrobenthic invertebrates. The collections will be applied as a quantitative method of determining water and habitat quality as compared to the Chironomidae.

3. Concurrent collections of fish will be taken by the staff of New Mexico Department of Game and Fish (with assistance from contractors).

4. Compile physical parameters at each collecting site: elevation, mean depth, width, velocity, flow volume, substratum type(s), turbidity, temperature, pH, specific

conductance, and color.

5. Determine selected chemical parameters at each collecting site: total dissolved solids, dissolved Na and K, total hardness, sulfates, alkalinity, chlorides, dissolved oxygen, total dissolved nitrogen, total soluble phosphorus, and soluble reactive phosphorus (i.e., orthophosphate).

6. Develop multivariate index functions for fish, macroinvertebrates, and environmental parameters using canonical correspondence analysis (ter Braak 1986, 1987). From this, a macroinvertebrate and fish-based Index of Biotic Integrity will be developed. The validity of using the Thienemann net technique alone as well as the collections of Ephemeroptera, Plecoptera, and Trichoptera will be assessed for New Mexico waters.

7. Prepare an illustrated atlas of chironomid pupal exuviae similar to the format used in Langton (1984). Prepare a checklist of taxa and dichotomous keys to the Plecoptera, Ephemeroptera, and Trichoptera.

8. Prepare performance report.

RESULTS AND DISCUSSION

Over the past seven years, sampling has been conducted at 154 aquatic sites representing the major river basins in New Mexico, including the San Juan, Zuni, San Francisco, Gila, Mimbres, Rio Grande, Tularosa, Salt, Pecos, and Canadian/Arkansas basins. Results and discussions of analyses of the data from these collections are presented in numeric order by job objective.

Objectives 1 and 2.

Benthic macroinvertebrates have been identified from 136 sample sites. These represent collections from the Canadian (including Dry Cimarron), RioGrande, Gila (including San Francisco), and San Juan (including Zuni) drainages. The 18 samples that remain to be identified are from Gulf Coast drainages. Larval Chironomidae, Trichoptera, Ephemeroptera, Plecoptera and other taxa from the 18 aforementioned samples have yet to be enumerated and identified, respectively. All of the remaining in-hand Thienemann (15), UV-night light (17), and sweep-net macrobenthos samples have been sorted. Some 3727 midge exuvial slides, 1023 midge adult slides, 828 midge larva slides, and 76 midge pharate-adult slides have been prepared and delivered to Dr. Sublette for identification. New record sheets for samples examined during this segment of the project together with the corrected sheets are given in Appendix 4.

In addition, the manuscript *Mayfly fauna of New Mexico* by W. P. McCafferty, C. Lugo-Ortiz, and G. Z. Jacobi was published in the Great Basin Naturalist. Most of the mayfly location records cited after 1991 are acknowledged to the IBI project and support from the Federal Aid Grant F-59-R

Based on the results of collections prior to and those of this survey, 12 families including 81 species of Ephemeroptera have been found in New Mexico. "Of the major drainage systems in the state, the Gila system is the most species rich with 48 species, followed by the Rio Grande (46), Pecos (39), Canadian (28), and San Juan (25). Eighteen New Mexico mayfly species are known exclusively from western drainages in the state (San Juan, Zuni, San Francisco, Gila) and 23 species are known exclusively from eastern drainages (essentially all drainages east of the continental divide: Dry Cimarron, Canadian, Rio Grande, Pecos)" (McCafferty et al. 1997). New Mexico is rich in mayfly species when compared to adjoining states: Arizona (9 families, 66 species); Colorado (14 families, 100 species); Texas (11 families, 92 species); and Chihuahua, Mexico (5 families, 27 species). Many species are rare, known from only one location. One of these, the large burrowing mayfly *Hexagenia bilineata* constitutes a new state record found during our survey only at one location, just upstream from Harkey Crossiing on the Black River (Eddy County), a tributary of the lower Pecos River. The pool habitat containing calcareous sediments is the only one of this type found, so far, in New Mexico.

Objective 3.

The database for contemporaneous fish collection records was completed for all sites sampled to date (154 sites). In addition, plausible presence-absence records of the historic (circa 1550), natural occurring fish fauna were compiled for these sample sites. This will facilitate comparisons of the aquatic ecoregions with the native fish faunal regions.

Presence/absence data of native fish species were used to delineate fish faunal regions. The fish species faunal regions are confined generally to drainage basins, although some faunal regions span drainage boundaries. In the mountains, two faunal regions are common to the Rio Grande, Pecos, and Canadian/Arkansas River drainages, one represents depauperate headwater streams and the other represents more diverse streams. Separate faunal regions are described for mountain streams of the upper and lower Colorado River drainages. These faunal regions of the Colorado River drainage differ primarily in their native species for the genera *Oncorhynchus*, *Catostomus*, and *Rhinichthys*. From foothills to lowlands, a single fish species faunal region in each drainage is sufficient to describe the assemblages in the upper and lower Colorado River and the Canadian/Arkansas River drainages. Within the Rio Grande and Pecos River drainages foothill to lowland sites on the river mainstems are divided into two fish faunal regions, a middle elevation transition zone and a lowland mainstem zone. Upland to lowland tributaries to the Pecos River are recognized as a separate fish faunal region. Fish in two contemporary endorheic basins form the remaining faunal regions, i.e., lowland springs of the Tularosa Basin and the Mimbres River Basin. Fish faunal regions have also been delineated for fish genera and for an ecological classification that captures differences in reproduction.

In general, fish faunal regions bear little resemblance to aquatic ecoregions in the state. Fish species richness in New Mexico river drainages is positively correlated with drainage basin area. A manuscript of these findings is appended to this report (Appendix 2). The co-authors of this report intend to publish these findings in a peer reviewed scientific journal.

Objectives 4 and 5.

Physical and chemical sampling has been completed for 154 sample sites and most of the data from these investigations have been entered into a database. Where field collection records were not available, data was obtained from the New Mexico Surface Water Quality Bureau STORET database for New Mexico and incorporated into our master database. Twenty-five chemical, physical and climate variables were used to delineate general boundaries for aquatic ecoregions in New Mexico. The purpose of this is to facilitate the study of fish and benthic macroinvertebrate distributions within regions where the composition of the biotic communities might be expected to be similar. Four aquatic ecoregions have been identified that intersect major drainage boundaries and physiographic provinces. This indicates an underlying similarity among sites that is more related to elevation and growing season length rather than to physiography, surface or subsurface geology. Aquatic Ecoregion 1 includes sites above about 2135 m (7000 ft) in at least five major drainage basins in the state. Within Aquatic Ecoregion 1, there are two subgroups of sites which differ mainly in substrate composition; one group, generally at higher elevation, has a higher percentage of boulder substrate and lower percentages of gravel and sand than does the other group. Aquatic Ecoregion 2 includes sites from about 1675 m (5500 ft) elevation up to about 2135 m. These sites differ from the higher elevation sites of Aquatic Ecoregion 1 by having a significantly higher percentage of silt substrate, higher substrate embeddedness, longer growing season length, and greater watershed area. Aquatic Ecoregion 3 represents sites from about the 180 frost free isoline, located variously between about 1340 m and 1370 m (about 4400 ft and 4500 ft) elevation up to about 1675 m. Aquatic Ecoregion 4 includes sites with a growing season length greater than 180 frost free days. In New Mexico, this is restricted to the downstream ends of the Rio Grande, Pecos, Canadian, Mimbres, Tularosa, and Gila drainages. The multivariate analyses used to define the aquatic ecoregions were also useful for identifying "outlier" sites, i.e., sites that were very different from other sites near them. A manuscript of these findings is appended to this report (Appendix 3). The co-authors of this report intend to publish these findings in a peer reviewed scientific journal.

Objective 6.

The effects of environmental stressors on fishes have traditionally been assessed in New Mexico at low levels of biological organization. Retrospective assessments of stress on aquatic communities have had two foci. First, stress assessment has been oriented toward the health of individual fish and it has focused on measuring physiological functions of individual fish, rates of deformities or disease, condition, incidence of parasitism, and tolerance to specific contaminants. The second perspective for assessment of stress in fish has been focused on site-specific trends in the abundance, growth rate, and distribution of populations. At the community level, assessment has involved simple comparisons of taxonomic richness or indices of diversity estimated for different points in time. Our efforts are directed toward extending site-specific assessment to a regional framework. To accomplish this, we need to understand how benthic macroinvertebrate, chironomid and fish faunal assemblages are structured by underlying physical, chemical, and climatic features of their environment prior to large-scale impacts by humans. The report in Appendix 2 (and to a lesser degree, the report in Appendix 1)

demonstrates how native fish faunal regions provide a baseline from which we can assess contemporary changes in fish community structure. Definition of changes in fish assemblages can provide an important metric for inclusion in an IBI.

To date, much of our research has sought to find meaningful patterns of variation in the organization of biological communities. Through study of the aquatic biota and the chemical, physical, and climatic features of their environment, we have identified factors responsible for the distribution and/or abundance of aquatic biota in New Mexico. Information about community structure, and how it is affected by underlying physical, chemical, and climatic processes, will enable us to determine expected biotic community structure for an aquatic ecoregion. Expected community structure then provides a baseline against which sites can be compared. The ability to compare sites within an aquatic ecoregion or a fish faunal region will facilitate development of IBI's that are sensitive and objective indicators of accumulative stress at the community level of ecological organization. Appended reports (appendices 1, 2 and 3) represent stages in a study to determine how knowledge of fish-environment relationships can be employed in the development of IBI's for New Mexico streams.

To be effective, an IBI must be applied to a geographical set of waters that have similar ecological features (Stewart and Loar, 1994) defined either on the basis of environmental or faunal site attributes. However, it remains to be determined if the aquatic ecoregion classification will provide an adequate framework, or, if one of the fish faunal region classifications will prove more useful.

The concept of ecoregions has been developed as a means of stratifying the landscape (Omernik, 1986, 1987; Hughes and Larson, 1988). Ecoregions group naturally similar ecosystems and therefore group sites that have potential to be similar in aquatic chemistry, physical features, and biota (Hughes and Larson, 1988). The use of ecoregions can enhance the effectiveness of an ecological monitoring program because ecoregional division of sites can control variance which in turn makes it easier to detect potential problems (Stewart and Loar, 1994). However, an ecoregion landscape stratification only groups streams by their potential to support qualitatively similar biotic communities. It ignores variation between sites caused by endemic fish species. With respect to development of IBI's, it seems necessary that the indices include information about the native fish species endemic to different drainages.

With respect to the ultimate objective of our project to use fishes in IBI's, it is unclear if any single set of fish faunal regions will provide a sufficient basis for landscape stratification. The large number of fish species faunal regions (12) may yield an insufficient number of sites within one or more regions such that statistical power to detect habitat impairment may be lost. The genera faunal regions (6) would yield better statistical power, but they would not provide an accurate perspective with respect to endemic species. The guild faunal regions provide an attractive subdivision of the landscape into meaningful ecological zones, but the presence of only 12 guilds among the native fish fauna in the state could prove problematic.

Objective 7.

The photographic atlas from which a manuscript for the handbook of pupal exuviae of Chironomidae will be developed has been further updated to include photomicrographs of most taxa now known from New Mexico. In order to develop a publishable manuscript these photomicrographs are being converted to line drawings which are much more legible in publication than half tone photographs. The line drawings are being prepared by scanning the photomicrographs into the computer using a flatbed scanner by importing a gray scale scan into memory and then converting it into a line drawing by using a layering technique (Adobe Photoshop 4.0) comparable to using tracing paper over a photo in making a conventional drawing. Conversion of these line drawings from the photographic atlas is in progress. In several instances outstanding published figures have been used by redrawing them to conform to material from New Mexico. The results to date are shown in Appendix 5. Not all of the samples taken during the study have been examined. As these are inventoried and possible new taxa added, the atlas and the manuscript will be updated before the final manuscript is assembled for publication. As identifications have progressed earlier record sheets have been modified by corrections of taxa names which have been elucidated through new material taken at other sites. Several species identified as "sp. 1-P, sp. 2-P", etc., now have species names associated and are corrected on the previous record sheets. Two species of chironomids new to science from this study have been recently described. These are given in Sublette et al. (1998). Aspects of their ecology have been described in Stevens et al. (1998).

Preliminary keys to the larval and adult trichopteran families occurring in New Mexico have been generated (Appendix 6). The key to larvae is that of Wiggins (1996) and the key to adults is that of Merritt and Cummins (1996); both keys have representative New Mexico families highlighted. The figures in each of these publications are the best available to entomologists and fishery practitioners. Therefore, a copy of each of these publications should be available whenever the appended keys are used. As a recommendation, copies of these two works with appropriate microscopical aids should be readily available to appropriate fisheries personnel throughout New Mexico. Preliminary keys (Wiggins, 1996) to the genera of larval caddisflies of New Mexico have also been included. Caddisfly genera reported in the open literature as well as those identified from IBI collections have been highlighted in the individual family keys. With one exception, only families with genera reported from New Mexico have been included. The exceptional family is Phryganeidae; without doubt representatives of this taxon occur in New Mexico. The preliminary New Mexico keys to the family level include all the North American entries of Wiggins (1996) and Merrittt and Cummins (1996). A number of families and genera most certainly occurring in New Mexico but not yet reported should be included in any preliminary working key. Realizing new records at the family and generic level is possible using these expanded North American keys. Once the remaining adult material from UV-night light and sweep-net collections has been identified, more definitive keys will be generated. Wherever possible, keys to the species level will be forthcoming.

Taxonomic keys to the Plecoptera (stoneflies) and Ephemeroptera and lists of known species of these two orders are given in appendices 7 and 8, respectively.

Objective 8.

A final report has been prepared.

RECOMMENDATIONS

Our future research on this project includes six aspects. First, work is in progress to provide a statistical description of fish faunal change from the probable historic native fauna at each of our sample sites to faunal composition in contemporary samples. Preliminary results suggest that multivariate principal components may describe effectively the fish faunal change specific to drainages and reaches within drainages. Second, we intend to analyze contemporary fish distributions with respect to a large suite of environmental variables. Third, we have benthic macroinvertebrate samples identified to family and subfamily levels from which we will deduce benthic macroinvertebrate faunal regions and compare them with our aquatic ecoregions and our fish faunal regions. Fourth, we will examine chironomid midge data identified to species level to deduce chironomid faunal regions.

The fifth segment of our future research will be devoted to development of IBI's that will emphasize identification of sites with impaired habitat. We anticipate that these IBI's will involve a combination of water and habitat quality measures and multiple aspects of the fish and benthic macroinvertebrate biota. For the final segment of the project, we intend to carry out sampling at new sites so that the efficacy of the IBI's can be validated.

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Aquatic Ecoregions of New Mexico

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Abstract

Twenty-five chemical, physical, and climate variables were used in multivariate statistical analyses to delineate general boundaries for aquatic ecoregions in New Mexico. The purpose of this project is to identify river reaches that share similarity in water chemistry, physical habitat, and climate. Four aquatic ecoregions have been identified. Aquatic Ecoregion 1 includes sites above about 2135 m (7000 ft), including river reaches in at least five major drainage basins in New Mexico. Within Aquatic Ecoregion 1, there are two subgroups of sites which differ mainly in relative proportions of substrate particle sizes. Aquatic Ecoregion 2 includes sites from about 1675 m (5500 ft) elevation up to about 2135 m. These sites differ from sites in Aquatic Ecoregion 1 by having a significantly higher percentage of silt substrate, higher substrate embeddedness, longer growing season length, greater watershed area, and more highly mineralized waters. Aquatic Ecoregion 3 encompasses river reaches from about 1675 m elevation down to an isoline depicting 180 frost-free days. Aquatic Ecoregion 4 includes sites below 1675 m where the growing season exceeds 180 frost-free days. Within Aquatic Ecoregion 4 there are two groups of sites that differ in the degree of mineralization of the water. The multivariate analyses used to define the aquatic ecoregions were also useful for identifying "outlier" sites, i.e., sites that were very different from other sites near them as well as identifying sites atypical of their aquatic ecoregion.

Introduction

This report describes the results of analyses of chemical, physical and climatic environmental variables for 136 aquatic sites on rivers in New Mexico. The purpose of the project is to define aquatic ecoregions for the entire state. An aquatic ecoregion is defined as a geographic region within which stream sites have a high degree of similarity in water chemistry, climate, and physical features of the habitat available to aquatic biota.

Definition of aquatic ecoregions is the first step in a project aimed at developing indices of biotic integrity (IBI's) within aquatic ecoregions that can be used to aid in the management of New Mexico's fishery resources. Biotic integrity is an organizing, self-correcting capability of the biota of an ecosystem that enables populations and communities of organisms to recover from disturbance and regain an end-state that is normal and good (Regier, 1993). "Normal and good" can be something other than pristine or naturally whole.

Much research has been focused recently on development of IBI's. To be effective, an IBI must be applied to a geographical set of waters that have similar ecological features (Stewart and Loar, 1994). The concept of ecoregions has been developed as a means of stratifying the landscape (Omernik, 1986, 1987; Hughes and Larson, 1988; Bailey, 1996). Ecoregions group naturally similar ecosystems and therefore group sites that have the potential to be similar in aquatic chemistry, physical features, and biota (Hughes and Larson, 1988). The use of ecoregions can enhance the effectiveness of an ecological monitoring program because ecoregional division of sites can control statistical variance which in turn makes it easier to detect potential problems (Stewart and Loar, 1994).

The ultimate objective of our project is to find meaningful patterns of variation in the organization of biological communities. Through study of the aquatic biota and the chemical, physical, and climatic features of their environment, we hope to identify factors responsible for the distribution and/or abundance of aquatic biota in New Mexico. Information about community structure, and how it is affected by underlying physical, chemical, and climatic processes, will enable us to determine expected biotic community structure for an aquatic ecoregion. Expected community structure then provides a baseline against which sites can be compared. The ability to compare sites within an aquatic ecoregion will facilitate development of an IBI that is protective of aquatic biota and that facilitates remedial or mitigative action.

Over the past four years, sampling has been conducted at aquatic sites representing the major river drainages in New Mexico. Specimen collection and processing is still underway. This paper describes the results of statistical analyses on environmental data and the resulting aquatic ecoregions obtained for the state.

Methods

Study Area

The study area for this paper included 136 river habitats across New Mexico. Seven major drainages and two closed basins were represented in the sampling, i.e., (1) upper Colorado River drainage (San Juan River and tributaries), (2) Arkansas River drainage, (3) Canadian River drainage, (4) Pecos River drainage, (5) Rio Grande drainage, (6) the Little Colorado River drainage, (7) the lower Colorado River drainage (Gila and San Francisco rivers), (8) the

Mimbres River basin, and (9) the Tularosa Basin. The Mimbres and Tularosa basins are closed, with no surface outflow. Elevation of study sites ranged from 866 m elevation (Pecos River near the Texas-New Mexico state line) up to 3217 m elevation (Jack's Creek in the Pecos River drainage).

Data Collection

Water quality data for most locations were obtained from samples collected in the field. Water sampling followed the protocol suggested in the "Quality Assurance Project Plan for Water Quality Management Programs" (NMED, 1992). Two one-liter polyethylene containers (single use only) of raw, unfiltered water were used for the analysis of major ions/cations, filterable and nonfilterable residues, and nutrients. The nutrient sample was treated with two ml of concentrated H_2SO_4 after the container was filled with water. Both samples were placed in ice chests, cooled on ice to 4°C, and transported to the New Mexico Environment Department (NMED) Scientific Laboratory Division (SLD) in Albuquerque for analysis. Analysis methods followed protocols in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1989). Contemporaneous water samples were not available from some study sites; water quality data for these sites were obtained from the STORET database (NMED). Water quality variables scored for each collection site included: alkalinity, ammonia, bicarbonate, calcium, chloride, hardness, Kjeldahl nitrogen, magnesium, nitrate/nitrite nitrogen, potassium, sodium, sulfate, total dissolved residues, total phosphorus, and total suspended solids.

Values for the following physical and climatic variables were obtained for each collection site: substrate embeddedness, growing season length (average number of frost-free days), elevation (mamsl), watershed area, and percent composition for six substrate particle sizes.

Stream bed materials (percent composition) were estimated on-site for six particle sizes (boulder, cobble, gravel, sand, silt, and clay) classified along three transects at each site following the method suggested by Platts et al. (1983). For each transect, the dominant substrate particle size was recorded at equi-spaced intervals [≤ 3.5 m (10 ft)] such that a minimum of ten observations were obtained. Stream substrate embeddedness was scored on-site at four categorical levels, i.e., 1 (0-25% substrate embeddedness), 2 (26-50%), 3 (51-75%), and 4 (76-100%). Elevation for each site was obtained from 7.5 minute U. S. Geological Survey topographic maps for New Mexico. Watershed area upstream from each site was estimated by taking the watershed area for the nearest USGS gauging station in the drainage and adding or subtracting square miles counted from topographic maps to reflect the location of the sample site with respect to the gauging station. Growing season length was estimated for each sample site by linear interpolation between isolines given by Bennett (1986).

Data Analysis

An earlier report described the results of preliminary analyses that were conducted on data for 38 sites restricted to the upper Rio Grande drainage in New Mexico (Jacobi et al., 1995). From those analyses, it was determined that aquatic ecoregions could probably be defined statewide using a combination of multivariate ordination and cluster analysis. The procedures found to be superior in those analyses were used herein and are described below.

To reduce the dimensionality and to circumvent problems of colinearity of some of the 25 environmental variables, principal components analysis (Johnson and Wichern, 1982) was performed. Principal components analysis is a multivariate ordination technique that is useful for reducing the variation in a large set of individual variables to a smaller set of multivariate combinations of variables (Corkum and Ciborowski, 1988; Stewart and Loar, 1994). Principal components are uncorrelated axes (orthogonal, or, at 90 degree angles) of variation in multivariate space. The principal components are obtained in such a way that the first axis represents the direction of greatest variation in multivariate space, the second axis accounts for the next most variation, and so forth.

Principal components with eigenvalues (amount of variance explained) greater than one were extracted from the environmental correlation matrix for sites using the FACTOR procedure of SAS (SAS Institute, Inc., 1989a). Use of the correlation matrix was equivalent to standardization of variables and it eliminated scaling problems that may arise with a covariance matrix when all of the variables are not on the same scale of measurement. The set of important (eigenvalues greater than one) principal components were then subjected to an orthogonal rotation (varimax criterion, Harmon, 1976, p. 290-299) to improve their interpretability. (After rotation, the principal components are referred to as factors.) Standardized factor scores for each site were obtained on each of the varimax-rotated factors. Thus, the original 25 environmental variables were reduced to fewer multivariate factors having different environmental variables determining their extent and direction in multivariate space. Because ordination is a qualitative statistical procedure with no formal hypothesis tests

performed, transformation of data was not necessary, other than use of the correlation matrix as described above, and no transformations were made prior to analysis.

Using scores on the rotated environmental factors as input data, cluster analysis was performed to elucidate similarities among different river sites in New Mexico. Euclidean statistical distances between sites were obtained and a cluster "tree" was constructed using Ward's clustering algorithm (Ward, 1963). All cluster analyses were performed using routines in STATISTICA (StatSoft, 1994, release 4.5). Cluster analysis has been demonstrated to have utility in defining groups of sites with similar characteristics (e.g., Cowley, 1979; Hawkes et al., 1986; Corkum, 1989; Conquest et al., 1994; Jacobi et al., 1995). Following elucidation of clusters of sites based on the multivariate environmental factors, analysis of variance (GLM procedure, SAS Institute, Inc., 1989b) was performed to obtain a post hoc assessment of which multivariate environmental factors and which individual environmental variables were most important in separating aquatic ecoregions.

The procedures described above were applied in three sets of analyses. First, data for all sites were subjected to a preliminary analysis. At the time of the preliminary analysis, there were missing data for elevation, total dissolved residues, and total suspended solids for a few sites. To maximize the number of sites represented in the preliminary analysis, the initial principal components analysis used only 23 variables and 134 sites, excluding total dissolved residues and total suspended solids. The results of the preliminary analysis indicated a clear grouping of sites above about 1675 m elevation from sites below that elevation.

Following the preliminary analysis, data were divided into two sets, i.e., sites at an elevation greater than or equal to 1676.3 m (5500 ft) and sites below that elevation. The second and third sets of analyses were carried out on the respective subgroups of sites after missing values for elevation, total dissolved residues and total suspended solids were obtained. Prior to conducting the analyses for lower elevation sites (<1676.3 m), a decision was made to exclude two sites thought to be atypical of the other river sites, i.e., Del Rio Drain, an irrigation return flow ditch near Las Cruces, and, Mound Spring in the southern portion of the Tularosa Basin. Twenty-five environmental variables were used in the analyses for sites at an elevation greater than or equal to 1676.3 m.

The initial analyses for sites below 1676.3 m indicated considerable heterogeneity in the groupings of sites and this heterogeneity was caused by three factors, i.e., an extreme range of mineral content of the surface waters, watershed areas ranging from 1 to 27832 square miles (2.6 to 72053.7 square kilometers), and the presence of coarse substrate particle sizes at river sites downstream from dams. To simplify interpretation of site groupings, the following variables were excluded from the analyses for the lower elevation sites: embeddedness, watershed area, and percentages for boulder, cobble, gravel, sand, and clay. The remaining 18 environmental variables were used in the analyses. To accommodate the extreme range in mineral content of the water, six sites were excluded from computations to obtain the principal components, i.e., Salt Creek, Malpais Spring, the Pecos River (Lake Arthur Falls and above the Delaware River), the Delaware River, and the Canadian River (9 mi east of Logan). These six sites were scored on the factors obtained using the remaining 34 sites and were included in the subsequent cluster analyses.

GIS Mapping

Maps depicting site locations and ecoregion designations obtained through statistical analyses were produced by the Earth Data Analysis Center (EDAC), Albuquerque, New Mexico. Data files were manipulated in ArcInfo 7.0.4 (Environmental Systems Research Institute, Inc., 1982-1996) and the graphic display was produced with ArcView Geographic Information System (GIS) 3.0 (Environmental Systems Research Institute, Inc., 1992-1996). The digital hydrology and elevation base map layers were obtained from Resource Geographic Information System, the New Mexico GIS Clearinghouse.

Results

Four aquatic ecoregions in New Mexico were defined using cluster analysis on scores for multivariate environmental factors (Figure 1). These ecoregions are given the provisional names Aquatic Ecoregion 1, Aquatic Ecoregion 2, Aquatic Ecoregion 3, and Aquatic Ecoregion 4. Definition of these four aquatic ecoregions involved separate statistical analyses for sites above and below about 1675 m elevation.

Environmental Variation for Sites Above 1675 Meters Elevation

Of the 136 aquatic stream sites represented in the data, 96 were located at elevations higher than 1675 m. Data for these 96 sites were subjected to principal components analysis and the resultant principal components were rotated using the varimax criterion (Table 1). The analysis yielded eight multivariate environmental factors with eigenvalues greater than one and these eight factors together accounted for about 79% of the variation in the sample.

The first environmental factor represented a water hardness gradient, with high loadings for calcium, hardness, sodium, sulfate, total dissolved residue, and percent clay substrate. Factor 1 accounted for about 25.5% of the variance. Factor 2 had high loadings for alkalinity, bicarbonate, and percent silt substrate and it accounted for about 10% of the variation. The third multivariate environmental factor (about 9% of variation) contrasted elevation with growing season length and watershed area, which covaried inversely with elevation. The fourth factor (8% of variation) was dominated by high loadings for chloride and potassium and factor 5 was dominated by ammonia and Kjeldahl nitrogen (7.8% of variation). Factor 7 contrasted percent boulder substrate with percent gravel and percent sand; this factor described about 6% of the sample variance. The eighth factor had a single high loading for nitrate/nitrite nitrogen and accounted for about 5% of the variation.

Scores on the eight multivariate environmental factors were obtained for each site and were used as input data for cluster analysis. The cluster tree (Figure 2) indicated three major clusters and a loose aggregation of potential outlier sites. From the cluster tree, it was difficult to determine which clusters were more and less similar. The loose aggregation of sites in cluster 4 suggested those sites could be outliers with respect to sites in clusters 1, 2, and 3.

Analysis of variance (ANOVA) was carried out on the factor scores (SAS Institute, Inc. 1989b); multiple range tests among clusters were carried out using the REGWQ option of the GLM procedure of SAS. Multiple range tests indicated that sites in cluster 4 were indeed extreme for factor 1 (hardness), factor 4 (chloride/potassium), factor 6 (embeddedness, total phosphorus, and total suspended solids), and factor 8 (nitrate/nitrite nitrogen). Sites in cluster 1 tended to have higher values for alkalinity, bicarbonate, and silt (factor 2) than did sites in

clusters 2, 3, or 4. Cluster 1 sites also tended to have a longer growing season and watershed area than sites in clusters 2 or 3. Sites in cluster 3 differed significantly ($P<0.05$) from sites in other clusters with respect to the percent boulder versus percent gravel and percent sand substrate.

The ANOVA on the factor scores was somewhat complicated to interpret; hence, ANOVA was also carried out individually on the 25 environmental variables (Table 2). Sites in clusters 1 and 4 differed significantly ($P<0.05$) from sites in clusters 2 and 3 for alkalinity, bicarbonate, embeddedness, growing season length, elevation, and total suspended solids. Sites in cluster 1 differed ($P<0.05$) from sites in the other three clusters in the percent of silt substrate. Sites in cluster 4 (outlier sites) differed significantly ($P<0.05$) from sites in clusters 1, 2, and 3 for calcium, chloride, hardness, magnesium, nitrate/nitrite nitrogen, potassium, sodium, sulfate, total dissolved residues, total phosphorus, and percent clay substrate. Clusters 2 and 3 differed significantly ($P<0.05$) only for substrate particle sizes, i.e., percent boulder, percent gravel, and percent sand.

The picture that emerged was that sites in clusters 2 and 3 were more similar to each other than they were to sites in cluster 1; hence, clusters 2 and 3 were taken to represent the highest elevation aquatic ecoregion and were designated Aquatic Ecoregion 1. Sites in cluster 1, being at a generally lower elevation were designated Aquatic Ecoregion 2. The mean elevations by cluster (Table 2) suggested 7000 ft (about 1675 m) as a boundary between the aquatic ecoregions.

In general, the eight outlier sites in cluster 4 (Figure 2) represented highly mineralized waters or sites that were extreme for one or more environmental variables. Sites with highly mineralized waters included two sites on the lower Jemez River downstream from Soda Dam, a series of highly mineralized artesian springs with extensive travertine deposits, the lower Cimarron River above Boys Ranch, and the Canadian River at Tinaja and at the Gonzales Ranch. The lower Chama River above Espanola had an extreme value for total phosphorus and total suspended solids. Diamond Creek (at James Cabin) and the Pecos River above Lisboa Springs Fish Hatchery were outlier sites for nitrate/nitrite nitrogen.

The cluster tree for sites above 1675 m elevation (Figure 2) indicated two subgroups of sites were present in clusters 1 and 2 and three subgroups could be identified in cluster 3. For cluster 1, subgroups 1a and 1b differed significantly ($P<0.05$) in alkalinity, bicarbonate, and percent silt substrate; subcluster 1b had values 2-3 times higher than subcluster 1a. Subcluster 1b also included five higher elevation sites that had alkaline waters and a high percentage of fine substrate particles. These Aquatic Ecoregion 1 sites that were grouped with most of the Aquatic Ecoregion 2 sites in cluster 1 included Coyote Creek (Rainsville), Peñasco River (below Bluff Spring), Polvadera Creek (Forest Road 422), Sacramento River (Otero County, above Scott Able Creek), Bluewater Creek (above Bluewater Reservoir), and Agua Chiquita (below Barrel Springs).

For cluster 2, subclusters denoted 2a and 2b on Figure 2 differed significantly ($P<0.05$) in Kjeldahl nitrogen and percent gravel substrate; subcluster 2a had values 1.5-2 times higher than subcluster 2b. Included in subcluster 2b was a notable group of Aquatic Ecoregion 2 sites that had relatively soft water and a high percentage of coarse substrate particle sizes. These

Aquatic Ecoregion 2 sites that were clustered with Aquatic Ecoregion 1 sites included Las Animas Creek (below Negro Bill Spring and below Kelso Cabin), the Mimbres River (Cooney Campground), the Gallinas River (USGS Montezuma Gauge), the Chama River (above Heron Lake, below Heron Lake, below Rio Nutrias, and below Rio Gallina), and the Gila River West Fork (above the Gila River East Fork).

Among the subclusters in cluster 3, significant differences ($P<0.05$) existed for alkalinity, bicarbonate, calcium, growing season length, hardness, elevation, and total dissolved residues. In general, most of the differences involved subcluster 3c. Four of the five sites in subcluster 3c were lower elevation Aquatic Ecoregion 2 sites that had a high percentage of boulder and cobble substrate. These "misplaced" Aquatic Ecoregion 2 sites included the Dry Cimarron River (near Folsom Falls), the Peñasco River (at Cleve Ranch), the Rio Pueblo (above the Rio Grande), and the Guadalupe River (above the Gilman tunnels). Three additional Aquatic Ecoregion 2 sites with high percentages of coarse substrate particle sizes were grouped with Aquatic Ecoregion 1 sites in subcluster 3b, i.e., the Red River (above the Rio Grande), the Chama River (below El Vado Lake), and the Pecos River (at Forked Lightning Ranch).

Environmental Variation for Sites Below 1675 m Elevation

The final set of analyses was conducted on data for 40 aquatic stream sites in New Mexico that were located below about 1675 m (5500 ft) elevation. Principal components analysis yielded 6 components with eigenvalues greater than one that accounted for 91% of the variation. These six components were subjected to varimax rotation (Table 3). The first multivariate environmental factor for sites below 5500 ft elevation represented a water hardness factor

similar to that observed for sites above 5500 ft elevation. The first factor, which explained about 26% of the variation in the sample, had high loadings for calcium, hardness, magnesium, sulfate, and total dissolved residue.

Factor 2 (18% of variation) had high coefficients for ammonia, Kjeldahl nitrogen, and potassium. Factor 3, which represented alkalinity and bicarbonate, described 13% of the variation among sample sites. The fourth factor (12.6% of variation) was dominated by total phosphorus, total suspended solids, and percent silt substrate. Factor 5 contrasted elevation with growing season length and this contrast explained about 12% of the variance. Factor 6 (10% of variance) contrasted salinity (sodium and chloride) with nitrate/nitrite nitrogen.

Cluster analysis yielded three groups of sites below 1675 m elevation (Figure 3). Differences between the three clusters were assessed with multiple range tests in ANOVA (Table 2). Cluster 1 had significantly higher ($P<0.05$) elevation and significantly shorter growing season length (frost-free days) than did clusters 2 and 3, which did not differ significantly in elevation or growing season length. Sites with a growing season of less than 180 days were assigned to Aquatic Ecoregion 3 and sites with a growing season of 180 days or more were classified as Aquatic Ecoregion 4.

Cluster 3 included sites with a high degree of mineralization of the water. These sites had significantly higher values ($P<0.05$) for calcium, chloride, hardness, magnesium, sodium, and sulfate than did cluster 1 or cluster 2. Thus, two categories of sites can be distinguished by the ionic content of the surface water within Aquatic Ecoregion 4.

Subclusters of sites can be distinguished in Figure 3. Within cluster 1, subcluster 1a sites had significantly higher ($P<0.05$) alkalinity and bicarbonate, a longer mean growing season length, and a lower mean elevation than subcluster 1b sites. Within cluster 2, sites in subcluster 2b had higher total phosphorus, higher total suspended solids, and a higher percentage of silt substrate; sites in subcluster 2a had values for sodium and chloride that were 4-5 times higher than those for subcluster 2b. For the group of sites denoted cluster 3, subcluster 3a had significantly higher ($P<0.05$) nitrate/nitrite nitrogen, total suspended solids, and percent silt substrate . Subcluster 3b had significantly lower levels of magnesium than did subclusters 3a or 3c. Subcluster 3c had significantly higher chloride, sodium, and total dissolved residues.

Discussion

Based upon multivariate statistical analyses, four aquatic ecoregions have been identified for New Mexico (Figure 1) that intersect boundaries of major drainage basins and physiographic provinces and that are largely inconsistent with terrestrial ecoregions defined for New Mexico (Omernik, 1986, 1987; Bailey, 1995). Aquatic Ecoregion 1 included sites above about 2135 m (7000 ft) elevation. This ecoregion, represented in at least five drainage basins, included sites in the north-central mountains (Sangre de Cristo, San Juan, Jemez Ranges), the Zuni Mountains in west-central New Mexico, the southwestern mountains (Black Range, Mogollon Mountains, and San Francisco Mountains), and the Sacramento and Guadalupe mountains in southeastern New Mexico. Within Aquatic Ecoregion 1, there were two subgroups of sites that differed mainly in substrate composition; one group, generally at higher elevation, had a

higher percentage of boulder substrate and lower percentages of gravel and sand substrates than did the other subgroup.

Aquatic Ecoregion 2 was defined to occupy areas between 1675 m and 2135 m elevation. The sites in this ecoregion differed from the higher elevation sites in Aquatic Ecoregion 1 by having a significantly higher percentage of silt substrate, higher substrate embeddedness, longer growing season, and greater watershed area. Sites in Aquatic Ecoregion 2 were located in the north-central mountains, west-central mountains, southwestern mountains, and southeastern mountains.

Aquatic Ecoregion 3 was defined to include sites at an elevation less than 1675 m elevation and a growing season of less than 180 frost-free days. This aquatic ecoregion has its upper boundary near the pinon-juniper vegetation zone in the foothills. Aquatic Ecoregion 3 included sites on the lower San Juan River from about Blanco to the state line, the Rio Grande from Cochiti Lake to about the Sevilleta National Wildlife Refuge, the Pecos River from about Villanueva State Park to near Santa Rosa, the Canadian River from the southern Colfax County line to the upper end of Conchas Lake, the Gila River to near Riverside, and the San Francisco River downstream to the Arizona state line.

Aquatic Ecoregion 4 encompassed sites below 1675 m elevation where the growing season exceeds 180 frost-free days. This ecoregion included the Rio Grande from the Sevilleta National Wildlife Refuge to the Texas state line, the Canadian River from Conchas Lake to the Texas state line, the Pecos River from Santa Rosa downstream to the Texas state line, the Gila

River from Riverside to the Arizona State line, the lower end of the Mimbres River, and the Tularosa Basin.

The variation in aquatic habitats in New Mexico appeared to be related to elevational gradients, i.e., as elevation decreased, increases were observed in ionic content, hardness, alkalinity, salinity, growing season length, and percentage of small substrate particle size. Thus, elevations were taken to represent the boundaries between Aquatic Ecoregions 1, 2, and 3, and growing season length was used as the boundary between Aquatic Ecoregions 3 and 4.

Although specific elevations were chosen to be representative of the ecoregion boundaries, common sense is necessary when using these ecoregion designations. For example, it is commonly observed that north-facing slopes in mountainous regions are cooler to a lower elevation than are slopes that are exposed to direct solar radiation; hence, the boundary for Aquatic Ecoregion 1 could be somewhat lower than 2135 m on north-facing slopes. Likewise, latitudinal gradients can mimic elevational gradients with respect to temperature and growing season. Thus, the boundary between aquatic ecoregions 1 and 2 in southern New Mexico could lie at slightly higher elevations than in northern New Mexico. Our ecoregion boundaries are not intended to define absolute dividing lines between aquatic ecoregions because such sharp transitions are rarely found in the continuum of a river system. Our purpose is to provide a division of river sites into less variable groupings within which we can develop indices of biotic integrity.

There are several regions in New Mexico that were not represented in our sample. We plan additional sampling to include a number of sites in aquatic ecoregions 3 and 4, including (1)

the Sierra Blanca area in south-central New Mexico (Bonito Creek and Rio Ruidoso), (2) the Sandia and Manzano mountains (Las Huertas and Tajique creeks), (3) the middle Rio Grande (Albuquerque to Bernardo), (4) artesian spring flows (e.g., Bitter Lakes and upper Black River), (5) streams in the northeastern quadrant of the state such as Taiban Creek, Carrizozo Creek, Corrumpa Creek, Perico Creek, Carrizo Creek, Ute Creek, Trementina Creek, Conchas River, and Rio Agua Negra, and (6) the lower Jemez River drainage downstream of San Ysidro.

Aquatic Ecoregions Compared to Terrestrial Ecoregions of Omernik and Bailey

Omernik (1986, 1987) and Bailey (1994a,b, 1995, 1996; Bailey et al., 1994) have proposed terrestrial ecoregions for the United States based on broad-scale patterns of vegetation, landform, and climate. The ecoregion boundaries for these classifications differ markedly in New Mexico and there is no clear reason to adopt either when considering riverine systems.

Bailey (Bailey, 1996, p. 157) asserted that aquatic and riparian systems do not need a separate classification because aquatic and riparian systems are closely associated with terrestrial systems. We disagree. A comparison of our aquatic ecoregion classification in New Mexico (Figure 1) with terrestrial ecoregion designations (Figures 4a and 4b) reveals minimal similarity between aquatic and terrestrial ecoregions.

A depiction of Omernik's ecoregions for New Mexico are shown in Figure 4a and those of Bailey are shown in Figure 4b. When compared to the aquatic ecoregions described in this report, we find approximate consistency with Omernik's terrestrial ecoregions in only a few areas. The most similar area between our aquatic and Omernik's terrestrial ecoregions is in

the southern Rocky Mountains in north-central New Mexico. However, our analyses indicate that Aquatic Ecoregion 1 is found throughout New Mexico at higher elevation; Omernik designated mountain ranges outside the southern Rocky Mountains as a different terrestrial ecoregion (Figure 4a). Aquatic Ecoregion 2 overlaps four of Omernik's ecoregions (22, 23, 24, and 26), Aquatic Ecoregion 3 overlaps five of Omernik's ecoregions (22, 23, 24, 25, and 26), and Aquatic Ecoregion 4 includes parts of three of his ecoregions (24, 25, and 26).

The concordance between aquatic ecoregions and terrestrial ecoregions is no better when considering Bailey's ecoregion classification for New Mexico (Figure 4b). Aquatic Ecoregion 1 includes parts of Bailey's 310, M310, 330, and M330 ecoregions. Aquatic Ecoregion 2 spans parts of terrestrial ecoregions 310, M310, 320, 330, and M330. Similarly, Aquatic Ecoregion 3 overlaps with 310, M310, 320, and 330 ecoregions. Aquatic Ecoregion 4 includes parts of three terrestrial ecoregions (310, M310, and 320). The lack of concordance between aquatic ecoregions and terrestrial ecoregions is clear, and it suggests that aquatic systems may require their own classification, especially in regions with highly variable landform.

Aquatic Ecoregions Compared to Drainage Basin Boundaries

Boundaries for seven major river drainages and nine closed basins are shown in Figure 4c. In general, aquatic ecoregions traverse drainage divides at higher elevation and at lower elevations they occupy distinct areas of several different drainages. Comparison of Figures 1 and 4c indicate that use of drainages would require development of many more IBI's that would use of the four aquatic ecoregions. Thus, use of hydrologic units or drainages for IBI's

would be less efficient and far less powerful statistically than would fewer, more extensive aquatic ecoregions. For example, the drainage basis for the proposed ecosystem management concept (U. S. Fish and Wildlife Service, 1995) would require development of at least 17 separate IBI's in New Mexico.

Preliminary analyses of fish faunal regions in the upper Rio Grande (Jacobi et al., 1995) indicated a modest degree of drainage specificity in fish species assemblages. Our a priori expectation is that this drainage specificity in fish species assemblages will be more pronounced on a statewide basis because of the distinct native fish species assemblages of the major river drainages (Sublette et al., 1990). In order to develop IBI's within aquatic ecoregions that span drainage boundaries, it will be necessary to consider faunal composition on some basis other than a species-level classification. Use of generic classification, reproductive guilds (Balon, 1975, 1985), trophic guilds (e.g., Simberloff and Dayan, 1991; Austen et al., 1994), or some other classification scheme will probably be necessary to develop ecoregion-specific IBI's based on fishes. Alternatively, there is less reason to expect as much drainage specificity in benthic macroinvertebrate assemblages. Our project will evaluate both fish and benthic macroinvertebrates as metrics for IBI's.

Aquatic Ecoregions Compared to Physiographic Provinces

It was observed consistently at higher and lower elevations in our analyses that the major aspect of variation among sites was along a dissolved ion concentration gradient. Because dissolved ions contributing to water hardness and salinity come primarily from dissolution of rocks (Allan, 1995), it was thought that perhaps a map of physiographic provinces might bear

similarity to the aquatic ecoregions. Physiographic provinces of New Mexico are shown in Figure 4d (Hawley, 1986a,b).

A physiographic province is a region that differs significantly from adjacent regions in its particular pattern of landforms. Each province has a distinctive geology and particular combinations of topographic and hydrologic features (Hawley, 1986a). New Mexico has a diversity of landforms that reflect a variety of geomorphic processes that range from deep-seated volcanism to surficial erosion and sedimentation by wind and water.

When aquatic ecoregions (Figure 1) are compared to physiographic provinces (Figure 4d), we find that the only area of relatively close similarity is in the southern Rocky Mountain region of north-central New Mexico. Aside from north-central New Mexico, we find little additional similarity between aquatic ecoregions and physiographic provinces.

Aquatic Ecoregions and Fishery Management

Our statistical analyses suggest that aquatic stream habitats should be considered in a framework independent of terrestrial ecoregions, hydrologic units, and physiographic provinces. Clearly, the physical, chemical, and climatic variables we have analyzed for aquatic habitats vary in similar patterns in different regions of New Mexico. Aquatic ecoregions should provide a more efficient and powerful basis for development of IBI's than would use of hydrologic units or drainages and perhaps more biologically meaningful IBI's than would the use of terrestrial ecoregions.

Aquatic ecoregion-specific IBI's have important potential uses in fisheries management and in watershed protection. When properly constructed, an IBI will identify sites where species composition differs substantially from expectation. The ability to identify aberrant sites provides a basis for elucidating possible causes of depauperate faunal assemblages. In contrast to perspectives afforded by other land-partitioning strategies, the ecoregion perspective can afford a greater predictive capacity about the response of hydrologic units and their associated biota to a variety of management practices. Given these advantages, the aquatic ecoregion provides a logical spatial framework for formulating regional policy and management plans for fisheries and other aquatic natural resources. Complementing this, aquatic ecoregion-specific IBI's offer easily observable measures of ecosystem response to management.

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Acknowledgments

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Table 1. Multivariate environmental factors for 96 aquatic sites in New Mexico above 1675 m (5500 ft) in elevation.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Alkalinity	0.54274	**0.74403**	0.14773	0.18040	0.05055	-0.07559	-0.02959	0.06540
Ammonia	-0.03369	-0.13014	0.19706	0.02251	**0.81609**	0.09091	-0.16640	-0.02685
Bicarbonate	0.54486	**0.74642**	0.14827	0.18300	0.04941	-0.07544	-0.03377	0.06864
Calcium	**0.87937**	0.25904	0.17430	0.05027	0.06135	0.03368	-0.12177	0.05954
Chloride	0.21385	0.05964	0.00676	**0.85225**	0.03466	-0.05395	0.05228	-0.03412
Embeddedness	-0.04222	0.12631	0.13048	0.02449	-0.16029	**0.65380**	-0.02032	-0.30156
Growing Season	0.27648	0.21967	**0.76896**	0.25267	0.13690	0.04878	0.04467	0.07340
Hardness	**0.94573**	0.19011	0.16312	0.02584	0.02604	0.02350	-0.04012	0.00110
Kjeldahl N	-0.01181	-0.01273	-0.07414	-0.08292	**0.75709**	-0.02574	0.29809	-0.05698
Magnesium	**0.95445**	0.09088	0.10695	-0.01071	-0.05699	0.02816	0.02762	-0.04943
Elevation	-0.24430	-0.12655	**-0.80483**	-0.17928	-0.15762	-0.05497	-0.17580	0.00593
Nitrate/Nitrite	-0.03256	0.02904	0.10407	-0.06554	-0.08564	0.06270	0.05421	**0.86043**
Potassium	0.07875	0.09788	0.22821	**0.83988**	-0.08739	0.10837	0.07433	-0.03211
Sodium	**0.83846**	0.20246	0.14388	0.27581	-0.01267	-0.03457	0.09659	-0.04151
Sulfate	**0.96070**	-0.08986	0.13202	-0.02831	-0.01713	0.03128	0.00387	-0.07199
Total Residue	**0.95582**	0.13569	0.17170	0.11915	0.00343	-0.00390	0.02804	-0.05217
Total Phosphorus	0.06043	0.04250	0.06971	-0.01459	0.11218	**0.84004**	0.01832	0.19570
Total Solids	0.06093	-0.04249	0.19226	0.04888	0.60253	**0.69121**	-0.08459	0.13282
Watershed Area	0.06167	-0.10240	**0.74066**	-0.07749	-0.03078	0.19165	-0.13480	0.02748
% Boulder	-0.17278	-0.23863	-0.10937	-0.14022	-0.08364	-0.06633	**-0.73475**	0.09155
% Cobble	-0.17768	-0.53482	0.16467	0.31735	0.40933	-0.09782	-0.17901	-0.14825
% Gravel	-0.13141	-0.24361	-0.16258	0.03200	-0.00065	-0.19921	**0.72539**	0.36851
% Sand	-0.14099	0.32494	0.19236	-0.38488	-0.18071	0.14026	**0.44259**	-0.36951
% Silt	0.07302	**0.78567**	0.03174	0.05439	-0.15196	0.17634	0.08766	-0.12379
% Clay	**0.59349**	0.05730	-0.16967	0.10742	-0.05641	0.04287	0.08068	0.10300
Eigenvalue	6.369142	2.543563	2.265902	1.993040	1.947836	1.802876	1.524229	1.252801
% Variance Explained	25.5	10.2	9.1	8.0	7.8	7.2	6.1	5.0

The multivariate factors were obtained by a varimax rotation of principal components. Variables with high loadings on a factor appear in boldface type. "Total Residue" denotes total dissolved residues; "Total Solids" represents total suspended solids. Factor 1 represents a hardness gradient, Factor 2 is primarily alkalinity/bicarbonate with a high loading for silt substrate composition. Factor 3 is a multivariate contrast between elevation and growing season length and watershed area which vary inversely with elevation. Factor 4 is dominated by high loadings on chloride and potassium. Factor 5 represents nitrogen; factor 6 is substrate embeddedness, total phosphorus, and total suspended solids. Factor 7 denotes a contrast between boulder substrate composition and gravel/sand substrate composition. Factor 8 primarily represents nitrate/nitrite nitrogen.

Table 2. Multiple range tests between clusters for environmental variables measured at aquatic stream sites in New Mexico.

Variable		Sites ≥ 1675 m Elevation				Sites < 1675 m Elevation		
Alkalinity	(cluster number)	4	1	3	2			
	(cluster mean)	153	141	77	66			
	(nonsignificant subsets)	----------		----------		no significant differences		
Ammonia		no significant differences				no significant differences		
Bicarbonate		4	1	3	2			
		186	170	93	81			
		----------		----------		no significant differences		
Calcium		4	1	3	2	3	2	1
		87	43	34	22	440	104	60
			----------				----------	
Chloride		4	1	2	3	3	2	1
		28	7	6	5	1257	65	14
			----------				----------	
Embeddedness		1	4	2	3			
		1.9	1.5	1.3	1.3	variable not used		

Growing Season Length		4	1	3	2	2	3	1
		129	116	87	87	196	195	157
		----------		----------		----------		
Hardness		4	1	3	2	3	2	1
		368	145	102	76	1557	346	244
			----------				----------	
Kjeldahl Nitrogen		no significant differences				no significant differences		
Magnesium		4	1	3	2	3	2	1
		37	10	6	5	118	23	21
			----------				----------	
Elevation		3	2	1	4	1	2	3
		7944	7474	6498	6228	4793	4064	3753
		----------		----------			----------	
Nitrate/Nitrite Nitrogen		4	3	1	2	no significant differences		
		0.3	0.1	0.1	0.1			

Potassium		4	1	2	3	no significant differences		
		5	3	2	2			

Sodium		4	1	2	3	3	2	1
		71	21	8	7	762	76	43
			----------				----------	

(Table 2, continued) Variable	Sites ≥ 1675 m Elevation				Sites < 1675 m Elevation		
Sulfate	4	1	3	2	3	2	1
	284	44	27	17	1314	272	143
Total Dissolved Residue	4	1	3	2	no significant differences		
	658	237	135	128			
Total Phosphorus	4	1	2	3	no significant differences		
	1.7	0.1	0.1	0.1			
Total Suspended Solids	4	1	3	2	no significant differences		
	196	93	24	18			
Watershed Area	1	4	2	3	variable not used		
	1237	837	189	150			
% Boulder	3	2	1	4	variable not used		
	34	12	8	5			
% Cobble	no significant differences				variable not used		
% Gravel	2	4	1	3	variable not used		
	29	27	18	17			
% Sand	2	1	4	3	variable not used		
	23	20	8	7			
% Silt	1	4	2	3	no significant differences		
	20	9	8	4			
% Clay	4	1	2	3	variable not used		
	15	2	1	0.3			

For each variable, the first row of numbers denotes the number cluster on Figure 2 (sites ≥ 1675 m) or Figure 3 (sites < 1675 m). The second row of numbers are means ranked from highest to lowest in a left to right orientation. Nonsignificant (P>0.05) subsets of clusters are underlined. Multiple range tests (Ryan, 1959, 1960; Einot and Gabriel, 1975; Welsch, 1977) were used to control Type I error rate.

Table 3. Multivariate environmental factors for 40 aquatic sites in New Mexico below 1675 m (5500 ft) elevation.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Alkalinity	-0.02116	-0.05701	**0.97839**	0.11497	0.04600	0.04993
Ammonia	-0.05026	**0.95522**	-0.07292	0.00590	-0.11924	0.01543
Bicarbonate	-0.00441	0.00341	**0.96655**	-0.16976	0.03582	0.00984
Calcium	**0.96549**	-0.05956	-0.12190	-0.05318	0.16210	0.03355
Chloride	0.34958	0.04994	-0.05956	-0.05876	0.43187	**0.71864**
Growing Season	0.23403	-0.13837	-0.01709	0.09090	**0.89417**	0.11318
Hardness	**0.97053**	-0.09062	0.01920	-0.07414	0.14615	0.09545
Kjeldahl N	0.04930	**0.93299**	-0.05741	0.20949	-0.08250	-0.11830
Magnesium	**0.67320**	-0.23667	0.37978	0.38152	0.10544	0.30781
Elevation	-0.29461	-0.07532	-0.12195	0.07332	**-0.80579**	-0.15509
Nitrate/Nitrite	0.00061	0.24779	0.11368	0.47318	0.40375	**-0.62062**
Potassium	-0.10210	**0.89931**	0.05573	0.05920	0.17653	0.19950
Sodium	0.38794	0.21101	0.25640	0.00852	0.27022	**0.75051**
Sulfate	**0.97967**	0.02251	-0.00349	-0.04805	0.14489	0.08684
Total Residue	**0.93439**	0.04045	0.03686	-0.03700	0.22187	0.24905
Total Phosphorus	-0.14000	0.14902	-0.15310	**0.86054**	-0.11031	0.01841
Total Solids	-0.09712	0.57135	-0.07167	**0.77143**	-0.04189	-0.11003
% Silt	0.18454	-0.17865	0.35201	**0.66326**	0.34975	-0.18435
Eigenvalue	4.653341	3.178626	2.313887	2.263628	2.192203	1.779350
% Variance Explained	25.9	17.7	12.6	12.6	12.2	9.9

The multivariate factors were obtained by a varimax rotation of principal components. Variables with high loadings on a factor appear in boldface type. "Total Residue" denotes total dissolved residues; "Total Solids" represents total suspended solids. Factor 1 represents a hardness gradient, Factor 2 has high coefficients for ammonia, bicarbonate, and potassium. Factor 3 represents is dominated by alkalinity and bicarbonate. Factor 4 is a multivariate combination of total phosphorus, total suspended solids, and percent silt substrate. Factor 5 contrasts growing season length with elevation. Factor 6 is a contrast between salinity (sodium and chloride) and nitrate/nitrite nitrogen.

Figure Legends

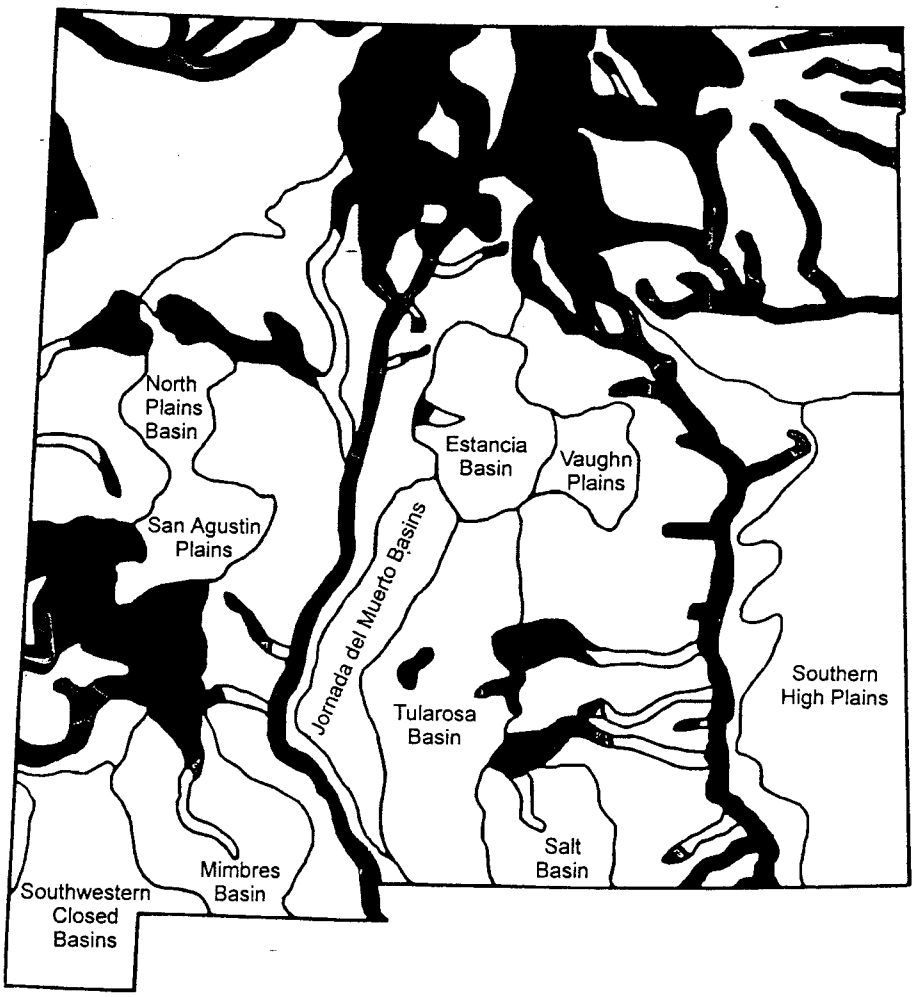
Figure 1. Aquatic ecoregions of New Mexico defined by multivariate statistical analysis. Aquatic Ecoregion 1, the highest ecoregion identified in the present study, has a lower boundary at about 2135 m (7000 ft) elevation. Aquatic Ecoregion 2 includes sites between 1675 m (5500 ft) and 2135 m elevation. Sites between 1675 m and an isoline representing 180 frost-free days lie in Aquatic Ecoregion 3. Aquatic Ecoregion 4 includes sites where the growing season is greater than 180 frost-free days.

Figure 2. Tree diagram from a cluster analysis on multivariate factor scores obtained for 96 sites in New Mexico above 1675 m elevation. Four clusters were apparent in the diagram, with clusters 1, 2, and 3 each having subclusters of sites. Multiple range tests between clusters indicated that clusters 2 and 3 were very similar for most of the environmental variables including elevation; hence, sites in these two clusters were assigned to Aquatic Ecoregion 1. The generally lower elevation sites in cluster 1 were assigned to Aquatic Ecoregion 2. An elevation of about 2135 m (7000 ft) was the approximate midpoint between the mean elevation for cluster one and the mean elevation for clusters 2 and 3 combined.

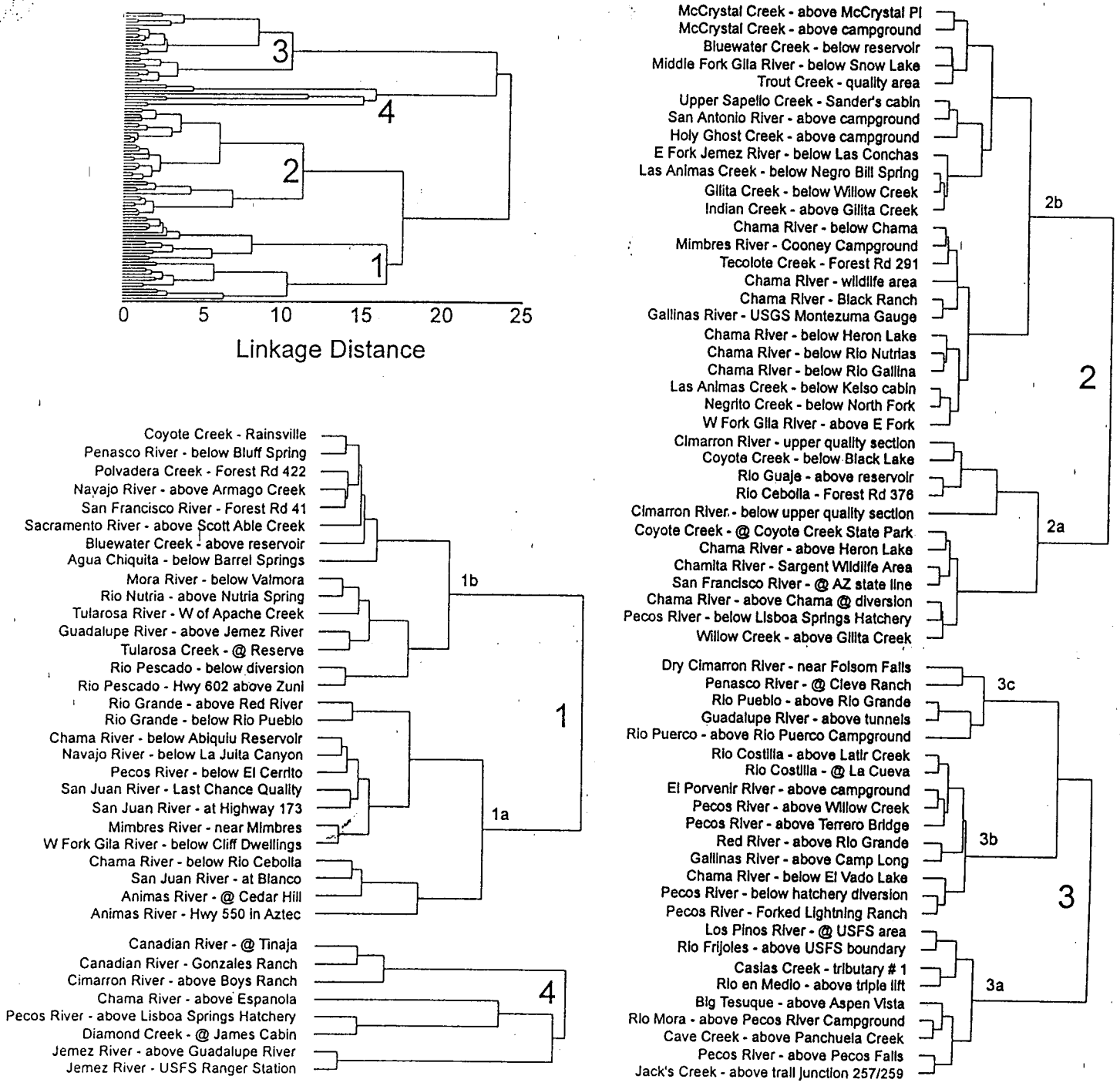
Figure 3. Tree diagram from cluster analysis on multivariate factor scores obtained for 40 sites in New Mexico below 1675 m elevation. Three groups of sites were apparent. Cluster 1 sites were higher elevation and were found to lie between about 1675 m (5500 ft) and an isoline depicting 180 frost-free days. Sites in cluster 1 were taken to represent Aquatic Ecoregion 3. Clusters 2 and 3 included lower elevation sites where the growing season exceeded 180 frost-free days. Cluster 3 sites differed from cluster 2 sites by having water with significantly higher mineral ion.

Figure 4. (a) Ecoregions in New Mexico defined by Omernik (1986, 1987). Ecoregion definitions are: 21 - Southern Rockies, 22 - Arizona/New Mexico Plateau, 23 - Arizona/New Mexico Mountains, 24 - Southern Deserts, 25 - Western High Plains, 26 - Southwestern Tablelands. (b) Ecoregions in New Mexico defined by Bailey (1995). Ecoregion definitions are: 310 - Tropical/Subtropical Steppe, M310 Tropical/Subtropical Steppe Mountains, 320 - Tropical/Subtropical Desert, 330 - Temperate Steppe, M330 - Temperate Steppe Mountains. (c) Major river drainages and closed basins in New Mexico. Definitions of numbers are: 1 - Arkansas River drainage (Dry Cimarron River), 2 - Canadian River drainage, 3 - Pecos River drainage, 4 - Rio Grande drainage, 5 - San Juan River drainage, 6 - Little Colorado River drainage, 7 - Gila/San Francisco River drainage, 8 - Mimbres River basin, 9 - Tularosa Basin. Closed basins with no outflow are designated by an "*". (d) Physiographic provinces in New Mexico (Hawley, 1986a). Province definitions are: A - Southern Rocky Mountain Province, B - Colorado Plateau Province (B1 - Navajo Section, B2 - Acoma-Zuni Section), C - Datil–Mogollon Section, D - Basin and Range Province (D1 - Mexican Highland Section, D1a - Rio Grande Subsection, D2 - Sacramento Section), E - Great Plains Province (E1 - Raton Section, E2 - Pecos Valley Section, E2a - Upper Pecos Valley Subsection, E2b - Lower Pecos Valley Subsection, E3 - Llano Estacado).

Aquatic Ecoregions of New Mexico



- Aquatic Ecoregion 1
  Elevation > 2135 m (7000 ft)
- Aquatic Ecoregion 2
  Elevation 1675-2135 m (5500-7000 ft)
- Aquatic Ecoregion 3
  Elevation < 1675 m (5500 ft) & < 180 frost-free days
- Aquatic Ecoregion 4
  Elevation < 1675 m (5500 ft) & > 180 frost-free days
- Dry Basins and Intermittent Drainages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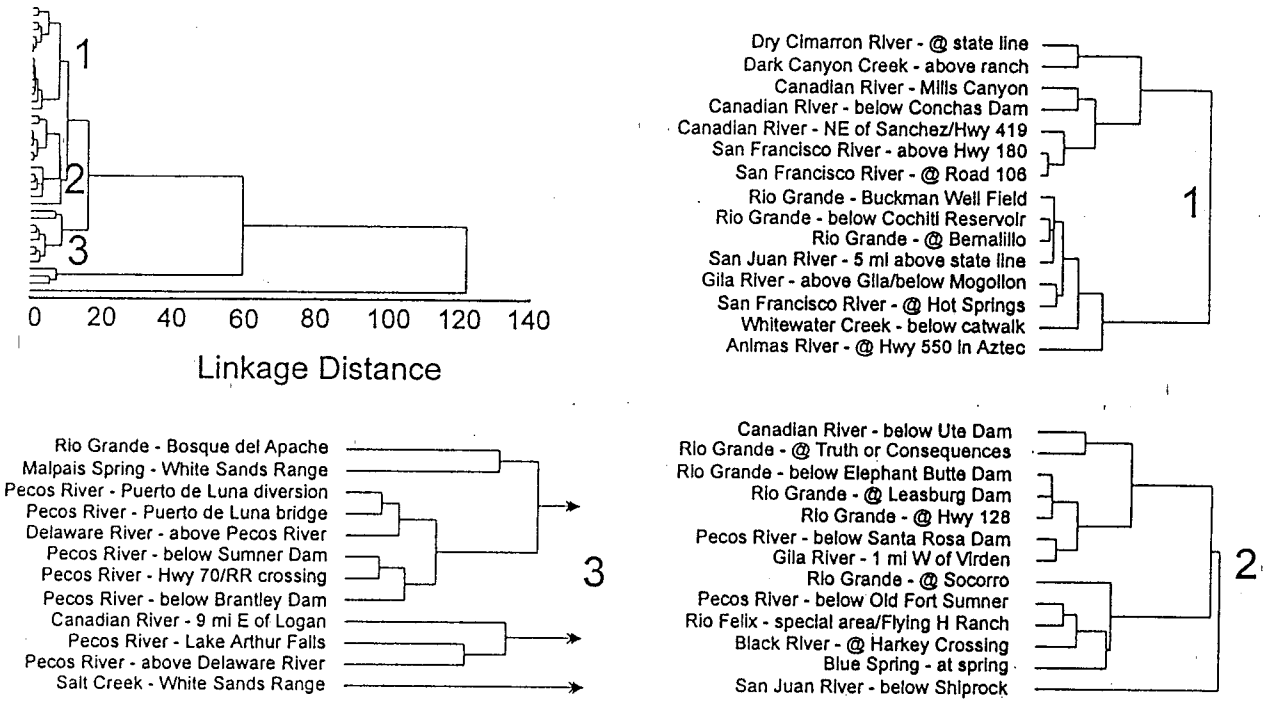
10
15
20
25
Linkage Distance
McCrystal Creek - above McCrystal Pl
McCrystal Creek - above campground
Bluewater Creek - below reservoir
Middle Fork Gila River - below Snow Lake
Trout Creek - quality area
Upper Sapello Creek - Sander's cabin
San Antonio River - above campground
Holy Ghost Creek - above campground
E Fork Jemez River - below Las Conchas
Las Animas Creek - below Negro Bill Spring
Gilita Creek - below Willow Creek
Indian Creek - above Gilita Creek
Chama River - below Chama
Mimbres River - Cooney Campground
Tecolote Creek - Forest Rd 291
Chama River - wildlife area
Chama River - Black Ranch
Gallinas River - USGS Montezuma Gauge
Chama River - below Heron Lake
Chama River - below Rio Nutrias
Chama River - below Rio Gallina
Las Animas Creek - below Kelso cabin
Negrito Creek - below North Fork
W Fork Gila River - above E Fork
Cimarron River - upper quality section
Coyote Creek - below Black Lake
Rio Guaje - above reservoir
Rio Cebolla - Forest Rd 376
Cimarron River - below upper quality section
Coyote Creek - @ Coyote Creek State Park
Chama River - above Heron Lake
Chamita River - Sargent Wildlife Area
San Francisco River - @ AZ state line
Chama River - above Chama @ diversion
Pecos River - below Lisboa Springs Hatchery
Willow Creek - above Gilita Creek
2b
2
2a
Coyote Creek - Rainsville
Penasco River - below Bluff Spring
Polvadera Creek - Forest Rd 422
Navajo River - above Armago Creek
San Francisco River - Forest Rd 41
Sacramento River - above Scott Able Creek
Bluewater Creek - above reservoir
Agua Chiquita - below Barrel Springs
Mora River - below Valmora
Rio Nutria - above Nutria Spring
Tularosa River - W of Apache Creek
Guadalupe River - above Jemez River
Tularosa Creek - @ Reserve
Rio Pescado - below diversion
Rio Pescado - Hwy 602 above Zuni
Rio Grande - above Red River
Rio Grande - below Rio Pueblo
Chama River - below Abiquiu Reservoir
Navajo River - below La Juita Canyon
Pecos River - below El Cerrito
San Juan River - Last Chance Quality
San Juan River - at Highway 173
Mimbres River - near Mimbres
W Fork Gila River - below Cliff Dwellings
Chama River - below Rio Cebolla
San Juan River - at Blanco
Animas River - @ Cedar Hill
Animas River - Hwy 550 in Aztec
1b
1a
1
Canadian River - @ Tinaja
Canadian River - Gonzales Ranch
Cimarron River - above Boys Ranch
Chama River - above Espanola
Pecos River - above Lisboa Springs Hatchery
Diamond Creek - @ James Cabin
Jemez River - above Guadalupe River
Jemez River - USFS Ranger Station
4
Dry Cimarron River - near Folsom Falls
Penasco River - @ Cleve Ranch
Rio Pueblo - above Rio Grande
Guadalupe River - above tunnels
Rio Puerco - above Rio Puerco Campground
Rio Costilla - above Latir Creek
Rio Costilla - @ La Cueva
El Porvenir River - above campground
Pecos River - above Willow Creek
Pecos River - above Terrero Bridge
Red River - above Rio Grande
Gallinas River - above Camp Long
Chama River - below El Vado Lake
Pecos River - below hatchery diversion
Pecos River - Forked Lightning Ranch
Los Pinos River - @ USFS area
Rio Frijoles - above USFS boundary
Casias Creek - tributary # 1
Rio en Medio - above triple lift
Big Tesuque - above Aspen Vista
Rio Mora - above Pecos River Campground
Cave Creek - above Panchuela Creek
Pecos River - above Pecos Falls
Jack's Creek - above trail junction 257/259
3c
3b
3a
3

Figure 2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Linkage Distance
Dry Cimarron River - @ state line
Dark Canyon Creek - above ranch
Canadian River - Mills Canyon
Canadian River - below Conchas Dam
Canadian River - NE of Sanchez/Hwy 419
San Francisco River - above Hwy 180
San Francisco River - @ Road 106
Rio Grande - Buckman Well Field
Rio Grande - below Cochiti Reservoir
Rio Grande - @ Bernalillo
San Juan River - 5 mi above state line
Gila River - above Gila/below Mogollon
San Francisco River - @ Hot Springs
Whitewater Creek - below catwalk
Animas River - @ Hwy 550 in Aztec
1
Rio Grande - Bosque del Apache
Malpais Spring - White Sands Range
Pecos River - Puerto de Luna diversion
Pecos River - Puerto de Luna bridge
Delaware River - above Pecos River
Pecos River - below Sumner Dam
Pecos River - Hwy 70/RR crossing
Pecos River - below Brantley Dam
Canadian River - 9 mi E of Logan
Pecos River - Lake Arthur Falls
Pecos River - above Delaware River
Salt Creek - White Sands Range
3
Canadian River - below Ute Dam
Rio Grande - @ Truth or Consequences
Rio Grande - below Elephant Butte Dam
Rio Grande - @ Leasburg Dam
Rio Grande - @ Hwy 128
Pecos River - below Santa Rosa Dam
Gila River - 1 mi W of Virden
Rio Grande - @ Socorro
Pecos River - below Old Fort Sumner
Rio Felix - special area/Flying H Ranch
Black River - @ Harkey Crossing
Blue Spring - at spring
San Juan River - below Shiprock
2

Figure 3

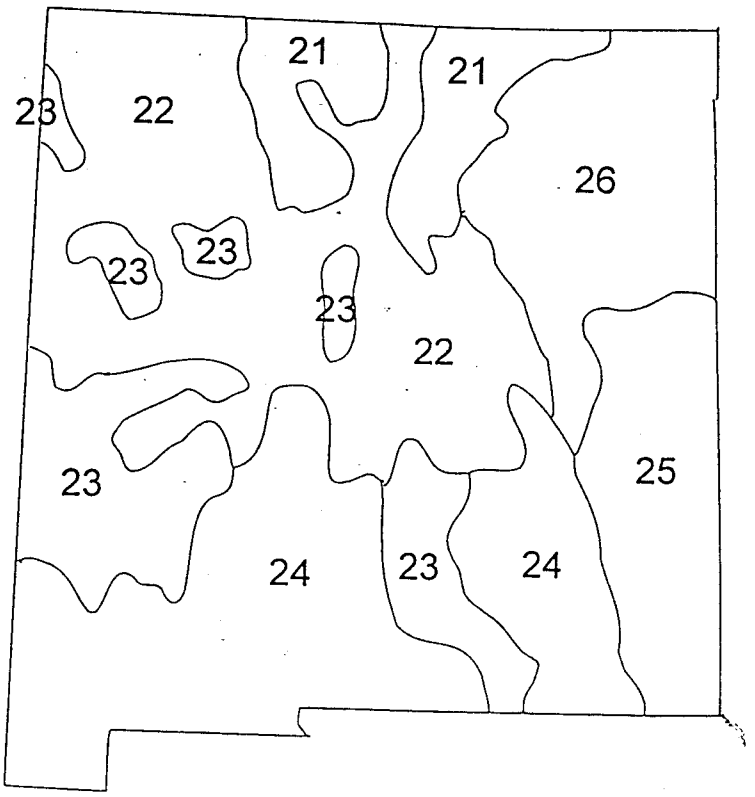


Figure 4a

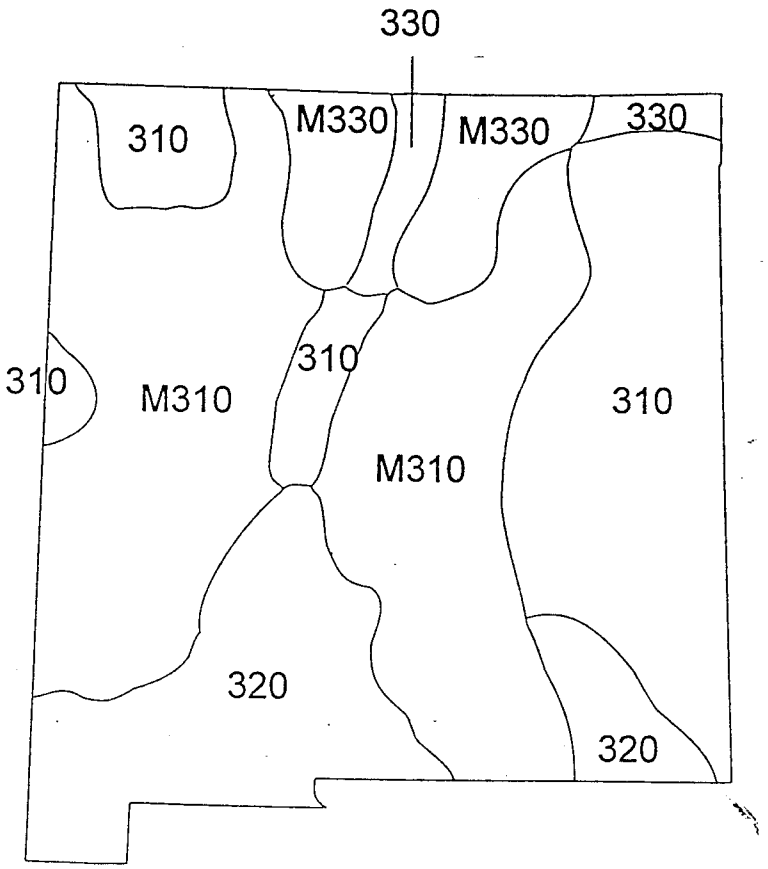
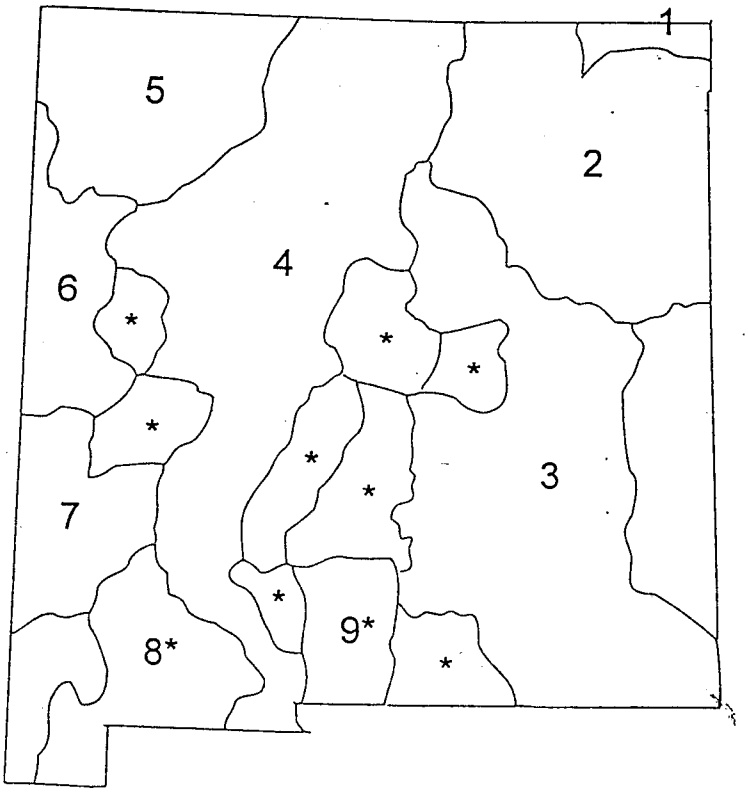


Figure 4b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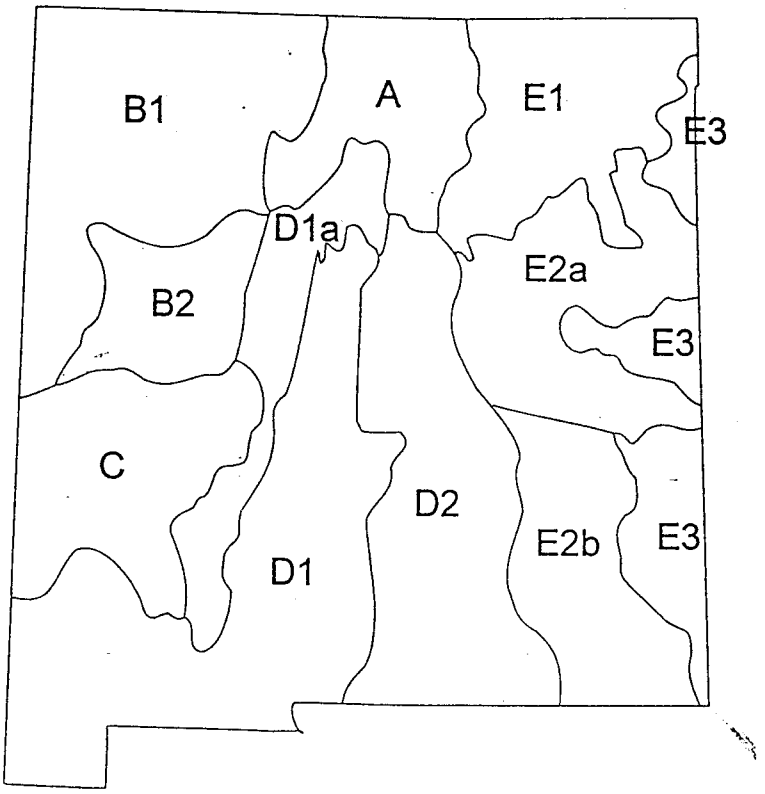

Figure 4d

- APPENDIX 5 -

KEYS TO THE PUPAE OF CHIRONOMIDAE (DIPTERA) FOUND IN NEW MEXICO

INTRODUCTION

Midges (Family Chironomidae) are among the most widely distributed freshwater insects in the world. These non-biting insects occur in virtually every aquatic habitat, from high mountain lakes and streams to lowland creeks and swamps. Even extreme habitats such as hot spring runs, rain water collected in axials of some leaves, and seeps on rock faces have their midge inhabitants. A few species are able to withstand desiccation in dried up vernal pools. Several species have become subaquatic or terrestrial, living in moist soil at the margins of streams and lakes, flower pots, rotting shelf fungi, etc. Several species are known which can survive in hyporheic moist sandof prairie streams after surface waters have disappeared.

The life cycle of the midge includes several stages, the egg, four larval stages (instars), pupa, and adult (Fig.1).

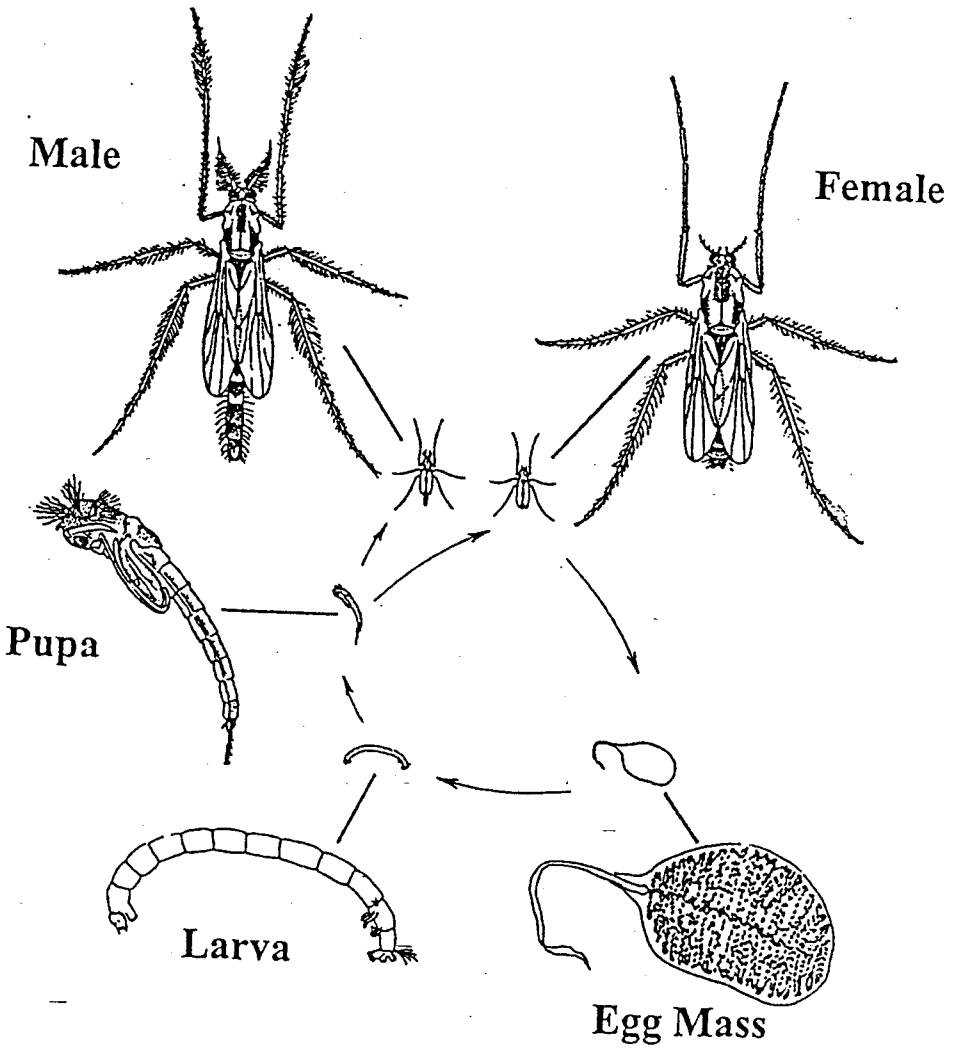

Fig. 1 - Life Cycle of a Midge (*Chironomus* sp.)

The larvae may live as filter feeders, scrapers, shredders, predators or ectoparasites. Some larvae are known which live in the stems and leaves of aquatic plants or burrowers; other species are burrowers in rotting wood in rivers and lakes. The pupal stage is usually of very short duration and is one in which larval tissues are broken down and redeployed as adult structures which develop within the pupal skin (exuviae).

After emerging from the pupal skin (exuviae), adults have a very short life span during which mating occurs. Most chironomids males form mating swarms of a dozen or so individuals in some species, and up to many millions in the large swarms of some lake dwelling species. The females fly into the swarm, select a male and mate. A few flightless or weak-flying species form aggregations of males (leks) on the ground or on the water's surface where mating occurs. In some small species, the life cycle can be short, as little as two weeks, but more commonly the length of the life span is up to a year. In some high arctic species the life cycle may be as long as seven years. High mountain species may have a shorter life span than arctic species, but it is probably greater than one year.

Because chironomid midge larvae are smaller than many other aquatic insects, they occupy a greater variety of habitats in any given aquatic ecosystem. Therefore, total number of species is usually much greater than those of the Plecoptera, Ephemeroptera and Trichoptera combined. These three orders, together with the family Chironomidae, comprise about 90% of the aquatic insects in many stream systems. Because of the greater species diversity the chironomids have a higher potential for environmental assessment. Unfortunately, most studies in the past have not been conducted at the species level for chironomids so their ecological value has been obscured.

Chironomid larvae have another significant attribute associated with their smaller size and greater ecological diversity. During spring run-off and storm spates, the increased flows in streams result in a most important biological interaction - molar action. As the increased flows occur boulders, cobble, gravel, and sand are continuously ground together ("molar action") which destroys many of the larger macroscopic invertebrates. Only those that are very able swimmers and can seek quiet side channels, or those that are small enough to find shelter in cracks and crevices in rocks, logs and other debris, can survive. Since chironomids are small, they survive in disproportion to the total numbers of species. This was first reported in a study of a Utah stream by James Moffett in 1928, and many other studies have confirmed this as a common phenomenon.

MODES OF STUDY OF CHIRONOMIDAE AND THE VALUE OF USING PUPAL EXUVIAE AS A NON-INVASIVE, SPECIES LEVEL INVESTIGATIVE TOOL

There are hundreds of studies of macrobenthic invertebrates reported from all kinds of lakes and streams throughout the world. In virtually all of these, identification of chironomids has been at the family level only or, at best, at the generic level because the conventional studies employed larval collections only. In most cases larvae can be identified to the genus level, but with much less precision to the species level. Chironomid taxonomy is based on adults, which can be identified with some precision to the species level. Methodology exists to capture adults as they emerge from streams or lakes so that a species-based ecology can be developed. However, such methods are labor intensive and invasive in the ecosystem and have not been used extensively.

Pupal exuviae were sorted into 20 ml scintillation vials in 100% ethanol and the vial labeled with a waterproof label. Slide labels were subsequently made from the vial label.

Pupal exuviae were individually slide mounted directly from the 100% ethanol into euparal, a cover glass added and the locality label applied. In repetitive monitoring surveys some investigators routinely mount as many as 50 exuviae on a slide. However, for an exploratory survey, individual slide mounts are preferred, as slides can be sorted by species determinations to form a reference collection.

PUPAL MORPHOLOGY

The principal features used in the keys which follow are illustrated in Figures 2 and 3. Most of these are found in Sæther (1980). In some instances new terms introduced which are not illustrated in Figures 2 and 3 will be labeled on illustrations accompanying the keys.

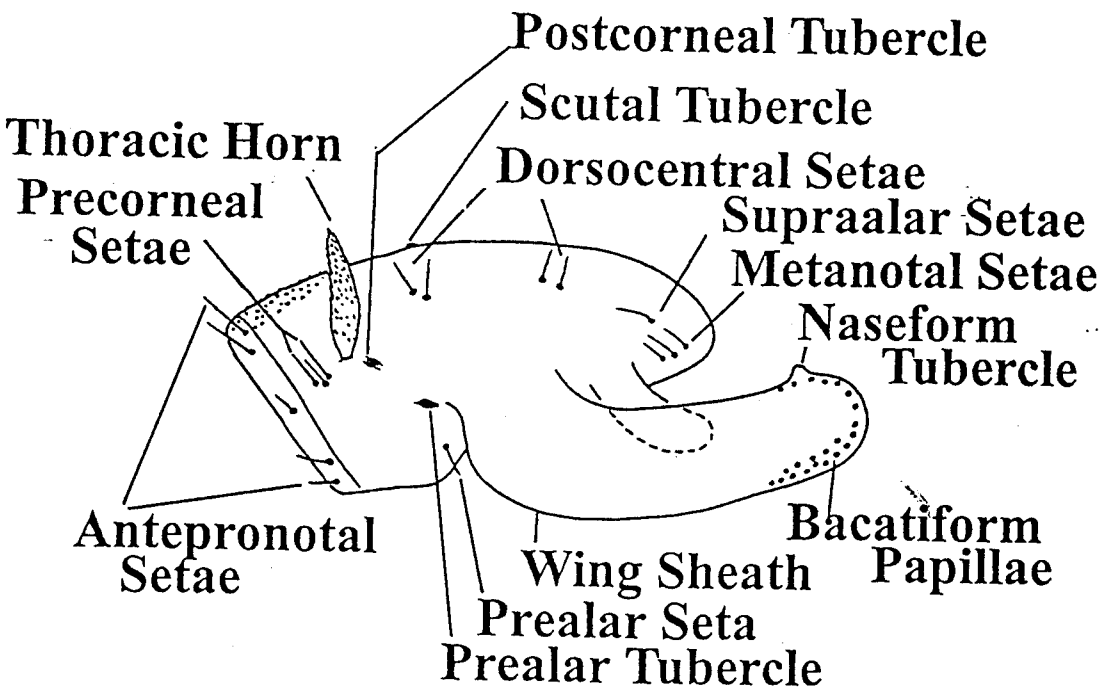

Fig. 2 - Pupal Thorax (Orthocladiinae), lateral view

Comprehensive treatment of the genera found in the Holarctic Region has been given by various authors in Wiederholm (1986). The only comprehensive treatment to species for pupae has been given by Langton (1991) for the Palearctic Region. Since many of the North American (Nearctic) species also occur in the Palearctic Region this is a valuable source for North American workers.

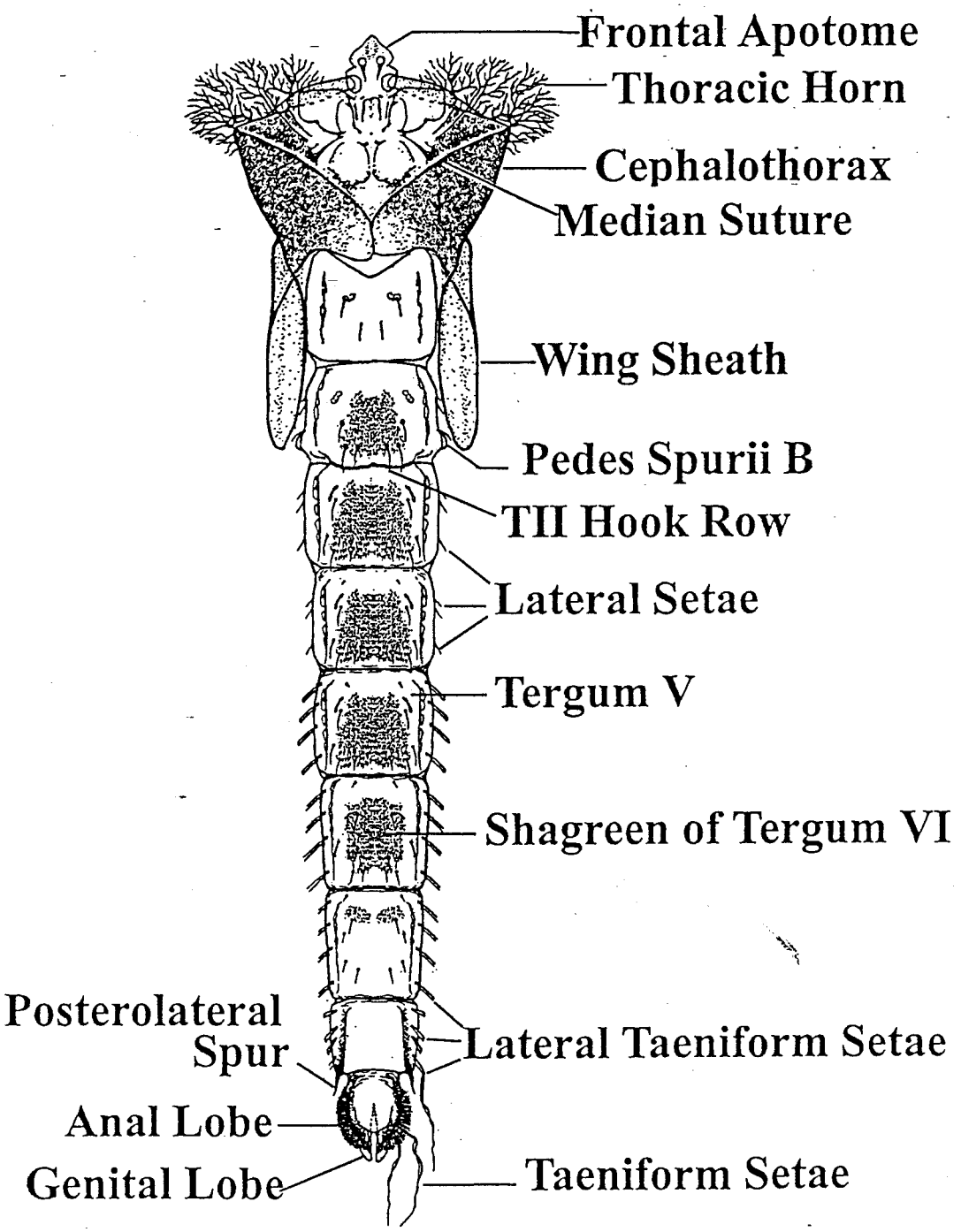

Fig. 3 - Pupal exuviae, dorsal view (*Chironomus* sp.)

KEY TO THE PUPAE OF THE SUBFAMILIES OF CHIRONOMIDAE FROM NEW MEXICO

1. Thoracic horn usually with a cap-like plastron plate at the apex and a distinct saccular central cavity (Fig.4); if plastron plate and horn sac lacking then anal lobe is pointed and has two coarse macrosetae (Fig.5); thoracic comb frequently present - - - - - - -Subfamily Tanypodinae, p.

1'. Thoracic horn never with a plastron plate and maybe cylindrical, tubular, saccular, branched, or absent; if anal lobe is pointed then it is without coarse macrosetae; thoracic comb never present - 2

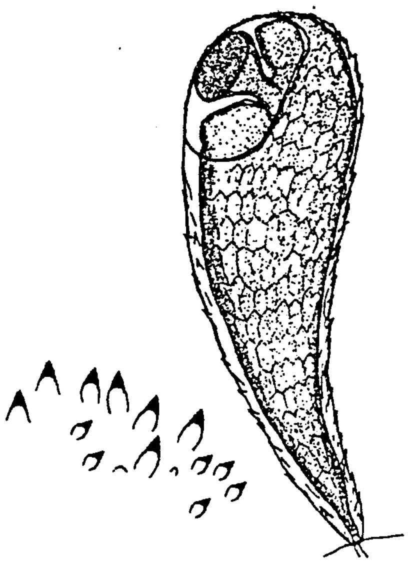

Fig.4 - Tanypodinae Thoracic Horn (*Telopelopia okoboji*)

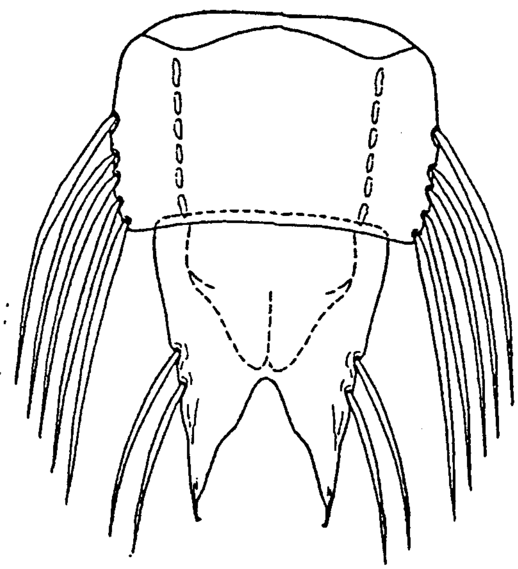

Fig. 5 - Tanypodinae TViii and Anal Lobe (*Telopelopia okoboji*)

2(1'). Apex of T II without a row of hooks; anal lobe fringed and with 3-5 coarse macrosetae (Fig.6); respiratory horn large and saccular (Fig.7) - - - - - - - - - Subfamily Prodiamesinae, p.

2'. Apex of TII usually with a hook row (Fig. 8); if lacking, then anal lobe is different and respiratory horn not large and saccular - 3

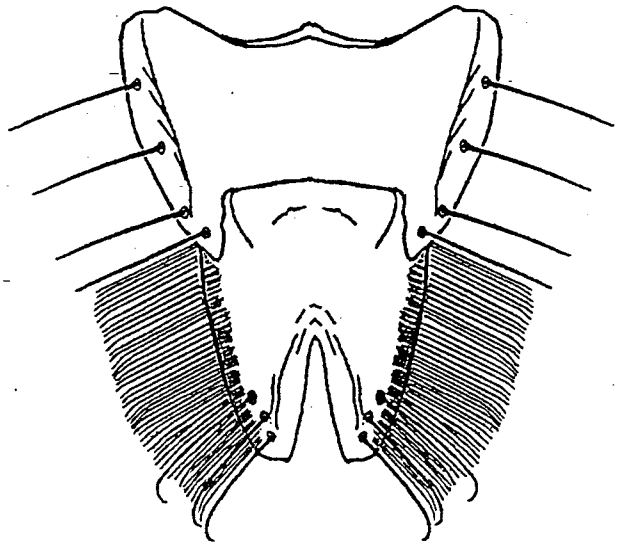

Fig. 6 - Prodiamesinae T VIII and anal lobe (*Odontomesa ferringtoni*)

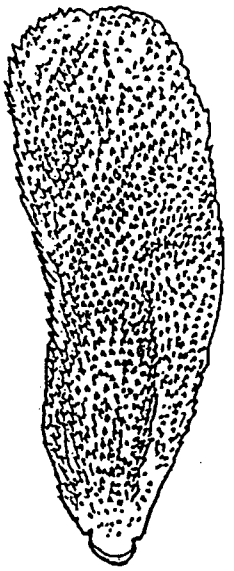

Fig. 7 - Prodiamesinae Thoracic horn

(

Odontonesa ferringtoni)

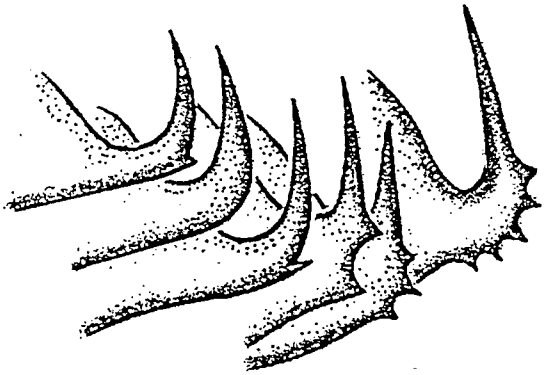

Fig. 8 - T II Posterior hooks (*Chironomus*)

3(2'). Apex of TII without a hook row; fore and middle leg sheaths extend directly posteriorly, not folded under the wing sheaths (Fig.9) - - - - - - - - - - - - - - - Subfamily Diamesinae, p.

3' Apex of TII with a hook row; if hook row is lacking, then fore and middle leg sheaths are folded under the wing sheaths (Fig.10) - 4

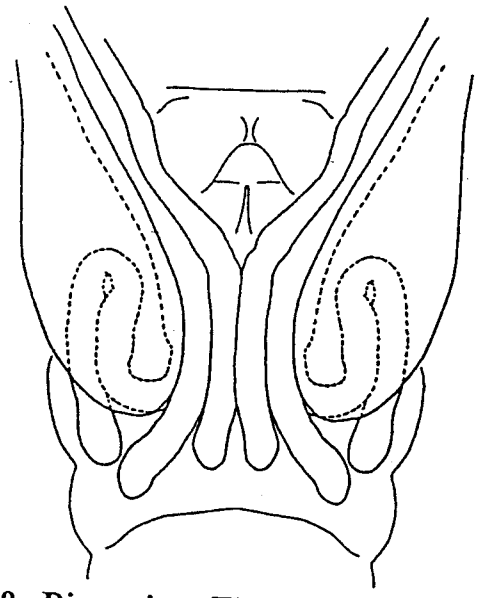

Fig. 9 - Diamesinae Thorax, ventral view (*Boreoheptagyia*)

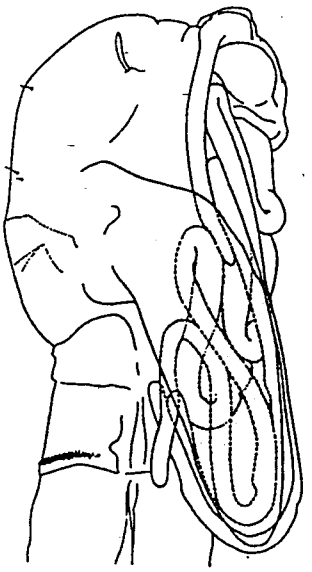

Fig. 10 - Orthocladinae cephalothorax, lateral view

4(3'). Thoracic horn fusiform (Fig.11), cylindrical, tubular or saccular but never branched, occasionally absent; anal lobe usually not fringed; if fringe present, then anal lobe and also usually T VIII without spurs or combs and with 3 apical or subapical macrosetae (Fig.12) ------- ---------- Subfamily Orthocladiinae, p.

4'. Thoracic horn unbranch to multibranched (cf.Fig.2); posterolateral corner of T VIII usually with a spur or comb of spines (Fig. 13); anal lobe usually fringed but macrosetae are always lacking ----------Subfamily Chironominae, p.

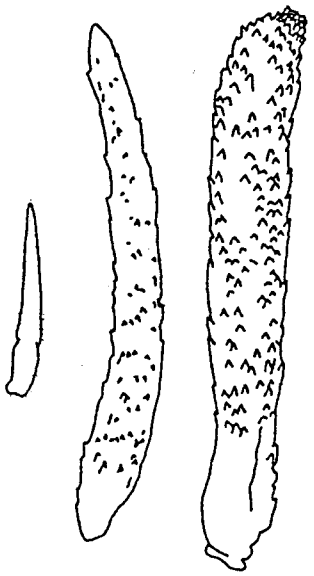

Fig. 11 - Orthocladiinae thoaracic horns (*Orthocladius*)

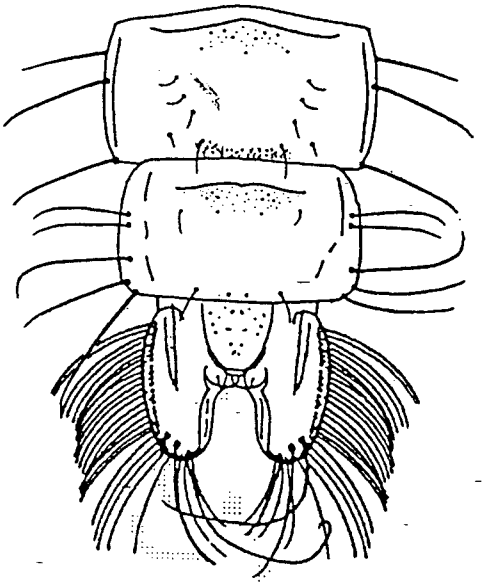

Fig. 12 - Orthocladiinae - T VII, VIII and anal lobe (*Rheocricotopus robacki*)

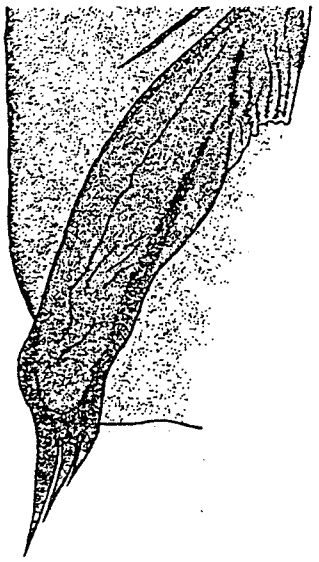

Fig. 13 - Chirononinae - posterolater spur of T VIII (Chironomus)

KEY TO THE PUPAE OF THE SUBFAMILY TANYPODINAE FROM NEW MEXICO

1. Anal lobes large and paddle-like, with a distinct fringe of long hair-like spinulae (Fig.14); thoracic horn large, trumpet-shaped or saccular with a distinct plastron plate; thoracic comb lacking ---------- 2

1'. Anal lobes smaller, usually triangular; if rounded, a small finger-like extension may be present; marginal fringe lacking or, if present, very weak or represented by a serrate row of short spinulae; thoracic horn cylindrical, trumpet-shaped or ovoid, with or without a plastron plate; thoracic comb usually present ---------- 4

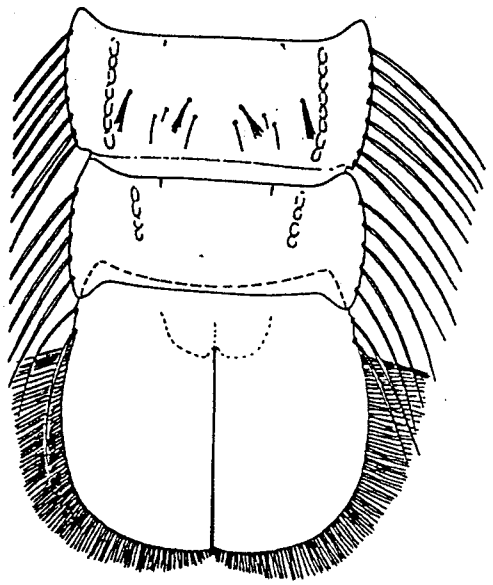

Fig. 14 - T VII, VIII and Anal lobe, *Coleotanypus scapularis*

2(1). Medial margins of anal lobes almost parallel and contiguous (Fig.14) ---------- Genus *Coelotanypus* Kieffer
Coelotanypus scapularis (Loew)

2'. Medial margins of anal lobe divergent ---------- 3

3(2'). Thoracic horn trumpet-shaped, surface denticulate but not reticulate (Fig. 15); T VII with 5-6 LS ---------- Genus *Alotanypus* Roback
Alotanypus venustus (Coq.)

3'. Thoracic horn saccular, surface reticulate (Fig.16); T VII with 12 LS ---------- Genus *Radotanypus* Fittkau & Murray -
Radotanypus submarginella (Sublette)

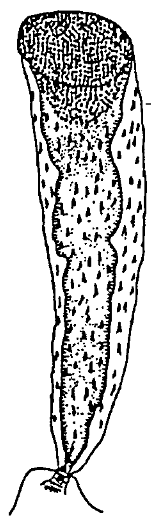

Fig. 15 - Thoracic horn, ***Alotanyypus venuaius***

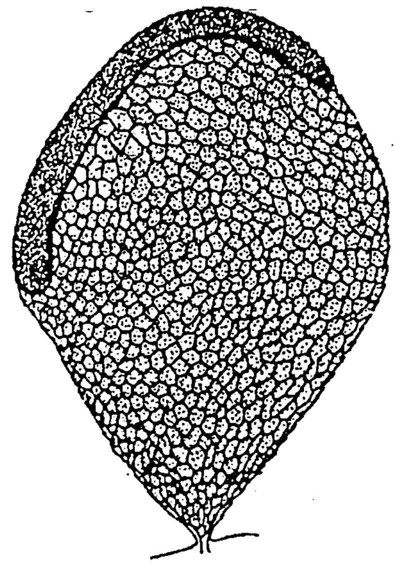

Fig. 16 - Thoracic horn, ***Radotanypus submargiuella***

4(1'). Anal lobes larger and more paddle-like, rounded on outer margin (Fig.17); T I with a medial scar; if lacking, then outer margins of anal lobe parallel-sided with fine denticles- Genus *Procladius* Skuse, p.

4'. Anal lobes smaller and triangular; if rounded on the outer margin then reduced in size; T I with or without a median scar - 5

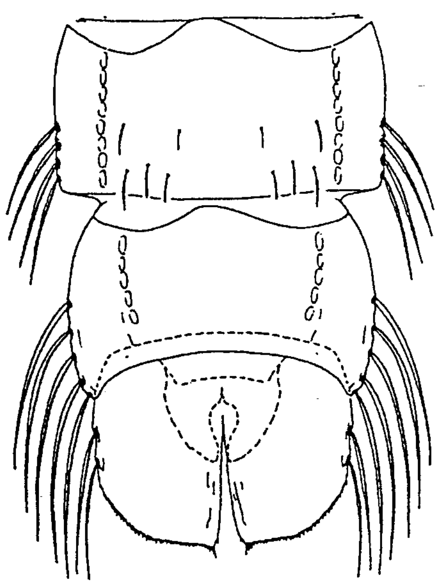

Fig. 17 - T VII, VIII and anal lobe, ***Procladius sp.***

5(4'). T I without a median scar; anal lobes reduced and rounded on the lateral margin, with or without an apical finger-like extension (Fig.18) - 6

5'. T I with a median scar (Fig. 19); anal lobes about twice as long as wide or longer - - 7

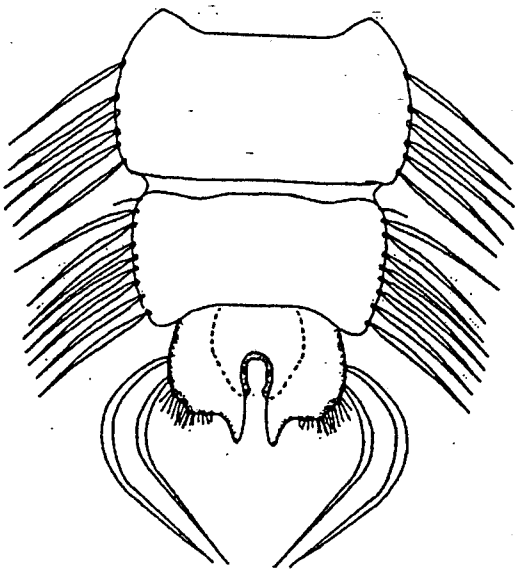

Fig. 18 - T VII, VIII and anal lobe,
Tanypus stellatus

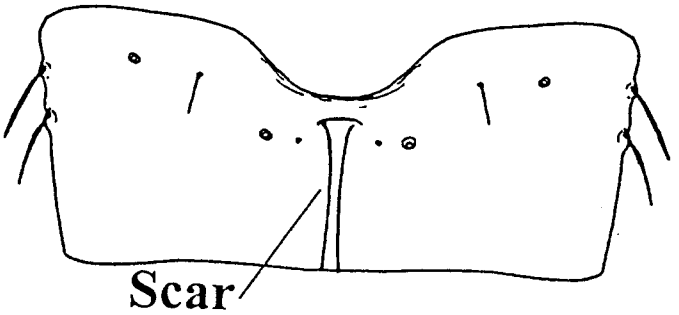

Fig. 19 - T I showing median scar
(Labrundinia)

6 (5. Thoracic horn elongate oval, without reticulations; plastron plate small, rounded (Fig. 20) ---------- Genus *Djalmabatista* Fittkau
Djalmabatista pulcher (Joh.)

6'. Thoracic horn globular, rounded to pointed oval; with distinct reticulations; plastron plate lacking (Fig.21) ---------- Genus *Tanypus* Meigen, p.

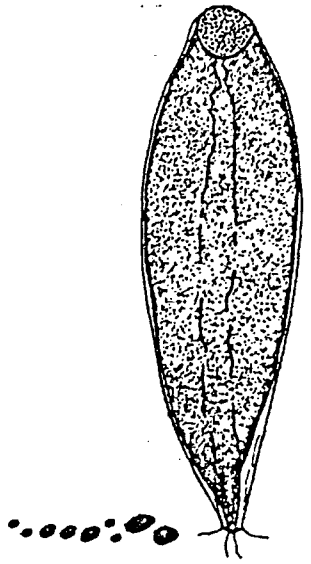

Fig. 20 - Thoracic horn and comb, *Djalmabatista pulcher*

7

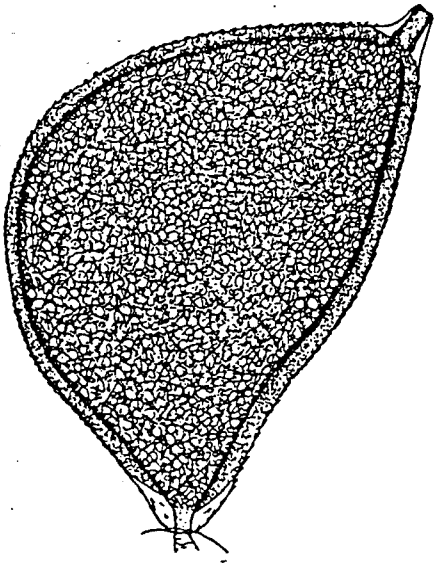

Fig. 21 - Thoracic horn, *Tanypus punctipennis*

(5'). Thoracic horn globular, horn sac fills lumen, reticulate (Fig.22); anal lobe length less than three times the width ---------- Genus *Ablabesmyia* Johannsen, p.

7'. Thoracic horn sac not filling lumen or lacking ---------- 8

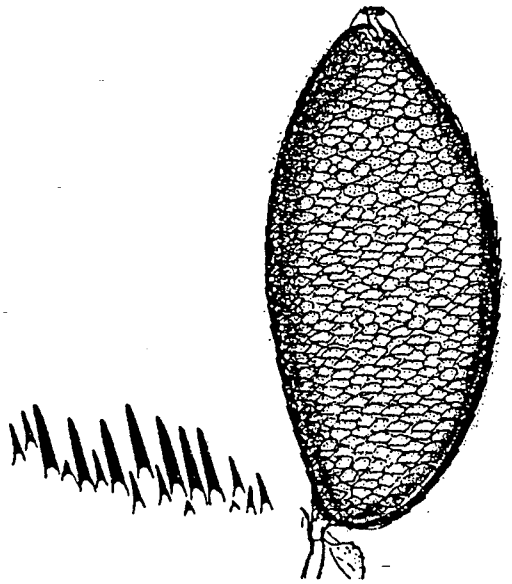

Fig. 22 - Thoracic horn and comb, *Ablabesmia*

8(7'). Thoracic horn cylindrical, with indistinct horn sac and lacking plastron plate (Fig.23) ---------- Genus *Rheopelopia* Fittkau, p.

8'. Thoracic horn cylindrical to trumpet-shaped usually with a distinct horn sac and plastron plate; if plastron plate is lacking an indistinct aeropyle may be present ---------- 9

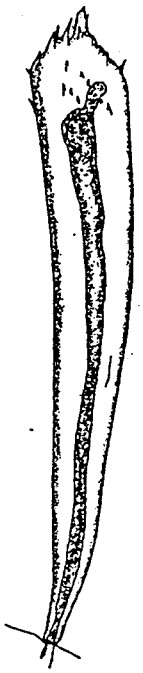

Fig. 23 - Thoracic horn, *Rheopelopia* sp. 1-P

9(8'). Anal lobe long and slender, about 4 times as long as wide, with coarse denticles along lateral margins (Fig.24) ---------- Genus *Labrundinia* Fittkau, p.

9'. Thoracic horn sac distinctly separated from wall of thoracic horn; anal lobe less than 4 times as long as wide, with or without weak lateral denticles ---------- 10

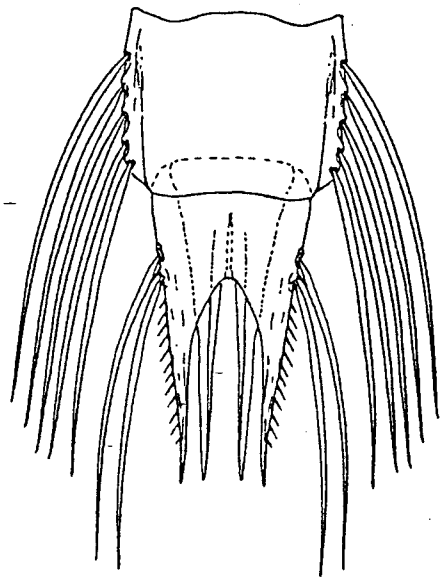

Fig. 24 - T VIII and anal lobe, *Labrundinia pilosella*

10(9'). Thoracic horn cylindrical with plastron plate lacking; weak aeropyle may be present (Fig.25) ----------Genus *Thienemannimyia* Fittkau, p.

10'. Plastron plate usually present; if lacking a distinct corona is present----------11

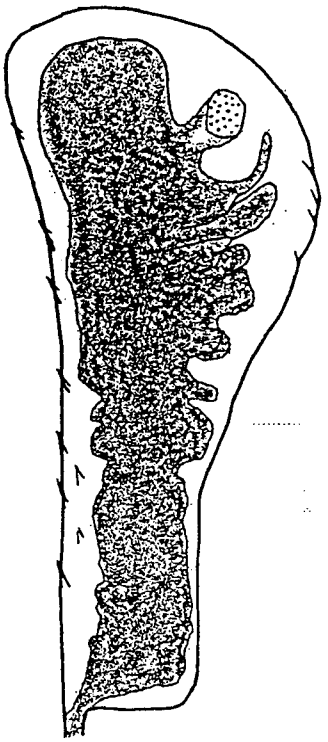

Fig. 25 - Thoracic horn,
Thienemanniemyia fuscipes

11(10'). Thoracic comb weak, occurring as low tubercles about as wide as high; thoracic horn very broad at the apex with a large plastron plate about as wide as the horn apex (Fig.26)- - --Genus *Conchapelopia* Fittkau

Conchapelopia pallens (Coq.)

11'. Thoracic comb well developed with spines higher than wide; if thoracic horn is broad at the apex then plastron plate much narrower than the maximum width --------------- 12

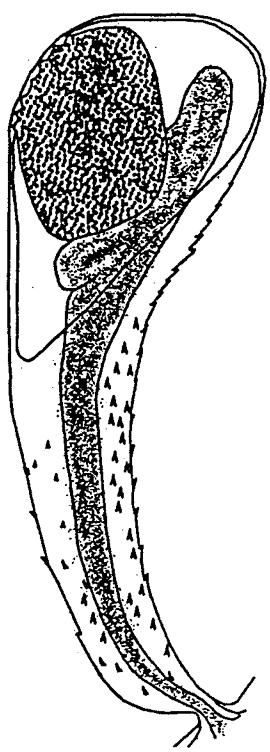

Fig. 26 - Thoracic horn, *Conchapelopia pallens*

12(11'). Genital sacs of male extending well past the apex of the anal lobes ------- 13

12'. Genital sacs about as long as the anal lobes or slightly shorter-------------- 14

13(12). Thoracic comb with denticles of moderate length; trumpet-shaped thoracic horn with a large corona but without plastron plate (Fig.27) - - - - - - - - Genus *Nilotanypus* Kieffer, p.

13'. Thoracic comb with long denticles; thoracic horn with a small plastron plate distinctly set off by a corona (Fig. 28) - Genus *Paramerina* Fittkau, p.

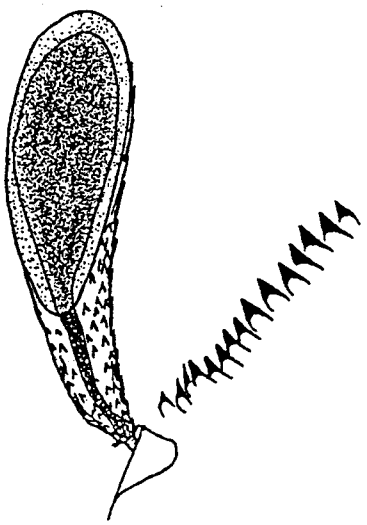

Fig. 27 - Thoracic horn and comb, ***Nilotanypus fimbriatus***

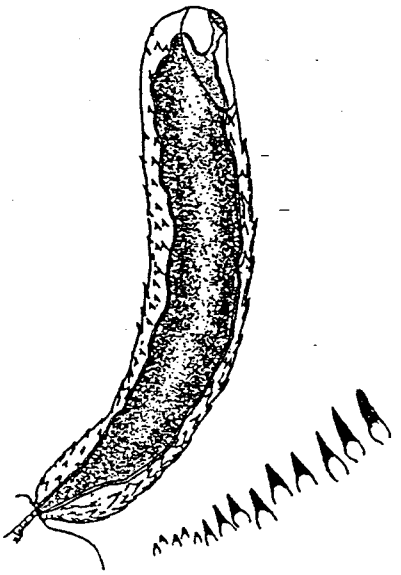

Fig. 28- Thoracic horn and comb, ***Paramerina smithae***

14(12'). Thoracic horn almost parallel-sided for much of its length; horn sac with several strong lobes (Fig.29) - Genus *Larsia* Fittkau, p.

14'. Thoracic horn trumpet-shaped; horn sac almost smooth - - - - - - - - - - - - - - - - - - 15

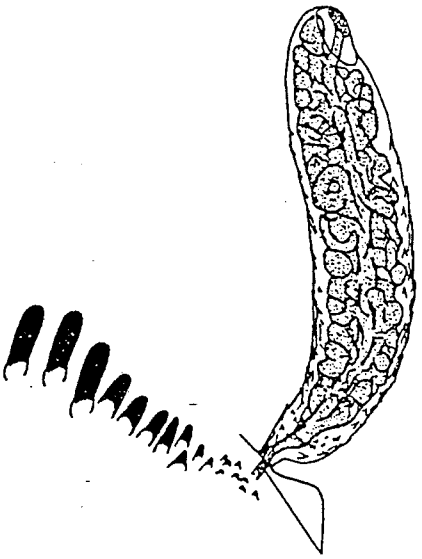

Fig. 29 - Thoracic horn and comb, ***Larsia lyra***

15(14'). Surface of thoracic horn with weak denticles but without reticulations (Fig. 30) - ---------- Genus *Pentaneura* Philippi, p.

15'. Surface of thoracic horn with weak to strong denticles and with reticulations --- 16

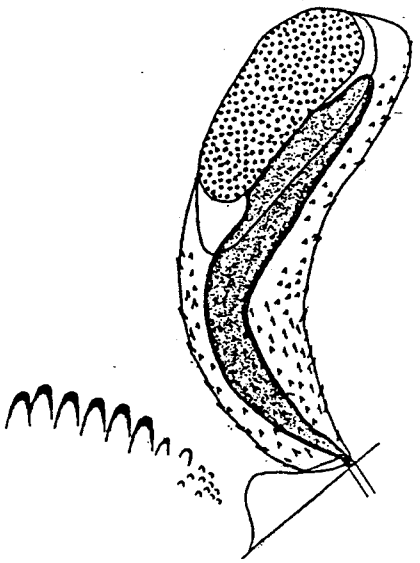

Fig. 30 - Thoracic horn and comb, *Pentaneura inconspicua*

16(15'). Thoracic horn with weaker reticulations and denticles; horn sac almost completely filling the horn lumen; plastron plate small (Fig.31) -- Genus *Telopelopia* Roback
Telopelopia okoboji (Walley)

16'. Thoracic horn with stronger reticulations and denticles; horn sac distinctly separate from horn wall; plastron plate larger (Fig. 32) -- Genus *Rheomyia* Roback
Rheomyia wartinbei (Roback)

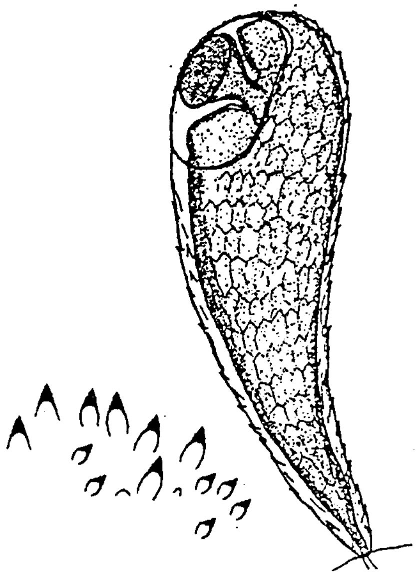

Fig. 31 - Thoracic horn and comb, ***Telopelopia okoboji***

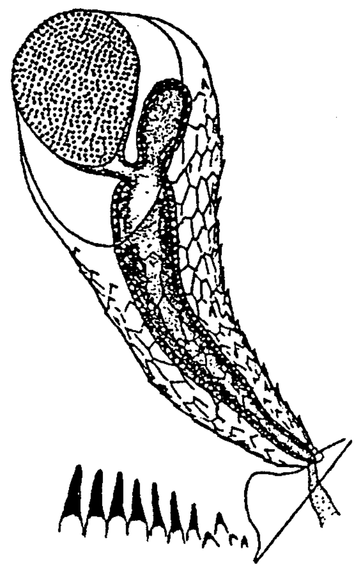

Fig. 32 - Thoracic horn and comb, ***Rheomyia wartinbei***

KEY TO THE PUPAE OF *ABLABESMYIA* FROM NEW MEXICO

1. Apex of the aeropyle tube T-shaped (Fig. 33) -- *Ablabesmyia (Karelia) illinoensis* (Malloch)

1'. Apex of the aeropyle tube club-shaped (Fig. 34) -------------------------- 2

2(1'). Wing pad with strong distinct veins; base of vein M evanescent or absent; T IV with a median longitudinal dark band and a transverse apical band (Fig. 35) -- *Ablabesmyia (A.) monilis* (L.)

2'. Wing pad with weaker veins; base of vein indistinct -- *Ablabesmyia (A.) mallochi* (Walley)

The pupa of *Ablabesmyia (K.) cinctipes* (Joh.) is unknown but it probably resembles *A. illinoensis*.

KEY TO THE PUPAE OF *LABRUNDINIA* FROM NEW MEXICO

The Genus *Mesosmittia* Brundin is known only from adults.

KEY TO THE PUPAE OF *BRILLIA* FROM NEW MEXICO

1. Wing sheaths with definite bacatiform papillae ---------- *Brillia* sp. 3-P.
1'. Wing sheaths smooth or with a faint indication of bacatiform papillae ---------- 2

2(1'). Thoracic horn fusiform, length less than 220 µm --- *Brillia flavifrons* (Johannsen)
2'. Thoracic horn bifurcate at tip, length 390 µm ---------- *Brillia retifinis* Sæther

The pupa of *Brillia laculata* Oliver & Roussel, which has been found as adults in New Mexico, is unknown but probably resembles that of *Brillia sera* Roback, its closest eastern counterpart. *Brillia* sp. 3-P. may be associated with this species.

THE SPECIES OF *BRYOPHAENOCLADIUS* IN NEW MEXICO

Most species of *Bryophaenocladius* are subaquatic, living in spring seeps, mosses, and in other madricolous environments. Consequently, pupal exuviae are rare in streams. The North American fauna is poorly known and many species are new to science awaiting description. Several of these know from adults occur in New Mexico and are listed below.

Bryophaenocladius pleuralis (Malloch)
Bryophaenocladius n. sp. 1
Bryophaenocladius n. sp. 2
Bryophaenocladius n. sp. 3
Bryophaenocladius n. sp. 5
Bryophaenocladius n. sp. 6
Bryophaenocladius n. sp. 7
Bryophaenocladius n. sp. 8
Bryophaenocladius n. sp. 9

KEY TO THE PUPAE OF *CHAETOCLADIUS IN NEW MEXICO*

1. The middle anal macroseta only slightly closer to the apical than it is from the proximal macroseta ---------- *Chaetocladius* sp. 1-P
1'. The 2 apical macrosetae very close together and far removed from the basal macroseta ---------- *Chaetocladius* sp. 2-P

KEY TO THE PUPAE OF *CORYNONEURA* FROM NEW MEXICO

1. S I with long, hair-like shagreen, at least on the anterolateral corners; anal lobe with 40 or more taeniate setae ---------- *Corynoneura arctica* Kieffer
1'. S I without hair-like shagreen; anal lobe with less than 40 taeniate setae--------- 2

2(1'). Swim fringe in the apical half of the anal lobe; S II with long, hair-like shagreen- *Corynoneura taris* Roback

2'. Swim fringe along the entire length of the anal lobe; S II with, at most, very weak sparse shagreen - 3

3(2'). Apical shagreen on each tergum very heavy, in two irregular rows; sternal shagreen only slighter weaker than the tergal shagreen - *Corynoneura* sp. 2-P

3'. apical shagreen only slightly heavier than the remainder; sternal shagreen very weak or absent - *Corynoneura lobata* Edwards

KEY TO THE PUPAE OF *CRICOTOPUS* FROM NEW MEXICO

1. Anal lobe posteriorly produced, with several fine apical denticles; anal macrosetae lacking - *Cricotopus (Nostococladius) nostocicola* Wirth

1'. Anal lobe not projected beyond the three anal macrosetae; anal lobe with sparse denticles or, usually, without denticles - 2.

2(1'). Anal macrosetae small, hair-like; ALR 0.30; bacatiform papillae present on wing sheaths - *Cricotopus* (n. subgen.) sp. 12-P

2'. Anal macrosetae normal, long and hooked-tip or short and heavier with straight tips; ALR usually > 0.30; bacatiform papillae absent- 3.

3(2'). Terga III-V (IV-V) with three clearly separated bands of shagreen; thoracic horn usually not tubular and having at least a few sparce denticles- 4.

3'. Terga II-VI with almost uniform shagreen, or if with three bands, then bands extensive and joined together with finer shagreen; thoracic horn tubular and without denticles - - - - - - - 24.

4(3). Anal lobe with several denticles - - - - *Cricotopus (Cricotopus) tremulus* (Linnaeus)

4'. Anal lobe denticles usually absent, if present, then with no more than 1-2 minute denticles - 5.

5(4'). Terga III-VIII with shagreen bands; one anal macroseta distinctly smaller than other two- *Cricotopus (Cricotopus) trifascia* Edwards

5'. Terga VII and VIII without shagreen bands (although weak shagreen may be present); anal macroseta subequal in length - 6.

6(5'). Sternum II with coarse spines - *Cricotopus* n. sp.1

6'. Sternum II without spines - 7.

7(6'). Thoracic horn broadened from near the base, W/L 0.25 or higher; tip abruptly tapered - 8.

7'. Thoracic horn narrower, fusiform to clavate, W/L <0.25; if >0.25, then tip more attenuate or rounded - 9.

8(7). Thoracic horn length 140 µm; PsB III absent; TVIII LS 5, posterior two setae heavy ---------- *Cricotopus* sp. 15-P

8'. Thoracic horn length 160 µm or greater; PsB III distinct; TVIII LS 4 of about uniform size ---------- *Cricotopus* sp. 16-P

9(7'). Thoracic horn length 200 mm or greater; if less than 200 mm then horn clavate with coarse denticles; PsB II and III present---------- 10.

9'. Thoracic horn usually less than 200 mm ; if clavate, then with weak denticles; PsB present or absent---------- 13.

10(9). Prefrontal setae present; thoracic horn with coarse denticles at tip---------- *Cricotopus* sp.6-P

10'. Frontal setae present; thoracic horn with coarse denticles along the side ------- 11.

11(10'). Anal lobe macrosetae 133-156 mm in length; exuviae pale yellowish brown --- ---------- *Cricotopus blinni* Sublette

11'. Anal macrosetae 160-192 mm; exuviae darker brown---------- 12.

12(11'). Anterior rugosity and posterior tubercles weak; thoracic horn with strong lateral denticles; TII hooks <85 ---------- *Cricotopus herrmanni* Sublette

12' Anterior rugosity stronger; posterior tubercles strong, scale-like; T II hooks >90 --- ---------- *Cricotopus* sp. 21-P

13(9'). PsB absent; T II hooks > 80; thoracic horn fusiform to saccular, without denticles or with a few weak denticles at the tip only---------- *Cricotopus (Cricotopus) fuscatus* Wirth

13'. PsB II or PsB II and III present; TII hooks usually < 80; thoracic horn, if fusiform, usually with heavier denticles at tip---------- 14.

14(13'). Only PsB II present; frontal setae present---------- 15.

14'. PsB II and III present; frontal setae present or absent---------- 16.

15(14). Thoracic horn fusiform, usually without spinulae or with sparse spinulae at tip, length <110 µm; ALR < 0.60 ---------- *Cricotopus (Cricotopus) globistylus* Roback

15'. Thoracic horn fusiform to subcylindrical with sparse spinulae always present, length >120 µm; ALR >0.60---------- *Cricotopus* sp. 18-P

16(14'). Cephalothorax setae unusually heavy, set on tubercles; much of cephalothorax covered with very heavy tubercles---------- 17.

16'. Cephalothoracic setae normal; tuberculation, if present, much weaker -------- 18.

17(16). T II without shagreen; TIII without medial band of shagreen; T IV-VI with medial band of shagreen very small ---------- *Cricotopus (Cricotopus)* sp. 11-P

17'. T II with shagreen; T III-VI with heavy medial bands; T II-VIII with fine lateral shagreen ---------- *Cricotopus (Isocladius) intersectus* (Staeger)

18(16'). Cephalothoracic tubercles moderately strong; medial shagreen band of T III weak ---------- *Cricotopus (Cricotopus) bicinctus* (Meigen)

18'. Cephalothoracic tubercles weak to virtually absent; medial shagreen on T III heavier, about as T IV, V, or if weaker, then thoracic horn inflated ---------- 19.

19(18'). Frontal setae absent; thoracic horn weakly clavate, with a few weak to moderate denticles; apical shagreen band of T II conspicuous ---------- *Cricotopus (Pseudocricotopus) bifurcatus* C. and O.

19'. Frontal setae present or absent; thoracic horn subcylindrical, fusiform or weakly inflated towards the base, or moderately inflated; TII apical shagreen absent or very sparse -- 20.

20(19'). Frontal setae absent; thoracic horn slightly inflated fusiform with weak apical denticles or moderately inflated without apical denticles; cephalothorax and abdomen pale brown ---------- 21.

20'. Frontal setae present; thoracic horn subcylindrical, fusiform, or weakly clavate; usually denticulate near tip; cephalothorax pale, T II-VI dark or cephalothorax and abdomen almost concolorous pale brown ---------- 22.

21(20). Thoracic horn usually subcylindrical to weakly clavate,with weak apical denticles; antennal pedicel sheath without tuberculate boss; TII usually with a weak apical shagreen band - ---------- *Cricotopus (Cricotopus) annulator* Goetghebuer

21'.Thoracic horn fusiform with the basal portion moderately inflated and apically with weak denticles; antennal pedicel sheath with a distinct medial boss which is tuberculate; TII without an apical shagreen band ---------- *Cricotopus (Cricotopus) slossonae* Malloch

22(20'). Thoracic horn inflated without apical spinulae (in Nearctic populations); medial shagreen band of T III weaker than that on T IV and V ---------- *Cricotopus (Cricotopus) vierriensis* Goetghebuer

22'. Thoracic horn fusiform to weakly clavate with weak to moderate spinulae near the tip; T III median shagreen band subequal to that of T IV and V ---------- 23.

23(22'). Thoracic horn weakly clavate, 173µm long; apical shagreen band subequal in width to the medial band but distinctly shorter than the posterior band ---- *Cricotopus* sp. 20-P

23'. Thoracic horn fusiform, 108-115µm long; apical shagreen band on T II-V subequal to the posterior and wider than the medial band----- *Cricotopus (Cricotopus) infuscatus*(Malloch)

24(3'). Thoracic horn smaller and subcylindrical to spindle shaped; abdomen with distinct bandsofshagreenwhichareconnectedbymuchfinershagreenorshagreenalmostuniformlydistributed ---------- 25.

24'. Thoracic horn usually more elongate, tubular, without denticles; abdominal shagreen heavy and much more uniform ---------- 26.

25(24).Thoracichornsubcylindrical,length154µm;thoraxwithdarkplacodesbutnottuberculate ---------- *Cricotopus (Isocladius)* sp. 23-P

25'. Thoracic horn spindle shaped, length 139-143 µm ---------- *Cricotopus (Isocladius) obnixus* (Walker)

26(24'). PsB II present; frontal setal width 4µm ---------- *Cricotopus (Isocladius) sylvestris* (Fabricius)

26'. PsB II absent; frontal setal width 2 µm ---------- *Cricotopus (Isocladius) pilitarsis* (Zett.)

The following species have been collected as adults but the pupae are not known:

Cricotopus luciae LeSage and Harrison
Cricotopus absurdus (Johannsen)
Cricotopus n. sp. 5
Cricotopus n. sp. 8
Cricotopus n. sp. 22
Cricotopus n. sp. 30

KEY TO THE PUPAE OF *EUKIEFFERIELLA* FROM NEW MEXICO

1. Thoracic horn lacking; recurved hooks at the apices of T III to VI in a complete row; posterior spines of t III-VI do not extend past the recurved hook row ---------- 2

1'. Thoracic horn present or absent; hook rows complete or interrupted in the middle; if hook rows complete, then thoracic horn present and posterior spine row extends past the hook row ---------- 4

2(1). Basal and apical spine rows connected by coarse shagreen, at least on T II-V ---------- *Eukiefferiella* sp. 2-P

2' Basal and apical spine rows without connecting shagreen ---------- 3

3(2'). T II with a basal band of spinulae; basal spinulae band of T III-VI much stronger; An MaS length 147-190 µm ---------- *Eukiefferiella* sp. 1-P

3'. T II basal spinulae band lacking; T III-VI basal spinulae band much weaker; An MaS length 130 µm ---------- *Eukiefferiella* n. sp. 4

4(1'). An MaS very short, less than 60 µm ---------- 5

4'. An MaS much longer, usually greater than 150 µm ---------- 6

5(4). Thoracic horn lacking; tergal hook rows complete; posterolateral margins of T II-V without denticles; T II-VI with a distinct subbasal band of coarse shagreen ---------- *Eukiefferiella coerulescens* Kieffer

5'. Short thoracic horn present; tergal hook rows widely interrupted in the middle; posterolateral margins of T II-V with small, distinct denticles; T II-VI with fine shagreen over much of each tergum ---------- *Eukiefferiella* sp. 4-P

6(4'). Thoracic horn base bulbous with terminal filament greatly exceeding the length of the bulb; posterior tergal spines long and heavy, extending well past the hook rows -------- 7

6'. Thoracic horn base bulbous to triangular in outline with filament equal to or less than the bulb length; posterior tergal spines shorter, not extending past the tergal hooks --------- 8

7(6). T II-VI with almost continuous heavy shagreen, with T VII-VIII having the heavy shagreen restricted to the basal half; sternal spines or hooks lacking ------ *Eukiefferiella* sp. 5-P

7'. T II-VI with only a heavy basal shagreen row; S VI-VII each with an apical hook row -- *Eukiefferiella* n. sp. 9

8(6'). Anal macrosetae (An MaS) of unequal length, 2 long and heavy, 1 slightly shorter and weaker, not wavy in appearance ----------------- *Eukiefferiella ilkleyensis* (Edwards)

8'. An MaS of equal length, usually slightly wavy in appearance ------------------ -- *Eukiefferiella claripennis* (Lundbeck)

KEY TO THE PUPAE OF *HYDROBAENUS* FROM NEW MEXICO

1. T IV shagreen with the middle band clearly separated from the posterior; apex of anal lobe with small denticles; apex of the male genital sheath with a small nipple-like projection --- -- *Hydrobaenus fusistylus* (Goetghebuer)

1'. T IV shagreen with bands fused; anal lobe without denticles; male genital sheath without nipple-like projection ----------------------------- *Hydrobaenus pilipes* (Malloch)

KEY TO THE PUPAE OF *KRENOSMITTIA* FROM NEW MEXICO

1. Thoracic horn short with a slightly bulbous base; anal lobe extensions relatively shorter; tergal and/or sternal denticles finer --- 2.

1'. Thoracic horn long, cylindrical throughout its length; anal lobe extensions very long; tergal and sternal denticles coarser------------- *Krenosmittia halvorseni* Cranston & Sæther

2(1). Tergal and sternal armature mostly a single row of coarse denticles at the apices; T II without denticles --------------------------- *Krenosmittia boreoalpina* (Goetghebuer)

2'. Tergal apices IV - VII with 2-3 rows of low denticles that are medially confluent; sterna mostly devoid of denticles; TII with a small cluster of 11 denticles at the median apex --- -- *Krenosmittia* sp. 1-P

THE GENUS *LIMNOPHYES* IN NEW MEXICO

This group of orthocladine midges is well represented in New Mexico with several species new to science awaiting description. Many species are madricolous and the pupal exuviae rarely enter the stream drift. The following adult species are represented in the New Mexican fauna:

Limnophyes brachytomus (Kieffer)
Limnophyes eltoni (Edwards)
Limnophyes fumosus (Johannsen)
Limnophyes natalensis (Kieffer)
Limnophyes pilicistulus Sæther
Limnophyes n. sp. 2
Limnophyes n. sp. 3
Limnophyes n. sp. 5

1. Thoracic horn with a strong groove adjacent to the apical aeropyle tube; thoracic horn more clavate (Fig. 36) ---------- *Labrundinia pilosella* (Loew)

1'. Thoracic horn with a very weak groove adjacent to the apical aeropyle tube; thoracic horn more triangular (Fig. 37) ---------- *Labrundinia maculata* (Roback)

KEY TO THE PUPAE OF *LARSIA* FROM NEW MEXICO

1. Plastron plate small with neck only slightly eccentric in insertion on the plastron (Fig. 38); T IV with a broad longitudinal dark band with an elongate oval fenestra in the center and with each tergal corner dark ---------- *Larsia lyra* (Sublette)

1'. Plastron plate larger; neck distinctly eccentric in insertion on the plastron (Fig. 39); T IV with more extensive dark markings ---------- 2

2(1'). Anterior half of T IV with a broad dark fascia (Fig. 40) ---------- *Larsia decolorata* (Malloch)

2'. T IV with more extensive dark markings ---------- 3

3(2'). T IV with a broad median dark fascia covering much of the tergum; posterior corners of T IV dark ---------- *Larsia* sp. 1-P

3'. T IV with a broad median dark fascia with a round fenestra on each side of the midline; anterior and posterior corners of T IV dark (Fig. 41) ---------- *Larsia* sp. 2-P

The pupal stage of *Larsia marginella* (Malloch) is not known.

KEY TO THE PUPAE OF *NILOTANYPUS* FROM NEW MEXICO

1. Thoracic horn greatly inflated (Fig. 42); posterior row of strong spines of terga IV-VII distinctly interrupted at the midline ---------- *Nilotanypus* sp. 2-P

1'. Thoracic horn only weakly inflated at the apex; posterior row of spines, if strong, not interrupted ---------- 2

2(1'). Apex of thoracic horn usually with a small spine (Fig. 43); posterior tergal spine rows strong ---------- *Nilotanypus* sp. 1-P (=*N.* sp. Roback 1986)

2'. Apex of thoracic horn without a spine; posterior tergal spine rows weak or strong -- 3

3(2'). Posterior spine rows scarcely heavier than the coarse shagreen that covers the terga (Fig. 44) ---------- *Nilotanypus fimbriatus* (Walker)

3'. Posterior tergal spine rows distinctly heavier than the tergal shagreen which is progressively coarser posteriorly (Fig. 45) ---------- *Nilotanypus kansensis* Roback

KEY TO THE PUPAE OF *PENTANEURA* FROM NEW MEXICO

1. Corona distinct, occupying at least one-half of the thoracic horn length, clearly separate from the plastron plate (Fig. 46) ---------- 2

1' Corona indistinct, scarcely distinquishable from the large plastron plate ----------

---------- *Pentaneura* sp. 1-P

2(1). Corona occupying about one-half or slightly less of the total thoracic horn length (Fig. 46) ---------- *Pentaneura inconspicua* (Malloch)

2. Corona occupying distinctly more than one-half of the horn length (Fig. 47) ------- ---------- *Pentaneura* sp. 2-P

KEY TO THE PUPAE OF *PROCLADIUS* FROM NEW MEXICO

1. Abdominal terga usually without dark markings: posteromedian apex of anal lobes rounded to almost a right angle (Fig 48) ---------- *Procladius*, Subgenus *Psilotanypus* - ---------- *Procladius (Psilotanypus) bellus* (Loew)

1'. Abdominal terga usually with dark markings; posteromedian apex of anal lobes produced ---------- *Procladius*, Subgenus *Holotanypus* ---------- 2

2(1'). Apex of anal lobe slightly concave just lateral to the apical denticles; lateral denticles more closely spaced (Fig. 49) ---------- *Procladius (H.) freemani* Sublette

2'. Apex of anal lobe very slightly concave to almost straight just lateral to the apical denticles; lateral denticles more widely spaced (Fig. 50) -------- *Procladius (H.) subletti* Roback

KEY TO THE PUPAE OF *RHEOPELOPIA* FROM NEW MEXICO

1. Apex of the thoracic horn rounded (Fig. 51); medial apex of the anal lobe V-shaped -- ---------- *Rheopelopia acra* (Roback)

1'. Apex of thoracic horn with a small spine (Fig. 52); medial apex of the anal lobe U-shaped ---------- *Rheopelopia* sp. 1-P

KEY TO THE PUPAE OF *TANYPUS* FROM NEW MEXICO

1. Lateral setae present only on T VII and VIII ---------- 2

1'. Lateral setae present on T II or T III to T VIII ---------- 4

2(1). Thoracic horn distinctly convex near the base (Fig. 53); T VIII with 5-10 lateral setae ---------- 3

2'. Thoracic horn more evenly tapered from the base (Fig. 54); T VIII with 4-5 lateral setae ----------*Tanypus carinatus* Sublette

3(2). T VIII with 7-10 lateral setae ---------- *Tanypus stellatus* Coquillett

3'. T VIII with 5 lateral setae ---------- *Tanypus parastellatus* Sublette

4(1'). T VIII with 16-21 lateral setae ---------- *Tanypus imperialis* Sublette

4'. T VIII with 40 or more lateral setae ---------- 5

5(4'). T VIII with 40-75 or more lateral setae ---------- 6

5'. T VIII with 90 or more lateral setae ---------- *Tanypus neopunctipennis* Sublette

6(5). T II with 16-45 and T III with 50-70 lateral setae - - - - - *Tanypus grodhausi* Sublette
6'. T II with 52-62 and T III with 78-90 lateral setae - - - - - - *Tanypus imperialis* Sublette

KEY TO THE PUPAE OF *THIENEMANNIMYIA* FROM NEW MEXICO

1. Thoracic horn with irregularly shaped horn sac, corona lacking; mesonotal tubercles sharp-tipped (Fig. 53) - *Thienemannimyia fusciceps* (Edwards)
1'. Thoracic horn with lumen completely filled by the smooth horn sac; corona very large; mesonotal tubercles acute but not sharp-tipped (Fig. 56) - - *Thienemannimyia barberi* (Coquillett)

KEY TO THE PUPAE OF DIAMESINAE FROM NEW MEXICO

1. Terga with conspicuous spines; thoracic horn present - - - - Genus *Diamesa* Meigen, p.
1'. Terga without spines, although coarse, rather blunt denticles may be present; thoracic horn absent - 2

2(1'). Apex of anal lobe with a denticulate tubercle (Fig. 57)- Genus *Potthastia* Kieffer, p.
2'. Apex of anal lobe pointed or rounded, never denticulate - - - - - - - - - - - - - - - - - - 3

3(2'). Apex of each anal lobe with medial branched seta; T V and VIII lateral setae all branched (Fig 58) - Genus *Pagastia* Oliver
Pagastia orthogonia Oliver
3. Apex of each anal lobe without a seta; T VII and VIII usually without branched setae - Genus *Pseudodiamesa* Goetghebuer
Pseudodiamesa branickii (Nowicki)

KEY TO THE PUPA OF THE GENUS *POTTHASTIA* FROM NEW MEXICO

1. Tip of anal lobe tubercle smooth but area just proximal with coarse, sharp denticles (Fig. 59) - *Potthastia montium* (Edwards)
1'. Tip of anal lobe tubercle with denticles (Fig. 60)- 2

2(1'). T I and II with apical shagreen bands - - - - - - - - - - - - -*Potthastia gaedii* (Meigen)
2'. T I and II without apical shagreen bands - - - - - - - - - - *Potthastia longimanus* Kieffer

KEY TO THE PUPAE OF *DIAMESA* FROM NEW MEXICO

1. Conspicuous small denticles at the base of and between the large sternal spines which are almost entirely dark as are the tergal spines (Fig. 61)- - - - - - - - - - -*Diamesa spinaces* Sæther
1'. Without or very sparse denticles at the base of the larger sternal spines; tergal and/or sternal spines with dark tips only- 2

2(1'). Thoracic horn slightly swollen at the base, evenly attenuate to the weakly spinose tip; terga with strong reticulations (Fig. 62)- *Diamesa leoña* Roback

2'. Thoracic horn cylindrical with the tip weakly tapered, with or without apical very fine spinulae; terga not reticulate ---------- 3

3(2'). Tergal and sternal spines of about equal length; basal half of each spine pale (Fig. 63) ---------- *Diamesa heteropus* (Coquillet)

3'. Sternal spines longer than tergal spines; tergal spines entirely dark or pale at base -- 4

4(3'). Tergal spines entirely dark; S IV-VII spines constricted basal to the tip-(Fig. 64) -- ---------- *Diamesa ancysta* Roback

4'. Tergal spines pale at base; S IV-VII spines evenly tapered to the tip (Fig. 65) ------ ---------- *Diamesa haydaki* Hansen

The pupa of *Diamesa davisi* Edward is unknown.

KEY TO THE PUPAE OF PRODIAMESINAE FROM NEW MEXICO

1. Pedes spurii B (PsB) spinulose at tips (Fig. 66) ---------- *Monodiamesa* Kieffer
Monodiamesa n. sp. 1

1'. PsB on T II without spinulose tips ---------- Genus *Odontomesa* Pagast—2

2(1'). Posterolateral extension of T VIII with two taeniform setae (Fig. 67) ---------- ---------- *Odontomesa ferringtoni* Sæther

2'. Posterolateral extension of T VIII with a single taeniform seta (Fig. 68) ---------- ---------- *Odontomesa fulva nearctica* Sæther

KEY TO THE PUPAE OF ORTHOCLADIINAE FROM NEW MEXICO

1. Anal lobe macrosetae lacking; small spines resembling short macrosetae may be present ---------- 2

1'. Anal lobe macrosetae present (Fig. 69) ---------- 6

2(1). Anal lobes elongate, acute, with fine spinulae at the apex (Fig. 70) ---------- 3

2' Anal lobes rounded at apex ---------- 4

3(2). T II with a broad row of weak hooks which is weakly divided in the middle; shagreen almost continuous on all terga; D_5 setae simple ---------- ---------- Genus *Cricotopus* van der Wulp
Subgenus *Nostococladius* Ashe & Murray
Cricotopus (N.)nostocicola Wirth

3'. T II hook row lacking; shagreen in two bands which may be weakly joined; some D_5 setae plumose (Fig. 71) ---------- Genus *Rheosmittia* Brundin
Rheosmittia n. sp. 1
Rheosmittia sp. 1-P

4(2'). Thoracic horn absent ---------- 5

4'. Thoracic horn present, short and sac-like or long, tubular and wrinkled (Fig. 72) ----

---------- Genus *Orthocladius* Wulp Subgenus *Euorthocladius*, p.

5(4'). Abdominal terga without spine patches or rows ---------- 38
5'. Abdominal terga II-VIII with basal and/or apical spine rows---------- 40

6(1'). Anal lobe with a fringe of long hair-like setae in addition to three macrosetae --- 7
6'. Anal lobe without a long setal fringe; anal macrosetae present ---------- 15

7(6). Pedes spurii B(PsB) on tergum II elongate, digitiform; intersegmental membrane) with darker polygonal areas (Fig. 73); T II hooks absent ----------
---------- Genus *Parametriocnemus* Goetghebuer
Parametriocnemus lundbeckii (Johannsen)

7'. PsB on T II lacking or, if present, low and mound-like; intersegmental membrane without markings; T II hooks present or absent ---------- 8

8(7'). PsB II and III present; T II with weak to strong hooks on a ridge-like protuberance; thoracic horn elongate, fusiform to weakly clavate---------- 9
8'. PsB II present or absent; PsB III absent; T II hooks present or absent; thoracic horn various or lacking---------- 10

9(8'). Some D-setae and L-setae set on tubercles; T III-VI with posterior spines (Fig. 74)
---------- Genus *Nanocladius* Kieffer, P.
9'. D- and L-setae not on tubercles; with posterior shagreen only----------
---------- Genus *Rheocricotopus* Thienemann & Harnisch, p.

10(8'). PsB II present (may be weak or lacking); thoracic horn present----------11
10'. PsB II absent; thoracic horn lacking ---------- 14

11(10). T II without hooks; terga covered with fine shagreen which becomes much coarser posteriorly---------- Genus *Paratrissocladius* Zavrel
Paratrissocladius sp. 1-P
11'. TII hooks present; terga covered with fine shagreen or some terga with posterior spines
---------- 12
shagreen

12(11'). T II hooks fine, in multiple rows; terga covered with weak shagreen only -----
---------- Genus *Hydrobaenus* Fries, p.
12'. T II hooks in two rows or, if multiple, on a ridge-like protuberance ---------- 13

13(12'). T II hooks weak, in two rows; terga with extensive fine shagreen only -------
---------- Genus *Brillia* Kieffer, p.
13'. TII hooks in multiple rows, on a ridge-like protuberance; some terga with posterior spines
---------- Genus *Psectrocladius* Kieffer, p.

14(10'). Wing sheaths with bacatiform papillae------ Genus *Corynoneura* Winnertz, p.
14'. Wing sheaths without bacatiform papillae ----- Genus *Thienemanniella* Kieffer, p.

15(6'). Thoracic horn lacking; PsB II and III lacking; terga with heavy apical spines - 16

15'. Thoracic horn present (if absent, then with recurved hooks on some of T III-VI); PsB II and III present or absent; terga with or without apical spines ---------- 21

16(15). Tergum I with an anterior and a posterior row of strong spines ---------- Genus *Cardiocladius* Kieffer

Cardiocladius platypus (Coq.).

The pupa of *Cardiocladius* n. sp. 1 is unknown

16'. Tergum I, at most, with fine shagreen ---------- 17

17 (16'). Anal macrosetae greatly reduced; posterior margin of terga with close-set blunt tubercles in one row or partially in two rows or with a single row of sharp spines --------- 18

17'. Anal macrosetae larger but terga with rows of sharp denticles; posterior margins without blunt tubercles ---------- 19

18(17).Posterior margin of terga with blunt tubercles; anal lobes without denticles ---------- Genus *Metriocnemus* Wulp

Metriocnemus n. sp. 2

Metriocnemus sp. 1-P

18'. Posterior margin of terga with sharp spines; anal lobes with several denticles ---------- Genus *Pseudorthocladius (s.s.)* Goetghebuer

Pseudorthocladius (P.) uniseratus Sæther & Sublette

19(17'). Anal lobes elongate, digitiform; posterior margins of terga with triangular denticles ---------- Genus *Lopescladius* de Oliveira,

19'. Anal lobes not as elongate; posterior margins of terga with slender pale denticles or spines ---------- 20

20 (19'). Anal macrosetae graduated in size, with the medial macroseta being the largest; lateral to the macrosetae are several denticles on the apex of the anal lobe; tergal spines short ---------- Genus *Synorthocladius* Thienemann

Synorthocladius semivirens (Kieffer)

20'. Anal macrosetae about equal in length; apex of anal lobe without denticles; terga with long tergal spines ----------Genus *Limnophyes* Eaton, P.

21(15'). Anal lobes greatly elongate, pointed; anal macrosetae very small ----------Genus *Krenosmittia* P.

21'. Anal lobes not greatly elongated and macrosetae well developed ---------- 22

22(21'). Tergum II without an apical row of hooks ---------- 23

22'. Tergum II with a weak to strong hook row ---------- 31

23(22). Anal lobes short, rounded, usually with apical weak denticles and one strong apical macroseta and one weaker macroseta which may be located on the side of the lobe; bacatiform papillae present ---------- Genus *Paraphaenocladius* Thienemann, P.

23'. Anal lobes longer, typically with three longer macroseta; bacatiform papillae absent, if present, then with three coarse macrosetae - 24

24(23'). Anal lobes apically pointed, frequently with apical denticles; PsB present on T II and often on T III, occasional absent - - - - - - - - - - - - - - - Genus *Parakiefferiella* Thienemann, p.

24'. Anal lobes rounded apically; PsB II and III absent - 25

25(24'). Terga II-VI with fine shagreen only - 26

25'. At least some of T II-VI with apical spines and/or hooks - - - - - - - - - - - - - - - - 27

26(25). Shagreen in three bands on T II-T V, with that of the middle band being separated into two lateral patches - Genus *Eudactylocladius* Thienemann

Eudactylocladius dubitatus (Johannsen)

26'. Shagreen in two transverse bands only - Genus *Parorthocladius* Thienemann

Parorthocladius sp. 1-P

27(25'). Terga II-VIII with an apical row of darkened triangular spines; tergal hooks lacking - 28

27'. Terga II-VIII with spines and some segments with hooks - - - - - - - - - - - - - - - - - 29

28(27). S II and III with rows of pale spines - - - - - - - - - - - - - - Genus *Heleniella* Gouin

Heleniella n. sp. 1

Heleniella sp.1-P.

28. S II and III without pale spines - Genus *Psilometriocnemus* Sæther *Psilometriocnemus triannulatus* Sæther

29(27'). Tergal spines lacking but conjunctiva IV/V and V/VI with a row of hooks - Genus *Tokunagaia* Sæther

Tokunagaia rowensis Sæther

Tokunagaia n. sp. 1

Tokunagaia sp. 1-P

29'. Tergal spines and conjunctival hooks present - 30

30(29'). Anal lobe with three apical macrosetae; wing sheaths without bacatiform papillae - Genus *Eukiefferiella* Thienemann

30'. Anal lobe with three apical macrosetae and one more medial macroseta; wing sheaths with bacatiform papillae - *Tvetenia* Kieffer

31(22'). Anal lobe with short, heavy spinose macrosetae, two at the apex of the lobe and one more laterad - Genus *Chaetocladius* Kieffer

31'. Anal lobe with three longer, lighter macrosetae which are clustered at or near the apex - 32

32(31'). Terga II-VI with anterior paired spine patches; thoracic horn slender, fusiform with denticles to near the base ----------Genus *Acricotopus* Kieffer

Acricotopus nitidellus Malloch

32'. Terga usually with three transverse bands of shagreen; if spine patches are present then thoracic horn with denticles only in the apical half ---------- 33

33(32'). With TII hooks mostly in two rows ---------- 35

33'. With TII hooks in three or more irregular rows ---------- 34

34(33"). Apex of anal lobe strongly developed forming an infolded claw-like structure-- ---------- Genus *Orthocladius* Wulp, Subgenus *Symposicladius*

Orthocladius, (S.) lignicola (Kieffer)

34'. Apex of anal lobe with or without apical spines; if infolded, not as strongly developed ---------- Genus *Orthocladius* Wulp, Subgenus *Orthocladius* s.s., P.

35. Strong frontal setae present on elongate, granulose frontal tubercles; TII hooks mostly in two uneven row ----------Genus *Paracladius* Hirvenoja

Paracladius conversus (Walker)

Paracladius alpicola(Zetterstedt)

35'. Frontal setae, if present, on weak frontal tubercles; TII in two even rows ------ 36

36(35'). T II hooks small, similar in size to the spinulae on conjunctiva T III/IV-V/VI; frontal setae absent ---------- Genus *Paratrichocladius* Santos Abreu, p.

36'. T II hooks larger, usually distinctly larger than the conjunctiva spinulae; frontal setae usually present ---------- 37

37(36'). Terga III-VI- with median and apical shagreen bands usually separate; thoracic horn fusiform, cylindrical or weakly clavate ------ Genus *Cricotopus* Wulp, *Cricotopus* s.s., p.

37'. Terga III-VI with median and apical shagreen usually continuous; thoracic horn elongate fusiform ---------- *Cricotopus,* Subgenus *Isocladius* Kieffer, p.

38(5). Conjunctiva without distinct shagreen bands, although weak scattered shagreen may be present ---------- 39

38'. Conjunctiva with definite bands of shagreen or fine hooklets ---------- ---------- *Pseudosmittia* Goetghebuer, p.

39(38). Antepronotal sclerite usually with a single median seta ---------- ---------- Genus *Smittia* Holmgren, p.

39'. Antepronotal sclerite usually with 2-3 setae - Genus *Bryophaenocladius* Thienemann

40(5'). T II-VIII with apical spine rows only; fused T IX + anal lobe with 2-3 short spines ----------Genus *Antillocladius* Sæther

Antillocladius n. sp. 1

40'. T II-VIII with both basal and apical spine rows, greatly reduced anal lobe with 4 very fine setae----------Genus *Camptocladius* van der Wulp

Camptocladius stercorarius (DeGeer)

KEY TO THE PUPAE OF *LOPESCLADIUS* FROM NEW MEXICO

1. T II-VIII with a basal band of coarse shagreen; anal lobe with conspicuous denticles-- *Lopescladius hyporheicus* Coffman & Roback

1'. T II-VIII without a basal shagreen band; anal lobe smooth --- *Lopescladius inermis* Sæther

THE GENUS *MESOSMITTIA* IN NEW MEXICO

Pupae of this genus have not been described. Although at least one species has been taken as adults from funnel traps in a swift stream, most species are probably subaquatic. The five species known as adults from New Mexico are listed below:

Mesosmittia acutistylus Sæther
Mesosmittia lobiger Sæther
Mesosmittia patrihortae Sæther
Mesosmittia prolixa Sæther
Mesosmittia n. sp. 1

KEY TO THE PUPAE OF *NANOCLADIUS* FROM NEW MEXICO

1. Thoracic horn fusiform to attenuate --- 2
1'. Thoracic horn clavate to globose --- 3

2(1). Thoracic horn slightly bulbous at base, then narrowly attenuate to the tip--- *Nanocladius anderseni* Sæther
2'. Thoracic horn fusiform --------------------- *Nanocladius distinctus* (Malloch)

3(1'). Thoracic horn weakly clavate -------------- *Nanocladius spiniplenus* Sæther
3'. Thoracic horn globose ---------------------Nanocladius *crassicornis* Sæther

KEY TO THE PUPAE OF *ORTHOCLADIUS (EUORTHOCLADIUS)* FROM NEW MEXICO

1. Terga with apical bands of coarse shagreen on T IV-VIII ---*Orthocladius (E.)* sp. 1-P
1'. With at least some terga with hooks or spines or both ---------------------- 2

2(1'). T II without hooks or spines; thoracic horn small, ovoid ----------------- 3
2'. T II with a posteromedian patch of fine hooks; thoracic horn subcylindrical, elongated, with a slight inflation at the tip -- 4

3(2). S VI with pedes spurii A (PsA) --------- *Orthocladius (E.) luteipes* Goetghebuer
3'. S VI without PsA----------------------------- *Orthocladius (E.) rivicola* Kieffer

4(2'). Apical spine row of T VI complete---------- *Orthocladius (E.)anteilis* Roback
4'. Apical spine row of T VI interrupted in the middle*Orthocladius (E.) rivulorum* Kieffer

One species is known only from the adult: *Orthocladius (Euorthocladius)* n.sp. 1.

KEY TO THE PUPAE OF *ORTHOCLADIUS (ORTHOCLADIUS)* FROM NEW MEXICO

1. T I-III with few to many small, circular sclerotized placodes near the posterior margin ----------2.
1'. T I-III without circular placodes----------3.

2(1). PsB II present, PsB III lacking; abdomen dark brown with apices of terga almost black; T I-VII and S I-VII with placodes ----------*Orthocladius rubicundus* (Mg.)
2'. PsB II and III present; abdomen pale brown; T I-III and S I-VII with placode ------ ---------- *Orthocladius carlatus* (Roback)

3(1'). Thoracic horn long and tubular, without denticles---------- ---------- *Orthocladius frigidus* (Zetterstedt)
3'. Thoracic horn fusiform to clavate, if without denticles, then very short ---------4.

4(3'). Intersegmental membranes with dark polyagonal plates---------- ---------- *Orthocladius dorenus* (Roback)
4'. Intersegmental membranes without dark plates----------5.

5. PsB II and III lacking; lateral intersegmental membrane margins distinctly darkened; anal lobe spurs lacking; anal macrosetal tips straight ----------*Orthocladius* sp. 4-P
5'. PsB II or PsB II and III present; lateral margins pale; anal lobe spurs present or absent; anal macrosetal tips usually curved, if straight, then ALR <0.55----------6.

6(5'). PsB II and III present ----------7.
6'. Only PsB II present----------9.

7(6). Anal lobe spurs present ----------8.
7'. Anal lobe spurs absent ---------- *Orthocladius* sp.5-P

8(7). Thoracic horn slender, fusiform; anterolateral margins of frontal apotome almost straight ---------- *Orthocladius* sp. 9-P
8'. Thoracic horn heavier, tip frequently slightly bent and base slightly inflated; antero-lateral margins of frontal apotome deeply concave---------- *Orthocladius mallochi* Kieffer

9(6'). ALR 0.55 or less ---------- 10.
9'. ALR usually greater than 0.60 ---------- 13.

10(9). ALR less than 0.40; anal macrosetal tips straight; anal lobe without fine lateral fringe ----------*Orthocladius robacki* Soponis

10'. ALR greater than 0.40; anal macrosetal tips hooked ---------- 11.

11(10'). Anal lobe spurs lacking; anal lobe with a distinct fringe of fine lateral filaments- ----------*Orthocladius subletti* Soponis

11'. Anal lobe spurs present; anal lobe without lateral filaments ---------- 12.

12(11'). Apical shagreen row on TIII and IV distinctly narrower than the posterior row, about as wide as the hook row on TII---------- *Orthocladius* sp.10-P

12'. Apical shagreen row on TIII and IV slightly wider than the posterior row and wider than the hook row on TII ---------- *Orthocladius manitobensis* Sæther

13(9'). Anal lobe spurs lacking---------- 14.

13'. Anal lobe spurs present---------- 17.

14(13). Median shagreen band of TIII lacking; TIV and TV with median and posterior shagreen bands fused to form a triangular shape ---------- *Orthocladius appersoni* Soponis

14'. Median band of shagreen present on TIII---------- 15.

15(14'). Anal lobe with a fringe of 13-15 lateral filaments; TII hooks 35-38 ---------- *Orthocladius* sp. 8-P

15'. Anal lobe without lateral filaments; TII hooks greater than 40---------- 16.

16(15') T II with well developed median and posterior bands of shagreen; T II hooks 57-111 ----------*Orthocladius trigonolabis* Edwards

16'. T II with a very weak posterior band of shagreen only; T II hooks44-56 ---------- *Orthocladius* sp. 15-P

17(13'). Thoracic papillae very heavy; thoracic horn denticles very heavy, frequently appearing serrate on one edge, base usually distinctly inflated on one side of the base ---------- *Orthocladius* sp. 6-P

17' Thoracic papillae usually weak, if heavy then frontal apotome without a distinct tubercle ---------- 18.

18(17'). Thorax with strong papillae dorsally and moderate rugosity ventrally; frontal apotome without distinct tubercles---------- *Orthocladius* sp 14-P

18'. Thorax with, at most moderate papillae; frontal apotome with weak to moderate tubercles ---------- 19.

19(18'). Exuviae pale golden brown; thorax rugose anteriorly near the median suture; TII hook row with fewer than 60 hooks---------- *Orthocladius oliveri* Soponis

19'. Exuviae darker brown to blackish-brown, usually with moderate papillae on the thorax.; TII hook row usually with more than 60 hooks------ *Orthocladius obumbratus* Johannsen

One anomalous pupa, designated as sp.11-P, was not included in the key.

Two species are known only as adults:

Orthocladius n. sp. 2
Orthocladius n. sp. 3

KEY TO THE PUPAE OF *PARAKIEFFERIELLA* IN NEW MEXICO

1. Anal lobes with massive inturned apical tips which are heavily denticulate; thoracic horn cylindrical, bluntly tapered at both ends ---------- *Parakiefferiella* sp. 4-P

1'. Anal lobes at most slightly inturned with denticles very weak or absent; thoracic horn elongate oval ----------2.

2(1'). PsB II absent; thoracic horn with coarse denticles at the tip *Parakiefferiella* n. sp. 4

2'. PsB II and III present; thoracic horn with very fine denticles at the tip---------- ---------- *Parakiefferiella subaterrima* (Malloch)

Two species are known only from adults:

Parakiefferiella n. sp. 2
Parakiefferiella n. sp. 3

KEY TO THE PUPAE OF *PARAPHAENOCLADIUS* FROM NEW MEXICO

1. Bacatiform papillae and nasiform tubercles absent; total length >3.5 mm PsB II absent ----------*Paraphaenocladius innasus* Sæther and Wang

1'. Bacatiform papillae present or absent; nasiform tubercles present; PsB II present; total length < 3.5 mm ---------- 2

2(1'). Bacatiform papillae absent; basal seta of anal lobe present ---------- ---------- *Paraphaenocladius nasthecus* Sæther

2'. Weak bacatiform papillae present; basal seta of anal lobe absent ---------- ---------- *Paraphaenocladius exagitans* (Johannsen)

KEY TO THE PUPAE OF *PSECTROCLADIUS* FROM NEW MEXICO

1. Anal lobe with 3-8 heavy anal macrosetae in addition to the fringe of taeniate setae -2.

1'. Anal lobe with one anterior and two posterior weak setae on each side , medial to the taeniate setal fringe----------*Psectrocladius(Allopsectrocladius)* *Psectrocladius (A.) spinifer* (Johannsen)

2(1). T III or IV-VI lacking medial spine patches ---------- ----------*Psectrocladius (Mesopsectrocladius)* *Psectrocladius (M.)* sp. 5-P

2'. T III or IV-VI with single or double spine patches *Psectrocladius (Psectrocladius)* -3.

3(2'). Spinous patch on T IV-VI double (may be weakly contiguous on T VI); frontal apotome with anterior tubercles ----------4.

3'. Spinous patch on T IV-VI single; frontal apotome with or without tubercles ------5.

4(3). TIII usually with a weak spinous patches; anal macrosetae 3 on each lobe; with 25-28 taeniate setae on each anal lobe ----------*Psectrocladius* n. sp. 4

4'. TIII lacking spinous patches; anal macrosetae usually 6 on each side; with 44-90 taeniate setae on each anal lobe----------*Psectrocladius barbimanus* (Edwards)

5(3'). With strong papellose tubercles on the anterior end of the frontal apotome ------ ----------*Psectrocladius simulans* (Johannsen)

5'.Frontalapotomewithoutanteriortubercles;frontalsetae,ifpresent,maybeonaweaktubercle ----------6.

6(5'). Thoracic horn broadened at the base, with very heavy denticles; precorneal setae on a prominent tubercle ----------*Psectrocladius* sp. 1-P

6'. Thoracic horn clavate to subcylindrical; if slightly widened at the base, then with weak denticles; precorneal setae not on a prominent tubercle----------7.

7(6'). Thoracic horn subcylindrical, with weak denticles towards the base; anal lobe taeniate setae 24-32----------*Psectrocladius vernalis* (Malloch)

7'. Thoracic horn slightly widened at the base, with coarser denticles towards the tip; taeniate setae 10-18----------*Psectrocladius* sp. 3-P

One species, *Psectrocladius* n. sp. 5, is known only from the adults.

THE GENUS *PSEUDOSMITTIA* IN NEW MEXICO

This is another of the subaquatic-terrestrial midge assemblage whose pupal exuviae are occasionally taken in the stream drift. Only one species, *Pseudosmittia digitata* Saether, has been taken in Thienemann net samples in New Mexico. Two addtional species known only as adults occur.

These are:

Pseudosmittia forcipata Goetghebuer
Pseudosmittia nanseni Kieffer

KEY TO THE PUPAE OF *RHEOCRICOTOPUS* FROM NEW MEXICO

1. Abdominal terga without central patches of spinulae ----------2.

1' Abdominal terga IV-VI with a distinct central patch of coarse spinulae---------- ----------*Rheocricotopus eminelobus* Sæther

2(1). Reticulation at the dorsal anterior apex of the thorax heavy; with two rows of spinulae anterior to the posterior hook row of TII ----------*Rheocricotopus* n. sp. 1

2. Reticulation much weaker; with one row of spinulae anterior to the T II hook row --- ---------- *Rheocricotopus robacki* (Beck and Beck)

THE GENUS *SMITTIA* IN NEW MEXICO

Most members of this genus occur in moist biotopes- damp soil, mosses, decomposing fungi or madricolous environments. At least one species is aquatic and pupal exuviae may occur in the stream drift. The following lists the species known from New Mexico:

Smittia aterrima Edwards
Smittia edwardsi Goetghebuer
Smittia n. sp. 9

KEY TO THE PUPAE OF *THIENEMANNIELLA* FROM NEW MEXICO

1. At least basal half of anal lobe bare; swim fringe restricted to the apical 0.5-0.25 --- 2
1'. Swim fringe more extensive with no more than the basal 0.25 of the anal lobe bare; apical spinulae heavy or weak; SII with or without hair-like shagreen ---------- 4

2(1). Basal 0.5 of anal lobe bare; SII with fine hair-like shagreen ---------- 3
2'. Basal 0.75 of anal lobe bare; swim fringe almost transversely oriented at apex of anal lobe; S II without fine shagreen ---------- *Thienemanniella* sp. 7-P

3(2). Spinulae at the apex of the shagreen bands very heavy --- *Thienemanniella* sp. 2-P
3'. Spinulae at the apex of the shagreen bands no heavier than the preceding 1-2 rows of shagreen ---------- *Thienemanniella* sp. 6-P

4(1'). Apical tergal shagreen spinulae of T III-VIII graduated in size posteriorly; S II with long hair-like shagreen ---------- *Thienemanniella* sp. 3-P
4'. Apical tergal spinulae much weaker, shagreen almost uniform in size over all terga, or apical tergal spinulae graduated in size; S II with or without long hair-like shagreen -------- 5

5(4'). shagreen graduated in size posteriorly; SII hair-like shagreen present or absent -- 6
5'. shagreen almost uniform over most of the terga or slightly heavier at the anterior end of each tergum; S II hair-like shagreen absent ---------- 7

6(4). Apical row of heavier tergal shagreen spinulae widely spaced; SII without hair-like shagreen ---------- *Thienemanniella similis* (Malloch)
6'. Apical row of spinulae more closely spaced; S II with hair-like shagreen - *Thienemanniella* n. sp. 2

7(5'). Taeniform setae of swim fin almost uniform in size and extending to the anterolateral corner of the swim fin; sternal shagreen coarser than tergal; posterior row of tergal spinulae very fine usually less than 10 in number ---------- *Thienemanniella* sp. 1-P
7'. Anterior 3-6 swim fringe setae smaller, filiform, gradually becoming larger and taeniform posteriorly; apical tergal spinulae row with about 12 or more denticles ---------- 8

8(7'). Anterior setae of the swim fin ending about 0.2 from the anterolateral corner; sternal and tergal shagreen about the same size with the posterior denticle row somewhat coarser -- *Thienemanniella xena* (Roback)

8'. Anterior setae of the swim fin extending to the anterolateral corner; shagreen slightly heavier towards the anterior end of each tergum; sternal shagreen greatly reduced with the heaviest being on TVII and VIII; posterior denticle rows of both terga and sterna about as heavy as the tergal shagreen -- *Thienemanniella* sp. 4-P

Thienemanniella n. sp. 2 and n. sp. 3 are known from New Mexico in the adult stage only.

KEY TO THE PUPAE OF *TOKUNAGAIA* FROM NEW MEXICO

1. Hook rows present only on T IV and V; An MaS long, of equal length and strongly hooked at the tips ---------------------------------- *Tokunagaia rowensis* (Sæther)

1'. Hook rows present on T III-V; An MaS, 2 long, 1 very short and fine -- *Tokunagaia* sp. 1-P

Tokunagaia n. sp. 2 from New Mexico is known only in the adult stage.

KEY TO THE PUPAE OF *TVETENIA* FROM NEW MEXICO

1. Recurved hooks present only on T III and IV; tergal spinulae rows clearly separated on the midline -- *Tvetenia paucunca* (Sæther)

1'. Recurved hooks present on T III-V (sometimes T VI); tergal spinulae rows joined at the midline by finer spinulae ---------------------------- *Tvetenia vitraces* (Sæther)

KEY TO THE PUPAE OF CHIRONOMINAE OF NEW MEXICO

1. Thoracic horn usually multibranched, at most reduced to two branches; wing sheath without bacatiform papillae and usually without a nasiform tubercle----- Tribe Chironomini, p.

1'. Thoracic horn always a single tubular extension (rarely absent), with short denticles, long chaetae or bare; wing sheaths usually with bacatiform papillae and/or nasiform tubercle-- Tribe Tanytarsini. p.

KEY TO THE PUPAE OF CHIRONOMINI OF NEW MEXICO

1. Thoracic horn with only two branches ---------------------------------- 2

1'. Thoracic horn with multiple branches ---------------------------------- 3

2(1). S I with two anterior pairs of usually spinulose tubercles; thoracic branches short and rather blunt ---------------------------------- Genus *Pseudochironomus* Malloch.

2'. S I without spinulose tubercles; thoracic horn branches longer, slender and with pointed apices -------------------------- Genus *Lauterborniella* Thienemann & Bause

Lauterborniella agrayloides (Kieffer)

3(1'). Terga II or III to VI with heavy, mace-like, mid-dorsal appendages ----------
----------Genus *Glyptotendipes* Kieffer
Glyptotendipes barbipes (Staeger)

3'. Terga without mace-like appendages---------- 4

4(3'). Cephalic tubercles with an apical group of spinulae---------- 5

4'. Cephalic tubercles each with a single apical or subapical seta, or bare and pointed, or cephalic tubercles lacking ---------- 6

5(4).Frontal setae very short, at most slightly longer than the apex of the cephalic tubercle
----------Genus *Phaenopsectra* Kieffer, p.

5'.Frontal setae longer and heavier, usually about twice as long as the apex of the frontal tubercle
---------- Genus *Endotribelos* Grodhaus
Endotribelos hesperium (Sublette)

6(4'). With a distinct tuft of caudomesial setae on the apex of the anal lobe----------
---------- Genus *Endochironomus* Kieffer, p.

6'. Apex of anal lobe without a tuft of setae ---------- 7

7(6'). Thoracic horn with one very long apically dissected branch which is more than half the total length of the pupa, with the other branch being short and plumose ----------
----------Genus *Cryptotendipes* Lenz, p.

7'. Thoracic horn either with a few simple branches or with a plumose tuft of branches- 8

8(7'). T II with well developed PsB which are spinulose------- Genus *Beckidia* Sæther
Beckidia tethys (Townes)

8'. T II, if with PsB of T II, if present, never spinulose---------- 9

9(8'). T VI with a small posteromedian elevation which may be rounded or elongated; T II hook row divided in the middle----------Genus *Cladopelma* Kieffer. p.

9'. T VI without a spinulose elevation although a posterior band of coarse shagreen may be present; if a slight elevation occurs on T VI, then T II hook row complete---------- 10

10(9'). Thoracic horn with only 4 branches which are weakly spinulate at the tips; T II-VI with paired longitudinal patches of coarse denticles ----------Genus *Zavreliella* Kieffer
Zavreliella varipennis (Coq.)

10'. Thoracic horn branches 5 or greater; paired patches of denticles lacking--------11

11(10'). With a heavy, bifurcate process extending back from the anal segment; cephalic tubercles either conical and simple or enlarged and horn-like; abdomen usually with heavy reticulations
---------- Genus *Cryptochironomus* Kieffer, p.

11'. Anal process lacking; cephalic tubercles simple or lacking; reticulations present or absent

12(11'). Thoracic horn branches 5-20 ---------- 13
12'. Thoracic horn branches from 30 to several hundred ---------- 17

13(12). With conspicuous long, curved frontal tubercles; cephalic tubercles and frontal setae lacking ---------- Genus *Microtendipes* Kieffer
Microtendipes caducus Townes
13'. Frontal tubercles or process usually lacking; if present, then either cephalic tubercles and/or frontal setae present ---------- 14

14(13').Wing sheath with a blunt nasiform papilla ----- Genus *Paralauterborniella* Lenz
Paralauterborniella nigrohalteralis (Malloch)
14'. Wing sheath without a distinct nasiform papilla ---------- 15

15(14'). Abdominal terga II-V with a strong anterior transverse band of shagreen; anal lobe without dorsal setae ---------- Genus *Polypedilum* Kieffer, p.
15'. Anterior transverse shagreen band weaker or absent; anal lobe with a dorsal seta - 16

16(15'). Anterior transverse band of weak shagreen on T II-VI; T II-III with 4 L-setae and T IV with 2 L-setae and 2 T-setae; wing sheath with a very indistinct nasiform papilla ---------- Genus *Apedilum* Townes, p.
16'. Terga without a distinct anterior transverse band of shagreen; T II-IV with 3 L-setae only; wing sheath clearly without a nasiform papilla ---------- Genus *Paratendipes* Kieffer, p.

17(12'). Cephalic tubercles and frontal setae lacking; frontal tubercles present as low rounded protuberances; thoracic horn with relatively few simple branches and one spinose branch ---------- 18
17'. Cephalic tubercles and/or frontal setae usually present; frontal tubercles lacking; thoracic horn with simple branches only which are usually more numerous ---------- 19

18(17). Terga II-V with both anterior and posterior transverse bands of heavier shagreen; T VIII comb of obtusely pointed or weakly rounded teeth which are slightly overlapping ---------- Genus *Stenochironomus* Kieffer, p.
18'. Terga without distinct anterior and posterior bands of heavier shagreen; T VIII comb of acutely pointed teeth some of which may overlap slightly ---------- Genus *Xestochironomus* Sublette & Wirth
Xestochironomus brunneus Borkent

19(17'). Frontal setae lacking; PsB lacking; shagreen heavy over most of the terga, with that on the midline being somewhat heavier; T VIII spur or comb lacking Genus *Robackia* Sæther
Robackia claviger (Townes)
19'. Frontal setae present; PsB present or absent; shagreen more uniform or heavier laterally or posteriorly; T VIII posterolateral spur or comb present or absent ---------- 20

20(19'). Pedicel sheath with a long conical tubercle; genital sheath with fine denticles at the apex ---------- Genus *Gillotia* Kieffer
Gillotia alboviridis (Malloch)

20'. Pedicel sheath without a tubercle or tubercle only weakly produced; genital sheath without denticles ---------- 21

21(20'). T VIII posterolateral spur or comb lacking; PsB lacking ---------- 22
21'. T VIII spur or comb present; if comb is lacking, then T VI with a small quadrate posteromedian elevation bearing coarse shagreen at the apex ---------- 24

22(21). Posterior hook row of T II complete ---------- Genus *Saetheria* Jackson
Saetheria n. sp. 1
22'. T II hook row medially divided ---------- 23

23(22'). T II hook row widely interrupted at the middle; PsB lacking ---------- Genus *Harnischia* Kieffer, p.
23'. T II hook row only narrowly divided in the middle; PsB present ---------- Genus *Parachironomus* Lenz (part), p.

24(21'). T VIII comb composed of pale slender parallel-sided spines ---------- Genus *Cyphomella* Sæther p.
24'. T VIII comb or spur of different shape ---------- 25

25(24'). T II PsB lacking ---------- 26
25'. T II PsB present ---------- 27

26(25). T II apical hook row very narrow, occupying less than 1/2 of the tergal width --- Genus *Paracladopelma* Harnisch, p.
26'. T II apical hook row occupying greater than 1/2 the tergal width ---------- Genus *Demicryptochironomus* Lenz, p.

27(25'). T II-VI with a heavier anterior transverse band of shagreen which may be contiguous with the median band; frontal apotome with an anterior acute projecting point and with heavy frontal setae set on heavy tubercles ---------- Genus *Stictochironomus* Kieffer, p.
27'. T II-VI without an anterior heavy band of shagreen, or if one is present, then posterior band is also present; frontal apotome usually with a more obtuse anterior projection; frontal tubercles, if prominent, usually with a weaker apical or subapical seta ---------- 28

28(27'). T II hook row interrupted in the middle ------ Genus *Microchironomus* Kieffer
Microchironomus nigrovittatus (Malloch)
28'. T II hook row complete ---------- 29

29(28'). T III/IV and IV/V conjunctiva without fine shagreen ---------- Genus *Goeldichironomus* Fittkau
Goeldichironomus holoprasinus (Goeldi)
29'. T III/IV and IV/V conjunctiva with fine shagreen ---------- 30

30(29'). T VIII with a heavy spur which is composed of several slender spines which are basally fused; T III/IV and IV/V conjunctiva with L-setae ------ Genus *Chironomus* Meigen, p.

30'. T VIII with a slender single or doubled spinous spur or with a weak comb; T III/IV and IV/V conjunctiva without L-setae ---------- Genus *Dicrotendipes* Kieffer, p.

A new genus and species of Chironomini related to *Paratendipes* is known only as adults from the San Francisco River in Catron County.

KEY TO THE PUPAE OF *APEDILUM* FROM NEW MEXICO

1. T VIII with a single coarse posterolateral spur which may have 1-2 scarcely discernible side denticles; alveoli of T-setae 4 and 5 embedded in the base of the spur---------- *Apedilum elachistus* Townes

1'. T VIII with a spur composed of 2-3 unequl sized spines; alveolus of T-seta 5 only embedded in spur base---------- *Apedilum subcinctum* Townes

KEY TO THE PUPAE OF *CHIRONOMUS* IN NEW MEXICO

This large and cosmopolitan genus is well represented in New Mexico, particularly from lentic environments. Since most streams have, however, some quiet water near margins and in backwaters the genus is also well represented in these biotopes. These blood-red larvae (hence, a common name for members of this family, "blood-worms") are restricted to soft, silty substrata and some species can tolerate very low oxygen conditions. The adults may swarm in enormous numbers from water bodies, such as sewage lagoons, that have high organic matter.

1. Terga IV-VI with heavy, somewhat irregular ridges which have coarse shagreen along the edges---------- *Chironomus stigmaterus* Say

1' Terga III-VI usually with a similar pattern of shagreen which is not ridged ------- 2

2. Frontal apotome, in addition to the two large seta-bearing tubercles, with two much smaller and weaker accessory tubercles anterior to the two main tubercles---------- 3

2'. Frontal apotome with the two large tubercles only; accessory tubercles vestigial but sometimes weakly indicated by slight ridges---------- 4

3. Accessory tubercles well defined; cephalothorax light brownish and abdomen largely pale; posteriormedian margin of the pedicel sheath with a conspicuous tubercle; shagreen on TIII-VI weaker, gradualy becoming heavier posteriorly --------- *Chironomus decorus* Johannsen

3' Accessory tubercles usually visible but not as well defined; cephalothorax blackish brown and abdomen with black lateral stripes; posteriormedial margin of the antennal pedicel with a low rugose ridge; posterior band of shagreen distinctly heavier than the anterior shagreen ---------- *Chironomus atrella* (Townes)

4. Abdomen 10.0 mm or greater; teniform setae of the anal lobe greater than 200, mostly 3-4X---------- 5

4'. Abdomen usually less than 8.0mm; teniform setae of the anal lobe less than 175, 1-3X; if abdomen greater than 10.0mm, then exuviae entirely dark ---------- 6

5.Cephalothorax dark, abdomen pale brown; swim fin largely dark ----------

---------- *Chironomus plumosus* (L.)

5' Cephalothorax pale yellowish-brown; abdomen pale with lateral stripes faint yellowish; swim fin pale with only setal alveoli dark--------- *Chironomus frommeri* Atchley and Martin

6. Exuviae entirely dark with heavy dark shagreen; TIV-VI with a mid-dorsal longitudinal sulcus containing weaker shagreen which is usually paler than the lateral shagreen areas; TVII with the posterior 2/3 reticulate: posterolateral spur of segment VIII with 5-10 spines; abdomen length 8-12.0mm ------ *Chironomus tentans* (Fab.), Amer.Auct.[=*dilutus* Shobanov, et al.,ms.]

6' Cephalothorax dark; abdomen pale, usually with a darker brown lateral stripe, or if exuviae dark, then with 5 or fewer spines in the posterolateral spur of segment VIII and abdomen less than 8.0mm in length ; mid-dorsal sulcus and TVII reticulation scarcely discernable or absent - 7

7. Cephalothorax heavily papillose, with supracorneal, postcorneal and prealar papillose tubercles; TVI shagreen area nearly quadrate, slightly wider anteriorly; frontal tubercles long and slender, distinctly longer than the basal width ---------- *Chironomus utahensis* Malloch

7'. Cephalothorax more weaky papillose, usually with distinct postcorneal and prealar tubercles which are at most weakly papillose, usually weakly striate with papillae weak or absent; TVI shagreen area usually more T-shaped, distinctly narrower at the apex than at the base, or shagreen area separated into anterior and posterior bands; frontal tubercle length usually less than the basal width or only slightly greate ---------- 8

8. Posterior coarse patch of shagreen on TVI greatly reduced or absent; anal lobe taeniform setae usually greater than 135 ---------- *Chironomus crassicaudatus* Malloch

8'. Posterior patch of shagreen on TVI well developed; taeniform setae 135 or usually less ---------- 9

9. Shagreen on TVI distinctly separated into anterior and posterior bands ---------- ---------- *Chironomus calligraphus* Goeldi

9. Shagreen continuous, area T-shaped or quadrate ---------- 10

10. Posterolater spur of segment VIII with 11-15 spines; teniform setae of anal lobe 120 or greater ---------- *Chironomus staegeri* Lundbeck

10' Posterolateral spur with fewer spines; anal lobe with 110 or fewer teniform setae --11

11. Pupal exuviae entirely dark; TII posterior hooks fewer than 100; teniform setae of anal lobe fewer than 88 ---------- 12

11'. Cephalothorax brown, abdomen pale with a very weak brownish lateral stripes; TII hooks greater than 100; teniform setae 88 or more ---------- 13

12. Shagreen pattern of TVI T-shaped, weaker than TIII-V, with the posterior band distinctly narrower than the anterior---------- *Chironomus maturus* Johannsen

12'. Shagreen pattern of TVI very similar to TIII-V, roughly quadrate, with the posterior band about as wide as the anterior band ---------- *Chironomus whitseli* Sublette and Sublette

13.Cephalothorax with coarse papillae in the anterior 1/3 near the median suture; anal lobe pale with a longitudinal median pale brownish band in the apical 2/3; TVIII spurs with 4-7 spines ---------- *Chironomus cucini* Webb

13'. Cephalothorax with weaker papillae in the anterior ½; anal lobe almost entirely dark; TVIII spurs with 3-4 spines ---------- *Chironomus* sp. 1-P

KEY TO THE PUPAE OF *CRYPTOCHIRONOMUS* FROM NEW MEXICO

1. Frontal apotome with simple conical frontal tubercles ---------- 2.
1'. Frontal apotome with frontal tubercles basally fused, in various shapes ---------- 6.

2(1). Terga I-V with heavy reticulation; sterna I-V with weaker reticulation; intersegmental membranes with heavy, dark placodes ---------- *Cryptochironomus digitatus* (Malloch)
2'. Terga with shagreen, but reticulation very weak or absent; intersegmental membrane with fine papillae, or with dark placodes ---------- 3(2').

3. Frontal tubercles about as long as basal width ---------- *Cryptochironomus* sp. 5-P
3'. Frontal tubercles distinctly longer than basal width ---------- 4.

4(3'). T VI-VIII with weak reticulation; intersegmental membranes with dark placodes; S I spinous tubercle single ---------- *Cryptochironomus* n. sp. 3
4'. T VI-VIII lacking reticulation; intersegmental membranes with fine papillae; S I spinous tubercle double on each side ---------- 5.

5(4'). Apical spinulae row of S II with heavy denticles, 3-4X at the middle, row longer---------- *Cryptochironomus* n. sp. 9
5'. Apical spinulae of S II weaker, 2X at the middle, row shorter ---------- *Cryptochironomus* sp. 4-P

6(1'). Frontal tubercles fused at the base, forming a large Y-shaped structure ---------- *Cryptochironomus* n. sp. 12
6'. Frontal tubercles fused at the base, but forming a larger, more complex structure--- 7.

7(6'). Frontal tubercles appear as two Y-shaped structures joined at the base ---------- *Cryptochironomus fulvus* (Johannsen)
7'. Frontal tubercles fused at the base forming a large bulbous structure from which arises two strong hooked arms which may have a small point visible near the apex ---------- *Cryptochironomus ponderosus* (Sublette)

Two species are known only as adults:

Cryptochironomus n. sp. 2
Cryptochironomus n. sp. 5

KEY TO THE PUPAE OF *CRYPTOTENDIPES* FROM NEW MEXICO

1. Frontal tubercles length greater than 2X basal width; posterior taeniate setae of the anal lobe unusually broadened, pale ---------- *Cryptotendipes* sp. 3-P

1'. Frontal tubercles about as long as basal width; posterior taeniae at most only slighter wider than remainder - 2.

2(1'). Tergal spines present at the apices of T VII and VIII; sternal spines present at the apices of S VI-VIII; taeniate setae of anal lobe dark, somewhat clustered towards the apex of the anal lobe - *Cryptotendipes darbyi* (Sublette)

2'. T VII-VIII spines absent; S VI-VIII spines absent; taeniate setae pale, evenly distributed around the margin of the anal lobe - 3.

3(2'). TII posterior hook row single, with 28-32 hooks; TII-VI posterior spines on a single raised mound - *Cryptotendipes* sp. 4-P

3' TII posterior hook row divided, with 11-16/11-16 hooks; posterior spine row single or double - 4.

4(3'). TIII-V posterior spine rows divided - - - - - - - - - - - - - - - - - - *Cryptotendipes* sp. 1-P

4'. TIII-V posterior spines in a single row - - *Cryptotendipes pseudotener* (Goetghebuer)

Two species of *Cryptotendipes* are known only from adults. These are:

Cryptotendipes n. sp. 1
Cryptotendipes n. sp. 2 (this new species is likely associated with *Cryptotendipes* sp. 1-P)

KEY TO THE PUPAE OF *CYPHOMELLA* FROM NEW MEXICO

1. Posterolateral comb of segment VIII composed of several fine teeth - *Cyphomella gibberea* Sæther

1'. Posterolateral comb composed of usually 3 fine teeth - - - - - - - - *Cyphomella* n. sp. 1

Two species are known only as adults. These are:

Cyphomella n. sp. 2
Cyphomella n. sp. 3

THE GENUS *DEMICRYPTOCHIRONOMUS* IN NEW MEXICO

This is another of the small chironomine genera in the *Harnischia*-complex. The three taxa elucidated from New Mexico are:

Demicryptochironomus fastigata (Townes
Demicryptochironomus cuneatus (Townes)
Demicryptochironomus sp. 2-P

THE GENUS *DICROTENDIPES* IN NEW MEXICO

Representatives of this genus are found in almost all lower elevation as well as in some higher elevation streams. Some species are tolerant of elevated mineral content in streams and will be the last to disappear under degrading water quality. Taxa known from the state are:

Dicrotendipes aethiops (Townes)
Dicrotendipes californicus (Johannsen)
Dicrotendipes crypticus Epler
Dicrotendipes fumidus (Johannsen)
Dicrotendipes modestus (Say)
Dicrotendipes neomodestus (Malloch)
Dicrotendipes nervosus (Staeger)

KEY TO THE PUPAE OF OF THE GENUS *ENDOCHIRONOMUS* IN NEW MEXICO

1. Exuviae pale yellowish ----------*Endochironomus subtendens* (Townes)
1'. Exuviae mostly dark----------*Endochironomus nigricans* (Johannsen)

KEY TO THE PUPAE OF THE GENUS *HARNISCHIA* IN NEW MEXICO

1. Cephalothorax moderately tuberculate; apical shagreen band of T II wider than the median gap of the T II hook row---------- *Harnischia curtilamellatus* (Malloch)
1'. Cephalothorax smooth; apical shagreen of T II in a rounded patch lying above the gap in the T II hook row ----------*Harnischia incidata* Townes

KEY TO THE PUPAE OF THE GENUS *PARACLADOPELMA* IN NEW MEXICO

1. TVIII with a small posterolateral spur ----------*Paracladopelma* sp. 1-P
1'. TVIII without a spur---------- 2

2. Cephalothorax with sparse, coarse tubercles near the anterior median raphe; apical row of spinulae of TII much finer than those of TIII-VI ---------- *Paracladopelma* n. sp. 2
2'. Cephalothorax without tubercles except those on the median hump; apical row of spinulae of TII about as coarse as those of TIII-VI----------*Paracladopelma* sp. 3-P

KEY TO THE PUPAE OF *PARACHIRONOMUS* IN NEW MEXICO

1. Pedes spurii A (PsA)of S IV absent; tubercles of cephalothorax fine---------- 2
1'. PsA present; tubercles of cephalothorax coarse, if fine over most of the surface, then with a few coarse tubercles near median suture ---------- 3

2(1). Fine spinulae present on S II--------- *Parachironmous tenuicaudatus* (Malloch)
2'. S II spinulae absent ----------
----------*Parachironomus monochromus,* Amer.auct., *nec van der Wulp* [=n. sp.3]

3(1'). Cephalothoracic tubercles fine except for a row of 2-3 coarse tubercles near the median suture; anal lobe fringe 40-43 ----------*Parachironomus directus* (Sublette)

3'. Cephalothoracic tubercles almost uniformly coarse; anal lobe fringe greater than 60 - ---------- 4

4(3'). S I with a low tubercle which bears fine, pale spinulae; S II also with fine, pale spinulae ---------- *Parachironomus abortivus* (Malloch)

4'. S I spinulae lacking; S II spinulae weak or absent ---------- 5

5(4'). S II spinulae lacking; T VIII with a posterolateral comb of 3-4 pale spines ------ ----------*Parachironomus frequens* (Johannsen)

5'. S II with a few weak spinulae; T VIII comb lacking ------ *Parachironomus* sp. 1-P.

The following taxa have not had pupal exuviae associated:

Parachironomus potamogeti (Townes)
Parachironomus n. sp. 1
Parachironomus n. sp. 2

KEY TO THE PUPAE OF THE GENUS *PARACLADOPELMA* IN NEW MEXICO

1. TVIII with a small posterolateral spur ----------*Paracladopelma* sp. 1-P

1'. TVIII without a spur---------- 2

2. Cephalothorax with sparse, coarse tubercles near the anterior median raphe; apical row of spinulae of TII much finer than those of TIII-VI ---------- *Paracladopelma* n. sp. 2

2'. Cephalothorax without tubercles except those on the median hump; apical row of spinulae of TII about as coarse as those of TIII-VI----------*Paracladopelma* sp. 3-P

Paracladopelma alphaeus (Sublette) and *Paracladopelma nereis* (Townes) are known only as adults from New Mexico.

THE GENUS *PARATENDIPES* IN NEW MEXICO

This genus is well represented in the warmer, lower elevation streams of New Mexico. The preferred biotope appears to be in sandy or sandy silt substrata. These taxa are found in the state:

Paratendipes albimaus (Meigen)
Paratendipes basidens Townes
Paratendipes fuscitibia Sublette
Paratendipes thermophilus Townes
Paratendipes n. sp. 1
Paratendipes n. sp. 2
Paratendipes sp. 1-P

KEY TO THE PUPAE OF *PHAENOPSECTRA* FROM NEW MEXICO

1. T VIII with a small comb of 4-6 dark spines ------ *Phaenopsectra profusa* (Townes)
1'. T VIII with a single posterolateral spur which may have 1-3 very weak closely appressed side teeth ----------*Phaenopsectra* sp. 1-P

KEY TO THE PUPAE *POLYPEDILUM* FROM NEW MEXICO

1. T II hooks < 40 ---------- 2
1'. T II hooks > 40 ---------- 8

2(1). Tergal shagreen almost uniform on T II-VI; intersegmental shagreen present or absent ---------- 3
2'. Tergal shagreen in definite bands (which may somewhat coalesce); intersegmental shagreen present---------- 4

3(2). Intersegmental shagreen absent; T VIII spur palmate, with 4-5 almost uniform teeth ---------- *Polypedilum* sp. 9-P
3'. Intersegmental shagreen present in 3-4 rows; TVIII spur with one heavy tooth and one weaker lateral tooth---------- *Polypedilum* sp. 10-P

4(2'). Intersegmental spinulae on T III/IV absent or represented by a few minute points on each side; basal shagreen band of T II absent or much weaker than on T III---------- 5
4'. Intersegmental spinulae on T III/IV about as heavy as on TIV/V; basal shagreen row of T II about as heavy as that on T III-V---------- 7

5(4). Anal lobe fringe of < 30 taeniate setae---------- 6
5'. Anal lobe fringe of > 40 taeniate setae---------- *Polypedilum* sp. 2-P

6(5). Basal band of shagreen on T III-V distinctly heavier than medial band and clearly separated from it---------- *Polypedilum* sp. 6-P
6'. Basal band of shagreen only slightly heavier and continuous with medial band ----- ----------*Polypedilum* sp.3-P

7(4'). Posterolateral spur of T VIII palmate ---------- *Polypedilum* sp. 4-P
7'. Posterolateral spur with one main spine and 3-6 large lateral spines ---------- ----------*Polypedilum griseopunctatus* (Malloch)

8(1'). T II hook row with several fine points at each end of the hook row---------- ----------*Polypedilum albicorne* (Meigen)
8'. T II hook row without lateral points ---------- 9

9(8'). T II hooks about equal to or smaller than the basal shagreen spinulae of T III --- ---------- 10
9'. T II hooks heavier than the basal shagreen spinulae of TIII---------- 14

10(9). Intersegmental spinulae of T III/IV and T IV/V multiserial; prealar tubercle scarcely discernible as a low mound ---------- 2

10'. Intersegmental spinulae in 1-2 rows, as coarse as T II hooks; prealar tubercle distinct ----------11

11(10'). Basal spinulae row of TIV with short denticles; median shagreen band continuous ---------- *Polypedilum cultellatum* Goetghebuer

11'. Basal spinulae row with longer denticles; with a clear space between the basal spinulae and the median shagreen; T VIII spur with one heavy spine and 1-2 weak medial spines---- ---------- *Polypedilum* sp. 8-P

12(10). T II hooks 50-60 ----------*Polypedilum parascalaenum* Beck

12'. T II hooks 70 or more ---------- 13

13(12'). T II hooks 71-76; hooks about as heavy as the basal band spinulae of T III; anterior third of thorax with heavy tubercles, multiserial near the antepronotum but tapering posteriorly to a single row ----------*Polypedilum* n.sp. 1

13'. T II hooks 84-97; hooks smaller than the basal band spinulae of T III; thoracic tubercles very weak, at most 2-3X at the middle third of the thorax --- *Polypedilum laetum* (Meigen)

14(9'). Shagreen on T III and T IV with a distinct bare band on the midline---------- ----------*Polypedilum digitifer* Townes

14'. Shagreen on T III and IV continuous along the midline ---------- 15

15(14'). T VIII with 5 taeniate setae ----------*Polypedilum* sp.1-P

15'. T VIII with 4 taeniate setae ---------- 16

16(15'). Intersegmental spinulae of T II/IV and IV/V in 1-3 rows; thoracic horn branches 6-8 ---------- 17

16'. Intersegmental spinulae multiserial; thoracic horn branches 12+ ---------- 19

17(16). Intersegmental spinulae 1-2X; T II hooks 70-74; swim fin setae 43-48 ------- ---------- *Polypedilum illinoense* (Malloch)

17'. Intersegmental spinulae 2-3X; T II hooks 50-57; swim fin setae 21-25 -------- 18

18(17') Basal shagreen patch heavier; T VIII spur dark; frontal seta length 90 mm----- ----------*Polypedilum scalaenum* (Schrank)

18'. Basal shagreen patch much weaker; T VIII spur pale; frontal seta length 45-60 mm - ---------- *Polypedilum californicum* Sublette

19(16'). T II hooks 75-85 ---------- *Polypedilum obelos* Sublette and Sasa

19'. T II hooks 50-70---------- 20

20(19'). Thoracic horn with 10-12 branches; with very weak tubercles on the middle third of the thorax ----------*Polypedilum pterospilus* Townes

20'. Thoracic horn with more than 20 branches; with heavy tubercles on the anterior third of the thorax ----------*Polypedilum* n. sp.3

The following taxa are known only as adults from New Mexico:

Polypedilum floridense Townes
Polypedilum isocerus Townes
Polypedilum sulaceps Townes
Polypedilum n. sp. 1
Polypedilum n. sp. 2

THE GENUS *PSEUDOCHIRONOMUS* IN NEW MEXICO

In New Mexico streams members of this genus are found more frequently at lower elevations in warmer water in gravel-sand to sand-silt substrata. The following taxa have been recorded:

Pseudochironomus julia (Curran)
Pseudochironomus pseudoviridis (Malloch)
Pseudochironomus richardsoni Malloch
Pseudochironomus n. sp. 1
Pseudochironomus sp. 2-P

THE GENUS *STENOCHIRONOMUS* IN NEW MEXICO

This genus has an unusual mode of existence, in that the larvae are obligate borers in living or dead plant material submerged in water. Only three taxa have been identified from New Mexico:

Stenochironomus (Stenochironomus) hilaris (Walker)
Stenochironomus (Stenochironomus) maculatus Borkent
Stenochironomus (Petalopholeus) sp. 1-P

THE GENUS *STICTICHIRONOMUS* IN NEW MEXICO

Members of this genus prefer soft sediments of oligotrophic or mesotrophic lakes or sandy-silt stream bottoms. The four taxa recognized from New Mexico are:
Stictochironomus marmoreus (Townes)
Stictochironomus naevus (Mitchell)
Stictochironomus unguiculatus (Malloch)
Stictochironomus n. sp.1

KEY TO THE PUPAE OF THE TRIBE TANYTARSINI FROM NEW MEXICO

1. Anal lobe with 2 stiff setae; T VIII without posterolateral spur or comb- Genus *Sublettea* Roback

1'. Anal lobe with a fringe of taeniform setae; T VIII with a combor spur - - - - - - - - - - 2

2(1'). T II-IV with oval to round anterior patches of spinulae, in some species also on V and VI - 3

2'. Tergal armature differing- 4

3(2). T VIII with a single posterolateral spur which may have a weak side tooth- Genus *Rheotanytarsus* Thienemann & Bause, p.

3'. T VIII with a comb of several teeth- - - - - - - - - - - - -Genus *Cladotanytarsus* Kieffer, p.

4(2'). T VIII with a spur which may be doubled or have 1-2 teeth basally - - - - - - - - - - 5

4'. T VIII with a posterolateral comb- 6

5(4). Frontal apotome strongly papillose as is the anterior half of the celphalothorax- Genus *Stempellina* Thienemann & Bause

Stempellina sp. 1 (incomplete specimen)

5'. Frontal apotome and cephalothorax smooth or weakly papillose - Genus *Stempellinella* Brundin

Stempellinella sp. 1-P

6(4'). Wing sheath usually with bacatiform papillae; T IV usually with a single patch of coarse denticles; if paired patches occur these are oval to rounded -Genus *Paratanytarsus* Thienemann & Bause, p

6'. Wing sheath without bacatiform papillae: T IV with paired, elongate shagreen patches - 7

7(6'). Thoracic horn tubular, attenuate to tip, with very weak denticles or entirely smooth; tergal armature of T IV and V never in transverse patches of coarse denticles- Genus *Tanytarsus* van der Wulp, p

7'. Thoracic horn tubular, basally inflated and with coarse chaetae apically; tergal armature of T IV and V in 2 transverse patches which may have longer denticles posteriorly- Genus *Micropsectra* Kieffer, p

The genus *Caladomyia* Säwedal, a group well represented in the Neotropical Region, is represented by one new species in New Mexico. The pupa of this species, *Caladomyia* n. sp. 1, has not been associated. No member of the genus has had the pupal stage associated for certain, although Säwedal (1981) described the pupa of one provisionally associated species from Brazil.

THE GENUS *CLADOTANYTARSUS* IN NEW MEXICO

Members of this genus oecur in a variety of water types but tend to be more abundant in lower elevation, warmer streams. A large number of North American species await description as new species. The following taxa have been collected from New Mexico streams:

Cladotanytarsus (Cladotanytarsus) n. sp. 6
Cladotanytarsus (Cladotanytarsus) n. sp. 7
Cladotanytarsus (Cladotanytarsus) n. sp. 8
Cladotanytarsus (Lenziella) cruscula (Sæther)
Cladotanytarsus sp. 1-P

THE GENUS *MICROPSECTRA* IN NEW MEXICO

This is another of the chironomine genera with wide ecological tolerance. Species are known from saline streams, thermal pools, temporary water bodies, madricolous habitats, as well as a broad spectrum of lakes and streams. The species appears to select sand-silt substrata preferentially. The following taxa are known from New Mexico:

Micropsectra logani (Johannsen)
Micropsectra nigripila (Johannsen)
Micropsectra polita (Malloch)
Micropsectra n. sp. 1
Micropsectra n. sp. 2
Micropsectra n. sp. 3
Micropsectra sp. 2-P

THE GENUS *PARATANYTARSUS* IN NEW MEXICO

Members of this genus have a broad ecological latitude with various species occurring in a great variety of both lentic and lotic waters. The following taxa are known from New Mexico:

Paratanytarsus dissimilis (Johannsen)
Paratanytarsus laccophilus (Edwards)
Paratanytarsus similatus (Malloch)
Paratanytarsus tolucensis Reiss
Paratanytarsus n. sp. 2
Paratanytarsus sp. 1-P
Paratanytarsus sp. 2-P

THE GENUS *RHEOTANYTARSUS* IN NEW MEXICO

This genus, in contrast to most chironomines, is an obligate rheophil, occurring in most kinds of flowing waters. The larval cases require a solid substratum as the tip of the case is extended into the water column above the substratum. In streams with sand-silt bottoms the cases are usually constructed on submerged woody debris or on phreatophyte roots. Numbers can be so great as to give a submerged twig a "mossy" appearance. The following taxa are known from New Mexico:

Rheotanytarsus exiguus (Johannsen)
Rheotanytarsus n. sp. 1
Rheotanytarsus n. sp. 2

Rheotanytarsus n. sp. 3
Rheotanytarsus n. sp. 4

KEY TO THE SPECIES OF *SUBLETTEA* IN NEW MEXICO

1. Transverse bands of fine shagreen on T II-V multiserial; long spines of T IV-V about the same number on both terga; fine denticles on anal lobe adjacent to the taeniate setae ------ ----------*Sublettea coffmani* (Roback)

1'. Transverse bands of much coarser shagreen and in 2-3 rows; T V with fewer coarse spines than T IV; fine denticles on anal lobe lacking---------- *Sublettea* sp.1-P

THE GENUS *TANYTARSUS* IN NEW MEXICO

This is one of the larger, more heterogeneous genera of the Holarctic Region. Several species groups are recognized from the adults with moderate congruence with pupal types. Ultimately, the genus will be split into several subgenera (or genera). At this time, the genus *Tanytarsus, sens lat.*, will be followed. The following taxa are recognized from New Mexico:

Tanytarsus dendyi Sublette
Tanytarsus fimbriatus Reiss & Fittkau
Tanytarsus mendax Kieffer
Tanytarsus pallidicornis (Walker)
Tanytarsus n. sp. 3
Tanytarsus n. sp. 5
Tanytarsus n. sp. 6
Tanytarsus n. sp. 7
Tanytarsus n. sp. 8
Tanytarsus n. sp. 9
Tanytarsus n. sp. 10
Tanytarsus n. sp. 12
Tanytarsus sp. 2-P
Tanytarsus sp. 3-P
Tanytarsus sp. 4-P
Tanytarsus sp. 5-P
Tanytarsus sp. 6-P
Tanytarsus sp. 7-P

Appendix 6

Key to Larvae of North American Families of Trichoptera (Wiggins, 1996) with Preliminary Designation of Families Occurring in New Mexico[NM]

1 Larva with portable case of sand grains resembling snail shell (Fig. 17.1C); anal claw with comb of teeth, not hook-shaped (Fig. 17.1D). Widespread

17 Helicopsychidae[NM], p.237

Larva with case not resembling snail shell, or larva not constructing portable case; anal claw. with apex forming stout hook (Fig. VA-D)

2

2 (1) Dorsum of all three thoracic segments largely covered by sclerotized plates (Figs. 3.10A, 7.5A)

3

Metanotum, and sometimes mesonotum, entirely membranous or largely so but with several pairs of smaller sclerites (Figs. 8.1B, 20.1B)

5

3 (2) Abdomen with ventrolateral rows of branched gills, and with brush of many long setae on anal proleg; posterior margin of meso- and metanotal plates lobate (Fig. 7.5A); larvae construct fixed retreats of detritus and rock fragments (Fig.7.5G). Widespread

7 Hydropsychidae[NM], p.126

Abdomen lacking ventrolateral gills and brush of setae on anal proleg (Fig. 3.IIA); posterior margin of meso- and metanotal plates straight (Fig. 3.10A,H)

4

4 (3) Anal prolegs projecting freely from abdomen, claw large and at least as long as its sclerotized basal segment (Fig. 6.1A); larvae construct fixed tubular retreats of sand. Southwest

6 Ecnomidae, p.123

Anal prolegs usually not projecting freely from abdomen, claw always very small (Fig. 3.11A); minute forms usually less than 6 mm long, with purse- or barrel-shaped portable cases (Figs. 3.1F,G; 3.9F), or flat silken domes fastened to rocks (Fig. 3.16D,E). Widespread

3 Hydroptilidae[NM], p.71

5 (2) Antennae long and prominent, at least 6 times as long as wide (Fig. 19.1B); and/or sclerotized plates on mesonotum lightly pigmented except for pair of dark curved lines on posterior half

(Fig. 19.1B); larvae construct portable cases of various materials. Widespread 19 Leptoceridae[NM], p. 249

Antennae of normal length, no more than 3 times as long as wide (Fig. IIIE), or not apparent; mesonotum never with pair of dark curved lines as above 6

6 (5) Mesonotum usually lacking selerotized plates (Fig. 8.1B), or with small sclerites covering not more than half of notum (Figs. 23.6B, 23.10B); pronotum never with anterolateral lobe (Fig. 23.6A, B) 7

Mesonotum largely covered by sclerotized plates, variously subdivided and usually pigmented, although sometimes lightly (Figs. 20.1B, 24.2B); pronotum sometimes with prominent anterolateral lobe (Fig. 13.1A,B) 15

7 (6) Abdominal segment IX with sclerotized plate on dorsum (Fig. 20.15c) 5

Abdominal segment IX with dorsum entirely membranous (Fig. 8.1E) 11

8 (7) Metanotal sa3 usually consisting of cluster of setae arising from small rounded or ovoid sclerite; prosternal horn present (Figs. 23.9A,B; 23.10A,B); larvae construct tubular portable cases, usually of plant materials. Widespread 23 Phryganeidae, p.374

Metanotal sa3 consisting of single seta without sclerite (Fig. 1.4B); prosternal horn absent (Fig. 1.4A); larvae either without case or with tortoise-like case of rock fragments 9

9 (8) Basal half of anal proleg broadly joined with segment IX (Fig. 1.4E).; anal claw with at least one dorsal accessory hook (Fig. 1.4A); larvae construct tortoise-like portable cases of rock fragments (Fig. 1.4F). Widespread 1 Glossosomatidae[NM], p.50

Most of anal proleg free from segment IX (Fig. 4.2E); anal claw without dorsal accessory hooks, although secondary lateral claw may be present (Fig. 4.2A); larvae free-living without portable cases but construct fixed pupal enclosures. Widespread 10

10 (9) Tibia, tarsus, and claw of fore leg articulated against

ventral lobe of femur to form chelate leg (Fig. 2.1C). Southwest
2 Hydrobiosidae[NM], p.67

Fore leg normal, not modified as above (Fig. 4.2D). Widespread
4 Rhyacophilidae[NM], p.110

11 (7) Labrum membranous and T-shaped (Fig. 8.1D), often withdrawn from view in preserved specimens; larvae construct fixed sack-like nets of silk (Fig. 8.2F). Widespread
8 Philopotamidae[NM], p.150

Labrum sclerotized, rounded and articulated in normal way (Fig. 9.5B)
12

12 (11) Tibia and tarsus fused together on all legs (Fig. 11.1A. D); mesopleuron extended anteriorly as lobate process (Fig. 11.1 D); larvae construct fixed tubular retreats. Southwestern
11 Xiphocentronidae, p.185

Tibiae and tarsi separate, mesopleuron unmodified (Fig. 9.4A)
13

13 (12) Trochantin of prothoracic leg broad and hatchet-shaped, separated from episternum by dark suture line (Fig. 10.4C); larvae construct fixed tubular retreats on rocks and logs (Fig. 10.1E). Widespread
10 Psychomyiidae[NM], p.174

Trochantin of prothoracic leg with apex acute, fused completely with episternum without separating suture (Fig. 9.3A)
14

14 (13) Tarsi of all legs strongly flattened, tibiae shorter than tarsi (Fig. 5.1A); larvae burrow in sandy deposits and construct tubes of sand grains (Fig. 5.1D). Eastern and central
5 Dipseudopsidae, p.118

Tarsi of all legs normal and not flattened, tibiae longer than tarsi (Fig. 9.2A); larvae construct exposed funnel-shaped capture nets (Fig. 9.3D) or flattened retreats Fig. 9.4E). Widespread
9 Polycentropodidae[NM], p.159

15 (6) Abdominal segment I lacking both dorsal and lateral humps (Fig. 14.2A), each metanotal sa1 lacking entirely (Fig. 14.2B), or represented only by single seta without sclerite (Fig. 14.4B);

larvae construct portable cases of various materials and arrangements. Widespread 14 Brachycentridae[NM], p.206

Abdominal segment I always with lateral hump on each side although not always prominent, and usually with median dorsal hump (Fig. 20.18A); metanotal sal always present, usually represented by sclerite bearing several setae Fig. 20.1B) but with at least single seta (Fig. 15.1B); larvae construct portable cases of various materials and arrangements 16

16 (15) Mesopleuron extended as an acute process (Fig. 16.1A,B); cases of rock fragments. Widespread 16 Goeridae, p.226

Mesopleuron not extended as an acute process (Fig. 20.31A,B) 17

17 (16) Labrum with transverse row of approximately 16 long setae across central part(Fig. 15.1D); cases of plant materials variously arranged. Eastern and western 15 Calamoceratidae[NM], p.218

Labrum not as above, usually with only 6 long setae across central part (Fig. 20.22D) 18

18 (17) Antenna situated close to anterior margin of eye (Fig. 18.1D); median dorsal hump of segment I lacking (Fig. 18.1A); cases of various materials and arrangements. Widespread 18 Lepidostomatidae[NM], p.241

Antenna not situated close to anterior margin of eye as above, approximately as close to anterior margin of head capsule as to eye (Fig. IIIE), or closer (Fig. 25.1 B); median dorsal hump of segment I almost always present (Fig. IVA) 19

19 (18) Antenna situated approximately midway between anterior margin of head capsule and eye (Fig. IIIA,E); prosternal horn usually present (Fig. VIA) although sometimes short; chloride epithelia usually present on some abdominal segments (Fig. IVA,D) 20

Antenna situated at or close to anterior margin of head capsule (Fig. 25.1B); prosternal horn and chloride epithelia never present (Fig. 25.1A) 23

20 (19) Mesonotal plates with anteromedian emargination (Figs.

26.2B; 26.4B); portable cases very slender (Fig. 26.1C), or stouter and usually with small stones arranged linearly along each side (Fig. 26.2C). Widespread
26 Uenoidae[NM], p. 413

Mesonotal plates lacking anteromedian emargination (Fig. 20.14B)
21

21 (20) Mandibles usually with uniform scraper blades (Figs. 12.1 D, 12.3D); or if mandibles toothed (Fig. 12.4D), metanotal sa1 with 25 or more setae on membrane between sclerites (Fig. 12.4B); metanotal sa1 sclerites sometimes lacking (Fig. 12.5B); larvae construct cases mainly of mineral materials. Widespread
12 Apataniidae[NM], p.190

Mandibles almost always toothed (Figs. 24.1E, 24.2H); metanotal sa1 lacking setae on membrane between sclerites, or fewer than 25 setae if present (Figs.20.20B, 20.21B)
22

22 (21) Primary mesonotal plates subdivided once (Fig. 24.2B) or twice (Fig. 24.1B); larvae construct portable cases mainly of mineral materials. Western, highly localized 24 Rossianidae, p.399

Primary mesonotal plates not subdivided (Fig. 20.20B); portable cases of plant or mineral materials. Widespread, common
20 Limnephilidae[NM], p.268

23 (19) Tarsal claw of hind leg modified to form short setose stub (Fig. 21.1A) or slender filament (Fig. 21.2A); portable cases of sand grains with lateral flanges (Fig. 21.1C). Widespread
21 Molannidae, p.352

Tarsal claws of hind legs not different in structure from those of other legs (Fig. 22.4A)
24

24 (23) Pronotum with transverse carina extended as rounded anterolateral lobes (Fig. 13.1A,B); portable cases of sand grains (Fig. 13.1C). Eastern, highly localized 13 Beraeidae, p. 203

Pronotum lacking transverse carina, anterolateral corners not lobed, often pointed (Figs. 22.1A; 22.6A)
25

25 (24) Dorsum of anal proleg with cluster of approximately 30 or more setae posteromesad of reduced lateral sclerite (Fig. 25.1D); fore trochantin relatively large, apex hook-shaped (Fig. 25.2D);

portable cases mainly of fine rock fragments (Fig. 25.1C).
Widespread 25 Sericostomatidae[NM], p.404

Dorsum of anal proleg with no more than 3-5 setae posteromesad of lateral sclerite, sometimes with short spines (Fig. 22.5F), lateral sclerite not reduced as above; fore trochantin smaller, apex not hook-shaped (Fig. 22.1A); portable cases of rock fragments.
Widespread 22 Odontoceridae[NM], p.359

Family Brachycentridae

Preliminary Key to New Mexico Genera

1 Middle and hind legs long, femora approximately same length as head capsule (Fig. 14.3A), tibiae produced distally into prominent process from which stout spurs arise (Fig. 14.3E). Widespread

14.3 *Brachycentrus*[NM]

Middle and hind legs shorter, femora much shorter than head capsule (Fig. 14.2A), tibiae not produced distally into prominent process, although spurs arise from about same point on unmodified tibiae (Fig. 14.2F)

2

2 (1) Ventral apotome of head longer than wide, somewhat narrowed at posterior end, larva with very short prosternal horn (Fig. 14.4D); case 4-sided, composed of short lengths of plant material placed transversely with loose ends often protruding (Fig. 14.4c)

3

Ventral apotome of head usually wider than long (Fig. 14.2D), sometimes squarish (Fig. 14.5D); larva without prosternal born; case cylindrical, composed of lengths of plant material wound around the circumference (Fig. 14.5C), or partially of silk (Fig. 14.2C), or of sand

4

3 (2) Each half of mesonotal plate largely entire, lateral quarter partially delineated by variable suture, posterior margin of mesonotum raised and coloured dark brown (Fig. 14.4B). Western

14.4 *Eobrachycentrus*

Each half of mesonotal plate subdivided into three separate sclerites, posterior margin not conspicuously raised or colored (Fig. 14.1B). Eastern

14.1 *Adicrophleps*

4 (2) Transverse ridge of pronotum extended to edge of prontoum (Fig. 14.5A); mesonotal sa1 usually with many setae extending along anterior border of sclerite, merging with sa3 (Fig. 14.5B), but sa1 a single seta in some species; sclerotized band on each side of anal opening (Fig. 14.5F). Widespread

14.5 *Micrasema*[NM]

Transverse ridge of pronotum not reaching edge of pronotum (Fig.

14.2A); mesonotal sa1 with only single seta (Fig. 14.2B); sclerotized band lacking from each side of anal opening. Western

14.2 *Amiocentrus*

Family Glossosomatidae

Preliminary Key to New Mexico Genera

1 Mesonotum without sclerites (Fig. 1.4B); head with ventromesal margins of genae thickened, median ventral ecdysial line approximately as long as each divergent branch enclosing ventral apotome (Fig. 1.4D); anal opening bordered on each side by dark, sclerotized line (Fig. 1.4E) (subfamily Glossosomatinae) 2

Mesonotum with two or three sclerites (Figs. 1.1A, 1.6A); head with ventromesal margins of genae not thickened, median ventral ecdysial line approximately 1 1/2 times longer than each divergent branch (Figs. 1.1B, 1.3B); anal opening usually lacking dark, sclerotized line on each side (Fig. 1.1 E) 3

2 (1) Pronotum in lateral view excised about two-thirds anterolaterally to accommodate coxa (Fig. 1.2C); venter of abdominal segments VIII and IX each with pair of setae (Fig. 1.2F). Western montane regions 1.2 *Anagapetus*

Pronotum in lateral view about one-third excised anterolaterally to accommodate coxa (Fig. 1.4C); venter of abdominal segment VIII lacking pair of setae. Widespread 1.4 *Glossosoma*[NM]

3 (1) Mesonotum with three sclerites (Fig. 1.6A);.head with ventral apotome reduced to slender, V-shaped sclerite (Fig. 1.6B). Widespread (subfamily Protoptilinae) 4

Mesonotum with two sclerites (Fig. 1.1A); head with anterior ventral apotome not slender as above (Fig. 1.1B). Widespread (subfamily Agapetinae) 1.1 *Agapetus*[NM]

4 (3) Each tarsal claw terminating in three acute points, one representing the basal seta, but all approximately equal in length (Fig. 1.5B). Southeastern 1.5 *Matrioptila*

Each tarsal claw terminating in normal single acute point, but with smaller basal seta (Figs. 1.3c, 1.6C) 5

5 (4) Tarsal claws with basal seta long and slender, arising from side of stout process at base of claw (Fig. 1.6C). Widespread
1.6 *Protoptila*

Tarsal claws with basal seta stout, larger than process at base of claw (Fig. 1.3C). Widespread 1.3 *Culoptila*[NM]

Family Hydroptilidae

Preliminary Key to New Mexico Genera

1 Final-instar larva with abdomen dorsoventrally depressed in form (Figs. 3.2, 3.6, 3.13, 3.16) 2

Final-instar larva with abdomen laterally compressed in form (Figs. 3.4, 3.10), or uniformly rotund (Figs. 3.7, 3.11) 5

2 (1) Abdomen with segments V and VI usually abruptly wider than IV in dorsal aspect (Figs. 3.6, 3.16); fixed retreats on rocks, flat silken domes resembling egg capsules of leeches (Fig. 3.6F). (tribe Leucotrichiini) 3

Abdomen with no segments abruptly wider than others (Figs. 3.2, 3.13) 4

3 (2) Abdominal segments with dorsal sclerite bearing two small, circular lacunae (Fig. 3.16A); basal seta of tarsal claw on all legs enlarged, claw appearing bifid (Fig. 3.16B). Montana 3.16 *Zumatrichia*

Abdominal segments with dorsal sclerite lacking circular lacunae (Fig. 3.6A); basal seta of tarsal claw on all legs not greatly enlarged (Fig. 3.6B). Widespread in the United States 3.6 *Leucotrichia*[NM]

4 (2) Abdominal segments with fleshy tubercle on each side (Fig. 3.13A,E); portable case of two flattened elliptical valves covered with liverwort fragments (Fig. 3.13F). Eastern and western mountains 3.13 *Palaeagapetus*

Abdominal segments lacking fleshy lateral tubercles as above; meso- and metanotal plates lacking mid-dorsal ecdysial suture, but suture present on pronotum (Fig. 3.2A); larva free-living without portable case. Southwestern 3.2 *Alisotrichia*

5 (1) Tarsal claws stout and abruptly curved, each with thick, blunt seta at base (Figs. 3.3D, 3.15D) 6

Tarsal claws slender, smoothly curved, each with thin, pointed seta at base (Fig. 3.4D-F), or basal seta lacking on middle and hind

legs (Fig. 3.8A) 7

6 (5) Dorsal abdominal setae stout, each with small selerotized area around base, dorsal rings of abdominal segments clearly delineated (Fig. 3.3A); larvae occur on red algae, portable case of two symmetrical silken valves incorporating this alga (Fig. 3.3E, F). Eastern 3.3 *Dibusa*

Abdominal setae slender, their bases lacking sclerotized area, dorsal rings indistinct (Fig. 3.15A); portable case of two symmetrical silken valves (Fig. 3.15E, F). Eastern and western 3.15 *Stactobiella*

7 (5) All tarsal claws with basal seta (Fig. 3.4D-F) 8

Tarsal claws of middle and hind legs lacking basal seta (Fig. 3.8A). Southwestern 3.8 *Metrichia*[NM]

8 (7) Protibia with prominent posteroventral lobe bearing short, very stout setae (Figs. 3.1C, 3.4D, 3.10C) 9

Protibia lacking prominent posteroventral lobe, pair of normal setae usually present (Figs. 3.7C, 3.11D) 13

9 (8) All three pairs of legs approximately the same length (Figs. 3.4A, 3.10G) 10

Middle and hind legs much longer than fore legs (Figs. 3.1A, 3.12A) 12

10 (9) Three filamentous gills arising from posterior end of abdomen, one from dorsomedian position on segment IX, other two at lateral sclerites of anal prolegs (Fig. 3.4A) 11

Posterior end of abdomen lacking 3 filamentous gills (Fig. 3.10G); portable case usually consisting of two silken valves covered with sand grains (Fig. 3.10J,K), but sometimes of single valve carried like tortoise shell (Fig. 3.10D,E). Widespread 3.10 *Ochrotrichia*[NM]

11 (10) Base of tarsal claws smoothly contoured with ventral margin of claw (Fig. 3.4E,F); portable case of two silken valves usually covered with sand grains, sometimes with diatoms (Fig. 3.4G,H). Widespread 3.4 *Hydroptila*[NM]

Base of tarsal claws, especially of middle and hind legs; quadrate and angular, not smoothly contoured with ventral margin of claw (Fig. 3.14A); portable case of two silken valves but with little additional material added to exterior surface (Fig. 3.14c). Arkansas

3.14 *Paucicalcaria*

12 (9) Antennae long and slender, longer than diameter of cluster of stemmata (Fig. 3.12B); posteroventral lobe of protibia prominent and linear (Fig. 3.12C); portable case entirely of silk, shaped like flattened flask open at bottom (Fig. 3.12F,G). Widespread

3.12 *Oxyethira*[NM]

Antennae shorter, length less than diameter of stemmata (Fig. 3. 1A); posteroventral lobe of protibia triangular (Fig. 3. 1C); portable case of two silken valves with algal filaments incorporated concentrically (Fig. 3.1F,G). Widespread

3.1 *Agraylea*[NM]

13 (8) Anal prolegs elongate and cylindrical, projecting prominently beyond general body outline (Fig. 3.7A)

(tribe Neotrichiini) 14

Anal prolegs short, conforming to general body outline, not projeefing prominently (Fig. 3.11A)

15

14 (13) Mesotibia with pair of short, stout setae located apically or nearly so (Fig. 3.7D); portable case of silk sometimes incorporating soft mineral material, cylindrical but usually with transverse or longitudinal ridges (Fig. 3.7F). Widespread

3.7 *Mayatrichia*[NM]

Mesotibia with pair of subapical setae located about one-third length of tibia from distal apex (Fig. 3.9D); portable case of fine sand grains, cylindrical (Fig. 3.9F). Widespread

3.9 *Neotrichia*[NM]

15 (13) Most abdominal segments with prominent dorsal and ventral lobes (Fig. 3.5A); portable case a flattened pouch of silk, posterior end open, anterior end reduced to small circular opening (Fig. 3.5E,F). Widespread

3.5 *Ithytrichia*[NM]

Abdominal segments lacking dorsal and ventral lobes (Fig. 3.11A); portable case of silk, somewhat pod-like in shape with longitudinal ridges (Fig. 3.11G,H,I). Widespread

3.11 *Orthotrichia*

Family Hydropsychidae

Preliminary Key to New Mexico Genera

1 Ventral surface of head with genae entirely separated by ventral apotome (Fig. 7.1C) (subfamily Arctopsychinae) 2

Ventral surface of head with genae at least partly contiguous (Figs. 7.3C, 7.9G) 3

2 (1) Dorsum of most abdominal segments with tuft of several slender setae and/or scale-hairs in sa2 and sa3 positions (Fig. 7.8B); ventral apotome of head usually but not always roughly rectangular (Fig. 7.8D). Widespread 7.8 *Parapsyche*

Dorsum of most abdominal segments with only one long seta in sa2 and sa3 positions, frequently with one or two shorter ones as well, but not a tuft as above (Fig. 7.1E); ventral apotome of head narrowed posteriorly (Fig. 7.1C). Widespread 7.1 *Arctopsyche*[NM]

3 (1) Ventral apotome of head in two parts, anterior and posterior, posterior ventral apotome at least half as long as median ecdysial line separating the two parts (Fig. 7.4D) (subfamily Diplectroninae) 4

Ventral apotome of head usually in two parts, but posterior ventral apotome reduced and much less than half as long as median ecdysial line (Fig. 7.9G), or posterior apotome lacking (Fig. 7.7E) 5

4 (3) Pronotum with transverse sulcus constricting posterior one-third or so of pronotum from anterior two-thirds (Fig. 7.4A,F). Eastern and western 7.4 *Homoplectra*

Pronotum lacking transverse sulcus as above, constricted only slightly at posterior border (Fig. 7.3A,B). Eastern and western 7.3 *Diplectrona*

5 (3) Abdominal gills consisting of elongate central stalk with numerous filaments arising more or less uniformly along entire length (Fig. 7.6A); fore trochantin never forked (Fig. 7.7B) (subfamily Macronematinae) 6

Abdominal gills with central stalk, but filaments fewer than above and not arising uniformly, frequently in apical tuft with fewer

gill filaments arising from basal part of central stalk (Fig. 7.2A); fore trochantin usually forked (Fig. 7.5B)
(subfamily Hydropsychinae) 7

6 (5) Tibia and tarsus of fore leg with dense setal fringe (Fig. 7.7B); dorsum of head flattened and with sharp carina (Fig. 7.7D). Eastern
7.7 *Macrostemum*

Tibia and tarsus of fore leg lacking dense setal fringe (Fig. 7.6A); dorsum of head without sharp carina (Fig. 7.6E). Southeastern Texas
7.6 *Leptonema*

7 (5) Submentum with anterior border entire (Fig. 7.10C), or with broad, shallow emargination; dorsum of abdomen with only closely spaced, flattened scale hairs, other setal types lacking (Fig. 7.10A). Southwestern
7.10 *Smicridea*[NM]

Anterior border of submentum with pronounced median division (Fig. 7.5F); dorsum of abdomen with hair-like setae only, or mingled with clavate or flattened scale hairs (Fig. 7.5A)
8

8 (7) Venter of prothorax with pair of prominent sclerites in intersegmental fold posterior to prosternal plate (Fig. 7.5C), anterior margin of frontoclypeus lacking small median notch (Fig. 7.5E). Widespread
7.5 *Hydropsyche*[NM]

Venter of prothorax with pair of sclerites, usually minute, in intersegmental fold posterior to lateral corners of prosternal plate (Fig. 7.2B); if these sclerites are larger than illustrated, anterior border of frontoclypeus usually with small median notch (Fig. 7.2D)
9

9 (8) Anterior ventral apotome of head with prominent anteromedian protuberance (Fig. 7.9G); lateral margin of mandibles flanged (Fig. 7.9E); abdomen with divided hair-like setae dorsally, scale hairs laterally; fore trochantin forked or not forked (Fig. 7.9B,C). Central and eastern
7.9 *Potamyia*

Anterior ventral apotome of head without anteromedian protuberance (Fig. 7.2E); lateral margin of mandibles not flanged (Fig. 7.2C); abdomen with only undivided hair-like setae dorsally and laterally, without scale hairs; fore trochantin forked (Fig. 7.2A). Widespread
7.2 *Cheumatopsyche*[NM]

Family Leptoceridae

Preliminary Key to New Mexico Genera

1 Middle legs with tarsal claw hook-shaped and stout, tarsus curved (Fig. 19.2A); case of transparent silk; slender (Fig. 19.2C). Northern and eastern 19.2 *Leptocercus*

Middle legs with tarsal claw normal, slightly curved, and slender, tarsus straight (Fig. 19.1A) 2

2 (1) Anal prolegs with sclerotized, concave plate on each side of anal opening, each plate with marginal spines, and extended into ventral lobe (Fig. 19.6G); case cylindrical, of small stones (Fig. 19.6C). Eastern 19.6 *Setodes*

Anal prolegs without sclerotized spiny plates as above, although patches of spines or setae may be present (Fig. 19.7A,B) 3

3 (2) Labrum with many secondary setae (Fig. 19.5D); maxillary palpi usually extended far beyond anterior edge of labrum, mandibles usually elongate and blade-hke with sharp apical tooth separated by gap from remainder of teeth (Fig. 19.5E); cases of several types and materials. Widespread 19.5 *Oecetis*[NM]

Labrum with primary setae only, scattered secondary seta lacking (Fig. 19.3B); maxillary palpi extended little, if any, beyond anterior edge of labrum, mandibles short and wide, teeth grouped closely together around central concavity (Fig. 19.3D) 4

4 (3) Mesonotum with pair of dark, curved bars on weakly sclerotized plates (Fig. 19.1B);abdomen disproportionately thick, gills usually in clusters (Fig. 19.1A); cases of several types and materials. Widespread 19.1 *Ceraclea*

Mesonotum without pair of dark bars on plates, abdomen more slender, gills single or entirely absent (Fig. 19.4A,B) 5

5 (4) Ventral apotome of head triangular (Fig. 19.4E) or not apparent; tibia of hind leg usually without middle constriction and no apparent subdivision (Fig. 19.4A) 6

Ventral apotome of head rectangular (Fig. 19.7D); tibia of hind leg with constriction near center, apparently dividing it into two parts (Fig. 19.7A)
7

6 (5) Base of each anal proleg with only ventral band of small spines on each side of anal opening (Fig. 19.4F), or without spines in this position; case long and slender, of various materials. Widespread
19.4 *Nectopsyche*[NM]

Base of each anal proleg with ventral patch of longer spines in addition to band of small spines (Fig. 19.3F)
7

7 (5,6) Hind legs with a few scattered long setae (Fig. 19.3A); metanotal sal with single seta (Fig. 19.3B); case irregular, of plant and rock materials (Fig. 19.3C). Widespread
19.3 *Mystacides*

Hind legs usually with close-set fringe of long setae (Fig. 19.7A); metanotal sal lacking (Fig. 19.7B); case long, slender spiral of plant pieces (Fig. 19.7C).
8

8 (7) Head usually with dark dorsal muscle scars on lighter brown background; posterior margin of head capsule with narrow, cream-coloured crescentic band (Fig. 19.8B). Northern and western
19.8 *Ylodes*

Head variously pigmented dorsally with two dark bands (Fig. 19.7B) or dark muscle scars on lighter brown background; posterior light crescent usually lacking, but if present, irregular in outline along posterior margin of head capsule. Widespread
19.7 *Triaenodes*[NM]

Family Limnephilidae

Preliminary Key to New Mexico Genera

1 Anterior margin of pronotum densely fringed with long setae (Fig. 20.10A); dorsum of head flattened and bearing two bands of closely packed scale-setae (Fig. 20.10B); case of wood and bark fragments arranged transversely, flattened dorsoventrally and tapered (Fig. 20.10C). Western 20.10 *Cryptochia*

Anterior margin of pronotum and dorsum of head without dense setae as above (Fig. 20.2B) 2

2 (1) Abdominal gills of single filaments (Fig. 20.9A) 3

Most abdominal gills of dorsal and ventral rows with branched filaments (Figs. 20.21A, 20.26A), lateral gills sometimes single (Fig. 20.17A) 17

3 (2) Metanotal sa1 and sa2 sclerites large in relation to metanotum, distance between sa2 sclerites approximately 2 to 3 times the maximum dimension of one sa2 sclerite (Fig. 20.14B); case a slender tube of rock fragments, frequently incorporating long pieces of plant material (Fig. 20.14C). Western 20.14 *Ecclisomyia*[NM]

Metanotal sa1 and sa2 sclerites smaller than above in relation to metanotum, distance between sa2 scierites more than twice the maximum dimension of one sa2 sclerite (Fig. 20.7B); sa1 sclerites sometimes fused into single median sclerite (Fig. 20.23B) 4

4 (3) Each mesonotal plate distinctly wider than long, and shorter mesally than laterally (Fig. 20.29B); abdominal segment VIII with transverse posterodorsal line of slender, closely spaced setae (Fig. 20.29E); cases of pieces of moss arranged transversely (Fig. 20.29C). Widespread, local 20.29 *Phanocelia*

Mesonotal plates of varying width, but length differing little from lateral margin to median line (Figs. 20.6B, 20.7B); abdominal segment VIII with or without posterodorsal line of setae, but less dense than above if present (e.g. Fig. 20.11D) 5

5 (4) Lateral humps of segment I with one or two sclerites

adjacent to base of hump, the sclerites often only lightly pigmented but distinguished by the smooth and relatively shinier surface (Figs. 20.7A, 20.22A, 20.34A, 20.36A) 6

Lateral humps of segment I without sclerites (Fig. 20.13A) 12

6 (5) Large single sclerite at base of lateral hump enclosing posterior half of hump and extending posterodorsad as irregular lobe (Fig. 20.7A); case of leaves or bark formed into flattened tube with lateral seam and narrow flange along each side (Fig. 20.7C). Transcontinental
20.7 *Chyranda*[NM]

One or two smaller selerites at base of lateral hump (Figs. 20.11A, 20.22A, 20.34A, 20.36A) 7

7 (6) One elongate sclerite at posterior edge of base of each lateral hump (Fig.20.23A) 8

Two or more sclerites, variously shaped and positioned, at base of each lateral hump (Figs. 20.11A, 20.34A) 10

8 (7) Sclerite at base of lateral hump elongate, its longest dimension almost equivalent to basal width of hump (Figs. 20.23A, 20.36A) 9

Sclerite at base of lateral hump shorter, its longest dimension equal to approximately one-half the basal width of hump (Fig. 20.22A); case usually a cylinder of smooth outline and thin walls, rarely three-sided, consisting largely of bark pieces irregularly arranged (Fig. 20.22C), occasionally of rock pieces. Western
20.22 *Homophylax*[NM]

9 (8) Metanotal sa1 sclerites fused on mid-dorsal line into single sclerite (Fig. 20.23B,D); segment II with ventral chloride epithelium, and segment IX with only a single seta laterad of dorsal sclerite (*H. argus*); or venter II without chloride epithelium, and segment IX with tuft of 3-6 setae laterad of dorsal sclerite (*H. hesperus*, Fig. 20.23A); case of wood pieces or leaves, irregular in outline (Fig. 20.23c). Eastern and western
20.23 *Hydatophylax*

Metanotal sa1 sclerites not fused on mid-dorsal line (Fig. 20.36B) although often close together; venter II without chloride epithelium, segment IX usually with single seta laterad of dorsal sclerite (Fig. 20.36A); case of twigs or gravel, or of leaves and occasionally three-sided (Fig. 20.36C). Widespread in east,

equal (Fig. 20.9B); cases of leaf pieces fastened together to form flanges at each side of flattened tube (Fig. 20.9C). Western
20.9 *Clostoeca*

Each mesonotal plate clearly wider than long (Fig. 20.6B); case a rough cylinder of leaf and bark fragments arranged irregularly (Fig. 20.6C). Known only from Minnesota 20.6 *Chilostigma*

16 (13) Head and pronotum strongly inflated and with pebbled texture (Fig. 20.13A,B); case of small rock fragments, tapered and curved, outline smooth (Fig. 20.13C). Western
20.13 *Ecclisocosmoecus*

Head and pronotum not unusually inflated (Fig. 20.33A,B), although dorsum of head flat in the one western species (Fig. 20.33D); scletotized areas not pebbled; case of rock fragments, tapered and curved, outline smooth (Fig. 20.33C). Eastern and western
20.33 *Pseudostenophylax*

17 (2) Most gills with two or three branches (Fig. 20.26A), none with more than four (Fig. 20.12A) 18

At least some gills with more than four branches (Figs. 20.21A, 20.25A, 20.35A) 39

18 (17) Dorsum of head with two contrasting dark bands extended from coronal suture to base of each mandible (Fig. 20.20B), and/or narrowed posterior portion of frontoclypeus with three light areas one at posterior extremity and usually one along each side (Figs. 20.8B, 20.26B) 19

Dorsum of head lacking bands or other well-defined contrasting areas, usually largely uniform in color (Fig. 20.1B), often with prominent spots (Fig. 20.3B) 25

19 (18) Dorsum of head with prominent dark bands contrasted against a light background, lateral bands extended from coronal suture to base of each mandible, median band on frontoclypeus (Figs. 20.20B, 20.27B) 20

Dorsum of head lacking dark lateral bands, but narrowed posterior portion of frontoclypeus with three light areas -- one along each side and one at the apex (Figs. 20.5B, 20.8C) 22

20 (19) Dark dorsal bands on head fused at junction of coronal and frontoclypeal sutures to form U-shaped marking, pronotum with narrow dark bands along anterior border and across dorsum (Fig. 20.27B); case usuafly of leaf pieces arranged transversely on dorsal and ventral surfaces (Fig. 20,27C), sometimes only longitudinally in final instar. Transcontinental

20.27 *Nemotaulius*

Dark, dorsal bands on head extended posterad beyond junction of coronal and frontoclypeal sutures to form V-shaped marking (Fig. 20.20B); pronotal markings variable

21

21 (20) Chloride epithelia present dorsally on abdominal segments, as well as ventrally and laterally (Fig. 20.20A); case of wood or leaf fragments (Fig. 20.20C), changed to fine gravel during final instar. Western

20.20 *Halesochila*

Chloride epithelia lacking dorsally, present only ventrally and sometimes laterally (Fig. 20.26A)

24

22 (19) Venter I usually with more than 100 setae merged from all setal areas (Fig.20.8D); small spines on head and pronotum (Fig. 20.8B); short, stout setae on lateral sclerite of anal proleg (Fig. 20.8A); case cylindrical, usually of pieces of twigs and bark, sometimes of small rock fragments (Fig. 20.8C). Western

20.8 *Clistoronia*[NM]

Venter I with fewer than 100 setae overall and primary setal areas discrete, usually without spines on head and pronotum; short, stout setae on lateral sclerite of anal proleg usually lacking; cases highly variable (e.g. Fig. 20.26)

23

23 (22) Chloride epithelia present both dorsally and ventrally on most abdominal segments (Fig. 20.5A); case of plant and rock materials (Fig. 20.5C). Northern, extending south in western mountains

20.5 *Asynarchus*[NM] (in part)

Chloride epithelia lacking dorsally, but present ventrally and occasionally laterally (Fig. 20.26A)

24

24(21,23) Mesothoracic femur with the two major ventral setae situated at either side of and equidistant from midpoint of femur (Fig. 20.26A); cases of a wide range of materials and architecture (e.g. Fig. 20.26C-F). Widely distributed throughout the continent

20.26 *Limnephilus*[NM] (in part)

Mesothoracic femur with the two major setae not equidistant from midpoint, but with proximal seta about midway between proximal end of femur and distal seta (Fig. 20.30A); case of fine gravel, sedge seeds, or snail shells (Fig. 20.30C). Western 20.30 *Philarctus*

25 (18) Femur of hind leg with two major setae arising from ventral edge, setae may be unequal (Fig. 20.17A) 26

Femur of hind leg with more than two major setae arising from ventral edge (Fig. 20.12A) 35

26 (25) Pronotum and lateral sclerite of anal proleg bearing sharp, stout, spine-like setae (Fig. 20.17A,B) 35

Pronotum without sharp, stout setae (Fig 20.3B) lateral sclerite of anal proleg never with setae as above 28

27 (26) Tibiae and tarsi of all legs with dark, contrasting band (Fig. 20.17A); case of twigs and bark arranged to form smooth cylinder (Fig. 20.17C). Transcontinental 20.17 *Glyphopsyche*

Tibiae and tarsi lacking dark band (Fig. 20.1 6A); case mostly of small stones with wood fragments forming smooth cylinder (Fig. 20.16C). Eastern 20.16 *Frenesia*

28 (26) Chloride epithelia present dorsally on at least some abdominal segments (Fig.20.5A) 29

Chloride epithelia lacking dorsally on abdominal segments (Fig. 20.26A) 32

29 (28) Metanotal sa2 represented by a few setae, usually two, without sclerite (Fig. 20.4B); case of elongate leaf pieces arranged in smooth cylinder (Fig. 20.4C). Northern and western 20.4 *Arctopora*

Metanotal sa2 with sclerite and more than two setae (Fig. 20.37B) 30

30 (29) Dorsum of head with numerous large spots often coalescing in places into diffuse blotches, or small discrete spots, especially on frontoclypeal apotome (Fig. 20.3B). 31

Dorsum of head with varied markings, but not spots as above (Fig. 20.5B); case of plant and rock materials (Fig. 20.5C). Northern, extended south in western mountains 20.5 *Asynarchus*[NM] (in part)

31 (30) Anterolateral corner of pronotum with small patch of spines (Fig. 20.3D); case of plant materials, usually cylindrical (Fig. 20.3C) but sometimes three-sided. Transcontinental 20.3 *Anabolia*[NM]

Anterolateral corner of pronotum lacking patch of spines 34

32 (28) Prosternal horn unusually long, extended ventrally well beyond distal edge of head capsule, approximately to mentum of labium (Fig. 20.32D); case cylindrical, of short, narrow pieces of plant material arranged transversely (Fig.20.32C). Eastern and northern 20.32 *Platycentropus*

Prosternal horn not unusually long, extended ventrally approximately to distal edge of head capsule (Fig. 20.26A); cases diverse, of plant or rock materials (Fig. 20.26C-F) 33

33 (32) Chloride epithelia only on ventral surface ofabdominal segments (Fig. 20.37A); mesonotal sa1 with a single seta (Fig. 20.37B); venter of abdominal segment I with a single seta at sa1 (Fig. 20.37E); case mainly of leaf pieces arranged lengthwise. Known only from arctic tundra of Yukon and Northwest Territories 20.37 *Sphagnophylax*

Chloride epithelia on ventral and occasionally on lateral surfaces of abdominal segments (Fig. 20.26A); mesonotal sa1 usually with more than one seta (Fig. 20.26B); venter of abdominal segment I usually with several setae at the sa1 position (Fig. 20.18E) 34

34(31,33) Dorsum of head light brownish yellow with numerous discrete, small dark spots (Fig. 20.18B); case of sedge or similar leaves arranged longitudinally to form cylinder (Fig. 20.18C). Northern and transcontinental 20.18 *Grammotaulius*

Dorsum of head with varied markings, usually darker than above; case of wide range of materials (Fig. 20.26C-F). Widely distributed throughout continent 20.26 *Limnephilus* (in part)

35 (25) Tibiae with several pairs of stout spur-like setae (Fig.

20.1A) 36

Tibiae with only one pair of stout spur-like setae, situated at the apex (Fig. 20.28A) 37

36 (35) Dorsum I with transverse row of setae posterior to median dorsal hump (Fig. 20.1B); scale-hairs on dorsum of head (Fig. 20.1B); venter II with two chloride epithelia (Fig. 20.1E); case of small pebbles arranged into slightly curved and flattened cylinder of irregular outline (Fig. 20.1C). Western 20.1 *Allocosmoecus*

Dorsum I usually lacking setae posterior to median dorsal hump (Fig. 20.12D); scale-hairs absent from dorsum of head; venter II with single chloride epithelium (Fig. 20.12E) sometimes with smaller epithelium at each side, or epithelia lacking on II; case of final instar constructed of small rock pieces (Fig. 20.12C), slightly depressed, with plant materials in cases of younger larvae. Western montane areas 20.12 *Dicosmoecus*[NM]

37 (35) Metanotal sa1 sclerites usually fused along mid-dorsal line into single sclerite (Fig. 20.2B), occasionally separated by a small gap; case a hollow twig with ring of bark pieces at anterior end (Fig. 20.2C), or entire case of wood fragments. Western, but extended to Saskatchewan 20.2 *Amphicosmoecus*

Metanotal sa1 sclerites always clearly separate (Fig. 20.15D, 20.28B) 38

38 (37) Pronotum with erect setae just behind anterior margin longest mesally, decreasing in length laterally, and widely spaced especially mesally (Fig. 20.15D); abdominal segment VII with single long posterodorsal seta on either side of midline, sometimes with 1 or 2 much smaller setae (Fig. 20.15C); lateral abdominal gills usually lacking from segment V, sometimes from IV or terminating at anterior position on IV (Fig. 20. 15A); case of wood or rock pieces (Fig. 20.15B,E). Western 20.15 *Eocosmoecus*

Erect setae just behind anterior margin of pronotum mostly of similar length, but with seta on each side of midline shorter and spaced closer to next lateral seta than intervals between remaining setae (Fig. 20.28B); abdominal segment VII with 1-5 posterodorsal setae on either side of midline (Fig. 20.28D); lateral abdominal gills terminating at anterior position on segment V (Fig. 20.28A); case a rough cylinder of thin bark fragments (Fig. 20.28c). Transcontinental 20.28 *Onocosmoecus*[NM]

39 (17) Femora of second and third legs with 3 to 5 major setae along ventral edge (Fig. 20.24A); case of bark and leaves (Fig. 20.24C) or of sand. Eastern
20.24 *Ironoquia*

Femora of second and usually third legs with two major setae along ventral edge (Fig. 20.21A)
40

40 (39) Metanotum with all setae confined to primary sclerites (Fig. 20.25B); case of lengths of sedge leaves arranged longitudinally to form cylinder (Fig. 20.25c), or of fragments of bark and leaves. Northern and transcontinental, higher elevations in western mountains from Alaska to California 20.25 *Lenarchus*[NM]

Metanotum with at least a few setae arising between primary sclerites (Figs. 20.21B, 20.35B)
41

41 (40) Lateral abdominal gills only on segment II and occasionally III, and of single filaments only (Fig. 20.35A); case of small rock fragments (Fig. 20.35C). High elevations in New Mexico, Colorado, and probably adjacent states
20.35 *Psychoronia*[NM]

Lateral series of abdominal gills usually extending to segment V, in some species only to III or IV, but at least some gills branched (Fig. 20.21A); case mostly of small rock fragments, sometimes with wood pieces as well (Fig. 20.2 IC). Widespread
20.21 *Hesperophylax*[NM]

Family Philopotamidae

Preliminary Key to New Mexico Genera

1 Anterior margin of frontoclypeal apotome with prominent notch (Fig. 8.1D), and coxa of fore leg with long process arising near distal end (Fig. 8.1C); venter of head with seta no. 18 located at level of posterior edge of ventral apotome (Fig. 8.1F). Widespread 8.1 *Chimarra*[NM]

Anterior margin of frontoclypeal apotome usually lacking prominent notch, although there may be some asymmetry (Fig. 8.2B), but coxa of fore leg lacking long process; venter of head with seta no. 18 located approximately half-way between posterior edge of ventral apotome and occipital foramen (Fig. 8.2E) 2

2 (1) Fore trochantin projecting freely anteriorly to form elongate, finger-like process (Fig. 8.2C,D); venter of head with seta no. 18 approximately same thickness as stoutest seta on dorsum of head (Fig. 8.2E). Widespread 8.2 *Dolophilodes*[NM]

Fore trochantin projecting freely only a short distance, thus forming very short process (Fig. 8.3D,E); venter of head with seta no. 18 stouter than any seta on dorsum of head (Fig. 8.3C). Widespread 8.3 *Wormaldia*

Family Phryganeidae

Preliminary Key to New Mexico Genera

1 Ventral surface of head with genae mostly contiguous, separated only near anterior border by small ventral apotome (Fig. 23.10D); case of both plant and rock pieces (Fig. 23.10C). Western (subfamily Yphriinae) 23.10 *Yphria*

Ventral surface of head with genae almost completely separated by ventral apotome (Fig. 23.2D) (subfamily Phryganeinae) 2

2 (1) Each mesonotal sa1 seta arising near anterior edge of rounded sclerite of diameter several times larger than sa3 sclerite (Fig. 23.6B); case of ring construction (Fig. 23.9C,D) 3

Mesonotal sa1 seta lacking rounded sclerite, or seta arising from center of small sclerite of diameter smaller than sa3 sclerite (Fig. 23.5B); case usually of ring or spiral construction 4

3 (2) Antennae long, approximately equal in length to diameter of cluster of stemmata (Fig. 23.3B). Northern and central 23.3 *Beothukus*

Antennae shorter than above (Fig. 23.6B). Eastern and central 23.6 *Oligostomis*

4 (2) Head and pronotum uniform light brown, without contrasting light and dark markings except for muscle scars on head (Fig. 23.5B); case of ring construction (Fig. 23.5C). Northeastern, central 23.5 *Hagenella*

Head and pronotum with dark markings contrasting prominently with light or brownish yellow ground color (Fig. 23.1B) 5

5 (4) Coxal combs of fore legs well developed, their structure (Fig. 23.1D,E) apparent at relatively low magnification of approximately 50X 6

Coxal combs of fore legs small (Fig. 23.9E), appearing as tiny raised points at a magnification of approximately 50X 7

6 (5) Small, pigmented sclerite (sternellum) usually present between prothoracic coxae (Fig. 23.1F);coxal combs on prothoracic legs with axis of base transverse to long axis of coxa (Fig. 23.1 D) coxal combs of mesothoracic legs with basal axes both transverse and parallel to long axis of coxa (Fig. 23.1E); case usually of spiral construction. Widespread 23.1 *Agrypnia*

Sternellum between prothoracic coxae lacking; coxal combs on both pro- and mesothoracic legs with basal axis transverse to long axis of coxa (Fig. 23.8E,F); case of spiral construction (Fig. 23.8D); Widespread 13.8 *Phryganea*

7 (5) Meso- and metanota with pair of longitudinal, irregular, dark bands (Fig. 23.2B); case of spiral construction (Fig. 23.8D) 8

Meso- and metanota mostly uniform in color without dark bands (Fig. 23.4B) 9

8 (7) Segments VI and VII with anterodorsal gills present, segment VII with posteroventral gills absent (Fig. 23.2A). Widespread 23.2 *Banksiola*

Segments VI and VII with anterodorsal gills absent, segment VII with posteroventral gills present (Fig. 23.2A). In North America only in Yukon and Alaska 23.7 *Oligotricha*

9 (7) Pronotum with dark line only along anterior border (Fig. 23.4B); case basically of spiral construction, but trailing ends give it a bushy, irregular appearance (Fig. 23 Ac). Central and northern 23.4 *Fabria*

Pronotum with transverse dark band on each side, more central in position and not along anterior border (Fig. 23.9B); case of ring construction (Fig. 23.9C,D). Transcontinental 23.9 *Ptilostomis*

Family Polycentropodidae

Preliminary Key to New Mexico Genera

1 Anal claw with several conspicuous pointed teeth arising from ventral, concave margin (Figs. 9.4A, 9.6A) 2

Anal claw lacking conspicuous pointed teeth on ventral concave margin (Fig. 9.5D), or with row of many tiny spines (Fig. 9.3A) 3

2 (1) Teeth on anal claw much shorter than claw, dorsal accessory hook present (Fig. 9.4A); pronotum with short, stout seta arising near each ventrolateral margin (Fig 9.4C). Widespread over much of continent, but not in the southwest 9.4 *Nyctiophylax*

Teeth on anal claw almost as long as claw, dorsal accessory hook absent (Fig. 9.6A); pronotum lacking short seta near each ventrolateral margin. Southwestern 9.6 *Polyplectropus*

3 (1) Basal segment of anal proleg approximately same length as distal segment and largely without setae, concave margin of anal claw with row of tiny spines (Fig. 9.3A,C). Widespread in eastern and central areas 9.3 *Neureclipsis*

Basal segment of anal proleg distinctly longer than distal segment and bearing many setae, concave margin of anal claw lacking tiny spines (Fig. 9.2C) 4

4 (3) Dorsal plate between claw and lateral sclerite of anal proleg with two dark bands separated mesally (Fig. 9.2D); meso- and metanotal sa1 setae approximately same length as longest sa2 setae (Fig. 9.2B). Eastern and central 9.2 *Cyrnellus*

Dorsal plate between claw and lateral sclerite of anal proleg with two dark bands fused mesally (Fig. 9.5E); metanotal and usually mesonotal sa1 setae not more than one-third as long as longest sa2 setae (Fig. 9.5B). 5

5 (4) Tarsus of fore leg elongate, about two-thirds as long as fore tibia, and anal claw curved approximately to 90° (Fig. 9.1A).[1] Mature larvae not more than 8 mm in length. South and east of a

line roughly from Arizona to Michigan, Ontario, and Maine.

9.1 *Cernotina*[1]

Tarsus of fore leg short, about one-half as long as fore tibia (Fig. 9.5A), or tarsus of fore leg elongate, approximately equal in length to fore tibia or slightly longer, or anal claw not curved as much as 90°. Mature larvae 10 mm and longer. Widespread

9.5 *Polycentropus*[NM 1]

[1] Please see Wiggins (1996), p. 161 for an explanation about the distinction between these two species.

Family Uenoidae

Preliminary Key to New Mexico Genera

1 Larvae extremely slender, pronotum broadest anteriorly in dorsal aspect (Fig. 26.IA,B); larvae lacking abdominal gills in North American genera; larval cases very slender, smoothly textured, constructed of small sand grains covered externally with silk (26. 1C), or constructed of silk alone (Fig. 26.5C). Western montane North America (subfamily Uenoinae) 2

Larvae not slender, pronotum broadest at about midpoint in dorsal aspect (Figs. 26.2, 26.4); abdominal gills usually present; larval cases not slender, coarsely textured, and constructed of rock fragments of various sizes (Fig. 26.4C), or with larger stones along each side (Fig. 26.2C). Eastern and western North America (subfamily Thremmatinae) 4

2 (1) Mesonotal sclerites with anterior margin straight except for separate notch in anteromesal corner of each sclerite, pronotum with anterior margin straight and anterolateral corner angulate (Fig. 26.5B). Western 26.5 *Sericostriata*

Mesonotal sclerites with anterior margin rounded, and single median notch between two sclerites, pronotum with anterior margin and anterolateral corner curved (Fig. 26.3B). 3

3 (2) Darkened posterolateral corner of each mesonotal sclerite extended approximately to mid-lateral point of sclerite (Fig. 26.3B); abdomen with filaments of lateral fringe arising over half or more of most segments (Fig. 26.3A). Western 26.3 *Neothremma*

Darkened posterolateral corner of each mesonotal sclerite not reaching mid-lateral point (Fig. 26.1B); abdomen with filaments of lateral fringe scattered and arising over less than half of most segments, but with prominent and discrete tuft of filaments at anterior edge of segment II (Fig. 26.1A). Western 26.1 *Farula*

4 (1) Pronotum with prominent longitudinal ridges (Fig. 26.4B); anteromedian notch of mesonotum weakly represented; case of rock fragments, strongly tapered and curved, outline smooth (Fig. 26.4C). Western 26.4 *Oligophlebodes*[NM]

Pronotum lacking longitudinal ridges, but mesonotum with prominent

anteromedian notch (Fig. 26.2B); case of coarse rock fragments, larger stones along each side (Fig. 26.2C). Eastern and western

26.2 *Neophylax*

Key to Adults of North American Families of Trichoptera (Merritt and Cummins, 1996) with Preliminary Designation of Families Occurring in New Mexico[NM]

1. Small insects, usually 5 mm or less in length; mesoscutum lacking setal warts, mesoscutellar setal warts transverse and meeting mesally to form an angulate ridge (Fig. 17.111); hind wings narrow and apically acute (Fig.. 17.112), often with a posterior fringe of long hairs, the longest approximating the width of the hind wing HYDROPTILIDAE[NM]

1′. Insects usually more than 5 mm long; mesoscutum frequently with setal warts (Fig. 17.117), mesoscutellar setal warts usually rounded or elongate (Figs. 17.115, 17.120); hind wings usually broader and rounded apically (Fig. 17.34), posterior fringe, when present, of relatively shorter hairs 2

2(1′). Dorsum of head with 3 ocelli (Fig. 17.120) 3

2′. Dorsum of head lacking ocelli (Fig. 17.129) 10

3(2). Maxillary palp of 5 segments, terminal segment 5 flexible, usually at least twice as long as preceding segment 4 (Fig. 17.114) PHILOPOTAMIDAE[NM]

3′. Maxillary palp of 3, 4, or 5 segments, terminal segment similar to others in structure, usually approximatety same length as preceding segment (Figs. 17.118, 17.123) 4

4(3′). Maxillary paip of 5 segments, segment 2 short, often rounded, and approximately same length as segment 1 (Fig. 17.118) 5

4′. Maxillary palp of 3, 4, or 5 segments, segment 2 slender and longer than segment 1 (Figs. 17.123, 17.125) 8

5(4). Maxillary palp with 2nd segment rounded and globose (Fig. 17.118) 6

5′. Maxillary palp with 2nd segment not globose, but of same general cylindrical shape as 1st (Fig. 17.121) HYDROBIOSIDAE[NM]

6(5). Fore tibia with a preapical spur (Fig. 17.116)
RHYACOPHILIDAE[NM]

6′. Fore tibia lacking a preapical spur (Fig. 17.119) 7

7(6′). Mesal setal warts of pronotum widely space (Fig.17.117)
GLOSSOSOMATIDAE[NM]

7′. Mesal setal warts of pronotum close together (as in Fig. 17.111, although not in contact)
HYDROPTILIDAE (Ptilocolepinae)[NM]

8(4′). Middle tibia with 2 preapical spurs (Fig. 17.136); spurs usually 2,4,4 PHRYGANEIDAE

8′. Middle tibia with 1 or no preapical spurs; spurs usually 1, 2-3, 4 9

9(8′). Anterior edge of hind wing with row of stout, hooked setae (Fig. 17.128) UENOIDAE[NM]

9′. Anterior edge of hind wing lacking row of stout hooked setae, although straight or slightly curved normal setae present; or if hooked setae present, vein R1 of hind wing abbreviated and not reaching wing margin (*Lepania*) LIMNEPHILIDAE[NM]
(major part[2], including *Lepania* and *Goereilla* of Goerinae)

10(2′). Maxillary palp with 5 or more segments (Fig. 17.133) 11

10′. Maxillary palp with fewer than 5 segments 15

11(10). Terminal segment of maxillary palp flexible, with numerous cross-striae and different in structure from preceding segments; usually at least twice as long as preceding segment (Fig. 17.131) 12

11′. Terminal segment of maxillary palp similar to others in structure and usually of approximately the same length as preceding segment (Fig. 17.121), or some segments with long hair brushes (Fig. 17.147) 15

12(11). Mesoscutum lacking setal warts or seta (Fig. 17.152)

12(11). Mesoscutum lacking setal warts or seta (Fig. 17.152)
HYDROPSYCHIDAE[NM]

12′. Mesoscutum with setal warts (Fig. 17.129) 13

13(12′). Mesoscutal setal warts quadrate and appressed along the median line over a large area approximately the size of the entire mesoscutellum (Fig. 17.137)
XIPHOCENTRONIDAE

13′. Mesoscutal setal warts circular, sometimes touching at the median line, but much smaller than the mesoscutellum (Fig. 17.129)
14

14(13′). Fore tibia with a preapical spur, or if spur absent (*Cernotina*), length of basal segment of tarsus less than twice the length of the longer apical spur (Fig. 17.130)
Polycentropodidae[NM 1]

14′. Fore tibia lacking a preapical spur, and length of basal segment of tarsus at least twice the length of the longer apical spur (Fig. 17.134)
PSYCHOMYIIDAE[NM]

15(10′, 11′) Mesoscutum lacking setal warts and setae (Fig. 17.138); tarsal segments, excepting basal one, with spines only around apex (Fig. 17.139)
BERAEIDAE

15′. Mesoscutum with setal warts (Fig. 17.148) or setal area (Fig. 17.141); tarsal segments with spines usually arranged irregularly (Fig. 17.124)
16

16(15′). Mesoscutal setae arising in diffuse area over almost entire length of mesoscutum (Fig. 17.141) 17

16′. Mesoscutal setae largely confined to pair of small discrete warts (Fig. 17.145)
19

17(16). Antennae with scape at most twice as long as pedicel, dorsum of head usually with posteromesal ridge (Fig. 17.140)
CALAMOCERATIDAE[NM]

17′. Antennae with scape at least 3 times longer than pedicel, dorsum of head lacking posteromesal ridge (Fig. 17.141) 18

18(17′). Antennae much longer than body, middle tibia lacking preapical spurs (Fig. 17.142) LEPTOCERIDAE[NM]

18′. Antennae little if any longer than body, middle tibia with 2 preapical spurs (Fig. 17.144) MOLANNIDAE

19(16′). Dorsum of head with posterior setal warts very large, extending from mesal margin df eye to mid-dorsal line and anteriorly to middle of head (Fig. 17,145);antennae never longer than fore wing HELICOPSYCHIDAE[NM]

19′. Dorsum of head with posterior setal warts relatively smaller than above (e.g., Fig. 17.146); or antennae 1 1/2 times longer than fore wing 20

20(19′). Mesoscutellum with 1 mesal setal wart (Fig. 17.146) 21

20′. Mesoscutellum with a pair of setal warts (Fig. 17.148), although sometimes touching along the mid-dorsal line (Fig. 17.153) 22

21(20). Mesoscutellum almost entirely covered by a single setal wart, setae arising over most of wart (Fig. 17.146); maxillary palpi always 5-segmented ODONTOCERIDAE[NM]

21′. Mesoscutellum with setal wart narrower, setae largely confined to periphery (Fig. 17.122); maxillary palpi 5-segmented in females, but 3-segmented in males LIMNEPHILIDAE (Goerini)

22(20′). Pronotum with 1 pair of setal warts, median fissure of mesoscutum deep (Fig. 17.151) SERICOSTOMATIDAE[NM]

22′. Pronotum with 2 pairs of setal warts, median fissure of mesoscutum not as deep as above (Fig. 17.148) 23

23(22′). Middle tibia with 1 or 2 preapical spurs arising at a point about one-third distance from apex of tibia (Fig. 17.149) or without preapical spurs; abdomen with openings of glands on venter V in a pair of rounded sclerotized lobes (Fig. 17.150) BRACHYCENTRIDAE[NM]

23′. Middle tibia with 2 preapical spurs arising from approximately

midpoint of tibia (Fig. 17.154); abdomen with glands on venter V not apparent

LEPIDOSTOMATIDAE[NM]

[1] The adult of Ecnomidae, recently described from Texas (Waltz and McCafferty 1983), keys to Polycentropodidae, but its fore wing has R_1 branched.

[2] The Apataniidae of Wiggins' (1996) key to the larvae is included in the Limnephilidae of this key to the adults.

Appendix 7

Taxonomic Key for mature larvae of Plecoptera (stoneflies) of New Mexico (Families only)

Plecoptera: Thorax with three pairs of segmented walking legs; wingpads external; gills, if present, finger like (not feathery); tarsal claws double; two tail filaments (cerci)

1a. Paraglossae and glossae of equal length 2

1b. Paraglossae much longer than glossae 6

2a. Sterna of abdomen with branched gills on first two or three segments ..... **Pteronarcidae**

2b. Sterna of abdomen without branched gills 3

3a. Second tarsal segment as long as or longer than the first segment ..... **Taeniopterygidae**

3b. Second tarsal segment shorter than the first segment 4

4a. Shape (form) much stouter (robust) with hindwing pads strongly divergent from the body axis ..... **Nemouridae**

4b. Shape much more elongated and cylindrical with hindwing pads nearly parallel 5

5a. Notch on inner margins of hindwing pad located on anterior third; abdominal segments one to nine divided by a membranous lateral fold; abdomen with middle segments wider than the basal or terminal segments; abdomen flattened ..... **Capniidae**

5b. Notch on inner margins of hindwing pad located on posterior third; abdominal segments with a membranous lateral fold on, at most, abdominal segments one through seven; abdomen with middle segments only slightly wider than basal or terminal segments; abdomen cylindrical ..... **Leuctridae**

6a. Branched gills present ventrally or laterally on the thorax; apex of the glossae rounded ..... **Perlidae**

6b. Branched gills absent from the thorax; apex of the glossae pointed 7

7a. Hindwing pads nearly parallel to the long axis of the body; dorsal surface without color or pattern; cerci only three/fourths the length of the abdomen ..... **Chloroperlidae**

7b. Hindwing pads diverging from the body axis; dorsal surface with a distinct pattern; cerci as long or longer than the abdomen ..... **Perlodidae**

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(Stoneflies) Preliminary Checklist of
New Mexico Plecoptera
G. Z. Jacobi

Family Nemouridae

**Amphinemura banksi* Baumann and Gaufin
A. mogollonica Baumann and Gaufin
**Malenka californica* (Claassen)
M. coloradensis (Banks)
M. flexura (Claassen)
Podmosta delicatula (Claassen)
Prostoia besametsa (Ricker)
Zapada cinctipes (Banks)
Z. frigida (Claassen)
Z. haysi (Ricker)

Family Taeniopterygidae

**Doddsia occidentalis* (Needham and Claassen)
Taenionema nigripenne (Banks)
T. pacificum (Banks)
T. pallidum (Banks)
***T. jacobii* Stanger and Baumann
***Taeniopteryx pecos* Baumann and Jacobi; synonym of *T. parvula*

Family Capniidae

**Bolshecapnia milami* (Nebeker and Gaufin)
**Capnia californica* (Claassen)
**C. coloradensis* Claassen
C. confusa Claassen
C. decepta (Banks)
C. vernalis Newport
Capnura fibula Claassen
**C. wanica* Frison
Capnia gracilaria Claassen
Eucapnopsis brevicaudata (Claassen)
**Isocapnia crinita* (Needham and Claassen)
**I. vedderensis* (Ricker)
**Mesocapnia arizonensis* (Baumann and Gaufin)
M. frisoni (Baumann and Gaufin)
**M. werneri* (Baumann and Gaufin)
**Utacapnia logana* (Nebeker and Gaufin)
**U. poda* (Nebeker and Gaufin)

Family Leuctridae

**Paraleuctra occidentalis* (Banks)
P. rickeri Nebeker and Gaufin
P. vershina Gaufin and Ricker
Perlomyia utahensis Needham and Claassen

Family Pteronarcyidae
Pteronarcella badia (Hagen)
Pteronarcys californica Newport

Family Perlodidae
Cultus aestivalis (Needham and Claassen)
Diura knowltoni (Frison)
Isogenoides elongatus (Hagen)
I. zionensis (Hanson)
Kogotus modestus (Banks)
Megarcys signata (Hagen)
Skwala americana (Frison)
Isoperla fulva Claassen
I. longiseta Banks
I. mormona Banks
I. patricia Frison
I. phalerata (Smith)
I. quinquepunctata (Banks)
I. sobria (Hagen)

Family Perlidae
**Acroneuria abnormis* (Newman)
Hesperoperla pacifica (Banks)
Claassenia sabulosa (Banks)

Family Chloroperlidae
Suwallia pallidula (Banks)
Sweltsa borealis (Banks)
S. coloradensis (Banks)
S. lamba (Needham and Claassen)
***S. hondo* (Baumann and Jacobi)
Triznaka pintada (Ricker)
T. signata (Banks)
Paraperla frontalis (Banks)
Alloperla severa (Hagen)

* State Records by G. Z. Jacobi (since 1978)
** New Species by GZJ (since 1978)

Appendix 8

Taxonomic Key for the mature larvae of Ephemeroptera (mayflies) of New Mexico (Families only)

Ephemeroptera: Thorax with three pairs of segmented walking legs; wingpads external; abdominal gills either feathery, plate-like, or leaf-like; tarsal claws single; two or three tail filaments

1a. Gills on abdominal segment two either absent or operculate.....2

1b. Gills on abdominal segment two present, variable, but never operculate 4

2a. Gills on abdominal segment two absent.....**Ephemerellidae**

2b. Gills on abdominal segment two operculate.....3

3a. Gills on abdominal segment two overlaping and rectangular in shape (longer than wide)..... .....**Caenidae**

3b. Gills on abdominal segment two rounded or triangular in shape.....**Tricorythidae**

4a. Abdominal gills two through seven elongated with fringed margins; head with anteriorly projecting tusks.....**Ephemeridae**

4b. Abdominal gills two through seven never double, elongated, and fringed in combination; head without anteriorly projecting tusks.....5

5a. Gills on abdominal segments two through five forked or double and elongated or with fingerlike projections or in clusters of filaments, and never ventral.....**Leptophlebiidae**

5b. Gills on abdominal segments two through five usually platelike and often with basal gill tufts or flaps, only rarely pointed.....6

6a. Fore legs with two rows of long hairs; gill tufts absent from bases of fore coxae..... .....**Oligoneuriidae**

6b. Fore legs without two rows of long hairs.....7

7a. Flattened body with horizontal head and outspread legs; mandibles concealed beneath flattened head capsule.....**Heptageniidae**

7b. Body elongate, streamlined; head vertical.....8

8a. Fore leg claws different from middle and hind leg claws; fore leg claws with bristles..... .....**Ametropodidae**

8b. Fore leg claws on all legs similar and without bristles.....9

9a. With two or three well-developed tails; if three tails present, then antennae 2x or 3x head width.....**Baetidae**

9b. With three well-developed tails; antennae shorter than 2x head width.....10

10a. Head with median frontal ridge below middle ocellus; mouthparts hairy; gill tufts present at bases of maxillae; forelegs with a double row of long setae on inner surface of femora and tibiae; gill tufts present at bases of fore coxae.....**Isonychiidae**

10b. Head, mouthparts, gill tufts on maxillae and bases of fore coxae, and forelegs other than above.....11

11a. Gills double on abdominal segments one and two only, or all seven pairs double; gills large, with abundant tracheation; claws shorter than tarsi of all legs.....**Siphlonuridae**

11b. Gills single, oval, and small with lateral and mesal or submesal sclerotized bands; crown of galea-lacinia of maxillae with many long pectinate spines; caudal filaments usually with a wide dark transverse band at the middle and a narrow band at the apex or with many small dark bands.....**Ameletidae**

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Checklist of New Mexico Ephemeroptera (Mayflies)

G. Z. Jacobi

Family Ameletidae

Ameletus dodsianus Zloty
A. falsus (McDunnough)
A. sparsatus McDunnough

Family Ametropodidae

Ametropus albrighti Traver

Family Baetidae

Acentrella insignificans (McDunnough)
A. turbida (McDurrough)

Baetis adonis Traver
B. bicaudatus Dodds
B. caelestis Allen and Murvosh
B. flavistriga McDonnough
B. magnus McCafferty and Walsh
B. notus Allen and Murvosh
B. tricaudatus Dodds

Baetodes deficiens Cohen and Allen
B. edmundsi Koss

Callibaetis furrugineus Eaton
C. fluctuans (Walsh)
C. montanus (Eaton)
C. pictus (Eaton)

Camelobaetidius musseri (Traver and Edmunds)
C. warreni (Traver and Edmunds)

Cloeodes macrolamellus Waltz and McCafferty

Fallceon quilleri (Dodds)

Labiobaetis apache McCafferty and Waltz
L. propinquus (Walsh)

Procloeon conturbatum (McDunnough)

Family Caenidae

Caenis bajaenis Allen and Murvosh
C. latipennis Banks

Family Ephemerellidae

Attenella margarita (Needham)

Drunella coloradensis (Dodds)
D. doddsi (Needham)
D. grandis grandis (Eaton)

Ephemerella altana Allen
E. inermis Eaton
E. infrequens McDunnough
E. mollitia Seemann

Serratella micheneri Traver
S. tibialils McDunnough

Timpanoga hecuba hecuba (Eaton)

Family Ephemeridae

Ephemera simulans Walker

Hexagenia bilineata (Say)

Family Heptageniidae

Cinygmula par Eaton

Epeorus albertae (McDunnough)
E. deceptivus (McDunnough)
E. longimanus (Eaton)
E. margarita Edmunds and Allen

Heptagenia elegantula (Eaton)
H. solitaria McDunnough

Leucrocuta petersi (Allen)

Nixe criddlei (McDunnough)
N. simplicioides (McDunnough)

Rhithogena hageni Eaton
R. morrisoni (Banks)
R. plana Allen and Chao
R. robusta Dodds
R. undulata (Banks)
R. vitta Allen and Chao

Family Isonychiidae

Isonychia intermedia (Eaton)
I. sicca (Walsh)

Family Leptophlebiidae

Choroterpes inornata Eaton

Leptophlebia bradleyi Needham

Neochoroterpes kossi (Allen)
N. nanita (Traver)
N. oklahoma (Traver)

Paraleptophlebia debilis (Walker)
P. heteronea (McDunnough)
P. memoralis (Eaton)

Thraulodes brunneus Koss
T. gonzalesi Traver and Edmunds
T. speciosus Traver

Traverella albertana (McDunnough)

Family Leptohyphidae

Leptohyphes apache Allen
L. condylus Allen

Tricorythodes corpulentus Kilgore and Allen
T. dimorphus Allen
T. explicatus Eaton
T. *minutus* Traver

Family Oligoneuriidae

Homoeoneuria alleni Pescador and Peters

Lachlania dencyanna Koss
L. saskatchewanensis Ide

Family Siphlonuridae

Siphlonurus occidentalis (Eaton)

WINTER STONEFLIES (PLECOPTERA) IN SEASONAL HABITATS IN NEW MEXICO, USA

GERALD Z. JACOBI AND STEVEN J. CARY

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Winter stoneflies (Plecoptera) in seasonal habitats in New Mexico, USA

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Abstract. Seasonal stream habitats in New Mexico supported 10 species of winter-emerging stoneflies. Winter precipitation in combination with low winter temperatures created a seasonal moisture surplus and seasonal streamflow in this semi-arid region. Study area streams were dry for long periods in spring and autumn. Two different types of seasonal (ahyporheic) habitats were identified. Small high mountain streams fed by seasonal snowmelt runoff (type M) were inhabited by *Capnia decepta, Eucapnopsis brevicauda, Isocapnia vedderensis, Capnia californica, Capnura wanica, Mesocapnia werneri, Taenionema jacobii,* and *Capnura fibula. Mesocapnia arizonensis* and *M. frisoni* seemed to specialize in low-elevation watercourses fed by winter rains and rising water tables (type L). Adaptations for survival during spring and autumn periods of no streamflow, desiccation, or flash flooding include small size, rapid development, and diapause during egg or larval stages.

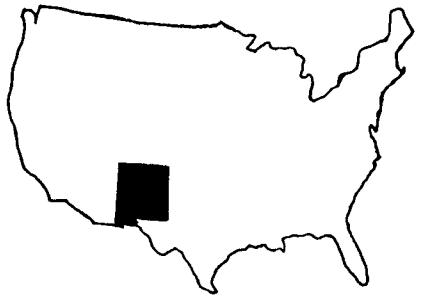
Key words: Plecoptera (stoneflies), seasonal streams, diapause, ahyporheic zones.

Stoneflies (Plecoptera) typically inhabit perennial streams with high gradients, low water temperature, high dissolved oxygen content, and gravel or cobble substrates. Some North American Plecoptera have been found in intermittent or temporary habitats (Knight and Gaufin 1967, Harper and Hynes 1970, 1972, Lehmkuhl 1971, Oberndorfer and Stewart 1977, Snellen and Stewart 1979, Gray 1981, Gray and Fisher 1981, Pugsley and Hynes 1985, and Nelson and Baumann 1990). Winter emerging taxa in the southwestern USA are found in watercourses that have traditional stonefly habitat characteristics in winter, but may be dry in most other seasons (Baumann and Gaufin 1969, Stewart et al. 1974, Baumann et al. 1977, Jacobi and Cary 1986, and E. C. Masteller, Pennsylvania State University, personal communication). Small size, rapid development, and egg and larval diapause are traits commonly cited (Harper and Hynes 1970, 1972, Hynes and Hynes 1975, Pugsley and Hynes 1985, and Stewart and Stark 1988) to explain how these organisms can occupy temporary habitats. Diapause as egg or larva is widespread in the winter-emerging species in the families Capniidae (Khoo 1968, Harper and Hynes 1972), Taeniopterygidae (Harper and Hynes 1970), Leuctridae (Hynes 1941, Snellen and Stewart 1979), and Nemouridae (Lehmkuhl 1971).

Re-examination of previous published data (Jacobi and Baumann 1983, Jacobi and Cary 1986) and unpublished data from more recent collections of winter stoneflies from isolated streams in the southwestern USA (primarily New Mexico) revealed that most of the species collected occurred in temporary habitats. The objectives of this study were to document the occurrence of stoneflies in temporary habitats, document the hydrology and seasonal regularity of these habitats, and discuss adaptive mechanisms for survival in isolated small streams in the southwestern USA. The ability to inhabit seasonal environments appears essential to the existence of many southwestern Plecoptera.

Study Area

Winter stoneflies were collected from several mountain ranges in New Mexico. These include the Magdalena Mountains, Black Range, Pinos Altos Mountains, Brushy Mountains, San Francisco Mountains, Gallo Mountains, Organ Mountains, Animas Mountains, Cooke's Peak, Mogollon Mountains, Johnson Mesa, Sangre de Cristo Mountains, Mount Taylor, and Zuni Mountains (Fig. 1). These are high mountain ranges (Appendix 1) isolated by extensive lowlands where adequate habitat is absent. Over geologic time, erosion of mountains and subse-



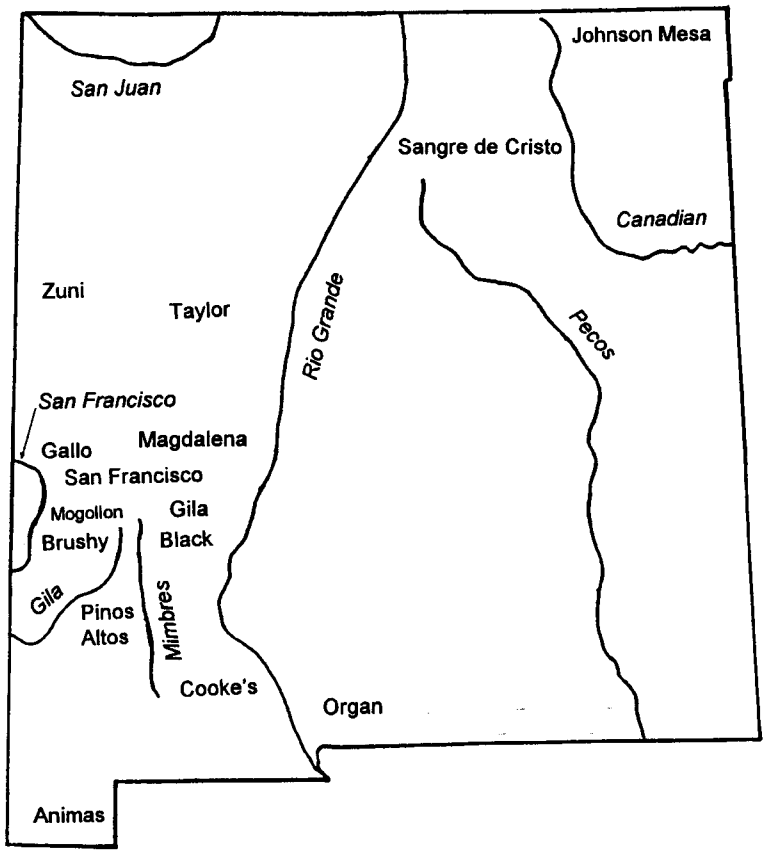


FIG. 1. New Mexico mountains and major rivers. River names are in italic.

quent deposition filled the intervening basins with unconsolidated sediments. These deposits may be 100s of m thick (Trauger 1972) and subsurface water levels may fluctuate greatly within these deposits. Some of these watersheds, e.g., the Mimbres River, are internally drained with no surface outlet. Other parts of the study area are drained by perennial rivers such as the Gila, San Francisco, Canadian, Pecos, and Rio Grande.

Average annual precipitation totals in New Mexico range from <20 cm in the Rio Grande Valley near Las Cruces to >75 cm in the high peaks of the Mogollon Mountains (New Mexico State Engineers Office 1967). Precipitation and moisture availability have a distinct seasonal cy-

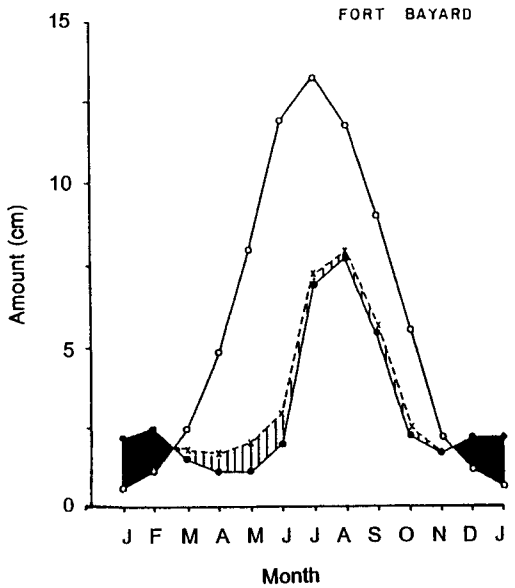


FIG. 2. Seasonal pattern of precipitation (solid circles), potential evapotranspiration (open circle), actual evapotranspiration (crosses), water deficit (white area between 2 upper curves), soil moisture utilization (striped area), and soil moisture recharge (black areas) near Fort Bayard in southwestern New Mexico. From Tuan et al. (1973).

cle (Tuan et al. 1973). A 3-mo summer rainy season (monsoon or "chubasco") contributes >50% of the annual precipitation whereas spring through early summer is the driest season (Fig. 2). Winter precipitation is much less than the summer rains, but winter is the only season with moisture surplus because of low evapotranspiration rates (Tuan et al. 1973 and Dunne and Leopold 1978).

Orographic effects on moisture availability are important in creating temporary habitats for stoneflies. In areas sharing similar climatic influences, high altitude terrains get far more precipitation than lowlands (Tuan et al. 1973). Another important orographic effect on moisture is related to temperature, which declines with increasing elevation at a rate of 2.78°C for every 305 m (Tuan et al. 1973). Much winter precipitation falls as snow at higher elevations but as rain at lower elevations.

Limited precipitation in May through June, and October through December, (Fig. 2) means that most small streams in the study area are dry at those times (Fig. 3). Although stream gauging data are not available for most small streams, we have traversed the state on numerous occasions and have seen our study streams dry during non-winter seasons and sometimes for consecutive years. Moreover, Reiland and Haynes (1963) documented that many New Mexico watercourses have zero flow for many months of typical years.

Independent of climate, "southwestern rivers flowing from mountains across deserts often have diminution of discharge both up- and down-stream from intermediate elevations" (Minckley and Brown 1982). From this generalization, we defined 3 types of stream habitats in the study area based on location in the landscape (Fig. 3). Intermediate elevation streams (Type P) are perennial or nearly perennial (interrupted). They combine water flows and sediments delivered from upland tributaries. They have moderate gradients with enough rubble and gravel alluvium to provide a useful hyporheic zone where larvae can survive during times of no surface flow in the channel. We use the term "ahyporheic" to describe seasonal habitats in which either there is no water flow beneath the channel or the wetted zone is deep, inaccessible, and unusable. The uppermost habitats (Type M) in watersheds are small montane streams with steep gradients, high flow velocities, and boulder and rubble substrates. These ephemeral streams flow in response to melting snow. They are ahyporheic because they have no flow in dry seasons and there is inadequate alluvium for water storage. Lowland streams (Type L) have gentle gradients and flow in response to rising water tables. Because underlying gravel and sand alluvium may be many m thick, the water table may fall far below the channel bottom in the dry season, causing an ahyporheic condition. Some stream sample locations are transitional (M/P or P/L).

Methods

We made collections throughout New Mexico during January, February, March, and April from 1979 through 1995. Initial reconnaissance of mountain ranges or lowlands was followed by exhaustive collections from watercourses using a variety of sampling methods. US Geological Survey, US Bureau of Land Management, and US Forest Service maps were used to locate potential sample locations. Every watercourse

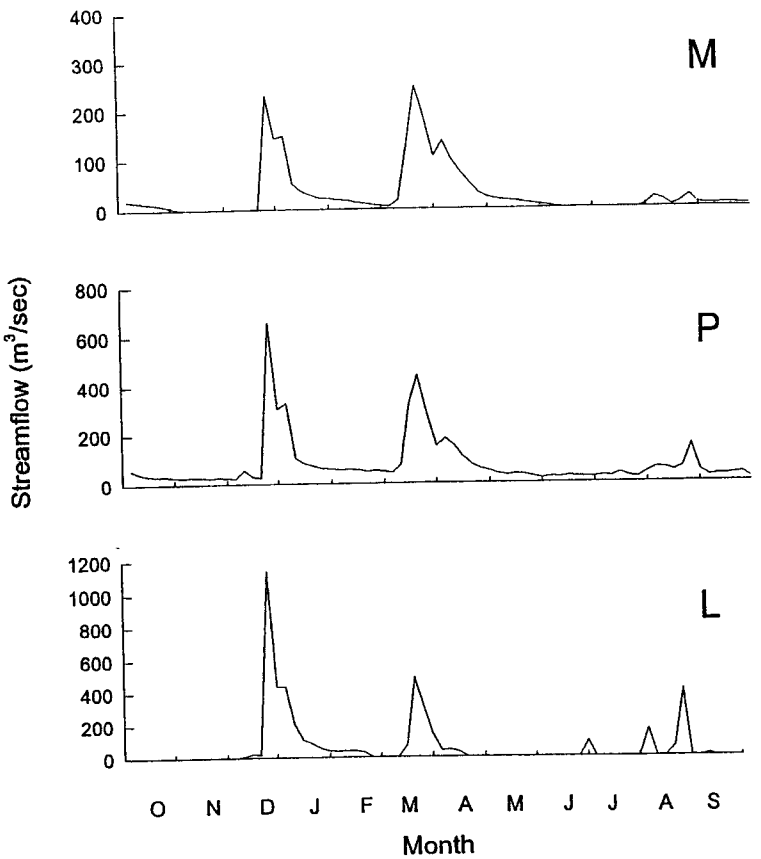


FIG. 3. Stream discharge in the Mimbres River, Grant Co., New Mexico, for water year 1965 (data from US Geological Survey). Habitat type M is 0.5 km N of the US Forest Service ranger station near the continental divide: elev. = 1901 m, drainage area = 252 km². Habitat type P is 2.4 km NW of Mimbres: elev. = 1888 m; drainage area = 392 km². Habitat type L is 2.4 km NE of Spaulding: elev. = 1448 m; drainage area = 1218 km².

encountered during our travels by road or footpath was sampled for at least 30 min and some locations were sampled on several occasions. Emerged adults and exuviae were hand picked from natural riparian materials such as rocks, logs, grasses, leaf packs, and woody vegetation. We also examined culverts, bridge abutments, bridge surfaces including the undersides, and rip-rap. A sweep net and beating sheet were used to collect adults from grasses, shrubs, and trees. If no adults were found, we searched for larvae and collected them with fingers or forceps from stream substrates. The presence of exuviae and the lack of larvae were noted and the location was revisited earlier in the season during a following year for collection of adults. If larvae were observed, the location was revisited later in the year or later in the season during a following year. On a few occasions, larvae were captured live, placed into jars with vented lids, and taken to a laboratory refrigerator to await emergence. Specimens were placed in 15-mL vials containing 70% ethyl alcohol for preservation. In the laboratory, specimens were identified, sexed, occasionally measured, and counted.

Results

Appendix 1 summarizes winter stonefly collections and provides stream types (M, L, and P) for the 10 species collected from 70 locations on 51 streams. Elevation of collection sites varied from 1293 m to 2350 m. The following Ple-

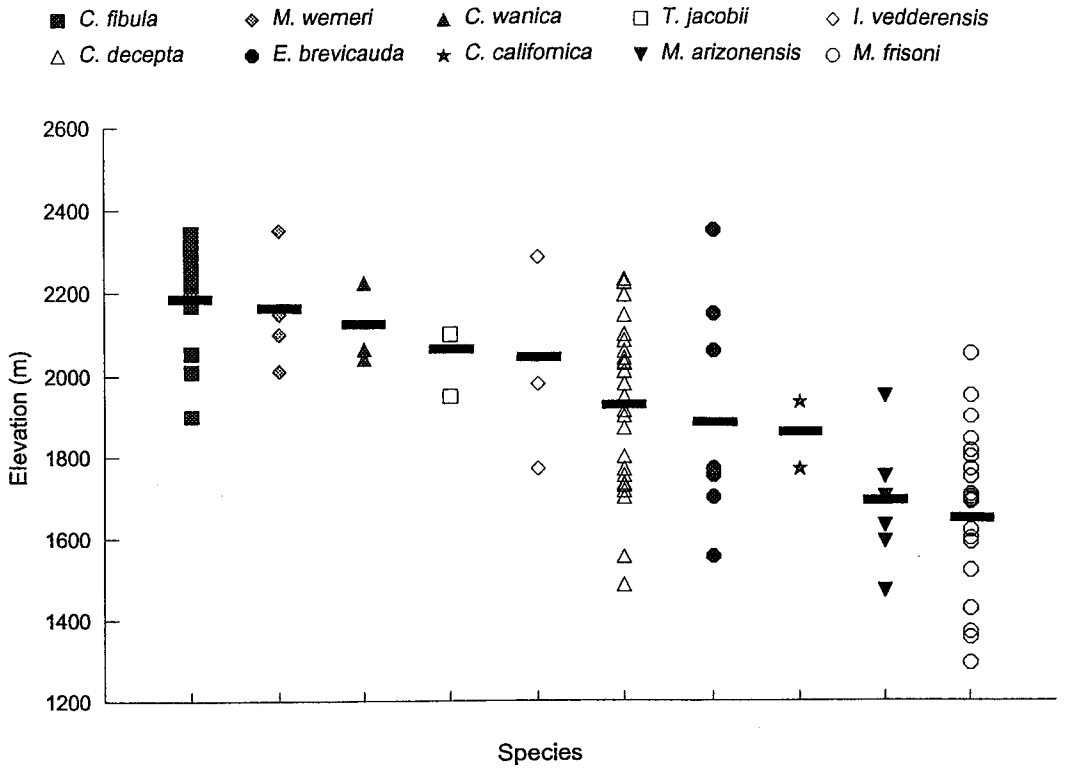


FIG. 4. Altitude of collection locations for winter-emerging stoneflies in the study area. Each point represents a collection elevation. A species may have been collected at one location several times. The horizontal bar represents the mean elevation of collection locations.

coptera were found to inhabit ahyporheic habitats (M and L) in New Mexico: *Eucapnopsis brevicauda* Claassen, *Isocapnia vedderensis* (Ricker), *Capnia decepta* (Banks), *Capnia californica* Claassen, *Capnura fibula* Claassen, *Capnura wanica* Frison, *Mesocapnia arizonensis* (Baumann and Gaufin), *M. frisoni* (Baumann and Gaufin), *M. werneri* (Baumann and Gaufin), and *Taenionema jacobii* Stanger and Baumann. Half of these winter-emerging species (*M. frisoni, C. decepta, M. arizonensis, C. fibula* and *E. brevicauda*) were also present in perennial stream reaches (P).

Plotting species occurrence along an elevational gradient showed some habitat differences among winter stonefly species (Fig. 4). *Capnura fibula* occured at a higher mean elevation (2174 m) than any other species in this study and observations were clustered within a narrow range of elevations (1900–2345 m). Three winter stoneflies (*C. wanica, M. werneri* and *T. jacobii*) were observed only at high elevation seasonal habitats, whereas 3 other species (*C. decepta, E. brevicauda* and *M. frisoni*) showed broad elevational ranges. Altitudinal ranges for *E. brevicauda* and *C. decepta* overlapped almost exactly. The lowest mean elevation of occurrence (1668 m) was for *M. frisoni* although we collected this species over a wide range of elevations (1293–2055 m). The mean elevation of occurrence for *M. arizonensis* was slightly higher (1684 m) but its range was narrower (1470–1950 m).

Capnia decepta (28 sites) and *M. frisoni* (21 sites) were the 2 winter-emerging species collected most frequently in the study area (Appendix 1). Despite their frequent occurrence, they were found at the same location only 3 times. Failure of these 2 widespread species to occur together suggested diversity among ahyporheic habitats.

The less frequently collected *Eucapnopsis brevicauda* (8 sites) was collected 6 times with *C. decepta*. Other species that were found preferentially with *C. decepta* or *E. brevicauda* included *M. werneri, C. fibula, T. jacobii, C. wanica, I. vedder-*

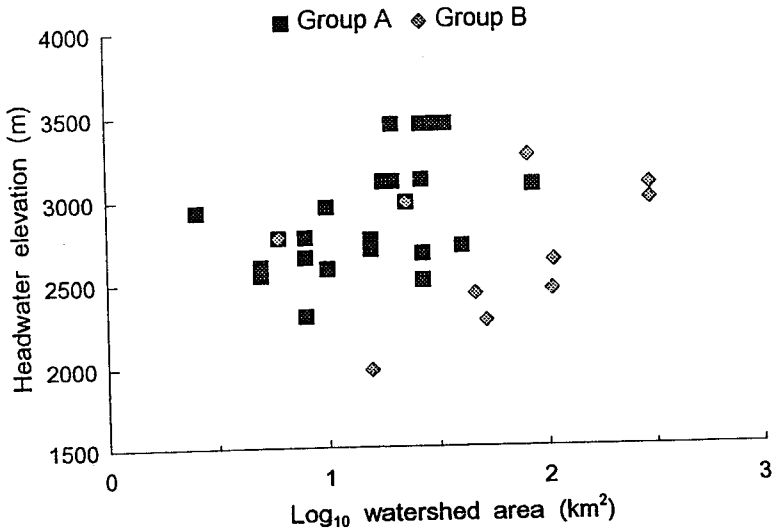


FIG. 5. Winter-emerging stoneflies in seasonal streams (types M and P) in New Mexico segregated by watershed area and headwater elevation. Group A consists of high elevation species: *M. werneri, C. fibula, C. wanica, I. vedderensis, T. jacobii, E. brevicauda, C. decepta,* and *C. californica*. Group B consists of lower elevation species: *M. arizonensis* and *M. frisoni*.

ensis, and *C. californica*. These associations suggest that these 8 species (Group A) share similar habitat requirements in New Mexico.

Mesocapnia arizonensis was observed at 7 localities. The only other species with which it shared a site was *M. frisoni*. Collectively these 2 species were found only 4 times with species in Group A and they had the lowest mean collection elevations (Fig. 4). They form Group B.

The maximum elevation of land in the contributing watershed in which a species was found was plotted against the watershed area upstream from the point of collection for seasonal streams, hydrologic types M and L (Fig. 5). Group A species occurred mainly in higher elevation streams with smaller watersheds (type M). Group B species occurred in low elevation streams with larger watersheds (type L). Group B species also occurred in some of the higher altitude streams.

Discussion

In this paper we have documented the presence of 10 species of winter stoneflies in ahyporheic environments. Thirteen other winter-emerging Plecoptera are found in New Mexico, but are not known to occur in temporary habitats (Jacobi and Baumann 1983). We first believed that observed occurrences in temporary habitats represented occasional introductions. For example, aquatic macroinvertebrates are known to colonize new habitats through flight by adults, drift by immatures, and upstream movement by larvae (Williams and Hynes 1976). After all, many study area streams have a perennial section (Type P) between the upstream (type M) and downstream (type L) ephemeral reaches that could serve as a continual source of new introductions.

Now we believe winter-emerging Plecoptera have lived and completed their life cycles in these ahyporheic environments since the wetter Pleistocene (Stewart et al. 1974, Jacobi and Cary 1986). Drift cannot explain the presence of up to 150 *M. frisoni* larvae/m^2, at a site 20 km downstream from perennial water, as occurred in Las Animas Creek 3 wk after a rising water table created surface flow at the collection site. Similarly, flight by adults cannot explain the presence of *C. californica* in Indian Creek, 50 km from the nearest known population in the Chiricahua Mountains in Arizona (E. C. Masteller, personal communication).

Survival in seasonal habitats is credible considering the presence of several adaptive mechanisms exhibited by study area organisms. For example, small adult size helps to minimize du-

ration of the developmental period (Hynes 1976, Stewart and Stark 1988), whereas a long development period (larger size) would be non-adaptive in short-lived habitats. The smallest adults (5.0–7.1 mm) were seen in *M. arizonensis* and *C. californica*—some of the smallest of North American Plecoptera. Brief development time has been reported for Lepidoptera that are sensitive to seasonal moisture (Ross 1995) and for some Ephemeroptera and Plecoptera in temporary habitats and those that periodically flood (Hynes 1941, 1976, Gray 1981, Nolte et al. 1996).

In some temporary or seasonal habitats, larvae migrate vertically within the hyporheic zone (Williams 1977). Smaller Plecoptera larvae might be able to penetrate farther down into the substrate of a desiccating streambed because they would be less hindered by the small size of interstices. Snellen and Stewart (1979) extracted substrate of an ephemeral stream to a depth of 1 m and found 1 half-grown larva of a small species, *Zealeuctra claasseni*, in Texas. Small size of larvae may be important for survival in hyporheic zones, but the ability to penetrate substrates is irrelevant in ahyporheic environments.

Diapause is widespread in winter-emerging Plecoptera and provides the group with a valuable survival mechanism. Diapause is known to occur in *M. arizonensis* in the region (Gray 1981) and for capniids in general in the egg stage (Harper and Hynes 1972, Snellen and Stewart 1979, Stewart and Stark 1988). Winter streamflow is essential for winter-emerging stoneflies, but dry conditions during the rest of the year may have minimal influence. Eggs are deposited when the stream is flowing, fall to the substrate, remain there while the streambed is dry for several months, then resume development when winter flows return (K. W. Stewart, University of North Texas, personal communication). Because the tolerant egg stage can withstand drying or other unsuitable external conditions, the organism is able to occupy an otherwise inhospitable habitat. Neither several months of desiccation nor summer flash floods appear to be serious obstacles to these taxa. The geographic extent of this phenomenon is likely to be much greater than previously thought, probably occurring throughout western North America.

Multi-year diapause is well documented among Lepidoptera (Scott 1986). Some desert Lepidoptera can stay in diapause for more than 15 y then conclude development when environmental conditions are right (Powell 1989). It is unknown how long winter-emerging Plecoptera can stay in diapause, but Snellen and Stewart (1979) suggest that it could be for several years. Species with multi-year diapause would have an additional advantage in southwestern streams with unpredictable winter flow from year to year.

Most winter stoneflies are weak fliers (Hynes 1976, Stewart and Stark 1988), in contrast to other aquatic insects that specialize in temporary environments and are strong fliers. Representatives of Coleoptera, Hemiptera, and Odonata in temporary habitats depend on flight to find, colonize, and use temporary habitats (Williams 1996). These strong-flying insects can fly many km to new habitats to complete their life cycles. Weak flight of southwestern winter-emerging Plecoptera (e.g., *C. fibula* males are brachypterous) is not maladaptive, despite the seasonality and disjunct nature of some local stream habitats. Our study Plecopera have no need to fly great distances to new habitats because other adaptations, such as egg diapause and small size, allow them to wait in the existing habitat until conditions are favorable for completion of the life cycle.

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APPENDIX 1. Winter stonefly records and supporting data from selected (70) collection sites. Hydrologic types are: M = small montane snowmelt-driven ahyporheic stream; P = perennial or near-perennial stream with hyporheic zone; L = lowland groundwater-driven ahyporheic stream.

Stream	Mountain range	County	Water-shed area (km^2)	Ele-vation (m)	Source (m)	Hydro-logic type	Species
Water Canyon	Magdalena	Socorro	18	2146	3100	M	*Capnia decepta*
			20	1981	3100	M	*C. decepta*
Las Animas Creek	Black	Sierra	311	1293	3075	L	*Mesocapnia frisoni*
Oak Springs Canyon	Black	Sierra	16	1590	1975	L	*M. frisoni*
Percha Creek	Black	Sierra	194	1600	2975	P/L	*M. frisoni*
Percha Creek	Black	Sierra	75	1605	2975	P/L	*M. frisoni*
Percha Creek	Black	Sierra	130	1750	2975	P	*Mesocapnia arizonensis*
Percha Creek	Black	Sierra	26	1870	2975	M/P	*C. decepta*
Percha Creek	Black	Sierra	23	1900	2975	M	*Capnura fibula*
							M. frisoni
							C. decepta
Sawpit Creek	Black	Sierra	8	1950	2650	M/P	*M. arizonensis*
Berrenda Creek	Black	Sierra	47	1700	2425	L	*M. arizonensis*
Chloride Creek	Black	Sierra	41	1913	2710	M	*C. decepta*
Macho Canyon	Black	Sierra	52	1630	2265	L	*M. arizonensis*
Iron Creek	Black	Grant	3	2350	2930	M	*Mesopcapnia werneri*
							Eucapnopsis brevicauda
Iron Creek	Black	Grant	8	2149	2930	M	*E. brevicauda*
							M. werneri
Gallinas Canyon	Black	Grant	49	2060	2930	M/P	*E. brevicauda*
							C. decepta
Dry Gallinas	Black	Grant	8	2033	2650	M	*C. decepta*
Mimbres River	Black	Grant	313	1730	3051	P	*C. decepta*
Hadley Draw	Cooke's	Luna	8	1700	2565	P/L	*M. arizonensis*
Indian Creek	Animas	Hidalgo	5	1935	2600	M	*Capnia californica*
Sotol Creek	Organ	Dona Ana	3	1800	2560	M/P	*C. decepta*
Sapello Creek	Pinos Altos	Grant	132	1844	2194	P	*M. frisoni*
Sapello Creek	Pinos Altos	Grant	212	1770	2194	P	*M. frisoni*
							C. decepta
							E. brevicauda
Gila River	Mogollon	Grant	4827	1356	3283	P	*M. frisoni*
E. Fork Gila River	Black	Catron	414	1620	2705	P	*M. frisoni*
E. Fork Gila River	Black	Grant	388	1690	2705	P	*M. frisoni*
W. Fork Gila River	Mogollon	Catron	1318	1716	3283	P	*C. decepta*
W. Fork Gila River	Mogollon	Catron	1297	1735	3283	P	*C. decepta*
W. Fork Gila River	Mogollon	Catron	1300	1730	3283	P	*C. decepta*
Cliff Dweller Canyon	Mogollon	Catron	5	1753	1829	M/P	*C. decepta*
							E. brevicauda
Little Creek	Mogollon	Catron	144	1700	2660	P	*C. decepta*
							E. brevicauda
							M. frisoni
Little Cherry Creek	Pinos Altos	Grant	16	2100	2755	M	*C. decepta*
							M. werneri
							Taenionema jacobii
Cherry Creek	Pinos Altos	Grant	18	2012	2740	M/P	*M. werneri*
							C. decepta
Bear Creek	Pinos Altos	Grant	34	1950	2780	M/P	*C. decepta*
							T. jacobii
Bear Creek	Pinos Altos	Grant	28	2100	2780	M/P	*T. jacobii*
Big Dry Creek	Mogollon	Grant	83	1470	3250	L	*M. arizonensis*

APPENDIX 1. Continued.

Stream	Mountain range	County	Water-shed area (km²)	Ele-vation (m)	Source (m)	Hydro-logic type	Species
Duck Creek	Mogollon	Grant	104	1370	2450	L	*M. frisoni*
Mule Creek	Brushy	Grant	44	1591	2119	P/L	*M. frisoni*
							M. arizonensis
Whitewater Creek	Mogollon	Catron	117	1427	3320	P	*M. frisoni*
		Catron	104	1555	3320	P	*C. decepta*
							E. brevicauda
Silver Creek	Mogollon	Catron	10	2030	2950	M	*C. decepta*
Mineral Creek	Mogollon	Catron	88	1486	3075	M	*C. decepta*
San Francisco River	San Francisco	Catron	4281	1521	2639	P	*M. frisoni*
		Catron	181	2250	2639	P	*C. fibula*
		Catron	3416	1707	2639	P	*M. frisoni*
		Catron	3108	1750	2639	P	*M. frisoni*
Cottonwood Canyon	San Francisco	Catron	31	1770	2675	M/P	*E. brevicauda*
							C. decepta
							Isocapnia vedderensis
							C. californica
Dry Leggett Creek	San Francisco	Catron	16	2238	2695	M	*C. fibula*
Starkweather Canyon	San Francisco	Catron	106	1800	2620	L	*M. frisoni*
Tularosa River	San Francisco	Catron	311	1814	2985	L	*M. frisoni*
Apache Creek	Gallo	Catron	311	1953	2860	L/P	*M. frisoni*
Yankee Gulch	Gallo	Catron	6	2055	2770	M	*M. frisoni*
							C. fibula
Bluewater tributary	Zuni	Cibola	6	2345	2550	M	*C. fibula*
Bluewater Creek	Zuni	Cibola	90	2309	2770	P	*C. fibula*
Bluewater tributary	Zuni	Cibola	8	2290	2770	M	*C. fibula*
Bluewater Creek	Zuni	Cibola	18	2287	2821	P	*C. fibula*
Rio Nutria	Zuni	McKinley	145	2171	2630	P	*C. fibula*
Water Canyon	Taylor	Cibola	27	2233	3445	M	*C. decepta*
			30	2195	3445	M	*C. decepta*
			35	2085	3445	M	*C. decepta*
Rinconada Creek	Taylor	Cibola	20	2043	3445	M	*C. decepta*
							Capnura wanica
Oak Creek	Johnson Mesa	Union	25	1900	2250	M/P	*C. fibula*
Trinchera Creek	Johnson Mesa	Colfax	8	2011	2300	M	*C. decepta*
							C. fibula
Rathbun Creek	Johnson Mesa	Colfax	10	2261	2580	M	*C. fibula*
San Isidro Creek	Johnson Mesa	Colfax	27	2231	2510	M	*C. fibula*
Chicorica Creek	Johnson Mesa	Colfax	27	2225	2668	M	*C. wanica*
							C. decepta
Water Canyon	Johnson Mesa	Colfax	38	2194	2688	M/P	*C. fibula*
			55	2066	2688	M/P	*C. wanica*
Le Cueva Creek	Sangre de Cristo	Santa Fe	27	1981	3109	M	*I. vedderensis*
El Porvenir Creek	Sangre de Cristo	San Miguel	60	2286	3500	P	*I. vedderensis*

U.S. Fish and Wildlife Service
Exhibit 9

FWS/OBS-83/28
SEPTEMBER 1983

PLAYA WETLANDS AND WILDLIFE ON THE SOUTHERN GREAT PLAINS: A CHARACTERIZATION OF HABITAT

Fish and Wildlife Service

In cooperation with
U.S. Environmental Protection Agency

U.S. Department of the Interior

A related publication on playa wetlands is also available from the U.S. Fish and Wildlife Service:

Playa wetlands and wildlife on the Southern Great Plains: A guide to habitat management. FWS/OBS-83/29.

FWS/OBS-83/28
September 1983

PLAYA WETLANDS AND WILDLIFE ON THE SOUTHERN GREAT PLAINS: A Characterization of Habitat

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Dr. Fred S. Guthery, Department of Range and Wildlife Management, Texas Tech University (Lubbock), was the principal advisor to the study team. Lori Hight of Nelson and Associates in Boulder, Colorado, developed or adapted the maps and other illustrations; Esther Goodyear provided the word processing service; and Patrice Braverman composed the report.

EXECUTIVE SUMMARY

The Southern Great Plains playa wetland region encompasses the Llano Estacado (Southern High Plains) of the Texas Panhandle and adjacent eastern New Mexico, and extends north of the Canadian River through the Oklahoma Panhandle into southwest Kansas and southeast Colorado. For study purposes, the region is partitioned into five zones having distinct land use, hydrologic, and soil characteristics. Because high-value playa wildlife habitat concentrates in one zone (Irrigated Cropland) near the center of the study region, most wildlife studies from which the habitat characterization is drawn will pertain to this zone. Every effort is made to show the environmental differences in other zones so varying habitat values may be inferred.

Although playa habitat is well known for its importance to migratory waterfowl in the Central Flyway, its value to resident wildlife is even more pronounced since wetlands are so scarce in this dry farmland region. The characterization incorporates recent research findings in a synthesis of knowledge about the habitat values of playa wetlands.

PLAYA REGIONAL GEOGRAPHY

Playas are either ephemeral or permanent lakes or wetlands, depending on the water depth and persistence, and on the presence of aquatic vegetation. Under the National Wetland Classification System, all playas are classified as palustrine or lacustrine wetlands. A variety of theories have been advanced to explain the origin of playas. There are approximately 25,000 playas within the 68,500-mi^2 (177,400-km^2) Southern Great Plains playa region, with an average surface density generally under 20 ac/mi^2 (about 3 ha/km^2 or 3% of land surface). The majority of playa basins are under 10 ac (4 ha), but they range as high as 600 ac (240 ha) covering the area of wetland soils. During a wet season, the average *water* surface density may be as high as 4 ac/mi^2 (2/3 ha/km^2) in the Irrigated Cropland Zone, but less than 0.2 ac/mi^2 (0.03 ha/km^2) in a dry season.

The semiarid regional climate varies from dry steppe to warm temperate, with annual precipitation averaging 15-22 in (38-56 cm), and mean annual evaporation of about 100 in (254 cm). The main geologic feature is the Ogallala Aquifer which supplies irrigation water often collected in playas, enhancing aquatic habitat, particularly in the west-central Texas Panhandle. Soils range from fine sand to silty clay loam, the latter associated with larger, shallower playas. Most of the study region is smooth plains and shortgrass prairie with production of grains, cotton, cattle, oil and gas as the primary land uses.

PLAYA BASIN ENVIRONMENT

The physical environment of playas is characterized by distinctive soil-water relationships. Soils are generally clays that form a highly impermeable seal, thereby increasing playa water-holding capacity. This feature promotes their use and modification for collection and recycling of irrigation tailwater, while also enhancing scarce wetland wildlife habitat. Soil texture and percolation vary significantly north and south through the playa region; water retention is maximum in the fine-texture area of the west-central Texas Panhandle. This area also has a higher average playa surface density, and irrigated farmland concentrates here.

Water ordinarily accumulates in unmodified playas during late spring and gradually subsides through the summer. Playas modified to store and reuse irrigation tailwater will sustain a larger water surface or volume over a longer period. Most water contained in unmodified playas and not used in irrigation is lost by evaporation before winter. Water quality in unmodified freshwater playas is generally uniform and suitable for irrigation as well as fish and wildlife habitats; saline playas have limited value.

ECOLOGY OF PLAYA BASINS

Variables affecting the value of playa wildlife habitat may include watershed size and the water surface area and depth; type, height, density, and interspersion of vegetation, and the extent of emergent vegetation; land use, particularly grazing and cultivation; and the extent of modification, particularly excavation and diking. There is considerable variation in annual precipitation and runoff and, therefore, in habitat values, especially for wildlife populations linked with the aquatic environment. Larger playas that collect irrigation tailwater and are not cultivated or heavily grazed appear to provide the best wildlife cover—vegetation that is tall, dense, diverse, and persistent. Those playas modified to concencentrate water can sustain more open water and emergent vegetation during dry years.

Cropland playas containing fresh open water provide valuable waterfowl loafing, roosting, watering, and foraging sites adjacent to grain fields used for feeding. Even without open water, playa wetlands provide important winter cover for upland game birds, raptors, and passerines. Playas offer valuable nesting cover for pheasant and some species of ducks. Coyotes, raccoons, rabbits, ground squirrels, and mice are among the abundant mammals at playa basins. Salamanders and frogs as well as snakes, lizards and turtles are found among the indigenous amphibians and reptiles; most fish populations are introduced. Invertebrates important in the food chain include grasshoppers, fairy shrimp, and snails. Playa habitats also may promote a number of diseases in wildlife—encephalitis, avian cholera, botulism, and duck schistosomiasis.

PLAYA USES AND MODIFICATIONS

The impoundment of natural runoff in playa basins during a wet year may reach the equivalent of all groundwater pumped annually from the Ogallala Aquifer in the Southern Great Plains. However, the accumulation of runoff, particularly in a dry year, may not coincide with optimum irrigation scheduling; stored water may evaporate and seep from playas before it is needed. Therefore, the practical use of playa water for irrigation would require basin modifications such as excavation and diking to concentrate water storage and reduce evaporation. Many irrigated cropland playas, particularly the larger ones, also receive irrigation runoff (tailwater) which is recycled; most of these basins have been altered to reduce evaporation. However, current efforts at water conservation, such as conversion to low-pressure aerial spraying, are expected to greatly reduce tailwater.

Many farmers plant crops into the margins of playas or, in smaller basins less subject to flooding and crop failure, cultivate the entire playa. Year-round grazing at rangeland playas is widespread; many larger cropland playas are grazed between harvest and planting. Numerous playa basins are modified to concentrate water for livestock use. Some playas are used for disposal of feedlot waste, but recycling of untreated feedlot runoff for irrigation could lead to groundwater pollution. Disposal of oil field brine in playas can contaminate surface and groundwater with salt, hydrocarbons, and other accumulations.

Hunting for pheasants, ducks, geese and cranes is the main recreational use of playas. Pheasants congregate at cropland playas during winter when cover is scarce. Large playas with abundant, shallow open water are more likely to be used by geese and cranes, as well as pintails and wigeons; many ducks such as mallard and green-winged teal are more attracted to smaller playas with dense emergent vegetation. There is some use of playa lakes as sport fisheries.

IMPACTS ON PLAYA WILDLIFE HABITAT

There are losses and gains among various playa lake and wetland wildlife communities of the Southern Great Plains as a result of agriculture and other human activities. Adverse impacts linked with crop production

focus on reduced habitat diversity or carrying capacity in playas disturbed by the cultivation of crops and burning of weeds; basin modifications to store irrigation tailwater, which reduces the highly productive littoral zone and concentrates waterfowl during dry periods, increasing the disease potential; and the application of chemicals for mosquito and weed control, increasing the potential for wildlife toxicity. Offsetting benefits include the availability of waste grain from irrigated row crops as a wildlife food source; increased density and diversity of wildlife cover from reception of irrigation tailwater in undisturbed playa basins; and preservation of some aquatic habitat during drought because of basin modifications to concentrate stored natural runoff and tailwater.

Impacts from livestock production stem from overgrazing of playas and potential pollution from feedlot runoff. On the other hand, managed grazing can benefit wildlife cover and food supplies, and collected feedlot runoff can help sustain aquatic habitat. Although basin modifications to concentrate water storage may aggravate avian cholera, other diseases are better controlled where shallow aquatic area is reduced by excavation and diking.

On balance, present agricultural practices, especially the collection of tailwater in undisturbed playas, may produce more benefits than liabilities for wildlife in the Southern Great Plains. However, the projected trends for curtailment of groundwater supplies and irrigated crop production indicate greatly reduced tailwater input to playas and, ultimately, reversion to dry land farming with adverse effects on wildlife dependent on a wetland environment. The importation of irrigation water from outside the region, as proposed in recent years, could ameliorate this future impact.

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4.3 OTHER WILDLIFE POPULATIONS AND INVERTEBRATES

Certain mammals, reptiles, amphibians, fish, and invertebrates are linked to playa environments. Concentration of water that provides a drinking source and promotes cover in a relatively dry, barren region is a prime factor in promoting the variety of other wildlife populations and invertebrates that inhabit playa basins.

Mammals of Playa Basins. Many large and small mammals, including some predators, are attracted to playa basins; cropland playas are particularly attractive (Figure 4-11). Pronghorn antelope, mule deer, and white-tailed deer are examples of large mammals that sometimes use playa habitats. At one time, the Texas High Plains was a region of pronghorn abundance (Leftwich and Simpson 1977). Their large numbers were tied to the surface waters found in draws and basins, as well as the integrity of the shortgrass prairie ecosystem (Bolen, Simpson and Stormer 1979). Simpson and Bolen (1981) reported that present populations of pronghorns occur in small groups on the larger ranches of the Southern High Plains (Llano Estacado). Mule deer of the region tend to congregate in the broken hill country, while white-tailed deer are generally found in the plains brushlands. Playa basins may be used by deer as a source of food and water.

Rodents and lagomorphs depend on playas for refuge and food, especially in the agriculturally intensive areas. These small animals are confined for the most part to the playas, draws, rangelands, and weedy areas throughout the farmed fields (Simpson and Bolen 1981; Curtis and Beierman 1980). Ragweed and kochia supported the highest density and diversity of small mammals; deer mice were the most common species encountered, followed by 13-lined ground squirrels and house mice (Simpson and Bolen 1981). In addition to jackrabbits, desert and eastern cottontails frequently are observed in playa basins; playas having permanent cover contribute a substantial portion of their diet (Simpson and Bolen 1981; Scribner and Krysl 1980). The size of the playa lake or wetland, water availability, and types of vegetation largely govern the population size and species composition of small mammals found within the basin.

Predators linked with playas include coyotes, badgers, raccoons, weasels, swift foxes, skunks, and oppossums. Coyotes frequently are sighted in or adjacent to playas where their needs for food, water and cover are satisfied. Whiteside and Guthery (1981) noted the high availability and diversity of playa food sources preferred by coyotes. Badger dens commonly are excavated from earth banks in modified playas or on the periphery of the unaltered basin; generally they are associated with rangeland playas (Simpson and Bolen 1981). Raccoons along with coyotes are the dominant furbearers of the playas (Curtis and Beierman 1980). Those playas containing dense vegetation and cover are preferred by raccoons; nearly 70% of their den sites are located within the basins of playas containing thick cover (Juen 1981). (A checklist of mammals that inhabit playa basins is found in Appendix C.)

Reptiles, Amphibians, and Fishes. Curtis and Beierman (1980) reported that, although reptiles are not commonly observed, amphibians are a typical resident of playa habitat. Except for Rose and Armentrout (1975), there has been little study of playa herpetology. Some of the more familiar reptiles observed around playa basins include the southern prairie lizard, Texas horned lizard, Great Plains skink, checkered garter snake, blotched water snake, western hognosed snake, yellow mud turtle, and western diamondback rattlesnake. Amphibians of the Southern Great Plains have a critical need for the aquatic habitat of playa basins. Following spring rains, breeding in playa wetlands reaches a peak, producing large numbers of young amphibians. Commercial harvest of salamanders and newts at playa basins is rare.

Figure 4-11. Cropland playa supporting a mix of wet meadow, tall disturbed forbs, and short- to mid-grass vegetation, yielding good wildlife values. Plowing does not heavily encroach upon the playa basin, allowing native vegetation to flourish and provide cover for many varieties of wildlife (Texas Tech University, Department of Range and Wildlife Management 1981).

Examples of amphibians associated with playas include eastern tiger salamanders, spadefoot toads, and leopard frogs.

Fisheries of playa lakes are quite limited; most lakes are uninhabited by fish (Curtis and Beierman 1980). Some of the larger playa lakes that hold water year-round have been stocked for sport fishing. Other, more ephemeral lakes have been stocked on a temporary basis for the purpose of mosquito control. Some of the species introduced into playa lakes include bluegill, goldfish, largemouth bass, black bullhead, channel catfish, carp, and golden shiner. A playa permanently flooded as a result of collecting both irrigation tailwater and feedlot runoff could be a good candidate for aquaculture because of the nutrient enrichment (Figure 4-12). (A further listing of reptiles, amphibians, and fish associated with playa environments is provided in Appendix D.)

Invertebrates of Playa Basins. Sublette and Sublette (1976) noted the importance of invertebrate production in playa basins to their basic food chains; the variety of species and their abundance is as diverse as the playas, depending on the character of playa vegetation. Rhodes and Garcia (1981) observed significantly higher insect production at unmodified playas as compared with modified basins. Over 60 species of macroinvertebrates were collected from two playas near Lubbock, Texas, by Merickel and Wangberg (1981). The most well-known invertebrate produced in playa lakes and wetlands is the mosquito. A playa is a prime environment for mosquito breeding, resulting in extensive efforts directed towards mosquito control (Lubbock City-County Health Unit 1962). Examples of other invertebrates produced in playa basins include fairy shrimp, snails, leeches, water striders, mayflies, bees, and grasshoppers. (A more extensive list of invertebrates found in playas is furnished in Appendix E.)

4.4 WILDLIFE DISEASES ASSOCIATED WITH PLAYAS

Thousands of waterfowl and other wildlife are lost each year to diseases that are endemic to playa basins. Biotic, climatic, physical, and land use factors combine to create and perpetuate conditions that promote encephalitis, avian cholera, botulism, and duck schistosomiasis.

St. Louis encephalitis and western equine encephalitis, arbovirus diseases, are endemic to the Southern Great Plains, causing periodic outbreaks in wildlife populations (Pence 1981). Avian or fowl cholera, a highly pathogenic bacterial disease caused by *Pasteurella multocida*, is also endemic to the region. This disease was first reported in wild ducks during a 1944 epidemic at the Muleshoe National Wildlife Refuge in the Texas Panhandle (Quortrup, Queen and Merovka 1946). Jenson and Williams (1964) reported that botulism, an extremely pathogenic bacterial disease caused by *Clostridium botulinum*, occurs seasonally in some playa basins. Another playa-associated disease, duck schistosomiasis, affects a great many waterfowl. The disease is caused by a parasitic blood fluke and is highly pathogenic to young birds.

Factors Contributing to Disease. Several factors contribute to the transmission of playa disease organisms to wildlife. Disease may be present in the soil or water and in host organisms, and reservoirs of infection may be present among birds already diseased. Large numbers of animals congregating at relatively small sites enhance disease transmission. Irrigation practices and climate may produce water fluctuations and broad expanses of shallow water, all of which contribute to the periodicity and endemic nature of these epizootics.

The two varieties of arboencephalitis found in the Southern Great Plains have a common vector in the mosquito, *Culex tarsalis* (Grubb, Parks and Sciple 1968). The

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APPENDIX A

Plants of Playas and Associated Habitats in the Southern High Plains (Llano Estacado) Study Area of Curtis and Beierman (1980).

Scientific Name	Common Name
FAM. EQUISETACEAE	
Equisetum arvense	Common horsetail
FAM. MARSILEACEAE	
Marsilea mucronata	Hairy pepperwort
FAM. TYPHACEAE	
Typha latifolia[1]	Common cattail
FAM. POTAMOGETONACEAE	
P. natans	Floatingleaf pondweed
P. pectinatus	Fennelleaf pondweed
Zannichellia palustris	Common poolmat
FAM. NAJADACEAE	
Najas flexilis	Southern waternymph
FAM. ALISMATACEAE	
Sagittaria cuneata	Northern arroweed
FAM. GRAMINEAE	
Agropyron smithii[1]	Western wheatgrass
Aristida spp.[1]	Threeawns
Bahia woodhousii	Bahiagrass
Bothriochloa saccharoides var. *torreyana*	Silver bluestem
Bouteloua barbata	Six-weeks grama
B. curtispendula	Sideoats grama
B. gracilis[1]	Blue grama
B. secalinus	Cheatgrass
Buchloe dactyloides[1]	Buffalograss
Cenchrus spp.	Sandbur
Chloris andropogonoides[1]	Windmillgrass
Cynodon dactylon	Common bermudagrass
Echinochloa crusgalli[1]	Barnyardgrass
Elymus canadensis[1]	Canada wildrye
Eragrostis cilianensis	Stinkgrass
E. intermedia	Plains lovegrass
Hilaria mutica	Tobosa
Hordeum jubatum[1]	Foxtail barley
Leptochloa sp.	Sprangletop
Muhlenbergia arenicola	Sand muhly
Panicum capillare[1]	Common witchgrass
P. hallii	Halls panicum

APPENDIX A (continued)

Scientific Name	Common Name
FAM. GRAMINEAE (continued)	
P. virgatum[1]	Switchgrass
P. obtusum	Vine mesquite
Schizachyrium scoparium	Little bluestem
Schleropogon brevifolius	Burrograss
Setaria italica	Foxtail bristlegrass
S. viridis	Green bristlegrass
Sorghum halepense[1]	Johnsongrass
S. vulgare var. *technicum*	Sorghum
Spartina pectinata	Prairie cordgrass
Sporobolus airoides	Alkali sacaton
S. asper var. *hookeri*	Meadow dropseed
S. cryptandrus	Sand dropseed
S. poiretii	Rattail smutgrass
Triticum aestivum[1]	Wheat
Vulpia octoflora var. *glauca*	Six-weeks fescue
Zea mays var. *indentata*[1]	Field corn
FAM. CYPERACEAE	
Carex spp.	Sedge
Cyperus esculentus	Chufa
Eleocharis macrostachya	Creeping spikerush
E. palustris[1]	Spikerush
Scirpus acutus	Hardstem bulrush
S. americanus	American bulrush
S. validus[1]	Softstem bulrush
FAM. JUNCACEA	
Juncus spp.	Rush
FAM. LILIACEAE	
Nothoscordum bivalus	Crowpoison
Yucca spp.	Yucca
FAM. SALICACEAE	
Populus deltoides	Eastern cottonwood
Salix sp.	Willow
FAM. ULMACEAE	
Celtis occidentalis	Hackberry
Ulmus parvifolia	Chinese elm
FAM. MORACEAE	
Maclura pomifera	Osage orange
Morus rubra	Red mulberry

APPENDIX A (continued)

Scientific Name	Common Name
FAM. URTICACEAE	
Urtica gracilis	Slim nettle
FAM. POLYGONACEAE	
Eriogonum spp.	Wildbuckwheat
Polygonella sp.	Jointweed
Polygonum aviculare[1]	Prostrate knotweed
P. coccineum[1]	Bigroot smartweed
P. lapathifolium	Curltop smartweed
Rumex crispus[1]	Curly dock
FAM. CHENOPODIACEAE	
Allenrolfea occidentalis	Pickleweed
Chenopodium album	Lambsquarters
Chenopodium sp.[1]	Goosefoot
Kochia scoparia[1]	Belvedere summercypress
Salsola kali[1]	Russianthistle
FAM. AMARANTHACEAE	
Amaranthus palmeri[1]	Palmer amaranth
Gossypium hirsutum	Cotton
FAM. AIZOACEAE	
Sesuvium portulacastrum	Purslane sesuvium
FAM. CRUCIFERAE	
Descurainia spp.	Tansymustard
Lepidium spp.[1]	Pepperweed
Lesquerella spp.[1]	Bladderpod
Rorippa sinuata[1]	Spreading yellowcress
Sisymbrium altissimum	Tumblemustard
FAM. LEGUMINOSAE	
Acacia greggii	Catclaw acacia
Amorpha canescens	Leadplant
Astragalus distortus	Bentpod milkvetch
Cassia fasciculata	Partridge pea
Gleditsia triacanthos	Common honeylocust
FAM. LEGUMINOSAE	
Hoffmanseggia densiflora	Indian rushpea
Lespedez striata	Japanese lespedeza
Medicago sativa	Alfalfa
Melilotus officinalis	Yellow sweetclover
Oxytropis lambertii	Lambert crazyweed
Prosopis glandulosa[1]	Honey mesquite

APPENDIX A (continued)

Scientific Name	Common Name
FAM. OXALIDACEAE	
Oxalis dillenii	Woodsorrel
FAM. ZYGOPHYLLACEAE	
Tribulus terrestris	Goathead
FAM. EUPHORBIACEAE	
Cnidoscolus texanus	Texas bullnettle
Croton spp.	Croton
Euphorbia marginata[1]	Snow-on-the-mountain
E. prostrate	Prostrate suphorbia
Stillingia sylvatica	Queensdelight
FAM. MALVACEAE	
Malva neglecta	Common mallow
Sphaeralcea spp.	Globemallow
FAM. TAMARICACEAE	
Tamarix gallica[1]	Saltcedar
FAM. CACTACEAE	
Opuntia leptocaulis	Tasajillo
Opuntia sp.[1]	Pricklypear
FAM. ONAGRACEAE	
Oenothera canescens[1]	Beakpod evening primrose
Oenothera sp.	Evening primrose
FAM. ASCLEPIADACEAE	
Asclepias syriaca	Milkweed
Asclepias sp.	Milkweed
FAM. CONVULVULACEAE	
Calystegia sepium	Hedge bindweed
Convolvulus arvensis	Field bindweed
Cuscuta gronovii[1]	Dodder
FAM. BORAGINACEAE	
Heliotropium curassavicum	Salt heliotrope
FAM. VERBENACEAE	
Phyla incisa[1]	Sawtooth fogfruit
Verbena bracteata[1]	Bigbract verbena
FAM. LABIATAE	
Salvia spp.	Sage

APPENDIX A (concluded)

Scientific Name	Common Name
FAM. SOLANACEAE	
Physalis heterophylla	Clammy groundcherry
Solanum elaeagnifolum[1]	Silverleaf nightshade
S. rostratum[1]	Buffalobur
FAM. SCROPHULARIACEAE	
Linaria vulgaris[1]	Common toadflax
FAM. MARTYNLACEAE	
Martynia louisianica	Common devilclaws
FAM. PLANTAGINACEAE	
Plantago aristata	Bottlebrush plantain
FAM. RUBIACEAE	
Diodia teres	Rough buttonweed
FAM. CUCURBITACEAE	
Cucurbita foetidissima	Buffalogourd
FAM. COMPOSITAE	
Ambrosia artemisiifolia	Common ragweed
A. cheiranthifolia	Ragweed
A. psilostachya[1]	Western ragweed
A. trifida	Giant ragweed
Aster spp.	Aster
Berlandiera sp.	Greeneyes
Cirsium arvense	Thistle
Coreopsis tinctoria	Plains coreopsis
Croptilon sp.	Croptilon
Engelmannia pinnatifida	Engelmann daisy
Erigeron canadensis[1]	Fleabane
Grindelia squarrosa[1]	Broadleaf gumplant
Helianthus ciliaris[1]	Blueweed sunflower
H. decapetalus[1]	Sunflower
Helianthus sp.	Sunflower
Hymenoxys odorata	Western bitterweed
Iva sativa	Sumpweed
Lactuca serriola	Prickly lettuce
Ratibida peduncularis var. *tagetes*[1]	Shortray prairie-coneflower
Senecio longilobus	Threadleaf groundsel
Sonchus oleraceous	Common sowthistle
Tragopogon porrifolius	Vegetable-oyster salsify
Xanthium strumarium	Cocklebur
Xanthocephalum sp.	Broomweed

[1] Indicates most commonly noted

APPENDIX B

Birds of Playas and Associated Habitats in the Southern High Plains (Llano Estacado) Study Area of Curtis and Beierman (1980).

Scientific Name	Common Name
FAM. PODEIPEDIDAE	
Podihymbus podiceps[1]	Pied-billed grebe
Podiceps caspicus	Eared grebe
FAM. ANATIDAE	
SUB. FAM. ANSERINAE	
Branta canadensis	Canada goose
Anser albifrons	White-fronted goose
Chen caerulescens	Snow goose
SUB. FAM. ANATINAE	
Anas platyrhynchos[1]	Mallard
A. acuta[1]	Pintail
A. strepera	Gadwall
Mareca americana[1]	American wigeon
Spatula clypeata[1]	Shoveler
Anas discors[1]	Blue-winged teal
A. cyanoptera	Cinnamon teal
A. carolinensis	Green-winged teal
SUB. FAM. AYTHYINAE	
Aythya americana[1]	Redhead
Aythya valisineria	Canvasback
SUB. FAM. OXYURINAE	
Oxyura jamaicensis	Ruddy duck
FAM. CATHARTIDAE	
Cathartes aura	Turkey vulture
Coragyps atratus	Black vulture
FAM. ACCIPITRIDAE	
Circus cyaneus[1]	Marsh hawk
Buteo lagopus	Rough-legged hawk
B. regalis	Ferruginous hawk
B. Swainsoni	Swainson's hawk
Aquila chrysaetos	Golden eagle
Haliaeetus leucocephalus	Bald eagle
FAM. FALCONIDAE	
Falco mexicanus	Prairie falcon
F. peregrinus	Peregrine falcon
F. sparverius	American kestrel
FAM. MELEAGRIDIDAE	
Meleagris gallopavo	Turkey

APPENDIX B (continued)

Scientific Name	Common Name
FAM. TETRAONIDAE	
Tympanuchus pallidinctus	Lesser prairie chicken
FAM. PHASIANIDAE	
Callipepla squamata	Scaled quail
Colinus virginianus	Bobwhite quail
Phasianus colchicus[1]	Ring-necked pheasant
FAM. ARDEIDAE	
Casmerodius albus	Great egret
Bubulcus ibis	Cattle egret
Ardea herodias[1]	Great blue heron
Florida caerulea	Little blue heron
Nycticorax nycticorax	Black-crowned night heron
FAM. THRESKIORNITHIDAE	
Plegadis chihi	White-faced ibis
FAM. GRUIDAE	
Grus americana	Whooping crane
Grus canadensis[1]	Sandhill crane
FAM. RALLIDAE	
Porzana carolina	Sora rail
Fulica americana	American coot
FAM. RECURVIROSTRIDAE	
Recurvirostra americana[1]	American avocet
Himantopus mexicanus	Black-necked stilt
FAM. CHARADRIIDAE	
Eupoda montana	Mountain plover
Charadrius alexandrinus	Snowy plover
C. vociferus[1]	Killdeer
FAM. SCOLOPACIDAE	
Numenius americanus	Long-billed curlew
Limosa fedoa	Marbled godwit
Bartramia longicauda	Upland sandpiper
Catoptrophorus semipalmatus	Willet
Totanus melanoleucus	Greater yellowlegs
Totanus flavipes	Lesser yellowlegs
Micropalama himantopus	Stilt sandpiper
Limnodromus scolopaceus	Long-billed dowitcher
Erolia sp.	Sandpiper

APPENDIX B (continued)

Scientific Name	Common Name
FAM. PHALAROPODIDAE	
Steganopus tricolor	Wilson's phalarope
Lobipes lobatus[1]	Northern phalarope
FAM. LARIDAE	
Larus pipixcan	Franklin's gull
SUB. FAM. STERNINAE	
Chlidonias niger	Black tern
FAM. COLUMBIDAE	
Zenaidura macroura[1]	Mourning dove
Columba livia	Rock dove (pigeon)
FAM. CUCULIDAE	
Coccyzus americanus	Yellow-billed cuckoo
Geococcyx californianus	Roadrunner
FAM. TYTONIDAE	
Tyto alba	Barn owl
FAM. STRIGIDAE	
Speotyto cunicularia[1]	Burrowing owl
Asio flammeus	Short-eared owl
FAM. CAPRIMULGIDAE	
Chordeiles minor	Common nighthawk
FAM. ALCEDINIDAE	
Megaceryle alcyon	Belted kingfisher
FAM. PICIDAE	
Asyndesmus lewis	Lewis' woodpecker
Dendrocopos pubescens	Downy woodpecker
FAM. TYRANNIDAE	
Muscivora forfic	Scissor-tailed flycatcher
Tyrannus tyrannus	Eastern kingbird
T. verticalis	Western kingbird
Myiarchus crinitus	Crested flycatcher
FAM. ALAUDIDAE	
Eremophila alpestris[1]	Horned lark
FAM. HIRUNDINIDAE	
Iridoprocne bicolor	Tree swallow
Hirundo rustica	Barn swallow

APPENDIX B (continued)

Scientific Name	Common Name
FAM. HIRUNDINIDAE (continued)	
Petrochelidon pyrrhonota	Cliff swallow
Tachycineta thalassina	Violet-green swallow
Stelgidopteryx ruficollis	Rough-winged swallow
Riparia riparia	Bank swallow
FAM. CORVIDAE	
Corvus corax	Common raven
C. cryptoleucus	White-necked raven
C. brachyrhynchos	Common crow
FAM. TROGLODYTIDAE	
Campylorhynchus brunneicapillus	Cactus wren
Salpinctes obsoletus	Rock wren
FAM. MIMIDAE	
Mimis polyglottos	Mockingbird
FAM. SYLVIIDAE	
Regulus calendula	Ruby-crowned kinglet
FAM. MOTACILLIDAE	
Anthus spinoletta	Water pipit
FAM. LANIIDAE	
Lanius ludovicianus	Loggerhead shrike
FAM. ICTERIDAE	
Sturnella neglecta[1]	Western meadowlark
Xanthocephalus xanthocephalus[1]	Yellow-headed blackbird
Agelaius phoeniceus[1]	Red-winged blackbird
Quiscalus quiscula	Common grackle
Molothrus ater	Brown-headed cowbird
Icterus galbula	Northern oriole
FAM. FRINGILLIDAE	
Richmondena cardinalis	Cardinal
Guiraca caerulea	Blue grosbeak
Carpodacus mexicanus	House finch
Passerculus sandwichensis	Savannah sparrow
Ammondramus savannarum	Grasshopper sparrow
Calamospiza melanocorys[1]	Lark bunting
Chondestes grammacus	Lark sparrow
Aimophila cassinii	Cassin's sparrow

APPENDIX B (concluded)

Scientific Name	Common Name
FAM. FRINGILLIDAE (continued)	
Spizella pusilla[1]	Field sparrow
Zonotrichia leucophrys	White-crowned sparrow

[1] Indicates most commonly noted

APPENDIX C

Mammals of Playas and Associated Habitats in the Southern High Plains (Llano Estacado) Study Area of Curtis and Beierman (1980).

Scientific Name	Common Name
ORDER CHIROPTERA	
Antrozous pallidus	Pallid bat
ORDER CARNIVORA	
Procyon lotor[1]	Raccoon
Mephitis mephitis	Striped skunk
Taxidea taxus[1]	Badger
Urocyon cinereoargentus	Gray fox
Vulpes macrotis	Desert fox (kit)
Canis latrans[1]	Coyote
Felis concolor	Cougar
Lynx rufus	Bobcat
ORDER RODENTIA	
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel
Cynomys ludovicianus[1]	Blacktail prairie dog
Geomys bursarius	Plains pocket gopher
Neotoma micropus	Gray wood rat
ORDER LAGOMORPHA	
Lepus californicus[1]	California jackrabbit
Sylvilagus floridanus[1]	Eastern cottontail
Sylvilagus auduboni[1]	Audubon cottontail
ORDER ARTIODACTYLA	
Antilocapra americana[1]	Pronghorn
Odocoileus hemionus	Mule deer

[1] Indicates most commonly noted

APPENDIX D

Amphibians, Reptiles, and Fishes of Playas and Associated Habitats in the Southern High Plains (Llano Estacado) Study Area of Curtis and Beierman (1980).

Scientific Name	Common Name
FAM. CHELYDRIDAE	
Kinosternon flavescens	Yellow mud turtle
FAM. TESTUDINIDAE	
Terrapene ornata	Ornate box turtle
FAM. IGUANIDAE	
Phrynosoma cornutum	Texas horned lizard
FAM. COLUBRIDAE	
Thamnophis marcianus[1]	Checkered garter snake
Thamnophis sauritus proximus	Western ribbon snake
Coluber constrictor foxi	Blue racer
Opheodrys vernalis	Smooth green snake
FAM. VIPERIDAE	
Crotalus atrox	Diamondback rattlesnake
Crotalus viridis viridis	Prairie rattlesnake
FAM. AMBYSTOMIDAE	
Ambystoma tigrinum[1]	Eastern tiger salamander
FAM. PELOBATIDAE	
Scaphiopus sp.	Spadefoot toad
FAM. BUFONIDAE	
Bufo cognatus[1]	Great Plains toad
FAM. HYLIDAE	
Acris crepitans	Cricket frog
Pseudacris clarki	Spotted chorus frog
FAM. RANIDAE	
Rana catesbeiana[1]	Bullfrog
Rana pipiens	Leopard frog
FAM. CENTRARCHIDAE	
Lepomis macrochirus	Bluegill sunfish
Micropterus salmoides	Largemouth bass
FAM. ICTALURIDAE	
Ictalurus melas	Black bullhead
Ictalurus natalis	Yellow bullhead

APPENDIX D (concluded)

Scientific Name	Common Name
FAM. ICTALURIDAE (continued)	
Ictalurus furcatus	Blue catfish
Ictalurus punctatus	Channel catfish
FAM. CYPRINIDAE	
Notemigonus crysoleucas	Golden shiner
Cyprinus carpio	Carp
Hybognathus hankinsoni	Brassy minnow
Pimephales promelas	Fathead minnow

[1] Indicates most commonly noted

APPENDIX E

Invertebrates of Playas and Associated Habitats in the Southern High Plains (Llano Estacado) Study Area of Curtis and Beierman (1980).

Scientific Name	Common Name
CLASS MOLLUSCA	Snails
CLASS CRUSTACEA	
ORDER NOTOSTRACA	
Apus sp.	Tadpole shrimp
ORDER ISOPODA	Water sow bugs
ORDER ANOSTRACA	
Eubranchipus sp.	Fairy shrimp
CLASS HIRUNDINEA	Leeches
CLASS INSECTA	
ORDER HEMIPTERA	
FAM. NOTONECTIDAE	Backswimmers
FAM. BELOSTOMATIDAE	Giant waterbugs
FAM. GERRIDAE	Water striders
ORDER HETEROPTERA	
FAM. CORIXIDAE	Water boatmen
ORDER COLEOPTERA	
Hyrophilus sp.	Water scavenger beetle
ORDER EPHEMEROPTERA	Mayflies
ORDER ODONATA	Dragonflies
	Damselflies
ORDER MEGALOPTEPA	Hellgrammites
ORDER DIPTERA	Midges
	Flies
	Mosquitoes
ORDER HYMENOPTERA	Bees
	Ants
ORDER ORTHOPTERA	Grasshoppers
	Crickets
ORDER LEPIDOPTERA	
Peiris sp.	Cabbage butterflies
Damaus sp.	Monarch butterflies

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This characterization incorporates recent research findings in a synthesis of knowledge about the habitat values of playa wetlands to migratory and resident wildlife. Variables which may affect the value of playa wildlife habitat include watershed size and the water surface area and depth; type, height, density, and interspersion of vegetation, and the extent of emergent vegetation; land use, particularly grazing and cultivation; and the extent of modification, particularly excavating and diking. The Southern Great Plains playa wetland region encompasses parts of the Texas Panhandle, adjacent eastern New Mexico, the Oklahoma Panhandle, Southwestern Kansas and southeastern Colorado.

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Exhibit 15

STREAM CORRIDOR RESTORATION

Principles, Processes, and Practices

AN INTERAGENCY PARTNERSHIP.

There's more to a stream than the rushing or meandering water. A stream corridor, or stream valley, is a complex and valuable ecosystem which includes the land, plants, animals, and network of streams within it. Recognition of the value of stream corridors has come with the understanding of what has been lost through uninformed or misguided actions on many streams and the watersheds that nourish them.

The U.S. has 3.5 million miles of rivers. The 1992 National Water Quality Inventory of 642,881 miles of these rivers stated that only 56 percent fully supported multiple uses, including drinking water supply, fish and wildlife habitat, recreation, and agriculture, as well as flood prevention and erosion control. In the remaining 44 percent of stream miles inventoried, sedimentation and excess nutrients were the most significant causes of degradation. Sediment problems result from soil erosion from watersheds and streambanks.

Today, interest in restoring stream corridors is expanding nationally and internationally, as indicated by increasing numbers of case studies, published papers, technology exchanges, research projects, symposia, etc. Stream corridors are increasingly recognized as critical ecosystems supporting interdependent uses and values.

A preview of this publication is now available here!

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STREAM CORRIDOR RESTORATION

Principles, Practices, and Processes

Preface

"Water is the most critical resource issue of our lifetime and our children's lifetime.
The health of our waters is the principal measure of how we live on the land"

--- Luna Leopold

Restoration practitioners share simultaneously in the good fortune and responsibility of participating in a new endeavor -- stepping beyond the current concept of natural resources conservation to a newer concept of restoring the living environment to an ecologically viable condition -- to create places that improve rather than degrade over time. Oliver Wendell Holmes once said, "A mind stretched by a new idea can never go back to its original dimension."

This document is a result of an unprecedented cooperative effort among fifteen Federal agencies and partners to produce a common reference on stream corridor restoration. It responds to a growing national and international public interest in restoring stream corridors. Increasingly, feature articles, case studies, and published papers focus on stream corridors as critical ecosystems in our living environment. The recent 25th anniversary of the Clean Water Act also has helped focus attention on stream corridor restoration. This document encapsulates the rapidly expanding body of knowledge related to stream corridors and their restoration. It makes no endorsement of one particular approach to restoration over another; nor is it intended as a policy document of any participating Federal agency. It includes the full range of possibilities facing restoration practitioners, including no action or passive approaches, partial intervention for assisted recovery, and substantial intervention for managed recovery.

The document encourages locally led, public involvement in restoration planning and implementation. The challenges in restoring thousands of miles of degraded stream corridors must involve the participation of government agencies, public and private landowners, permit holders, and local volunteer, civic, and conservation groups and individuals. We encourage users of this document to supplement it with new literature, and regionally or locally specific information. You will find this document on the Internet at: **http://www.usda.gov/stream_restoration** We encourage restoration practitioners to share new information and case studies with others to advance the art and science of stream corridor restoration.

We intend for the contents of this document to both entice and challenge the reader by what they suggest --not only work to be studied and expanded, but work to be initiated. The dedication of those who contributed to its production will emerge on the landscape as restored, productive stream corridors, if the document provokes further interest, thought, and continued cooperative action.

The Federal Interagency Stream Restoration Working Group

STREAM CORRIDOR RESTORATION

Links to Cooperating Agencies

Document outline

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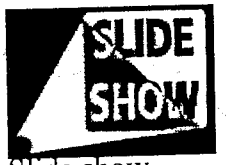

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Part I

2

Stream Corridor Processes, Characteristics, and Functions

2.A Hydrologic and Hydraulic Processes
2.B Geomorphic Processes
2.C Physical and Chemical Characteristics
2.D Biological Community Characteristics
2.E Functions and Dynamic Equilibrium

Chapter 1 provided an overview of stream corridors and the many perspectives from which they should be viewed in terms of scale, equilibrium, and space. Each of these views can be seen as a "snapshot" of different aspects of a stream corridor.

Chapter 2 presents the stream corridor in motion, providing a basic understanding of the different processes that make the stream corridor look and function the way it does. While Chapter 1 presented still images, this chapter provides "film footage" to describe the processes, characteristics, and functions of stream corridors through time.

Section 2.A: Hydrologic and Hydraulic Processes

Understanding how water flows into and through stream corridors is critical to restorations. How fast, how much, how deep, how often, and when water flows are important basic questions that must be answered to make appropriate decisions about stream corridor restoration.

Figure 2.1: A stream corridor in motion.
Processes, characteristics, and functions shape stream corridors and make them look the way they do.

Section 2.B: Geomorphic Processes

This section combines basic hydrologic processes with physical or geomorphic functions and characteristics. Water flows through streams but is affected by the kinds of soils and alluvial features within the channel, in the floodplain, and in the uplands. The amount and kind of sediments carried by a stream

largely determines its equilibrium characteristics, including size, shape, and profile. Successful stream corridor restoration, whether active (requiring direct changes) or passive (management and removal of disturbance factors), depends on an understanding of how water and sediment are related to channel form and function and on what processes are involved with channel evolution.

Section 2.C: Physical and Chemical Characteristics

The quality of water in the stream corridor is normally a primary objective of restoration, either to improve it to a desired condition, or to sustain it. Restoration should consider the physical and chemical characteristics that may not be readily apparent but that are nonetheless critical to the functions and processes of stream corridors. Changes in soil or water chemistry to achieve restoration goals usually involve managing or altering elements in the landscape or corridor.

Section 2.D: Biological Community Characteristics

The fish, wildlife, plants, and humans that use, live in, or just visit the stream corridor are key elements to consider in restoration. Typical goals are to restore, create, enhance or protect habitat to benefit life. It is important to understand how water flows, how sediment is transported, and how geomorphic features and processes evolve; however, a prerequisite to successful restoration is an understanding of the living parts of the system and how the physical and chemical processes affect the stream corridor.

Section 2.E: Functions and Dynamic Equilibrium

The six major functions of stream corridors are: habitat, conduit, barrier, filter, source, and sink. The integrity of a stream corridor ecosystem depends on how well these functions operate. This section discusses these functions and how they relate to dynamic equilibrium.

2.D Biological Community Characteristics

Successful stream restoration is based on an understanding of the relationships among physical, chemical, and biological processes at varying time scales. Often, human activities have accelerated the temporal progression of these processes, resulting in unstable flow patterns and altered biological structure and function of stream corridors. This section discusses the biological structure and functions of stream corridors in relation to geomorphologic, hydrologic, and water quality processes. The interrelations between the watershed and the stream, as well as the cause and effects of disturbances to these interrelationships are also discussed. Indices and approaches for evaluating stream corridor functions are provided in Chapter 7.

Terrestrial Ecosystems

The biological community of a stream corridor is determined by the characteristics of both terrestrial and aquatic ecosystems. Accordingly, the discussion of biological communities in stream corridors begins with a review of terrestrial ecosystems.

Ecological Role of Soil

Terrestrial ecosystems are fundamentally tied to processes within the soil. The ability of a soil to store and cycle nutrients and other elements depends on the properties and microclimate (i.e., moisture and temperature) of the soil, and the soil's community of organisms (**Table 2.10**). These factors

Table 2.10: Groups of organisms commonly present in soils.

Animals		
Macro	Subsisting largely on plant materials	
	Small mammals—squirrels, gophers, woodchucks, mice, shrews	
	Insects—springtails, ants, beetles, grubs, etc	
	Millipedes	
	Sowbugs (woodlice)	
	Mites	
	Slugs and snails	
	Earthworms	
	Largely predatory	
	Moles	
	Insects—many ants, beetles, etc	
	Mites, in some cases	
	Centipedes	
	Spiders	
Micro	Predatory or parasitic or subsisting on plant residues	
	Nematodes	
	Protozoa	
	Rotifers	
Plants		
Roots of higher plants		
Algae		
	Green	
	Blue-green	
	Diatoms	
Fungi		
	Mushroom fungi	
	Yeasts	
	Molds	
Actinomycetes of many kinds		
Bacteria		
	Aerobic	Autotropic
		Heterotropic
	Anaerobic	Autotropic
		Heterotropic

REVERSE

*See **Section C** for further discussion of the ecological functions of soils.*

also determine its effectiveness at filtering, buffering, degrading, immobilizing, and detoxifying other organic and inorganic materials.

Terrestrial Vegetation

The ecological integrity of stream corridor ecosystems is directly related to the integrity and ecological characteristics of the plant communities that make up and surround the corridor. These plant communities are a valuable source of energy for the biological communities, provide physical habitat, and moderate solar energy fluxes to and from the surrounding aquatic and terrestrial ecosystems. Given adequate moisture, light, and temperature, the vegetative community grows in an annual cycle of active growth/production, senescence, and relative dormancy. The growth period is subsidized by incidental solar radiation, which drives the photosynthetic process through which inorganic carbon is converted to organic plant materials. A portion of this organic material is stored as above- and below-ground biomass, while a significant fraction of organic matter is lost annually via senescence, fractionation, and leaching to the organic soil layer in the form of leaves, twigs, and decaying roots. This organic fraction, rich in biological activity of microbial flora and microfauna, represents a major storage and cycling pool of available carbon, nitrogen, phosphorus, and other nutrients.

The distribution and characteristics of vegetative communities are determined by climate, water availability, topographic features, and the chemical and physical properties of the soil, including moisture and nutrient content. The characteristics of the plant communities directly influence the diversity and integrity of the faunal communities. Plant communities that cover a large area and that are diverse in their vertical and horizontal structural characteristics can support far more diverse faunal communities than relatively homogenous plant communities, such as meadows. As a result of the complex spatial and temporal relationships that exist between floral and faunal communities, current ecological characteristics of these communities reflect the recent historical (100 years or less) physical conditions of the landscape.

The quantity of terrestrial vegetation, as well as its species composition, can directly affect stream channel characteristics. Root systems in the streambank can bind bank sediments and moderate erosion processes. Trees and smaller woody debris that fall into the stream can deflect flows and induce erosion at some points and deposition at others. Thus woody debris accumulation can influence pool distribution, organic matter and nutrient retention, and the formation of microhabitats that are important fish and invertebrate aquatic communities.

Streamflow also can be affected by the abundance and distribution of terrestrial vegetation. The short-term effects of removing vegetation can result in an immediate short-term rise in the local water table due to decreased evapotranspiration and additional water entering the stream. Over the longer term, however, after removal of vegetation, the baseflow of streams can decrease and water temperatures

can rise, particularly in low-order streams. Also, removal of vegetation can cause changes in soil temperature and structure, resulting in decreased movement of water into and through the soil profile. The loss of surface litter and the gradual loss of organic matter in the soil also contribute to increased surface runoff and decreased infiltration.

In most instances, the functions of vegetation that are most apparent are those that influence fish and wildlife. At the landscape level, the fragmentation of native cover types has been shown to significantly influence wildlife, often favoring opportunistic species over those requiring large blocks of contiguous habitat. In some systems, relatively small breaks in corridor continuity can have significant impacts on animal movement or on the suitability of stream conditions to support certain aquatic species. In others, establishing corridors that are structurally different from native systems or that are inappropriately configured can be equally disruptive. Narrow corridors that are essentially edge habitat may encourage generalist species, nest parasites, and predators, and, where corridors have been established across historic barriers to animal movement, they can disrupt the integrity of regional animal assemblages (Knopf et al. 1988).

Landscape Scale

The ecological characteristics and distribution of plant communities in a watershed influence the movement of water, sediment, nutrients, and wildlife. Stream corridors provide links with other features of the landscape. Links may involve continuous corridors between headwater and valley floor ecosystems or periodic interactions between terrestrial systems. Wildlife use corridors to disperse juveniles, to migrate, and to move between portions of their home range. Corridors of a natural origin are preferred and include streams and rivers, riparian strips, mountain passes, isthmuses, and narrow straits (Payne and Bryant 1995).

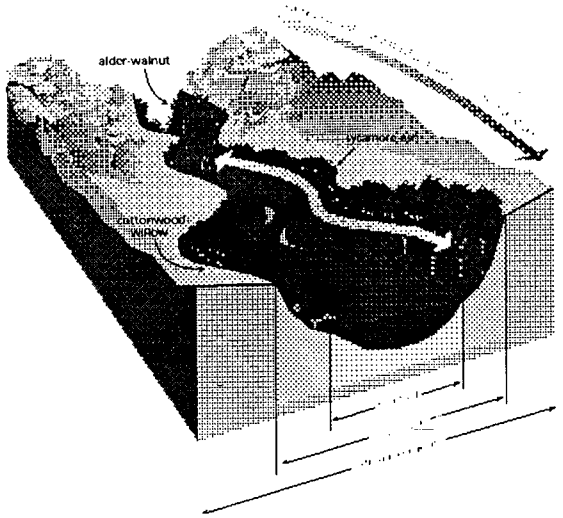
It is important to understand the differences between a stream-riparian ecosystem and a river-floodplain ecosystem. Flooding in the stream-riparian ecosystem is brief and unpredictable. The riparian zone supplies nutrients, water, and sediment to the stream channel, and riparian vegetation regulates temperature and light. In the river-floodplain ecosystem, floods are often more predictable and longer lasting, the river channel is the donor of water, sediment and inorganic nutrients to the floodplain, and the influx of turbid and cooler channel water influences light penetration and temperature of the inundated floodplain.

Stream Corridor Scale

At the stream corridor scale, the composition and regeneration patterns of vegetation are characterized in terms of *horizontal complexity*. Floodplains along unconstrained channels typically are vegetated with a mosaic of plant communities, the composition of which varies in response to available surface and ground water, differential patterns of flooding, fire, and predominant winds, sediment deposition, and opportunities for establishing vegetation.

A broad floodplain of the southern, midwestern, or eastern U.S. may support dozens of relatively distinct forest communities in a complex mosaic reflecting subtle differences in soil type and flood characteristics (e.g., frequency, depth, and duration). In contrast, while certain western stream systems may support only a few woody species, these systems may be structurally complex due to constant reworking of substrates by the stream, which produces a mosaic of stands of varying ages. The presence of side channels, oxbow lakes, and other topographic variation can be viewed as elements of structural variation at the stream corridor level. Riparian areas along constrained stream channels may consist primarily of upland vegetation organized by processes largely unrelated to stream characteristics, but these areas may have considerable influence on the stream ecosystem.

Figure 2.30: Canyon effect.
Cool moist air settles in canyons and creates microhabitat that occurs on surrounding slopes.



The River Continuum Concept, as discussed in Chapter 1, is also generally applicable to the vegetative components of the riparian corridor. Riparian vegetation demonstrates both a transriparian gradient (across the valley) and an intra-riparian (longitudinal, elevational) gradient (Johnson and Lowe 1985). In the west, growth of riparian vegetation is increased by the "canyon effect" resulting when cool moist air spills downslope from higher elevations (**Figure 2.30**). This cooler air settles in canyons and creates a more moist microhabitat than occurs on the surrounding slopes. These canyons also serve as water courses. The combination of moist, cooler edaphic and atmospheric conditions is conducive to plant and animal species at lower than normal altitudes, often in disjunct populations or in regions where they would not otherwise occur (Lowe and Shannon 1954).

Plant Communities

The sensitivity of animal communities to vegetative characteristics is well recognized. Numerous animal species are associated with particular plant communities, many require particular developmental stages of those communities (e.g., old-growth), and some depend on particular habitat elements within those communities (e.g., snags). The structure of streamside plant communities also directly affects aquatic organisms by providing inputs of appropriate organic materials to the aquatic food web, by shading the water surface and providing cover along banks, and by influencing instream habitat structure through inputs of woody debris (Gregory et al. 1991).

Plant communities can be viewed in terms of their internal complexity (**Figure 2.31**). Complexity may include the number of layers of vegetation and the species comprising each layer; competitive interactions among species; and the presence of detrital components, such as litter, downed wood, and snags. Vegetation may contain tree, sapling, shrub (subtree), vine, and herbaceous subshrub (herb-grass-forb) layers. Microtopographic relief and the ability of water to locally pond also may be regarded as characteristic structural components.

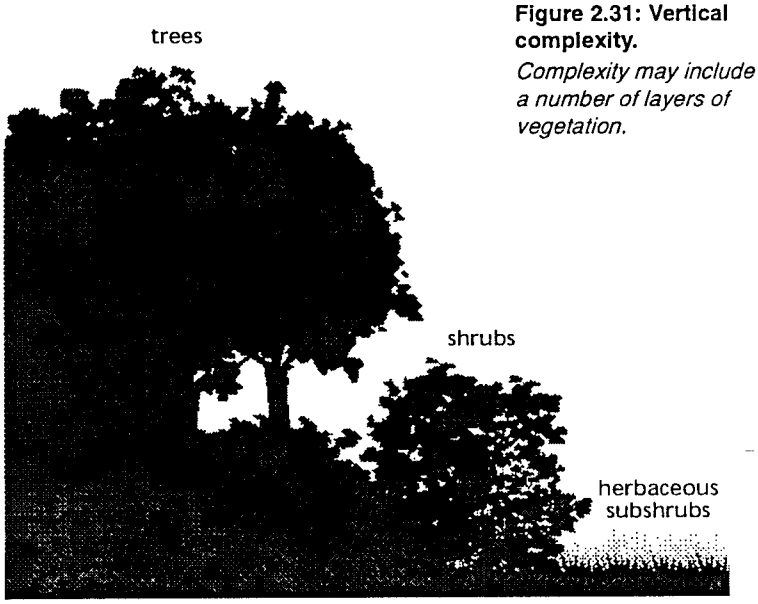


Figure 2.31: Vertical complexity.
Complexity may include a number of layers of vegetation.

Vertical complexity, described in the concept of diversity of strata or foliage height diversity in ecological literature, was important to studies of avian habitat by Carothers et al. (1974) along the Verde River, a fifth- or sixth-order stream in central Arizona. Findings showed a high correlation between riparian bird species diversity and foliage height diversity of riparian vegetation (Carothers et al. 1974). Short (1985) demonstrated that more structurally diverse vegetative habitats support a greater number of guilds (groups of species with closely related niches in a community) and therefore a larger number of species.

Species and age composition of vegetation structure also can be extremely important. Simple vegetative structure, such as an herbaceous layer without woody overstory or old woody riparian trees without smaller size classes, creates fewer niches for guilds. The fewer guilds there are, the fewer species there are. The quality and vigor of the vegetation can affect the productivity of fruits, seeds, shoots, roots, and other vegetative material, which provide food for wildlife. Poorer vigor can result in less food and fewer consumers (wildlife). Increasing the patch size (area) of a streamside vegetation type, increasing the number of woody riparian tree size classes, and increasing the number of species and growth forms (herb, shrub, tree) of native riparian-dependent vegetation can increase the number of guilds and the amount of forage, resulting in increased species richness and biomass (numbers). Restoration techniques can change the above factors.

The importance of horizontal complexity within stream corridors to certain animal species also has been well established. The characteristic compositional, structural, and topographic complexity of southern floodplain forests, for example, provides the range of resources and foraging conditions required by many wintering waterfowl to meet particular requirements of their life cycles at the appro-

priate times (Fredrickson 1978); similar complex relationships have been reported for other vertebrates and invertebrates in floodplain habitats (Wharton et al. 1982). In parts of the arid West, the unique vegetation structure in riparian systems contrasts dramatically with the surrounding uplands and provides essential habitat for many animals (Knopf et al. 1988). Even within compositionally simple riparian systems, different developmental stages may provide different resources.

Plant communities are distributed on floodplains in relation to flood depth, duration, and frequency, as well as variations in soils and drainage condition. Some plant species, such as cottonwood (*Populus* sp.), willows (*Salix* sp.), and silver maple (*Acer saccharinum*), are adapted to colonization of newly deposited sediments and may require very specific patterns of flood recession during a brief period of seedfall to be successfully established (Morris et al. 1978, Rood and Mahoney 1990). The resultant pattern is one of even-aged tree stands established at different intervals and locations within the active meander belt of the stream. Other species, such as the bald cypress (*Taxodium distichum*), are particularly associated with oxbow lakes formed when streams cut off channel segments, while still others are associated with microtopographic variations within floodplains that reflect the slow migration of a stream channel across the landscape.

Plant communities are dynamic and change over time. The differing regeneration strategies of particular vegetation types lead to characteristic patterns of plant succession following disturbances in which pioneer species well-adapted to bare soil and plentiful light are gradually replaced by longer-lived species that can regenerate under more shaded and protected conditions. New disturbances reset the successional process. Within stream corridors, flooding, channel migration, and, in certain biomes, fire, are usually the dominant natural sources of disturbance. Restoration practitioners should understand patterns of natural succession in a stream corridor and should take advantage of the successional process by planting hardy early-successional species to stabilize an eroding streambank, while planning for the eventual replacement of these species by longer-lived and higher-successional species.

Terrestrial Fauna

Stream corridors are used by wildlife more than any other habitat type (Thomas et al. 1979) and are a major source of water to wildlife populations, especially large mammals. For example, 60 percent of Arizona's wildlife species depend on riparian areas for survival (Ohmart and Anderson 1986). In the Great Basin area of Utah and Nevada, 288 of the 363 identified terrestrial vertebrate species depend on riparian zones (Thomas et al. 1979). Because of their wide suitability for upland and riparian species, midwestern stream corridors associated with prairie grasslands support a wider diversity of wildlife than the associated uplands. Stream corridors play a large role in maintaining biodiversity for all groups of vertebrates.

The faunal composition of a stream corridor is a function of the interaction of food, water, cover, and spatial arrangement (Thomas et al. 1979). These habitat components interact in multiple ways to provide eight habitat features of stream corridors:

- Presence of permanent sources of water.
- High primary productivity and biomass.
- Dramatic spatial and temporal contrasts in cover types and food availability.
- Critical microclimates.
- Horizontal and vertical habitat diversity.
- Maximized edge effect.
- Effective seasonal migration routes.
- High connectivity between vegetated patches.

Stream corridors offer the optimal habitat for many forms of wildlife because of the proximity to a water source and an ecological community that consists primarily of hardwoods in many parts of the country, which provide a source of food, such as nectar, catkins, buds, fruit, and seeds (Harris 1984). Upstream sources of water, nutrients, and energy ultimately benefit downstream locations. In turn, the fish and wildlife return and disperse some of the nutrients and energy to uplands and wetlands during their movements and migrations (Harris 1984).

Water is especially critical to fauna in areas such as the Southwest or Western Prairie regions of the U.S. where stream corridors are the only naturally occurring permanent sources of water on the landscape. These relatively moist environments contribute to the high primary productivity and biomass of the riparian area, which contrasts dramatically with surrounding cover types and food sources. In these areas, stream corridors provide critical microclimates that ameliorate the temperature and moisture extremes of uplands by providing water, shade, evapotranspiration, and cover.

The spatial distribution of vegetation is also a critical factor for wildlife. The linear arrangement of streams results in a maximized edge effect that increases species richness because a species can simultaneously access more than one cover (or habitat) type and exploit the resources of both (Leopold 1933). Edges occur along multiple habitat types including the aquatic, riparian, and upland habitats.

Forested connectors between habitats establish continuity between forested uplands that may be surrounded by unforested areas. These act as feeder lines for dispersal and facilitate repopulation by plants and animals. Thus, connectivity is very important for retaining biodiversity and genetic integrity on a landscape basis.

However, the linear distribution of habitat, or edge effect, is not an effective indicator of habitat quality for all species. Studies in island biogeography, using habitat islands rather than oceanic islands, demonstrate that a larger habitat island supports both a larger population of birds and also a larger number of species (Wilson and Carothers 1979). Although a continuous corridor is most desirable, the next preferable situation is minimal frag-

mentation, i.e., large plots ("islands") of riparian vegetation with minimal spaces between the large plots.

Reptiles and Amphibians

Nearly all amphibians (salamanders, toads, and frogs) depend on aquatic habitats for reproduction and overwintering. While less restricted by the presence of water, many reptiles are found primarily in stream corridors and riparian habitats. Thirty-six of the 63 reptile and amphibian species found in west-central Arizona were found to use riparian zones. In the Great Basin, 11 of 22 reptile species require or prefer riparian zones (Ohmart and Anderson 1986).

Birds

Birds are the most commonly observed terrestrial wildlife in riparian corridors. Nationally, over 250 species have been reported using riparian areas during some part of the year.

The highest known density of nesting birds in North America occurs in southwestern cottonwood habitats (Carothers and Johnson 1971). Seventy-three percent of the 166 breeding bird species in the Southwest prefer riparian habitats (Johnson et al. 1977).

Bird species richness in midwestern stream corridors reflects the vegetative diversity and width of the corridor. Over half of these breeding birds are species that forage for insects on foliage (vireos, warblers) or species that forage for seeds on the ground (doves, orioles, grosbeaks, sparrows). Next in abundance are insectivorous species that forage on the ground or on trees (thrushes, woodpeckers).

Smith (1977) reported that the distribution of bird species in forested habitats of the Southeast was closely linked to soil moisture. Woodcock (*Scolopax minor*) and snipe (*Gallinago gallinago*), red-shouldered hawks (*Buteo lineatus*), hooded and prothonotary warblers (*Wilsonia citrina, Protonotaria citrea*), and many other passerines in the Southeast prefer the moist ground conditions found in riverside forests and shrublands for feeding. The cypress and mangrove swamps along Florida's waterways harbor many species found almost nowhere else in the Southeast.

Mammals

The combination of cover, water, and food resources in riparian areas make them desirable habitat for large mammals such as mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), and elk (*Cervus elaphus*) that can use multiple habitat types. Other mammals depend on riparian areas in some or all of their range. These include otter (*Lutra canadensis*), ringtail (*Bassarisdus astutus*), raccoon (*Procyon lotor*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), swamp rabbit (*Sylvilagus aquaticus*), short-tailed shrew (*Blarina brevicauda*), and mink (*Mustela vison*).

Riparian areas provide tall dense cover for roosts, water, and abundant prey for a number of bat species, including the little brown bat (*Myotis lucifugus*), big brown bat (*Eptesicus fuscus*), and the pallid bat (*Antrozous pallidus*). Brinson et al. (1981) tabulated results from several studies on mammals in

riparian areas of the continental U.S. They concluded that the number of mammal species generally ranges from five to 30, with communities including several furbearers, one or more large mammals, and a few small to medium mammals.

Hoover and Wills (1984) reported 59 species of mammals in cottonwood riparian woodlands of Colorado, second only to pinyon-juniper among eight other forested cover types in the region. Fifty-two of the 68 mammal species found in west-central Arizona in Bureau of Land Management inventories use riparian habitats. Stamp and Ohmart (1979) and Cross (1985) found that riparian areas had a greater diversity and biomass of small mammals than adjacent upland areas.

The contrast between the species diversity and productivity of mammals in the riparian zone and that of the surrounding uplands is especially high in arid and semiarid regions. However, bottomland hardwoods in the eastern U.S. also have exceptionally high habitat values for many mammals. For example, bottomland hardwoods support white-tail deer populations roughly twice as large as equivalent areas of upland forest (Glasgow and Noble 1971).

Stream corridors are themselves influenced by certain animal activities (Forman 1995). For example, beavers build dams that cause ponds to form within a stream channel or in the floodplain. The pond kills much of the existing vegetation, although it does create wetlands and open water areas for fish and migratory waterfowl. If appropriate woody plants in the floodplain are scarce, beavers extend their cutting activities into the uplands and can significantly alter the riparian and stream corridors. Over time, the pond is replaced by a mudflat, which becomes a meadow and eventually gives way to woody successional stages. Beaver often then build a dam at a new spot, and the cycle begins anew with only a spatial displacement.

The sequence of beaver dams along a stream corridor may have major effects on hydrology, sedimentation, and mineral nutrients (Forman 1995). Water from stormflow is held back, thereby affording some measure of flood control. Silts and other fine sediments accumulate in the pond rather than being washed downstream. Wetland areas usually form, and the water table rises upstream of the dam. The ponds combine slow flow, near-constant water levels, and low turbidity that support fish and other aquatic organisms. Birds may use beaver ponds extensively. The wetlands also have a relatively constant water table, unlike the typical fluctuations across a floodplain. Beavers cutting trees diminish the abundance of such species as elm (*Ulmus* spp.) and ash (*Fraxinus* spp.) but enhance the abundance of rapidly sprouting species, such as alder (*Alnus* spp.), willow, and poplar (*Populus* spp.).

Aquatic Ecosystems

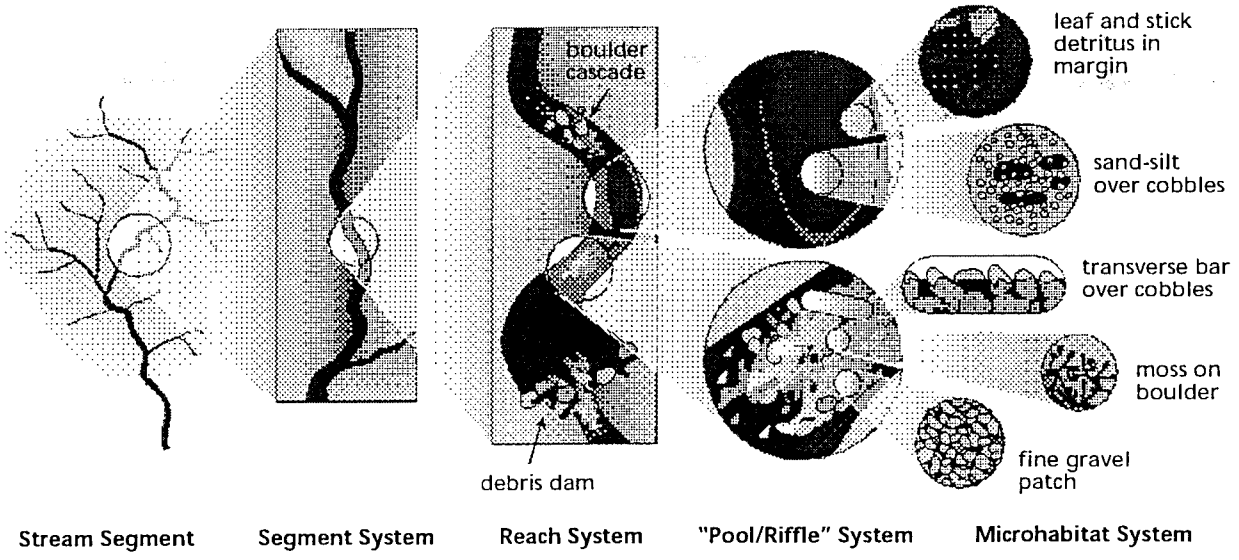
Aquatic Habitat

The biological diversity and species abundance in streams depend on the diversity of available habitats. Naturally functioning, stable stream systems promote the diversity and availability of habitats. This is one of the

primary reasons stream stability and the restoration of natural functions are always considered in stream corridor restoration activities. A stream's cross-sectional shape and dimensions, its slope and confinement, the grain-size distribution of bed sediments, and even its planform affect aquatic habitat. Under less disturbed situations, a narrow, steep-walled cross section provides less physical area for habitat than a wider cross section with less steep sides, but may provide more biologically rich habitat in deep pools compared to a wider, shallower stream corridor. A steep, confined stream is a high-energy environment that may limit habitat occurrence, diversity, and stability. Many steep, fast flowing streams are coldwater salmonid streams of high value. Unconfined systems flood frequently, which can promote riparian habitat development. Habitat increases with stream sinuosity. Uniform sediment size in a streambed provides less potential habitat diversity than a bed with many grain sizes represented.

Habitat subsystems occur at different scales within a stream system (Frissell et al. 1986) (**Figure 2.32**). The grossest scale, the stream system itself, is measured in thousands of feet, while segments are measured in hundreds of feet and reaches are measured in tens of feet. A reach system includes combinations of debris dams, boulder cascades, rapids, step/pool sequences, pool/riffle sequences, or other types of streambed forms or "structures," each of which could be 10 feet or less in scale. Frissell's smallest scale habitat subsystem includes features that are a foot or less in size. Examples of these *microhabitats* include leaf or stick detritus, sand or silt over cobbles or other coarse material, moss on boulders, or fine gravel patches.

Figure 2.32: Hierarchical organization of a stream system and its habitat subsystems. *Approximate linear spatial scale, appropriate to second- or third-order mountain stream.*



Steep slopes often form a step/pool sequence in streams, especially in cobble, boulder, and bedrock streams. Each step acts as a miniature grade stabilization structure. The steps and pools work together to distribute the excess energy available in these steeply sloping systems. They also add diversity to the habitat available. Cobble- and gravel-bottomed streams at less steep slopes form pool/riffle sequences, which also increase habitat diversity. Pools provide space, cover, and nutrition to fish and they provide a place for fish to seek shelter during storms, droughts, and other catastrophic events. Upstream migration of many salmonid species typically involves rapid movements through shallow areas, followed by periods of rest in deeper pools (Spence et al. 1996).

Wetlands

Stream corridor restoration initiatives may include restoration of wetlands such as riverine-type bottomland hardwood systems or riparian wetlands. While wetland restoration is a specific topic better addressed in other references (e.g., Kentula 1992), a general discussion of wetlands is provided here. Stream corridor restoration initiatives should be designed to protect or restore the functions of associated wetlands.

A wetland is an ecosystem that depends on constant or recurrent shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features that reflect recurrent sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where physicochemical, biotic, or anthropogenic factors have removed them or prevented their development (National Academy of Sciences 1995). Wetlands may occur in streams, riparian areas, and floodplains of the stream corridor. The riparian area or zone may contain both wetlands and non-wetlands.

Wetlands are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (Cowardin et al. 1979). For vegetated wetlands, water creates conditions that favor the growth of hydrophytes—plants growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content (Cowardin et al. 1979) and promotes the development of hydric soils—soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part (National Academy of Sciences 1995).

Wetland functions include fish and wildlife habitat, water storage, sediment trapping, flood damage reduction, water quality improvement/pollution control, and ground water recharge. Wetlands have long been recognized as highly productive habitats for threatened and endangered fish and wildlife species. Wetlands provide habitat for 60 to 70 percent of the animal species federally listed as threatened or endangered (Lohoefner 1997).

Riparian Mapping

The riparian zone is a classic example of the maximized value that occurs when two or more habitat types meet. There is little question of the substantial value of riparian habitats in the United States. The Fish and Wildlife Service has developed protocols to classify and map riparian areas in the West in conjunction with the National Wetlands Inventory (NWI). NWI will map riparian areas on a 100 percent user-pay basis. No formal riparian mapping effort has been initiated. The NWI is congressionally mandated to identify, classify, and digitize all wetlands and deepwater habitats in the United States. For purposes of riparian mapping, the NWI has developed a riparian definition that incorporates biological information consistent with many agencies and applies information according to cartographic principles. For NWI mapping and classification purposes, a final definition for riparian has been developed:

"Riparian areas are plant communities contiguous to and affected by surface and subsurface hydrological features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, and drainage ways). Riparian areas have one or both of the following characteristics: (1) distinctly different vegetative species than adjacent areas; and (2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland."

The definition applies primarily to regions of the lower 48 states in the arid west where the mean annual precipitation is 16 inches or less and the mean annual evaporation exceeds mean annual precipitation. For purposes of this mapping, the riparian system is subdivided into subsystems, classes, subclasses, and dominance types. (USFWS 1997)

The Federal Geographic Data Committee has adopted the U.S. Fish and Wildlife Service's *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin, et al. 1979) as the national standard for wetlands classification. The Service's National Wetlands Inventory (NWI) uses this system to carry out its congressionally mandated role of identifying, classifying, mapping, and digitizing data on wetlands and deepwater habitats. This system, which defines wetlands consistently with the National Academy of Science's reference definition, includes Marine, Estuarine, Riverine, Lacustrine, and Palustrine systems. The NWI has also developed protocols for classifying and mapping riparian habitats in the 22 coterminous western states.

The riverine system under Cowardin's classification includes all wetlands and deepwater habitats contained within a channel except wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens and habitats with water containing ocean-derived salts in excess of 0.5 parts per thousand (ppt).

It is bounded on the upstream end by uplands and on the downstream end at the interface with tidal wetlands having a concentration of ocean-derived salts that exceeds 0.5 ppt. Riverine wetlands are bounded perpendicularly on the landward side by upland, the channel bank (including natural and manufactured levees) or by *Palustrine wetlands*. In braided streams, riverine wetlands are bounded by the banks forming the outer limits of the depression within which the braiding occurs.

Vegetated floodplain wetlands of the river corridor are classified as Palustrine under this system. The Palustrine system was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie pothole and also includes small, shallow, permanent, or intermittent water bodies often called ponds. Palustrine wetlands may be situated shoreward of lakes, river channels, or estuaries, on river floodplains, in

isolated catchments, or on slopes. They also may occur as islands in lakes or rivers. The Palustrine system includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses and lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. The Palustrine system is bounded by upland or by any of the other four systems. They may merge with non-wetland riparian habitat where hydrologic conditions cease to support wetland vegetation or may be totally absent where hydrologic conditions do not support wetlands at all (Cowardin 1979).

The *hydrogeomorphic (HGM) approach* is a system that classifies wetlands into similar groups for conducting functional assessments of wetlands. Wetlands are classified based on geomorphology, water source and hydrodynamics. This allows the focus to be placed on a group of wetlands that function much more similarly than would be the case without classifying them. Reference wetlands are used to develop reference standards against which a wetland is evaluated (Brinson 1995).

Under the HGM approach, riverine wetlands occur in floodplains and riparian corridors associated with stream channels. The dominant water sources are overbank flow or subsurface connections between stream channel and wetlands. Riverine wetlands lose water by surface and subsurface flow returning to the stream channel, ground water recharge, and evapotranspiration. At the extension closest to the headwaters, riverine wetlands often are replaced by slope or depressional wetlands where channel bed and bank disappear, or they may intergrade with poorly drained flats and uplands. Usually forested, they extend downstream to the intergrade with estuarine fringe wetlands. Lateral extent is from the edge of the channel perpendicularly to the edge of the floodplain. In some landscape situations, riverine wetlands may function hydrologically more like slope wetlands, and in headwater streams with little or no floodplain, slope wetlands may lie adjacent to the stream channel (Brinson et al. 1995). **Table 2.11** summarizes functions of riverine wetlands under the HGM approach. The U.S. Fish and Wildlife Service is testing an operational draft set of hydrogeomorphic type descriptors to help bridge the gap between the Cowardin system and the HGM approach (Tiner 1997).

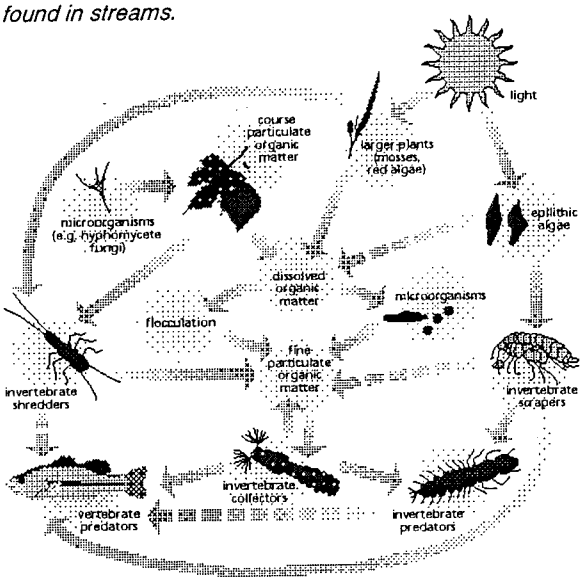
For purposes of regulation under Section 404 of the Clean Water Act, only areas with wetland hydrology,

Table 2.11: Functions of riverine wetlands.

Source: Brinson et al., 1995.

Hydrologic	Dynamic surface water storage
	Long-term surface water storage
	Subsurface storage of water
	Energy dissipation
	Moderation of ground-water flow or discharge
Biogeochemical	Nutrient cycling
	Removal of elements and compounds
	Retention of particulates
	Organic carbon export
Plant habitat	Maintain characteristic plant communities
	Maintain characteristic detrital biomass
Animal habitat	Maintain spatial habitat structure
	Maintain interspersion and connectivity
	Maintain distribution and abundance of invertebrates
	Maintain distribution and abundance of vertebrates

Figure 2.33: Stream biota.
Food relationships typically found in streams.



hydrophytic vegetation, and hydric soils are classified as regulated wetlands. As such, they represent a subset of the areas classified as wetlands under the Cowardin system. However, many areas classified as wetlands under the Cowardin system, but not classified as wetlands for purposes of Section 404, are nevertheless subject to regulation because they are part of the Waters of the United States.

Table 2.12: Ranges of densities commonly observed for selected groups of stream biota.

Biotic Component	Density (Individuals/Square Mile)
Algae	10^9 - 10^{10}
Bacteria	10^{12} - 10^{13}
Protists	10^8 - 10^9
Microinvertebrates	10^3 - 10^5
Macroinvertebrates	10^4 - 10^5
Vertebrates	10^0 - 10^2

Aquatic Vegetation and Fauna

Stream biota are often classified in seven groups—bacteria, algae, macrophytes (higher plants), protists (amoebas, flagellates, ciliates), microinvertebrates (invertebrates less than 0.02 inch in length, such as rotifers, copepods, ostracods, and nematodes), macroinvertebrates (invertebrates greater than 0.02 inch in length, such as mayflies, stoneflies, caddisflies, crayfish, worms, clams, and snails), and vertebrates (fish, amphibians, reptiles, and mammals) (**Figure 2.33**). The discussion of the River Continuum Concept in Chapter 1, provides an overview of the major groups of organisms found in streams and how these assemblages change from higher order to lower order streams.

Undisturbed streams can contain a remarkable number of species. For example, a comprehensive inventory of stream biota in a small German stream, the Breitenbach, found more than 1,300 species in a 1.2-mile reach. Lists of algae, macroinvertebrates, and fish likely to be found at potential restoration sites may be obtained from state or regional inventories. The densities of such stream biota are shown in **Table 2.12**.

Aquatic plants usually consist of algae and mosses attached to permanent stream substrates. Rooted aquatic vegetation may occur where substrates are suitable and high currents do not scour the stream bottom. Luxuriant beds of vascular plants may grow in some areas such as spring-fed streams in Florida where water clarity, substrates, nutrients, and slow water velocities exist. Bedrock or stones that cannot be moved easily by stream

currents are often covered by mosses and algae and various forms of micro- and macroinvertebrates (Ruttner 1963). Planktonic plant forms are usually limited but may be present where the watershed contains lakes, ponds, floodplain waters, or slow current areas (Odum 1971).

The benthic invertebrate community of streams may contain a variety of biota, including bacteria, protists, rotifers, bryozoans, worms, crustaceans, aquatic insect larvae, mussels, clams, crayfish, and other forms of invertebrates. Aquatic invertebrates are found in or on a multitude of microhabitats in streams including plants, woody debris, rocks, interstitial spaces of hard substrates, and soft substrates (gravel, sand, and muck). Invertebrate habitats exist at all vertical strata including the water surface, the water column, the bottom surface, and deep within the hyporheic zone.

Unicellular organisms and microinvertebrates are the most numerous biota in streams. However, larger macroinvertebrates are important to community structure because they contribute significantly to a stream's total invertebrate biomass (Morin and Nadon 1991, Bourassa and Morin 1995). Furthermore, the larger species often play important roles in determining community composition of other components of the ecosystem. For example, herbivorous feeding activities of caddisfly larvae (Lamberti and Resh 1983), snails (Steinman et al. 1987), and crayfish (Lodge 1991) can have a significant effect on the abundance and taxonomic composition of algae and periphyton in streams. Likewise, macroinvertebrate predators, such as stoneflies, can influence the abundance of other species within the invertebrate community (Peckarsky 1985).

Collectively, microorganisms (fungi and bacteria) and benthic invertebrates facilitate the breakdown of organic material, such as leaf litter, that enters the stream from external sources. Some invertebrates (insect larvae and amphipods) act as shredders whose feeding activities break down larger organic leaf litter to smaller particles. Other invertebrates filter smaller organic material from the water (blackfly larvae, some mayfly nymphs, and some caddisfly larvae), scrape material off surfaces (snails, limpets, and some caddisfly and mayfly nymphs) or feed on material deposited on the substrate (dipteran larvae and some mayfly nymphs) (Moss 1988). These feeding activities result in the breakdown of organic matter in addition to the elaboration of invertebrate tissue, which other consumer groups, such as fish, feed on.

Benthic macroinvertebrates, particularly aquatic insect larvae and crustaceans, are widely used as indicators of stream health and condition. Many fish species rely on benthic organisms as a food source either by direct browsing on the benthos or by catching benthic organisms that become dislodged and drift downstream (Walburg 1971).

Fish are ecologically important in stream ecosystems because they are usually the largest vertebrates and often are the apex predator in aquatic systems. The numbers and species composition of fishes in a given stream depends on the geographic location, evolutionary history, and

such intrinsic factors as physical habitat (current, depth, substrates, riffle/pool ratio, wood snags and undercut banks), water quality (temperature, dissolved oxygen, suspended solids, nutrients, and toxic chemicals), and biotic interactions (exploitation, predation, and competition).

There are approximately 700 native freshwater species of fish in North America (Briggs 1986). Fish species richness is highest in the Mississippi River Basin where most of the adaptive radiations have occurred in the United States (Allan 1995). In the Midwest, as many as 50 to 100 species can occur in a local area, although typically only half the species native to a region may be found at any one location (Horwitz 1978). Fish species richness generally declines as one moves westward across the U.S., primarily due to extinction during and following the Pleistocene Age (Fausch et al. 1984). For example, 210 species are found west of the Continental Divide, but only 40 of these species are found on both sides of the continent (Minckley and Douglas 1991). The relatively depauperate fauna of the Western U.S. has been attributed to the isolating mechanisms of tectonic geology. Secondary biological, physical, and chemical factors may further reduce the species richness of a specific community (Minckley and Douglas 1991, Allan 1995).

Fish species assemblages in streams will vary considerably from the headwaters to the outlet due to changes in many hydrologic and geomorphic factors which control temperature, dissolved oxygen, gradient, current velocity, and substrate. Such factors combine to determine the degree of habitat diversity in a given stream segment. Fish species richness tends to increase downstream as gradient decreases and stream size increases. Species richness is generally lowest at small headwater streams due to increased gradient and small stream size, which increases the frequency and severity of environmental fluctuations (Hynes 1970, Matthews and Styron 1980). In addition, the high gradient and decreased links with tributaries reduces the potential for colonization and entry of new species.

Species richness increases in mid-order to lower stream reaches due to increased environmental stability, greater numbers of potential habitats, and increases in numbers of colonization sources or links between major drainages. As one proceeds downstream, pools and runs increase over riffles, allowing for an increase in fine bottom materials and facilitating the growth of macrophytic vegetation. These environments allow for the presence of fishes more tolerant of low oxygen and increased temperatures. Further, the range of body forms increases with the appearance of those species with less fusiform body shapes, which are ecologically adapted to areas typified by decreased water velocities. In higher order streams or large rivers the bottom substrates often are typified by finer sediments; thus herbivores, omnivores, and planktivores may increase in response to the availability of aquatic vegetation and plankton (Bond 1979).

Fish have evolved unique feeding and reproductive strategies to survive in the diverse habitat conditions of North

America. Horwitz (1978) examined the structure of fish feeding guilds in 15 U.S. river systems and found that most fish species (33 percent) were benthic insectivores, whereas piscivores (16 percent), herbivores (7 percent), omnivores (6 percent), planktivores (3 percent), and other guilds contained fewer species. However, Allan (1995) indicated that fish frequently change feeding habits across habitats, life stages, and season to adapt to changing physical and biological conditions. Fish in smaller headwater streams tend to be insectivores or specialists, whereas the number of generalists and the range of feeding strategies increases downstream in response to increasing diversity of conditions

Some fish species are migratory, returning to a particular site over long distances to spawn. Others may exhibit great endurance, migrating upstream against currents and over obstacles such as waterfalls. Many must move between salt water and freshwater, requiring great osmoregulatory ability (McKeown 1984). Species that return from the ocean environment into freshwater streams to spawn are called *anadromous* species.

Species generally may be referred to as cold water or warm water, and gradations between, depending on their temperature requirements (Magnuson et al. 1979). Fish such as salmonids are usually restricted to higher elevations or northern climes typified by colder, highly oxygenated water. These species tend to be specialists, with rather narrow thermal tolerances and rather specific reproductive requirements. For example, salmonids typically spawn by depositing eggs over or within clean gravels which remain oxygenated and silt-free due to upwelling of currents within the interstitial spaces. Reproductive movement and behavior is controlled by subtle thermal changes combined with increasing or decreasing day-length. Salmonid populations, therefore, are highly susceptible to many forms of habitat degradation, including alteration of flows, temperature, and substrate quality.

Numerous fish species in the U.S. are declining in number. Williams et al. (1989) presented a list of North American fish species that the American Fisheries Society believed should be classified as endangered, threatened, or of special concern. This list contains 364 fish species warranting protection because of their rarity. Habitat loss was the primary cause of depletion for approximately 90 percent of the species listed. This study noted that 77 percent of the fish species listed were found in 25 percent of the states, with the highest concentrations in eight southwestern states. Nehlsen et al. (1991) provided a list of 214 native naturally spawning stocks of depleted Pacific salmon, steelhead, and sea-run cutthroat stocks from California, Oregon, Idaho, and Washington. Reasons cited for the declines were alteration of fish passage and migration due to dams, flow reduction associated with hydropower and agriculture, sedimentation and habitat loss due to logging and agriculture, overfishing, and negative interactions with other fish, including nonnative hatchery salmon and steelhead.

The widespread decline in the numbers of native fish species has led to current widespread interest in restoring the quality and quantity of habitats for fish. Restoration activities have frequently centered on improving local habitats, such as fencing or removing livestock from streams, constructing fish passages, or installing instream physical habitat. However, research has demonstrated that in most of these cases the success has been limited or questionable because the focus was too narrow and did not address restoration of the diverse array of habitat requirements and resources that are needed over the life span of a species.

Stream corridor restoration practitioners and others are now acutely aware that fish require many different habitats over the season and lifespan to fulfill needs for feeding, resting, avoiding predators, and reproducing. For example, Livingstone and Rabeni (1991) determined that juvenile smallmouth bass in the Jacks Fork River of southeastern Missouri fed primarily on small macroinvertebrates in littoral vegetation. Vegetation represented not only a source of food but a refuge from predators and a warmer habitat, factors that can collectively optimize chances for survival and growth (Rabeni and Jacobson 1993). Adult smallmouth bass, however, tended to occupy deeper pool habitats, and the numbers and biomass of adults at various sites were attributed to these specific deep-water habitats (McClendon and Rabeni 1987). Rabeni and Jacobson (1993) suggested that an understanding of these specific habitats, combined with an understanding of the fluvial hydraulics and geomorphology that form and maintain them, are key to developing successful stream restoration initiatives.

The emphasis on fish community restoration is increasing due to many ecological, economic, and recreational factors. In 1996 approximately 35 million Americans older than 16 participated in recreational fishing, resulting in over $36 billion in expenditures (Brouha 1997). Much of this activity is in streams, which justifies stream corridor restoration initiatives.

While fish stocks often receive the greatest public attention, preservation of other aquatic biota may also may be a goal of stream restoration. Freshwater mussels, many species of which are threatened and endangered, are often of particular concern (Williams et al. 1992). Mussels are highly sensitive to habitat disturbances and obviously benefit from intact, well-managed stream corridors. The south-central United States has the highest diversity of mussels in the world. Mussel ecology also is intimately linked with fish ecology, as fish function as hosts for mussel larvae (glochidia). Among the major threats they face are dams, which lead to direct habitat loss and fragmentation of remaining habitat, persistent sedimentation, pesticides, and introduced exotic species, such as fish and other mussel species.

Abiotic and Biotic Interrelations in the Aquatic System

Much of the spatial and temporal variability of stream biota reflects variations in both abiotic and biotic factors, including water quality, temperature, streamflow and flow

velocity, substrate, the availability of food and nutrients, and predator-prey relationships. These factors influence the growth, survival, and reproduction of aquatic organisms. While these factors are addressed individually below, it is important to remember that they are often interdependent.

Flow Condition

The flow of water from upstream to downstream distinguishes streams from other ecosystems. The spatial and temporal characteristics of streamflow, such as fast versus slow, deep versus shallow, turbulent versus smooth, and flooding versus low flows, are described previously in this chapter. These flow characteristics can affect both micro- and macro-distribution patterns of numerous stream species (Bayley and Li 1992, Reynolds 1992, Ward 1992). Many organisms are sensitive to flow velocity because it represents an important mechanism for delivering food and nutrients yet also may limit the ability of organisms to remain in a stream segment. Some organisms also respond to temporal variations in flow, which can change the physical structure of the stream channel, as well as increase mortality, modify available resources, and disrupt interactions among species (Resh et al. 1988, Bayley and Li 1992).

The flow velocity in streams determines whether planktonic forms can develop and sustain themselves. The slower the currents in a stream, the more closely the composition and configuration of biota at the shore and on the bottom approach those of standing water. High flows are cues for timing migration and spawning of some fishes. High flows also cleanse and sort streambed materials and scour pools. Extreme low flows may limit young fish production because such flows often occur during periods of recruitment and growth (Kohler and Hubert 1993).

Water Temperature

Water temperature can vary markedly within and among stream systems as a function of ambient air temperature, altitude, latitude, origin of the water, and solar radiation (Ward 1985, Sweeney 1993). Temperature governs many biochemical and physiological processes in cold-blooded aquatic organisms because their body temperature is the same as the surrounding water; thus, water temperature has an important role in determining growth, development, and behavioral patterns. Stream insects, for example, often grow and develop more rapidly in warmer portions of a stream or during warmer seasons. Where the thermal differences among sites are significant (e.g., along latitudinal or altitudinal gradients), it is possible for some species to complete two or more generations per year at warmer sites; these same species complete one or fewer generations per year at cooler sites (Sweeney 1984, Ward 1992). Growth rates for algae and fish appear to respond to temperature changes in a similar fashion (Hynes 1970, Reynolds 1992). The relationships between temperature and growth, development, and behavior can be strong enough to affect geographic ranges of some species (**Table 2.13**).

Table 2.13: Maximum weekly average temperatures for growth and short term maximum temperatures for selected fish (°C and °F).

Source: Brungs and Jones 1977.

Species	Max. Weekly Average Temp. for Growth (Juveniles)	Max. Temp. for Survival of Short Exposure (Juveniles)	Max. Weekly Average Temp. for Spawning[a]	Max. Temp. for Embryo Spawning[b]
Atlantic salmon	68°F	73°F	41°F	52°F
Bluegill	90°F	95°F	77°F	93°F
Brook trout	66°F	75°F	48°F	55°F
Common carp			70°F	91°F
Channel catfish	90°F	95°F	81°F	84°F[c]
Largemouth bass	90°F	93°F	70°F	81°F[c]
Rainbow trout	66°F	75°F	48°F	55°F
Smallmouth bass	84°F		63°F	73°F[c]
Sockeye salmon	64°F	72°F	50°F	55°F

[a] Optimum or mean of the range of spawning temperatures reported for the species.
[b] Upper temperature for successful incubation and hatching reported for the species.
[c] Upper temperature for spawning.

Water temperature is one of the most important factors determining the distribution of fish in freshwater streams, due both to direct impacts and influence on dissolved oxygen concentrations, and is influenced by local conditions, such as shade, depth and current. Many fish species can tolerate only a limited temperature range. Such fish as salmonids and sculpins dominate in cold water streams, whereas such species as largemouth bass, smallmouth bass, suckers, minnows, sunfishes and catfishes may be present in warmer streams (Walburg 1971).

Effects of Cover

For the purposes of restoration, land use practices that remove overhead cover or decrease baseflows can increase instream temperatures to levels that exceed critical thermal maxima for fishes (Feminella and Matthews 1984). Thus, maintenance or restoration of normal temperature regimes can be an important endpoint for stream managers.

Riparian vegetation is an important factor in the attenuation of light and temperature in streams (Cole 1994). Direct sunlight can significantly warm streams, particularly during summer periods of low flow. Under such conditions, streams flowing through forests warm rapidly as they enter deforested areas, but may also cool somewhat when streams reenter the forest. In Pennsylvania (Lynch et al. 1980), average daily stream temperatures that increased 12 °C through a clearcut area were substantially moderated after flow through 1,640 feet of forest below the clearcut. They attributed the temperature reduction primarily to inflows of cooler ground water.

A lack of cover also affects stream temperature during the winter. Sweeney (1993) found that, while average daily temperatures were higher in a second-order meadow stream than in a comparable wooded reach from April through October, the reverse was true from November through March. In a review of temperature effects on stream macroinvertebrates common to the Pennsylvania Piedmont, Sweeney (1992) found that temperature changes of 2 to 6 °C usually altered key life-history charac-

teristics of the study species. Riparian forest buffers have been shown to prevent the disruption of natural temperature patterns as well as to mitigate the increases in temperature following deforestation (Brown and Krygier 1970, Brazier and Brown 1973).

The exact buffer width needed for temperature control will vary from site to site depending on such factors as stream orientation, vegetation, and width. Along a smaller, narrow headwater stream, the reestablishment of shrubs, e.g., willows and alders, may provide adequate shade and detritus to restore both the riparian and aquatic ecosystems. The planting and/or reestablishment of large trees, e.g., cottonwoods, willows, sycamores, ash, and walnuts (Lowe 1964), along larger, higher order rivers can improve the segment of the fishery closest to the banks, but has little total effect on light and temperature of wider rivers.

Heat budget models can accurately predict stream and river temperatures (e.g., Beschta 1984, Theurer et al. 1984). Solar radiation is the major factor influencing peak summer water temperatures and shading is critical to the overall temperature regime of streams in small watersheds.

Dissolved Oxygen

Oxygen enters the water by absorption directly from the atmosphere and by plant photosynthesis (Mackenthun 1969). Due to the shallow depth, large surface exposure to air and constant motion, streams generally contain an abundant dissolved oxygen supply even when there is no oxygen production by photosynthesis.

Dissolved oxygen at appropriate concentrations is essential not only to keep aquatic organisms alive but to sustain their reproduction, vigor, and development. Organisms undergo stress at reduced oxygen levels that make them less competitive in sustaining the species (Mackenthun 1969). Dissolved oxygen concentrations of 3.0 mg/l or less have been shown to interfere with fish populations for a number of reasons (Mackenthun 1969, citing several other sources) (**Table 2.14**).

Level of Effect	Salmonid[a]	Nonsalmonid
Early life stages (eggs and fry)		
No production impairment	11 (8)	6.5
Slight production impairment	9 (6)	5.5
Moderate production impairment	8 (5)	5.0
Severe production impairment	7 (4)	4.5
Limit to avoid acute mortality	6 (3)	4.0
Other life stages		
No production impairment	8 (0)	6.0
Slight production impairment	6 (0)	5.0
Moderate production impairment	5 (0)	4.0
Severe production impairment	4 (0)	3.5
Limit to avoid acute mortality	3 (0)	3.0

[a] Values for salmonid early life stages are water column concentrations recommended to achieve the required concentration of dissolved oxygen in the gravel spawning substrate (shown in parentheses).

Table 2.14: Summary of dissolved oxygen concentrations (mg/L) generally associated with effects on fish in salmonid and nonsalmonid waters.
Source: USEPA 1987.

Depletion of dissolved oxygen can result in the death of aquatic organisms, including fish. Fish die when the demand for oxygen by biological and chemical processes exceeds the oxygen input by reaeration and photosynthesis, resulting in fish suffocation. Oxygen depletion usually is associated with slow current, high temperature, extensive growth of rooted aquatic plants, algal blooms, or high concentrations of organic matter (Needham 1969).

Stream communities are susceptible to pollution that reduces the dissolved oxygen supply (Odum 1971). Major factors determining the amount of oxygen found in water are temperature, pressure, abundance of aquatic plants and the amount of natural aeration from contact with the atmosphere (Needham 1969). A level of 5 mg/l of dissolved oxygen in water is associated with normal activity of most fish (Walburg 1971). Oxygen analyses of good trout streams show dissolved oxygen concentrations that range from 4.5 to 9.5 mg/l (Needham 1969).

pH

Aquatic organisms from a wide range of taxa exist and thrive in aquatic systems with nearly neutral hydrogen ion activity (pH 7). Deviations, either toward a more basic or acidic environment, increase chronic stress levels and eventually decrease species diversity and abundance (**Figure 2.34**). One of the more widely recognized impacts of changes in pH has been attributed to increased acidity of rainfall in some parts of the United States, especially areas downwind of industrial and urban emissions (Schreiber 1995). Of particular concern are environments that have a reduced capacity to neutralize acid inputs because soils have a limited buffering capacity. Acidic rainfall can be especially harmfull to environments such as the Adirondack region of upstate New York, where runoff already tends to be slightly acidic as a result of natural conditions.

Substrate

Stream biota respond to the many abiotic and biotic variables influenced by substrate. For example, differences in species composition and abundance can be observed among macroinvertebrate assemblages found in snags, sand, bedrock, and cobble within a single stream reach (Benke et al. 1984, Smock et al. 1985, Huryn and Wallace 1987). This preference for conditions associated with different substrates contributes to patterns observed at larger spatial scales where different macroinvertebrate assemblages are found in coastal, piedmont, and mountain streams (Hackney et al. 1992).

Stream substrates can be viewed in the same functional capacity as soils in the terrestrial system; that is, stream substrates constitute the interface between water and the hyporheic subsurface of the aquatic system. The *hyphorheic zone* is the area of substrate which lies below the substrate/water interface, and may range from a layer extending only inches beneath and laterally from the stream channel, to a very large subsurface environment. Alluvial floodplains of the Flathead River, Montana, have a hyphorheic zone with significant

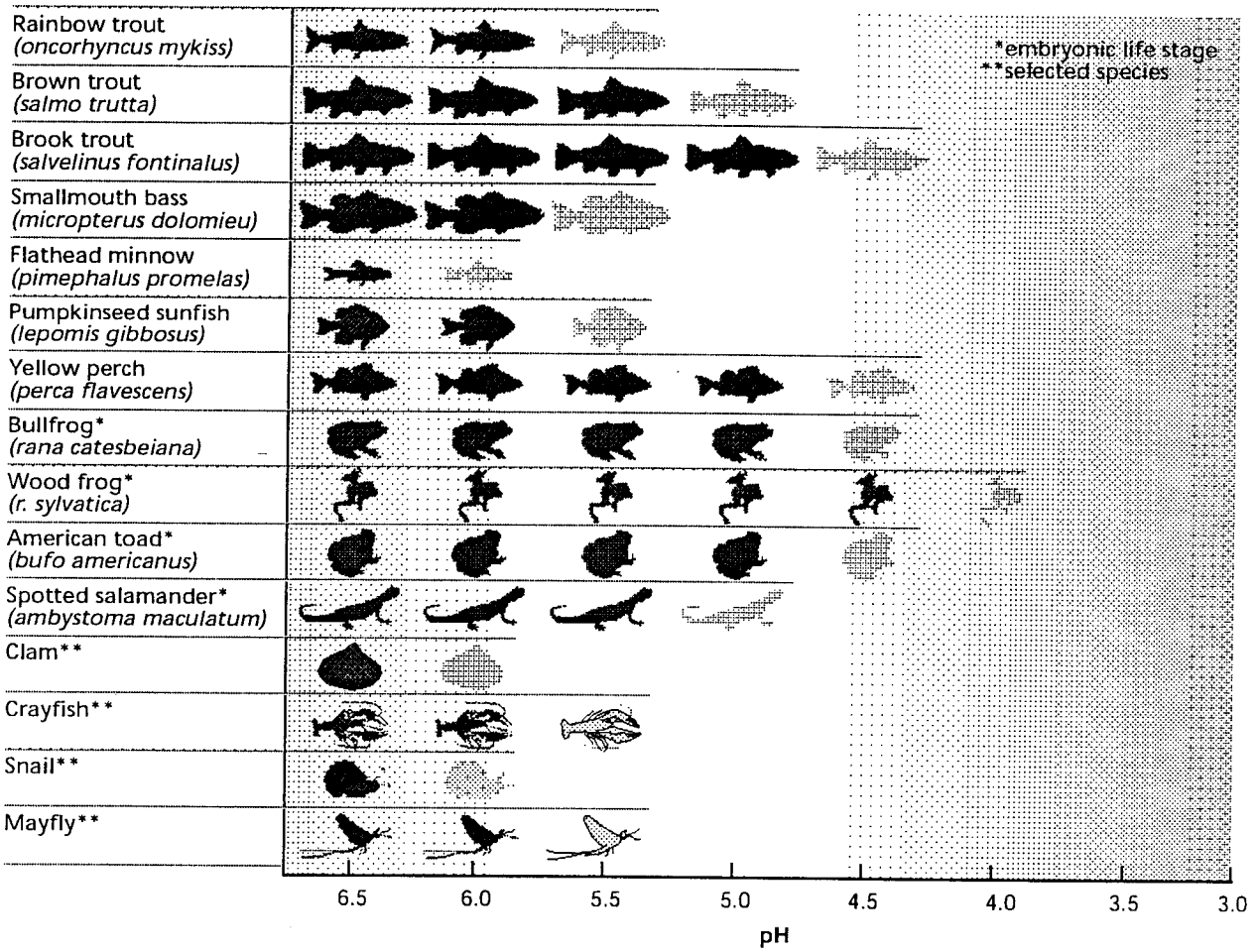


Figure 2.34: Effects of acid rain on some aquatic species.
As acidity increases (and pH decreased) in lakes and streams, some species are lost.

surface water/ground water interaction which is 2 miles wide and 33 feet deep (Stanford and Ward 1988). Naiman et al. (1994) discussed the extent and connectivity of hyphorheic zones around streams in the Pacific Northwest. They hypothesized that as one moves from low-order (small) streams to high-order (large) streams, the degree of hyphorheic importance and continuity first increases and then decreases. In small streams, the hyphorheic zone is limited to small floodplains, meadows, and stream segments where coarse sediments are deposited over bedrock. The hyphorheic zones are generally not continuous. In mid-order channels with more extensive floodplains, the spatial connectivity of the hyphorheic zone increases. In large order streams, the spatial extent of the hyphorheic zone is usually greatest, but it tends to be highly discontinuous because of features associated with fluvial activities such as oxbow lakes and cutoff channels, and because of complex interactions of local, intermediate, and regional ground water systems (Naiman et al. 1994) (**Figure 2.35**).

Stream substrates are composed of various materials, including clay, sand, gravel, cobbles, boulders, organic matter, and woody debris. Substrates

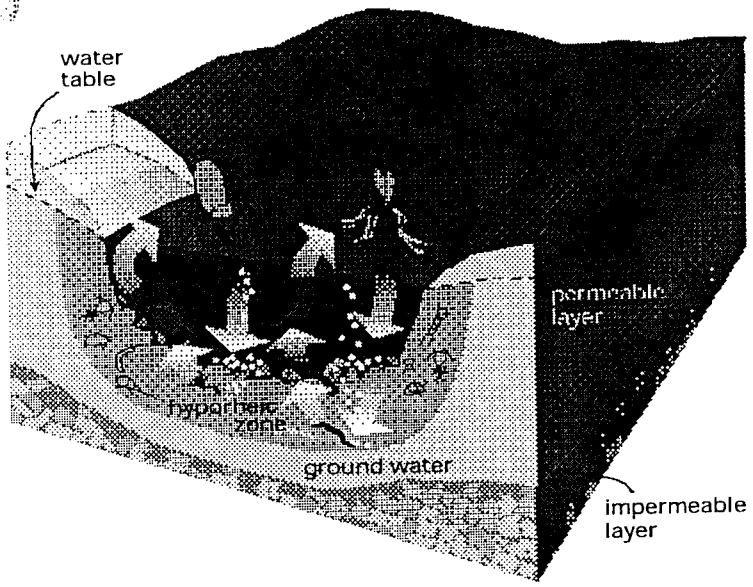


Figure 2.35: Hyphorheic zone.
Summary of the different means of migration undergone by members of the stream benthic community.

form solid structures that modify surface and interstitial flow patterns, influence the accumulation of organic materials, and provide for production, decomposition, and other processes (Minshall 1984). Sand and silt are generally the least favorable substrates for supporting aquatic organisms and support the fewest species and individuals. Flat or rubble substrates have the highest densities and the most organisms (Odum 1971). As previously described, substrate size, heterogeneity, stability with respect to high and baseflow, and durability vary within streams, depending on particle size, density, and kinetic energy of flow. Inorganic substrates tend to be larger upstream than downstream and tend to be larger in riffles than in pools (Leopold et al. 1964). Likewise, the distribution and role of woody debris varies with stream size (Maser and Sedell 1994).

In forested watersheds, and in streams with significant areas of trees in their riparian corridor, large woody debris that falls into the stream can increase the quantity and diversity of substrate and aquatic habitat or range (Bisson et al. 1987, Dolloff 1994). Debris dams trap sediment behind them and often create scour holes immediately downstream. Eroded banks commonly occur at the boundaries of debris blockages.

Organic Material

Metabolic activity within a stream reach depends on autochthonous, allochthonous, and upstream sources of food and nutrients (Minshall et al. 1985). Autochthonous materials, such as algae and aquatic macrophytes, originate within the stream channel, whereas allochthonous materials such as wood, leaves, and dissolved organic carbon, originate outside the stream channel. Upstream materials may be of autochthonous or allochthonous origin and are transported by streamflow to downstream locations. Seasonal flooding provides allochthonous input of organic material to the stream channel and also can significantly increase the rate of decomposition of organic material.

The role of primary productivity of streams can vary depending on geographic location, stream size, and season (Odum 1957, Minshall 1978). The river continuum concept (Vannote et al. 1980) (see *The River Continuum Concept* in section 1.E in Chapter 1) hypothesizes that primary productivity is of minimal importance in shaded headwater streams but increases in significance as stream size increases and riparian vegetation no longer limits the entry of light to stream periphyton. Numerous researchers have demonstrated that primary

productivity is of greater importance in certain ecosystems, including streams in grassland and desert ecosystems. Flora of streams can range from diatoms in high mountain streams to dense stands of macrophytes in low gradient streams of the Southeast.

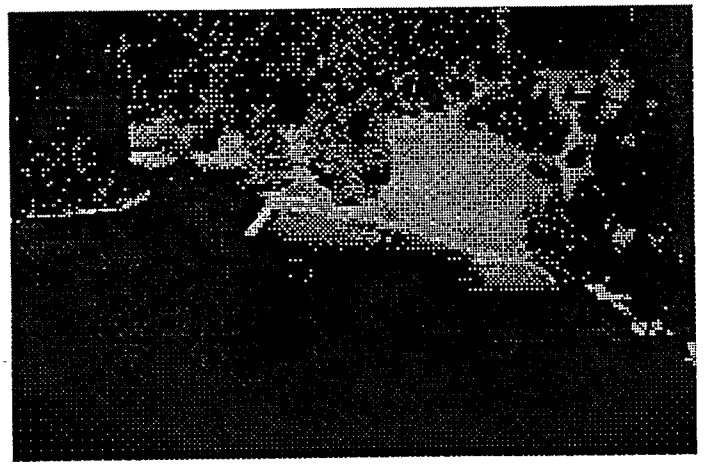
As discussed in Section 2.C, loading of nitrogen and phosphorus to a stream can increase the rate of algae and aquatic plant growth, a process known as *eutrophication*. Decomposition of this excess organic matter can deplete oxygen reserves and result in fish kills and other aesthetic problems in waterbodies.

Eutrophication in lakes and reservoirs is indirectly measured as standing crops of phytoplankton biomass, usually represented by planktonic chlorophyll a concentration. However, phytoplankton biomass is usually not the dominant portion of plant biomass in smaller streams, due to periods of energetic flow and high substrate to volume ratios that favor the development of periphyton and macrophytes on the stream bottom. Stream eutrophication can result in excessive algal mats and oxygen depletion at times of decreased flows and higher temperatures (**Figure 2.36**). Furthermore, excessive plant growth can occur in streams at apparently low ambient concentrations of nitrogen and phosphorus because the stream currents promote efficient exchange of nutrients and metabolic wastes at the plant cell surface.

In many streams, shading or turbidity limit the light available for algal growth, and biota depend highly on allochthonous organic matter, such as leaves and twigs produced in the surrounding watershed. Once leaves or other allochthonous materials enter the stream, they undergo rapid changes (Cummins 1974). Soluble organic compounds, such as sugars, are removed via leaching. Bacteria and fungi subsequently colonize the leaf materials and metabolize them as a source of carbon. The presence of the microbial biomass increases the protein content of the leaves, which ultimately represents a high quality food resource for shredding invertebrates.

The combination of microbial decomposition and invertebrate shredding/scraping reduces the average particle size of the organic matter, resulting in the loss of carbon both as respired CO_2 and as smaller organic particles transported downstream. These finer particles, lost from one stream segment, become the energy inputs to the downstream portions of the stream. This unidirectional movement of nutrients and organic matter in lotic systems is slowed by the temporary retention, storage, and utilization of nutrients in leaf packs, accumulated debris, invertebrates, and algae.

Figure 2.36: Stream eutrophication.
Eutrophication can result in oxygen depletion.



Organic matter processing has been shown to have nutrient-dependent relationships similar to primary productivity. Decomposition of leaves and other forms of organic matter can be limited by either nitrogen or phosphorus, with predictive N:P ratios being similar to those for growth of algae and periphyton. Leaf decomposition occurs by a sequential combination of microbial decomposition, invertebrate shredding, and physical fractionation. Leaves and organic matter itself are generally low in protein value. However, the colonization of organic matter by bacteria and fungi increases the net content of nitrogen and phosphorus due to the accumulation of proteins and lipids contained in microbial biomass. These compounds are a major nutritive source for aquatic invertebrates. Decaying organic matter represents a major storage component for nutrients in streams, as well as a primary pathway of energy and nutrient transfer within the food web. Ultimately, the efficiency of retention and utilization is reflected at the top of the food web in the form of fish biomass.

Organisms often respond to variations in the availability of autochthonous, allochthonous, and upstream sources. For example, herbivores are relatively more common in streams having open riparian canopies and high algal productivity compared to streams having closed canopies and accumulated leaves as the primary food resource (Minshall et al. 1983). Similar patterns can be observed longitudinally within the same stream (Behmer and Hawkins 1986).

Terrestrial and Aquatic Ecosystem Components for Stream Corridor Restoration

The previous sections presented the biological components and functional processes that shape stream corridors. The terrestrial and aquatic environments were discussed separately for the sake of simplicity and ease of understanding. Unfortunately, this is frequently the same approach taken in environmental restoration initiatives, with efforts placed separately on the uplands, riparian area, or instream channel. The stream corridor must be viewed as a single functioning unit or ecosystem with numerous connections and interactions between components. Successful stream corridor restoration cannot ignore these fundamental relationships.

The structure and functions of vegetation are interrelated at all scales. They are also directly tied to ecosystem dynamics. Particular vegetation types may have characteristic regeneration strategies (e.g., fire, treefall gaps) that maintain those types within the landscape at all times. Similarly, certain topographic settings may be more likely than others to be subject to periodic, dramatic changes in hydrology and related vegetation structure as a result of massive debris jams or occupation by beavers. However, in the context of stream corridor ecosystems, some of the most fundamental dynamic interactions relate to stream flooding and channel migration.

Many ecosystem functions are influenced by the structural characteristics of vegetation. In an undeveloped watershed, the movement of water and other materials is moderated by veg-

etation and detritus, and nutrients are mobilized and conserved in complex patterns that generally result in balanced interactions between terrestrial and aquatic systems. As the character and distribution of vegetation is altered by removal of biomass, agriculture, livestock grazing, development, and other land uses, and the flow patterns of water, sediment, and nutrients are modified, the interactions among system components become less efficient and effective. These problems can become more pronounced when they are aggravated by introductions of excess nutrients and synthetic toxins, soil disturbances, and similar impacts.

Stream migration and flooding are principal sources of structural and compositional variation within and among plant communities in most undisturbed floodplains (Brinson et al., 1981). Although streams exert a complex influence on plant communities, vegetation directly affects the integrity and characteristics of stream systems. For example, root systems bind bank sediments and moderate erosion processes, and floodplain vegetation slows overbank flows, inducing sediment deposition. Trees and smaller woody debris that fall into the channel deflect flows, inducing erosion at some points and deposition at others, alter pool distribution, the transport of organic material, as well as a number of other processes. The stabilization of streams that are highly interactive with their floodplains can disrupt the fundamental processes controlling the structure and function of stream corridor ecosystems, thereby indirectly affecting the characteristics of the surrounding landscape.

In most instances, the functions of vegetation that are most apparent are those that influence fish and wildlife. At the landscape level, the fragmentation of native cover types has been shown to significantly influence wildlife, often favoring opportunistic species over those requiring large blocks of contiguous habitat. In some systems, relatively small breaks in corridor continuity can have significant impacts on animal movement or on the suitability of stream conditions to support certain aquatic species. In others, establishment of corridors that are structurally different from native systems or inappropriately configured can be equally disruptive. Narrow corridors that are essentially edge habitat may encourage generalist species, nest parasites, and predators, and where corridors have been established across historic barriers to animal movement, they can disrupt the integrity of regional animal assemblages (Knopf et al. 1988).

Some riparian dependent species are linked to streamside riparian areas with fairly contiguous dense tree canopies. Without new trees coming into the population, older trees creating this linked canopy eventually drop out, creating ever smaller patches of habitat. Restoration that influences tree stands so that sufficient recruitment and patch size can be attained will benefit these species. For similar reasons, many riparian-related raptors such as the common black-hawk (*Buteogallus anthracinus*), gray hawk (*Buteo nitidus*), bald eagle (*Haliaeetus leucocephalus*), Cactus ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*), and Cooper's hawk (*Accipiter cooperii*), depend upon various

sizes and shapes of woody riparian trees for nesting substrate and roosts. Restoration practices that attain sufficient tree recruitment will greatly benefit these species in the long term, and other species in the short term.

Some aspects related to this subject have been discussed as ecosystem components and functions under other sections. Findings from the earliest studies of the impacts of fragmentation of riparian habitats on breeding birds were published for the Southwest (Carothers and Johnson 1971, Johnson 1971, Carothers et al. 1974). Subsequent studies by other investigators found similar results. Basically, cottonwood-willow gallery forests of the North American Southwest supported the highest concentrations of noncolonial nesting birds for North America. Destruction and fragmentation of these riparian forests reduced species richness and resulted in a nearly straight-line relationship between numbers of nesting pairs/acre and number of mature trees/acre. Later studies demonstrated that riparian areas are equally important as conduits for migrating birds (Johnson and Simpson 1971, Stevens et al. 1977).

When considering restoration of riparian habitats, the condition of adjacent habitats must be considered. Carothers (1979) found that riparian ecosystems, especially the edges, are widely used by nonriparian birds. In addition he found that some riparian birds utilized adjacent nonriparian ecosystems. Carothers et al. (1974) found that smaller breeding species [e.g., warblers and the Western wood pewee (*Contopus sordidulus*)] tended to carry on all activities within the riparian ecosystem during the breeding season. However, larger species (e.g., kingbirds and doves) commonly foraged outside the riparian ecosystem in adjacent habitats. Larger species (e.g., raptors) may forage miles from riparian ecosystems, but still depend on them in critical ways (Lee et al. 1989).

Because of more mesic conditions created by the canyon effect, canyons and their attendant riparian vegetation serve as corridors for short-range movements of animals along elevational gradients (e.g., between summer and winter ranges). Long-range movements that occur along riparian zones throughout North America include migration of birds and bats. Riparian zones also serve as stopover habitat for migrating birds (Stevens et al. 1977). Woody vegetation is generally important, not only to most riparian ecosystems, but also to adjacent aquatic and even upland ecosystems. However, it is important to establish clear management objectives before attempting habitat modification.

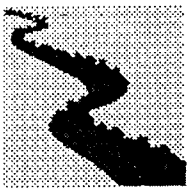
Restoring all of a given ecosystem to its "pristine condition" may be impossible, especially if upstream conditions have been heavily modified, such as by a dam or other water diversion project. Even if complete restoration is a possibility, it may not accomplish or complement the restoration goals.

For example, encroachment of woody vegetation in the channel below several dams in the Platte River Valley in Nebraska has greatly decreased the amount of important wet meadow habitat. This area has been declared critical habitat for the whooping crane

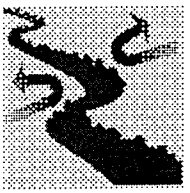
(*Grus americana*) (Aronson and Ellis 1979), for piping plover, and for the interior least tern. It is also an important staging area for up to 500,000 sandhill cranes (*Grus canadensis*) from late February to late April and supports 150 to 250 bald eagles (*Haliaeetus leucocephalus*). Numerous other important species using the area include the peregrine falcon (*Falco peregrinus*), Canada goose (*Branta canadensis*), mallard (*Anas platyrhynchos*), numerous other waterfowl, and raptors (U.S. Fish and Wildlife Service 1981). Thus, managers here are confronted with means of reducing riparian groves in favor of wet meadows.

2.E Functions and Dynamic Equilibrium

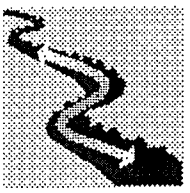
Figure 2.37: Critical ecosystem functions.
Six functions can be summarized as a set of basic, common themes recurring in a variety of settings.


Habitat

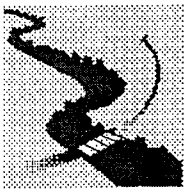
Habitat-*the spatial structure of the environment which allows species to live, reproduce, feed, and move.*


Barrier

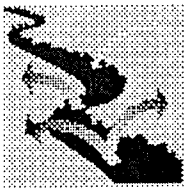
Barrier-*the stoppage of materials, energy, and organisms.*


Conduit

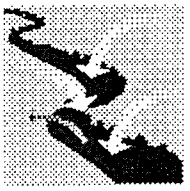
Conduit-*the ability of the system to transport materials, energy, and organisms.*


Filter

Filter–*the selective penetration of materials, energy, and organisms.*


Source

Source—*a setting where the output of materials, energy, and organisms exceeds input.*


Sink

Sink—*a setting where the input of water, energy, organisms and materials exceeds output.*

Throughout the past two chapters, this document has covered stream corridor structure and the physical, chemical and biological processes occurring in stream corridors. This information shows how stream corridors function as ecosystems, and consequently, how these characteristic structural features and processes must be understood in order to enable stream corridor functions to be effectively restored. In fact, reestablishing structure or restoring a particular physical or biological process is not the only thing that restoration seeks to achieve. Restoration aims to reestablish valued functions. Focusing on ecological functions gives the restoration effort its best chance to recreate a self-sustaining system. This property of sustainability is what separates a functionally sound stream, that freely provides its many benefits to people and the natural environment, from an impaired watercourse that cannot sustain its valued functions and may remain a costly, long-term maintenance burden.

Section 1.A of Chapter 1 emphasized matrix, patch, corridor and mosaic as the most basic building blocks of physical structure at local to regional scales. Ecological functions, too, can be summarized as a set of basic, common themes that recur in an infinite variety of settings. These six critical functions are habitat, conduit, filter, barrier, source, and sink (**Figure 2.37**).

In this section, the processes and structural descriptions of the past two chapters are revisited in terms of these critical ecological functions.

Two attributes are particularly important to the operation of stream corridor functions:

- *Connectivity*- This is a measure of how spatially continuous a corridor or a matrix is (Forman and Godron 1986). This attribute is affected by gaps or breaks in the corridor and between the corridor and adjacent land uses (**Figure 2.38**). A stream corridor with a high degree of connectivity among its natural communities promotes valuable functions including transport of materials and energy and movement of flora and fauna.
- *Width*- In stream corridors, this refers to the distance across the stream and its zone of adjacent vegetation cover. Factors affecting width are edges, community composition, environmental gradients, and disturbance effects of adjacent ecosystems, including those with human activity. Example measures of width include average dimension and variance, number of narrows, and varying habitat requirements (Dramstad et al. 1996)

Width and connectivity interact throughout the length of a stream corridor. Corridor width varies along the length of the stream and may have gaps. Gaps across the corridor interrupt and reduce connectivity. Evaluating connectivity and width can provide some of the most valuable insight for designing restoration actions that mitigate disturbances.

The following subsections discuss each of the functions and general relationship to connectivity and width. The final subsection discusses dynamic equilibrium and its relevance to stream corridor restoration.

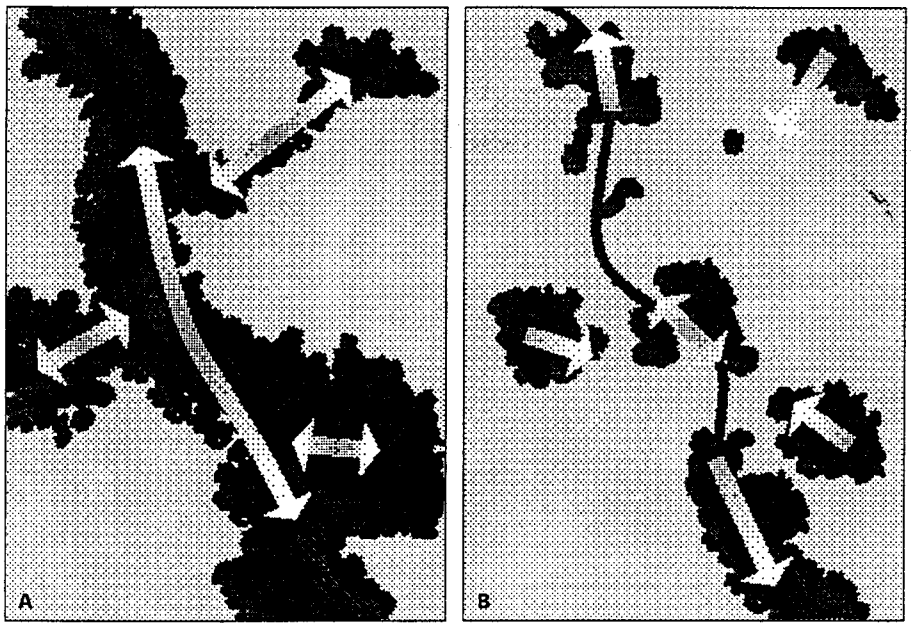
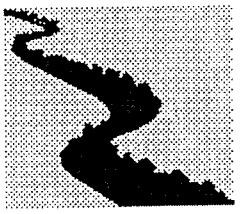


Figure 2.38: Landscapes with *(A)* high and *(B)* low degrees of connectivity.
A connected landscape structure generally has higher levels of functions than a fragmented landscape.

Habitat Functions



Habitat is a term used to describe an area where plants or animals (including people) normally live, grow, feed, reproduce, and otherwise exist for any portion of their life cycle. Habitats provide organisms or communities of organisms with the necessary elements of life, such as space, food, water, and shelter.

Under suitable conditions often provided by stream corridors, many species can use the corridor to live, find food and water, reproduce, and establish viable populations. Some measures of a stable biological community are population size, number of species, and genetic variation, which fluctuate within expected limits over time. To varying degrees, stream corridors constructively influence these measures. The corridor's value as habitat is increased by the fact that corridors often connect many small habitat patches and thereby create larger, more complex habitats with larger wildlife populations and higher biodiversity.

Habitat functions differ at various scales, and an appreciation of the scales at which different habitat functions occur will help a restoration initiative succeed. The evaluation of habitat at larger scales, for example, may make note of a biotic community's size, composition, connectivity and shape.

At the landscape scale, the concepts of matrix, patches, mosaics and corridors are often involved in describing habitat over large areas. Stream corridors and major river valleys together can provide substantial habitat. North American flyways include examples of stream and river corridor habitat exploited by migratory birds at landscape to regional scales.

Stream corridors, and other types of naturally vegetated corridors as well, can provide migrating forest and riparian species with their preferred resting and feeding habitats during migration stopovers. Large mammals such as black bear are known to require large, contiguous wild terrain as home range, and in many parts of the country broad stream corridors are crucial to linking smaller patches into sufficiently large territories.

Habitat functions within watersheds may be examined from a somewhat different perspective. Habitat types and patterns within the watershed are significant, as are patterns of connectivity to adjoining watersheds. The vegetation of the stream corridor in upper reaches of watersheds sometimes has become disconnected from that of adjacent watersheds and corridors beyond the divide. When terrestrial or semiaquatic stream corridor communities are connected at their headwaters, these connections will usually help provide suitable alternative habitats beyond the watershed.

Assessing habitat function at the stream corridor and smaller scales can also be viewed in terms of patches and corridors, but in finer detail than in landscapes and watersheds. It is also at local scales that transitions among the

Edge and Interior Habitat

Two important habitat characteristics are edges and interior (**Figure 2.39**) Edges are critical lines of interaction between different ecosystems. Interior habitats are generally more stable, sheltered environments where the ecosystem may remain relatively the same for prolonged periods. Edge habitat is exposed to highly variable environmental gradients. The result is a different species composition and abundance than observed interior habitat. Edges are important as filters of disturbance to interior habitat. Edges can also be diverse areas with a large variety of flora and fauna.

Edges and interiors are scale-independent concepts. Larger mammals known as interior forest species may need to be miles from the forest edge to find desired habitat, while an insect or amphibian may be sensitive to the edges and interiors of the microhabitat under a rotted log. The edges and interiors of a stream corridor, therefore, depend upon the species being considered. As elongated, narrow ecosystems that include land/water interfaces and often include natural/human-made boundaries as well at the upland fringe, stream corridors have an abundance of edges and these have a pronounced effect on their biota.

Edges and interiors are each preferred by different sets of plant and animal species, and it is inappropriate to consider edges or interiors as consistently "bad" or "good" habitat characteristics. It may be desirable to maintain or increase edge in some circumstances, or favor interior habitats in others. Generally speaking, however, human activity tends to increase edge and decrease interior, so more often it is restoring or protecting interior that merits specific management action.

Edge habitat at the stream corridor boundary typically has higher inputs of solar energy, precipitation, wind energy, and other influences from the adjacent ecosystems. The difference in environmental gradients at the stream corridor's edge results in a diversified plant and animal community interacting with adjacent ecosystems. The effect of edge is more pronounced when the amount of interior habitat is minimal.

Interior habitat occurs further from the perimeter of the element. Interior is typified by more stable environmental inputs than those found at the edge of an ecosystem. Sunlight, rainfall, and wind effects are less intense in the interior. Many sensitive or rare species depend upon a less-disturbed environment for their survival. They are therefore tolerant of only "interior" habitat conditions. The distance from the perimeter required to create these interior conditions is dependent upon the species' requirements.

Interior plants and animals differ considerably from those that prefer or tolerate the edge's variability. With an abundance of edge, stream corridors often have mostly edge species. Because large ecosystems and wide corridors are becoming increasingly fragmented in modern landscapes, however, interior species are often rare and hence are targets for restoration. The habitat requirements of interior species (with respect to distance from edge are a useful guide in restoring larger stream corridors to provide a diversity of habitat types and sustainable communities.

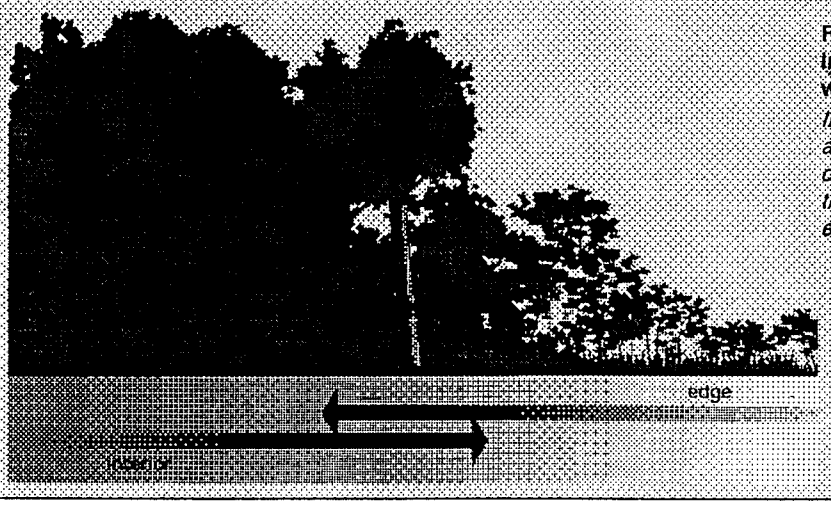


Figure 2.39: Edge and interior habitat of a woodlot
Interior plants and animals differ considerably from those that prefer or tolerate the edge's variability.

various habitats within the corridor can become more important. Stream corridors often include two general types of habitat structure: interior and edge habitat. Habitat diversity is increased by a corridor that includes both edge and interior conditions, although for most streams, corridor width is insufficient to provide much interior habitat for larger vertebrates such as forest interior bird species. For this reason, increasing interior habitat is sometimes a watershed scale restoration objective.

Habitat functions at the corridor scale are strongly influenced by connectivity and width. Greater connectivity and increased width along and across a stream corridor generally increases its value as habitat. Stream valley morphology and environmental gradients (such as gradual changes in soil wetness, solar radiation, and precipitation) can cause changes in plant and animal communities. More species generally find suitable habitat conditions in a wide, contiguous, and diverse assortment of native plant communities within the stream corridor than in a narrow, homogeneous or highly fragmented corridor.

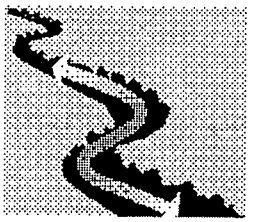
When applied strictly to stream channels, however, this might not be true. Some narrow and deeply incised streams, for example, provide thermal conditions that are critical for endangered salmonids.

Habitat conditions within a corridor vary according to factors such as climate and microclimate, elevation, topography, soils, hydrology, vegetation, and human uses. In terms of planning restoration measures, corridor width is especially important for wildlife. When planning for maintenance of a given wildlife species, for example, the dimension and shape of the corridor must be wide enough to include enough suitable habitat that this species can populate the stream corridor. Corridors that are too narrow may provide as much of a barrier to some species' movement as would a complete gap in the corridor.

On local scales, large woody debris that becomes lodged in the stream channel can create morphological changes to the stream and adjacent streambanks. Pools may be formed downstream from a log that has fallen across a stream and both upstream and downstream flow characteristics are altered. The structure formed by large woody debris in a stream improves aquatic habitat for most fish and invertebrate species.

Riparian forests, in addition to their edge and interior habitats, may offer vertical habitat diversity in their canopy, subcanopy, shrub and herb layers. And within the channel itself, riffles, pools, glides, rapids and backwaters all provide different habitat conditions in both the water column and the streambed. These examples, all described in terms of physical structure, illustrate once again the strong linkage between structure and habitat function.

Conduit Function



The conduit function is the ability to serve as a flow pathway for energy, materials, and organisms. A stream corridor is above all a conduit that was formed by and for collecting and transporting water and sediment. In addition, many other types of materials and biota move throughout the system.

The stream corridor can function as a conduit laterally, as well as longitudinally, with movement by organisms and materials in any number of directions. Materials or animals may further move across the stream corridor, from one side to another. Birds or small mammals, for example, may cross a stream with a closed canopy by moving through its vegetation. Organic debris and nutrients may fall from higher to lower floodplains and into the stream within corridors, affecting the food supply for stream invertebrates and fishes.

Moving material is important because it impacts the hydrology, habitat, and structure of the stream as well as the terrestrial habitat and connections in the floodplain and uplands. The structural attributes of connectivity and width also influence the conduit function.

For migratory or highly mobile wildlife, corridors serve as habitat and conduit simultaneously. Corridors in combination with other suitable habitats, for example, make it possible for songbirds to move from wintering habitat in the neo-tropics to northern, summer habitats. Many species of birds can only fly for limited distances before they must rest and refuel. For stream corridors to function effectively as conduits for these birds, they must be sufficiently connected and be wide enough to provide required migratory habitat.

Stream corridors are also conduits for the movement of energy, which occurs in many forms. The gravity-driven energy of stream flow continually sculpts and modifies the landscape. The corridor modifies heat and energy from sunlight as it remains cooler in spring and summer and warmer in the fall. Stream valleys are effective airsheds, moving cool air from higher to lower elevations in the evening. The highly productive plant communities of a corridor accumulate energy as living plant material, and export large amounts in the form of leaf fall or detritus. The high levels of primary productivity, nutrient flow, and leaf litter fall also fuel increased decomposition in the corridor, allowing new transformations of energy and materials. At its outlet, a stream's outputs to the next larger water body (e.g., increased water volume, higher temperature, sediments, nutrients, and organisms) are in part the excesses of energy from its own system.

One of the best known and studied examples of aquatic species movement and interaction with the watershed is the migration of salmon upstream for spawning. After maturing in the ocean, the fish are dependent on access to their upstream spawning grounds. In

the case of Pacific salmon species, the stream corridor is dependent upon the resultant biomass and nutrient input of abundant spawning and dying adults into the upper reaches of stream systems during spawning. Thus, connectivity is often critical for aquatic species transport, and in turn, nutrient transport upstream from ocean waters to stream headwaters.

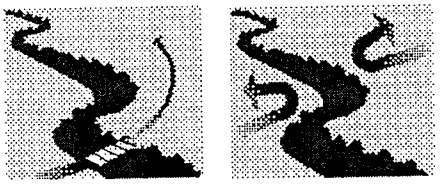
Streams are also conduits for distribution of plants and their establishment in new areas (Malanson, 1993). Flowing water may transport and deposit seeds over considerable distances. In flood stage, mature plants may be uprooted, relocated, and redeposited alive in new locations. Wildlife also help redistribute plants by ingesting and transporting seeds throughout different parts of the corridor.

Sediment (bed load or suspended load) is also transported through the stream. Alluvial streams are dependent on the continual supply and transport of sediment, but many of their fish and invertebrates can also be harmed by too much fine sediment. When conditions are altered, a stream may become either starved of sediment or choked with sediment down-gradient. Streams lacking appropriate amounts of sediment attempt to reestablish equilibrium through downcutting, bank erosion and channel erosion. An appropriately structured stream corridor will optimize timing and supply of sediment to the stream to improve sediment transport functions.

Local areas in the corridor are dependent on the flow of materials from one point to another. In the salmonid example, the local upland area adjacent to spawning grounds is dependent upon the nutrient transfer from the biomass of the fish into other terrestrial wildlife and off into the uplands. The local structure of the streambed and aquatic ecosystem are dependent upon the sediment and woody material from upstream and upslope to create a self-regulating and stable channel.

Stream corridor width is important where the upland is frequently a supplier of much of the natural load of sediment and biomass into the stream. A wide, contiguous corridor acts as a large conduit, allowing flow laterally and longitudinally along the corridor. Conduit functions are often more limited in narrow or fragmented corridors.

Filter and Barrier Functions



Stream corridors may serve as barriers that prevent movement or filters that allow selective penetration of energy, materials and organisms. In many ways, the entire stream corridor serves beneficially as a filter or barrier that reduces water pollution, minimizes sediment transport, and often provides a natural boundary to land uses, plant communities, and some less mobile wildlife species.

Materials, energy, and organisms which moved into and through the stream corridor may be filtered by structural attributes of the corridor. Attributes affecting barrier and filter functions include connectivity (gap

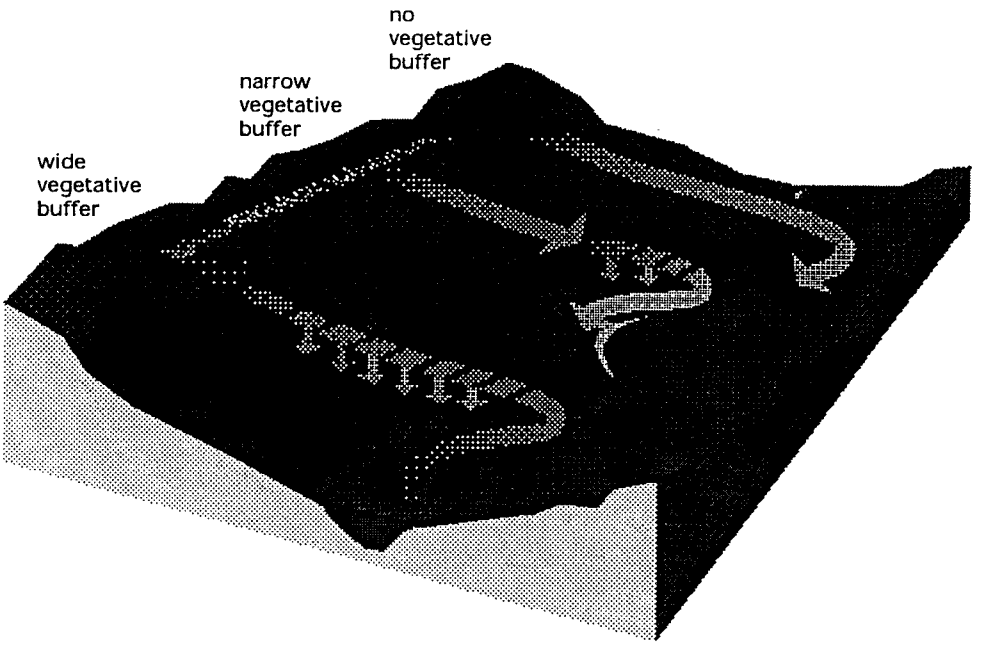


Figure 2.40: The width of the vegetation buffer influences filter and barrier functions
Dissolved substances, such as nitrogen, phosphorus, and other nutrients, entering a vegetated stream corridor are restricted from entering the channel by friction, root absorption, clay, and soil organic matter.
Adapted from *Ecology of Greenways: Design and Function of Linear Conservation Areas.* Edited by Smith and Hellmund. © University of Minnesota Press 1993.

frequency), and corridor width (**Figure 2.40**). Elements which are moving along a stream corridor edge may also be selectively filtered as they enter the stream corridor. In these circumstances it is the shape of the edge, whether it is straight or convoluted, which has the greatest effect on filtering functions. Still, it is most often movement perpendicular to the stream corridor which is most effectively filtered or halted.

Materials may be transported, filtered, or stopped altogether depending upon the width and connectedness of a stream corridor. Material movement across landscapes toward large river valleys may be intercepted and filtered by stream corridors. Attributes such as the structure of native plant communities can physically affect the amount of runoff entering a stream system through uptake, absorption, and interruption. Vegetation in the corridor can filter out much of the overland flow of nutrients, sediment, and water.

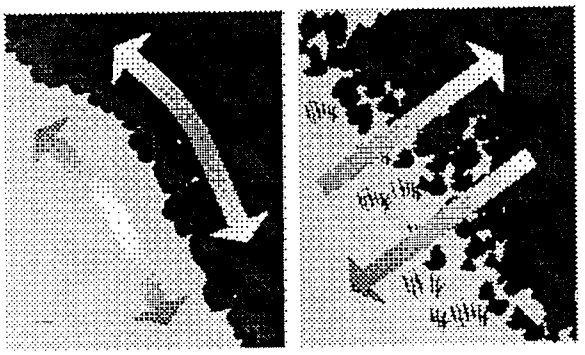
Siltation in larger streams can be reduced through a network of stream corridors functioning to filter excessive sediment. Stream corridors filter many of the upland materials from moving unimpeded across the landscape. Ground water and surface water flows are filtered by plant parts below and above ground. Chemical elements are intercepted by flora and fauna within stream corridors. A wider corridor provides more effective filtering, and a contiguous corridor functions as a filter along its entire length.

Breaks in a stream corridor can sometimes have the effect of funneling damaging processes into that area. For example, a gap in contiguous vegetation along a stream corridor can reduce

the filtering function by focusing increased runoff into the area, leading to erosion, gullying, and the free flow of sediments and nutrients into the stream.

Edges at the boundaries of stream corridors begin the process of filtering. Abrupt edges concentrate initial filtering functions into a narrow area. A gradual edge increases filtering and spreads it across a wider ecological gradient. (**Figure 2.41**).

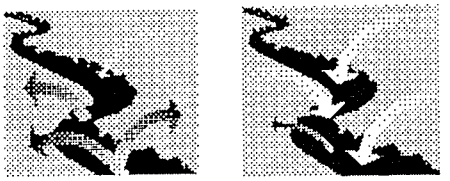
Movement parallel to the corridor is affected by coves and lobes of an uneven corridor's edge. These act as barriers or filters for materials flowing into the corridor. Individual plants may selectively capture materials such as wind-borne sediment, carbon, or propagules as they pass through a convoluted edge. Herbivores traveling along a boundary edge, for example, may stop to rest and selectively feed in a sheltered nook. The wind blows a few seeds into the corridor, and those suited to the conditions of the corridor may germinate and establish a population. The lobes have acted as a selective filter collecting some seeds at the edge and allowing other species to interact at the boundary (Forman 1995).



(a) *(b)*

Figure 2.39: Edges can be (a) abrupt or (b) radual.
Abrupt edges, usually caused by disturbances, tend to discourage movement between ecosystems and promote movement along the boundary. Gradual edges usually occur in natural settings, are more diverse, and encourage movement between ecosystems.

Source and Sink Functions



Sources provide organisms, energy or materials to the surrounding landscape. Areas that function as sinks absorb organisms, energy, or materials from the surrounding landscape. Influent and effluent reaches, discussed in Section 1.B of Chapter 1, are classic examples of sources and sinks. The influent or "losing" reach is a source of water to the aquifer, and the effluent or "gaining" reach is a sink for ground water.

Stream corridors or features within them can act as a source or a sink of environmental materials. Some stream corridors act as both, depending on the time of year or location in the corridor. Streambanks most often act as a source, for example, of sediment to the stream. At times, however, they can function as sinks while flooding deposits new sediments there. At the landscape scale, corridors are connectors to various other patches of habitats in the landscape and as such they are sources and conduits of genetic material throughout the landscape.

Stream corridors can also act as a sink for storage of surface water, ground water, nutrients, energy, and sediment allowing for materials to be temporarily fixed in the corridor. Dissolved substances, such as nitrogen, phosphorus, and other nutrients, entering a vegetated stream corridor are restricted from entering the channel by friction,

root absorption, clay, and soil organic matter. Although these functions of source and sink are conceptually understood, they lack a suitable body of research and practical application guidelines.

Forman (1995) offers three source and sink functions resulting from floodplain vegetation:

- Decreased downstream flooding through floodwater moderation and/or uptake
- Containment of sediments and other materials during flood stage
- Source of soil and water organic matter

Biotic and genetic source/sink relationships can be complex. Interior forest birds are vulnerable to nest parasitism by cowbirds when they try to nest in too small a forest patch. For these species, small forest patches can be considered sinks that reduce their population numbers and genetic diversity by causing failed reproduction. Large forest patches with sufficient interior habitat, in comparison, support successful reproduction and serve as sources of more individuals and new genetic combinations.

Dynamic Equilibrium

The first two chapters of this document have emphasized that, although stream corridors display consistent patterns in their structure, processes, and functions, these patterns change naturally and constantly, even in the absence of human disturbance. Despite frequent change, streams and their corridors exhibit a dynamic form of stability. In constantly changing ecosystems like stream corridors, stability is the ability of a system to persist within a range of conditions. This phenomenon is referred to as *dynamic equilibrium.*

The maintenance of dynamic equilibrium requires that a series of self-correcting mechanisms be active in the stream corridor ecosystem. These mechanisms allow the ecosystem to control external stresses or disturbances within a certain range of responses thereby maintaining a self-sustaining condition. The threshold levels associated with these ranges are difficult to identify and quantify. If they are exceeded, the system can become unstable. Corridors may then undergo a series of adjustments to achieve a new steady state condition, but usually after a long period of time has elapsed.

Many stream systems can accommodate fairly significant disturbances and still return to functional condition in a reasonable time frame, once the source of the disturbance is controlled or removed. Passive restoration is based on this tendency of ecosystems to heal themselves when external stresses are removed. Often the removal of stress and the time to recover naturally are an economical and effective restoration strategy. When significant disturbance and alteration has occurred, however, a stream corridor may require several decades to restore itself. Even then, the recovered system may be a very different type of stream that, although at equilibrium again, is of severely diminished ecological value in comparison with its previous potential. When restoration practitioners' analysis indicates lengthy recov-

In constantly changing ecosystems like stream corridors, stability is the ability of a system to persist within a range of conditions. This phenomenon is referred to as *dynamic equilibrium.*

Stability, Disturbance, and Recovery

Stability, as a characteristic of ecosystems, combines the concepts of resistance, resilience, and recovery. *Resistance* is the ability to maintain original form and functions. *Resilience* is the rate at which a system returns to a stable condition after a disturbance. *Recovery* is the degree to which a system returns to its original condition after a disturbance. Natural systems have developed ways of coping with disturbance, in order to produce recovery and stability. Human activities often superimpose additional disturbances which may exceed the recovery capability of a natural system. The fact that change occurs, however, does not always mean a system is unstable or in poor condition.

The term mosaic stability is used to denote the stability of a larger system within which local changes still take place. Mosaic stability, or the lack thereof, illustrates the importance of the landscape perspective in making site-specific decisions. For example, in a rapidly urbanizing landscape, a riparian system denuded by a 100-year flood may represent a harmful break in already diminished habitat that splits and isolates populations of a rare amphibian species. In contrast, the same riparian system undergoing flooding in a less-developed landscape may not be a geographic barrier to the amphibian, but merely the mosaic of constantly shifting suitable and unsuitable habitats in an unconfined, naturally functioning stream. The latter landscape with mosaic stability is not likely to need restoration while the former landscape without mosaic stability is likely to need it urgently. Successful restoration of any stream corridor requires an understanding of these key underlying concepts.

ery time or dubious recovery potential for a stream, they may decide to use active restoration techniques to reestablish a more functional channel form, corridor structure, and biological community in a much shorter time frame. The main benefit of an active restoration approach is regaining functionality more quickly, but the biggest challenge is to plan, design and implement correctly to reestablish the desired state of dynamic equilibrium.

This new equilibrium condition, however, may not be the same that existed prior to the initial occurrence of the disturbance. In addition, disturbances can often stress the system beyond its natural ability to recover. In these instances restoration is needed to remove the cause of the disturbance or stress (passive) or to repair damages to the structure and functions of the stream corridor ecosystem (active).