Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: An ecologically based inventory and estimation of the effects of land use practices

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December 1999

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EXECUTIVE SUMMARY

Six lakes and five streams in Pictured Rocks National Lakeshore were analyzed for impacts from human activities. Two activities identified as being likely to affect aquatic habitat were road building and timber harvesting. Both of these land uses can increase the rate of soil erosion resulting in heavy sediment loads which affect biota in lakes and streams.

Prior to sampling, risk analyses were developed for both timber harvesting and road building within the park and buffer zone. GIS analyses were performed to identify areas of the park prone to erosion caused by such activities.

The following six lakes were sampled for this report: Beaver Lake, Chapel Lake, Legion Lake, Grand Sable Lake, Miners Lake, and Section 26 Lake. For each lake, Secchi disk depth, pH, alkalinity, total phosphorus, and Kjeldahl nitrogen were sampled and trophic status was assessed.

The five streams sampled were Mosquito River, Miners River, Hurricane River, Seven Mile Creek, and Sullivan Creek. Streams samples included substrate size analysis, benthic macroinvertebrate analysis, and fish analysis. Substrate size was analyzed since road building and timber cutting were likely to have an impact on substrate distribution. Macroinvertebrate community response to substrate size was assessed using a multivariate statistical analysis called Canonical Correspondence Analysis. In addition, five community metrics were developed including density, taxa richness, Shannon's Diversity, Simpson's *D* and EPT. Fish were collected to provide baseline data for future studies.

Results indicate that lakes and streams within the park are currently in good health. Risk analysis provided detailed maps of areas where road building and timber cutting would create the most disturbance and allow management a tool to plan future activities. Chemical, physical and biological monitoring tools were developed from the lake and stream sampling program. Baseline data is presented which may be used to compare results from future impact studies.

I. INTRODUCTION

. In order to protect natural resources and natural features in mid-sized and smaller units of the National Park Service, problems of regional management in lands outside the parks must be addressed. Management of streams which have watersheds outside park boundaries and large lakes bordering on the parks is an obvious example of water resources requiring broad regional approaches to management. This approach is particularly important to Pictured Rocks National Lakeshore (PIRO) whose enabling legislation created a specific *buffer zone* to protect watersheds within surrounding non-fee lands, while providing continued use of these lands for other purposes. The effectiveness of this *buffer zone* must be assessed and managed on the basis of sound scientific information since logging and low density housing are presently permitted

Water quality as a component of aquatic environmental quality falls under both federal and state legislation. A number of anthropogenic factors affect the physical, chemical, and biological attributes of aquatic ecosystems. Those streams that receive discharge from outside sources are specifically permitted under state regulatory licenses, and are referred to as *point sources.* All other sources of potential impact including agricultural and urban runoff, impacts due to forestry practices and many industries fall into the category *non-point source*. Estimating and mitigating the effects from this latter category is a complex process and one of current research efforts.

One way of estimating the potential for non-point source impact is to develop a data base on land use and identify the various categories potentially affecting water quality and aquatic environmental quality. This approach would allow management of water quality in the larger context of regional land management. Risk analysis combining an appropriate ecological inventory of critical biological communities should be developed as biological indicators of water

quality sensitive to impacts from land use change. While this approach will be applied specifically to the aquatic natural resources in PIRO, it has generic applicability to the preservation of natural resources in other parks. Because of the strong influence of activities outside their boundaries small and medium sized parks are more vulnerable to threats and the development of techniques of risk analysis is appropriate in the preservation of natural resources.

Effective management of natural resources within protected areas such as national parks requires new strategies for integrative environmental assessment and monitoring. Many parks are now facing critical environmental problems affecting whole regions where development has been accelerated. These problems include large scale changes in land use, complex chemical pollution of aquatic and terrestrial ecosystems, regional air pollution, coastal degradation, loss of wetlands, introduction of exotic species, loss of biodiversity, and man-induced climate change. All involve long-term, large scale environmental degradation. Major ecosystems such as large lakes, major rivers, estuaries, and even large scale biogeographical regions are subject to multiple anthropogenic disturbances (Hunsaker et al., 1990).

The value of protected natural resources contained in units of the National Park System falls into two categories. The first, most obvious, is outlined by the 1916 Organic Act establishing the National Parks system itself, as well as by the specific legislation creating individual parks. Preservation of natural resources, of esthetic and scientific value, is a preeminent purpose of the National Park Service requiring special vigilance. Park resources have special unique scientific value in the light of alterations of natural resources due to increasing land use and development in regions directly adjacent to the parks. This prospective of parks resource is addressed in the recent National Academy of Sciences (1992) report under the section of "Parks

for Science" which recognizes the special value that protected unimpaired ecosystems offers to basic scientific research.

Secondly, National Parks and protected areas are beginning to be perceived as centers of environmental quality. Protection of environmental quality in National Parks, in terms of the aquatic resources, is specifically addressed in federal and state water quality legislation under the anti degradation statutes and by the Outstanding Natural Resource Waters classification (USEPA, 1990). Moreover, the program of establishing reference streams of high ecological integrity within each of the USEPA's eco regions (Omernik 1986) enhances the value of resources in National Parks and provide a standard for ecological health to be maintained by state and federal regulatory agencies outside the parks. In addition, the states and provinces surrounding the Great Lakes are attempting to promulgate a no increased chemical discharge regulation and to restore ecologically impaired streams that flow into the Great Lakes (GLWQB, 1991). As a result, streams in parks and within protected watersheds draining into the Great Lakes will become critical in determining natural background and natural variability of chemical constituents, are used to assess those streams affected by non-point source loadings, and also to determine attainment of restoration efforts on an impacted stream in the Great Lakes Watershed.

This report provides a general strategy and categorizes the type of information necessary to provide the critical knowledge establishing an ecological basis on which to assess potential impact of development at an early stage, or in an anticipatory fashion. This strategy will provide a scientific framework and the data necessary to interpret the ecological base supporting aquatic natural resources in Pictured Rocks National Lakeshore and apply an integrated program to determine and manage risks to those resources.

I.1 Risk Analysis

Some forms of regional economic development are inevitable. However, such development should not, and need not, take place at the expense of existing natural resources, particularly those resources in protected areas. Assessment of the risks to ecosystems and their resources must be included in the planning process of regional development and resource management (Husker et al., 1990).

Risk analysis in the life sciences in the past has focused on the factors directly affecting human health and mortality. For example, calculations can be made on the risk to the human population due to factors such as smoking, the use of certain medicines, or the development of nuclear generating plants. In the field of environmental sciences risk analysis has been applied to the use of pesticides and the release of industrial chemicals using estimations of chemical fate, and batteries of laboratory toxicity tests to estimate the direct effects of such chemicals on representatives of important resource organisms (O'Neill et al., 1982). However, these methods of assessment do not estimate indirect effects on other organisms, the effects at higher levels of organization, for example at the community or ecosystem level, nor do they estimate the effects from non-chemical and multiple impacts (Barnthouse et al., 1986).

Natural resource inventories in the past have been efforts to make catalogs of existing species, to determine their distributions, the limits of their geographical ranges, and to estimate the standing stock of major resource species (i.e., volume of timber or numbers of fish) (Kim and Knutson, 1986). Natural resource inventories provide key elements in an ecosystem risk analysis program that will provide an ecosystem level risk assessment if several steps are included.

A strategy for assessing and managing risks involving large scale ecological change using

natural resource inventories includes:

1] Development of the concept of *ecosystem health,*

2] Development of *regional profiles* of ecosystem health in terms of the critical ecological characteristics and,

3] Formulation of *ecological endpoints* to determine ecological health and provide a basis for management.

This approach will develop information from an aquatic resource inventory at PIRO to identify changes before large scale damage has occurred. This strategy and information will be used to predict ultimate change and plan mitigation of the potential ecological damage. This form of assessment is retroactive in that it evaluates change that has already taken place, but is also proactive, in that it uses estimations of change at an early stage and ecological knowledge from inventories to estimate the final state of a resource or ecosystem due to impacts from development. The present condition of the resource or ecosystem, and the source of stress is the beginning point of analysis.

I.1.1 Development of the concept of ecosystem health

The development of the concept of *ecosystem health* should be derived from thorough knowledge of ecological theory and include a number of physical, chemical, and biological attributes directly responsible for the existence and maintenance of the ecosystem (Schaeffer et al, 1988, Boyle et al., 1991). In addition to the measurable attributes, the age or stage of succession of an ecosystem need to be considered. Ecosystems at early stages of development will have different characteristics and susceptibilities to stress than more mature ecosystems.

The aquatic natural resources in PIRO consist of a number of streams and inland lakes.

The streams are, from west to east: Miner's River, Mosquito River, Chapel Creek, Seven Mile Creek, Sullivan Creek, and Hurricane River some of which rise in the buffer zone and flow through a distinct set of fluvial geomorphic zones (Loope and Holman, 1991) into Lake Superior. The physical characteristics of individual stream reaches within distinct geomorphic zones (e.g., upland primary and secondary reaches of relatively high gradient, upland wetland areas of low gradient, cataracts, inland lakes, and lowland reaches of moderate gradient) are controlled primarily by changes in stream gradients and the ability of the stream to transport sediment (i.e., stream power). The primary lakes within PIRO are: Beaver, Chapel, Grand Sable, Legion, Miners, and Section 36 Lakes. The character of the primary lakes, as well as the streams in addition to varying longitudinally, vary from east to west within the park due changes in underlying geologic controls and surface geomorphology (Hughes, 1975; Montgomery and Buffington, 1993).

In order to expand the interpretability and use of resource inventories, it is useful to conceptualize the information obtained in the framework of an *ecological paradigm*. The term ecological paradigm can be defined as a specific model or set of hypothesis encompassing comprehensive characterization of resources at the population, community, or ecosystem level of organization. Ecological theory provides the basis for management, diagnosis and treatment of the ecosystem in the same fashion that human anatomy and physiology provides the basis for the practice of human medicine.

The ecological health of PIRO's aquatic resources cannot be adequately assessed unless the entire system is considered as an intergraded unit. For example, the physical and biological character of a stream system reflects the long-term constraints of the surrounding geology,

climate, vegetation and land use patterns (Beschta and Platts, 1986). Stream attributes (i.e., gradient, energy, and velocities) and geomorphology (habitat features; i.e., pools, riffles, backwaters, etc.) along the longitudinal channel profile are directly controlled by the attributes of the surrounding watershed. The watershed collects the water falling within its bounds and directs it to the stream by either surface runoff or ground water flow. The geology of a basin, the degree of bedrock weathering, and soil development influence the ionic absorption, storage, mineral assimilation, and ultimately the potential productivity and biodiversity of the system. Geologic structure and land cover (both land use and vegetation type) have a strong influence on slope stability and steepness which in turn controls erosion and sediment loading to the stream, stream stability, and the rate at which and in many cases the quality of water reaching the stream channel. As a result, the physical and chemical attributes and ultimately the biotic components of the stream system are an accumulation of watershed processes.

All these factors must be considered when classifying stream systems and associated aquatic communities (Lotspeich, 1980). The conventional wisdom regarding logging impacts in the Upper Peninsula Michigan holds that large amount of sand was deposited over a large-scale into the stream channels due to older timber harvesting practices (US Forest Service, 1986). Controlled logging practices, in general, appear to have little or no long term effect on chemical water quality (Padric, 1980). Mullen (1988) found no detectable effect of limited selective cutting within PIRO's Mosquito River watershed on water quality. However, the deposition of large quantity of sand will dramatically affect stream geomorphology (i.e., reducing overall stream depth, filling pools, covering gravel), and ultimately trout habitat and production of benthic macroinvertebrates (Alexander and Hansen, 1986).

I.1.2 Regional profiles of ecosystem health in terms of critical ecological characteristics

Environmental risks to natural resources occur at geographic scales ranging from local, to regional, to global. Protection of natural resources within the units of the National Park Service must be addressed at the appropriate scale to accomplish effective stewardship. In many cases, threats from activities outside park boundaries inflict degradation to resources within. Aquatic ecosystems arising outside park boundaries are particularly vulnerable to degradation. As a result, addressing the management of such aquatic systems and the risk to their integrity needs to be done on a regional scale (Suter et al., 1987).

Pictured Rocks National Lakeshore comprises two zones: 1] a *"Shoreline Zone"*, 33,550 acres along the shore of Lake Superior owned outright by NPS and, 2] 37,850 acre, *"Inland Buffer Zone"* established to protect the remainder of the watershed. Although, the buffer zone is privately owned and certain forestry practices are allowed, the legislation establishing PIRO specifically mandates sustained yield and resource management compatible with resource protection within the NPS owned portion. Logging is allowed in the inland buffer zone of PIRO and large scale harvests of timber and land disruption could occur, posing threats to receiving aquatic systems.

In order to assess these threats a regional approach is needed. Regional ecological risk analysis of the effects of land use change on the aquatic ecosystems will be developed to manage and protect PIRO streams and lakes which have watersheds outside park boundaries and require broad regional approaches to management.

A number of anthropogenic factors affect the physical, chemical, and biological attributes of aquatic ecosystems. Those that are specifically permitted under state regulatory license are

referred to as *point source*. All other sources of potential impact including agricultural and urban runoff, impacts due to forestry practices and many industries fall into the category *non-point source*. Estimating and mitigating the effects from this latter category is a complex process and one of current research efforts.

One way of estimating the potential for non-point source impacts are to develop a geographic information system (GIS) data base on land use and identify the various categories potentially affecting water quality and aquatic environmental quality. This approach will allow management of water quality in the larger context of regional land management. Risk analysis combined with an appropriate ecological inventory of critical physical, chemical, and biological characteristics will be developed as indicators of aquatic environmental and water quality sensitive to impacts from land use change.

I.1.3 Formulation of ecological endpoints to determine ecological health and provide a basis for management.

In a fashion similar to human medicine approaches, sets of ecological endpoints will be formulated from the formal theory in ecological paradigms. An ecological endpoint is defined as an ecological parameter whose normal operating limits can be determined for the ecosystem in question. A major effort in ecosystem risk analysis is the identification of appropriate ecological endpoints that are indicators of ecological health and sensitive to early stages of anthropomorphic change. In order to relate to human society these ecological endpoints should be associated with social, cultural, or economic consequences. From an operational aspect, ecological endpoints should be easily measured, quantifiable, and amenable to statistical analysis. Moreover, they should be sensitive to early or defined status of ecological stress to allow for mitigation measures

to be employed (Suter, 1990).

Examples of endpoints include: quantitative estimates of density of commercially important species or charismatic megafauna, invasion or introduction of pest species on a large scale, changes in the concentration of critical nutrients (either additions or losses), especially those nutrients such as nitrogen and phosphorus known to control primary production, and measures of community structure such as density, species richness, diversity, similarity, and dominance. Ecological endpoints can be arranged in profiles and used to characterize and monitor through time the ecological health of the resource and ecosystem in question in the case of PIRO. Risk analysis of land use changes on aquatic resources at PIRO will emphasize and formulate the inventories of the physical attributes of stream ecosystems in conjunction with community level benthic macroinvertebrate indices and trophic status of the lake systems into the appropriate endpoints in a monitoring system.

The objectives of this study are to analyze the status of major lakes and streams in Pictured Rocks National Lakeshore for critical ecological components that are sensitive to environmental stress. These critical ecological components include an array of physical, chemical, and biological variables that together constitute a profile of ecological health. A complimentary effort presented here is the development of a methodology to identify areas of potential risk to water resources due to land use change. Finally, based on the determination of ecological status and analysis of the ecological variability combined with the land use risk analysis determination, we propose a monitoring program that will be sensitive to early impacts to aquatic natural resources.

II MATERIALS & METHODS

II.1 Lakes

Six lakes were sampled in Pictured Rocks National Lakeshore in 1994, 1995, and 1996: Beaver Lake, Chapel lake, Legion Lake, Grand Sable Lake, Miners Lake, and Section 36 Lake. At the maximum summer stratification, at the end of July or beginning of August, temperature and dissolved oxygen concentration profiles by depth were measured in the middle of each lake. Secchi disc depth was determined and water samples were taken at the surface, ½ Secchi disc depth, Secchi disk depth and twice Secchi disk depth, and analyzed for pH, alkalinity, total phosphorus, and Kjeldahl nitrogen (Table 1).

Table 1. Physical, chemical and biological variables measured in the inland lakes and streams of Pictured Rocks National Lakeshore 1994, 1995, 1996

Variable	Method	Level of detection
Temperature	Thermistor probe	1C°
Discharge	US Bureau of Reclamation (1984)	1cfs
pH	Combination electrode	0.1 pH unit
alkalinity	Titration with 0.002 N SO_4 (EPA 1974)	1.0mg/L as $CaCO_3$
Dissolved oxygen	Polarographic probe	0/1mg/L
Kjeldahl nitrogen	Digestion & NH_3 determination (EPA 1974)	0.01mg/l as N
Total phosphorus	Digestion & molybdenum blue (EPA 1974)	1.0 µg/L
Secchi Disk	Wetzel & Likens (1984)	1 cm
Benthic invertebrates	Wetzel & Likens (1984)	264 *u*m mesh net

II.2 Streams

A hierarchical sampling scheme was used in this study to aid in measuring aquatic macroinvertebrate community response to geomorphological and physical characteristics of the stream and its valley. At the largest scale was valley which was described as either confined (narrow valley floors which restrict lateral movement of a stream) or unconfined (a wide valley floor which allows greater lateral movement of a stream with accompanying meander development). Physical characteristics of stream channels and flow dynamics will differ between the two valley types (Montgomery and Buffington, 1993). Nested within valley type, reach type was described using criteria from Montgomery and Buffington (1993) as either bedrock, planebed, pool-riffle, or regime. Another category, sand flats, was also added to distinguish between planebed reaches of higher velocity flows with substrates gravel size or larger (planebed) and those stream sections comprised solely of sand with very low flow velocity. Reach type was determined after the stream sample section was selected.

Stream sample sections were established in each valley type, the number established based on valley length. Although an effort was made to distribute sample sections evenly throughout the valley sections of the Mosquito, Hurricane, and Miners rivers, difficulties of stream access due to thickness of vegetation and lack of nearby roads or trails resulted in some clustering of sample section locations along the mid-reach (cedar swamp) of Miners River. The next (smaller-scale) level of the hierarchy was habitat type (pool, riffle, glide) based on criteria in Bisson et al. (1982). The smallest-scale level of the hierarchical design, nested within habitat type, was substrate type: fines (mud/silt, sand), cobble/gravel, bedrock, organic debris (i.e., leaf packs), and large woody debris (LWD). Macrophytes and mosses were present in some streams, but not in adequate

amounts for statistical analysis. Therefore, although some incidental collections were made from these organic substrates, they were not considered separately.

Sampling

Five streams were sampled during this three-year project. Mosquito River was sampled in the first year of study. Field technicians walked the length of the river, starting near its mouth at Lake Superior, until the channel features became indistinct near the headwaters. A stream sample section was established approximately every 400 m as the technicians worked their way upstream, resulting in a total of 17 sample sections. Geographic Information System products were developed in 1995 (Table 2) that, along with a Global Positioning System unit and aerial reconnaissance, provided a means of predetermining approximate valley section boundaries and sample section locations prior to actual field work. The GIS/GPS method of determining sample section locations was used in 1995-96, replacing the systematic method used in 1994 on the Mosquito River.

Benthic macroinvertebrate and physical data were collected from the Mosquito River in 1994 and from the Miners and Hurricane rivers in 1995. Sullivan and Sevenmile creeks were sampled in 1996; benthic macroinvertebrates were again collected in the Mosquito, Hurricane, and Miners rivers the final year of study. Prior to data collection, stream sample section locations were selected. As discussed above, sample sections were systematically established every 400 m in the Mosquito River. For the Hurricane and Mosquito rivers, the number and approximate distribution of site locations were determined using the GIS longitudinal profiles and topographic maps before the start of field work. Field reconnaissance by the project leader and/or the project supervisor at specific river sections provided additional information on accessibility of

certain river sections by the field technicians and distribution of sample sections based on river access.

Table 2. Stream sample section coordinates in UTMs Zone 16, NAD27

Mosquito 1 = 539065,5152438	Hurricane 1 = 568092,5162079	Miners 1 = 536626,5140769
Mosquito 2 = 539408,5152370	Hurricane 2 = 567966,5162154	Miners 2 = 536588,5140984
Mosquito 3 = 539642,5152197	Hurricane 3 = 567730,5162225	Miners 3 = 536577,5141134
Mosquito 4 = 539940,5152018	Hurricane 4 = 567534,5162258	Miners 4 = 536653,5141332
Mosquito 5 = 540286,5151984	Hurricane 5 = 567169,5162397	Miners 5 = 536612,5141590
Mosquito 6 = 540217,5151716	Hurricane 6 = 566752,5162869	Miners 6 = 536678,5142095
Mosquito 7 = 540050,5151525	Hurricane 7 = 566314,5163203	Miners 7 = 536580,5142338
Mosquito 8 = 540050,5151200	Hurricane 8 = 565832,5163455	Miners 8 = 536545,5142986
Mosquito 9 = 539875,5151025	Hurricane 9 = 565323,5163750	Miners 9 = 536520,5143243
Mosquito 10 = 539825,5150650	Hurricane 10 = 564935,5164492	Miners 10 = 536470,5143485
Mosquito 11 = 539900,5150350	Hurricane 11 = 565062,5164832	Miners 11 = 536437,5143988
Mosquito 12 = 540030,5150032	Hurricane 12 = 565205,5165228	Miners 12 = 536355,5144214
Mosquito 13 = 540169,5149849	Hurricane 13 = 565024,5165433	Miners 13 = 536195,5144467
Mosquito 14 = 540300,5149464	Hurricane 14 = 564940,5165774	Miners 14 = 535888,5145682
Mosquito 15 = 540441,5149170	Hurricane 15 = 564708,5166077	Miners 15 = 535905,5145914
Mosquito 16 = 540449,5148924	Hurricane 16 = 564666,5166510	Miners 16 = 536012,5146544
Mosquito 17 = 540576,5148489	Hurricane 17 = 564535,5167020	Miners 17 = 535657,5146977
	Hurricane 18 = 564260,5167362	Miners 18 = 535703,5147947
	Hurricane 19 = 564041,5167829	Miners 19 = 535207,5148385
	Hurricane 20 =563681,5168035	Miners 20 = 535184,5148764

Twenty sample sections were established for both the Hurricane and Miners rivers. The spacing of these sites was mainly determined by valley section length. Longer reaches had more sample sections, which were placed at roughly equidistant intervals throughout the valley. Interval length ranged from 350-800 m (Figures 1, 2, 3, 4, 5,and 6). In some instances, sample sections were located at particular sites of interest. None were placed closer than 200 m to transition areas between valley types. Once the location was set, a central transect, representative of the local average river width, was then established. Each stream sample section was marked at the central transect with PVC pipe and rebar, and with field flagging as needed.

So as to standardize the length of the stream sample section as river width changed from its headwaters to its mouth at Lake Superior, each stream sample section length was set at six bankfull widths to include a sequence of deep (pool) and shallow (riffle or glide) habitats. Transects were spaced one bankfull width apart, with three upstream of the central transect and three downstream. Each transect was set perpendicular to the direction of water flow.

Data were collected both at the transects and within the sample section. A tape was stretched across the stream at seven transects (center plus three upstream and downstream), perpendicular to the direction of flow, and anchored at each end. Four measures were taken at each transect: 1) bankfull width (based on high flow evidence); 2) wetted width; 3) water depth, taken at water's edge, $^1/_4$, $^1/_4$, and $^3/_4$ stream width; and 4) linear measure of substrate types present immediately below the tape. Within each sample section, each habitat type present was recorded, with its corresponding length. Pebble counts (Wohlman 1954) were taken in one of each habitat type.

Benthic macroinvertebrates were sampled by habitat and substrate. Within one of each habitat type (pool, riffle, glide) present within a sample section, kick nets with 264 μm mesh size were used to

semi-quantitatively sample fines, cobble/gravel, and bedrock. (Collections from the Mosquito R. were by substrate only.) The D-ring nets were placed vertically on the stream bottom and approximately one square foot of the substrate immediately upstream of the net and to a depth of 10 cm (except on bedrock) was sampled. Small gravels and fines were sifted and larger particles were rubbed within the mouth of the net so that dislodged invertebrates would be washed into the net. Three kick-net samples were taken in each substrate found in > 10% of the habitat, by surface area. Three minutes of sampling effort was used for each sample. Large woody debris pieces were sampled by scraping the wetted portion with the dip net to obtain an invertebrate sample from approximately 20-30 linear feet of wood surface. The above samples were placed in jars, taken to the lab and refrigerated; within 1-2 days, the invertebrates were separated from debris and placed in vials filled with 70% ethanol. Coarse organic debris samples comprised three grab samples which filled 1/3 of a screen-bottom bucket. These samples were sorted in the field; macroinvertebrates were preserved in a vial with 70% ethanol at the end of the day.

Fish collections were made in 1995 and 1996 within selected sample sections on the Mosquito, Hurricane, and Miners rivers. Fishery biologists from the Michigan Department of Natural Resources and the U.S. Fish and Wildlife Service used an ABP-3 battery powered backpack shocking unit to sample fish in nine sample sections on the Mosquito and eight sample sections on the Hurricane rivers in 1995. In 1996, one section of the Hurricane and four from the Miners rivers were also sampled. Fish were collected using the one-pass method, counted, measured, and identified in the field and released in the same area from which they were taken.

Individual metrics were calculated on the benthic macroinvertebrate community according to formulas in Boyle (1991). Canonical correspondence analysis on the physical and invertebrate

community data was performed using the program CANOCO 4 (ter Braak and Šmilauer, 1998)

II.3 Geographic Information System Analysis

To derive a risk analysis map of PIRO we used remote sensing data from several sources and applied The Universal Soil Loss Equation (USLE) adapted for use on forested lands (Dissmeyer and Foster, 1984). The USLE is expressed as:

$$A = R * K * L * S * C;$$

where

A is soil loss per unit area;

R is the rainfall runoff factor;

K is the soil erodibility factor;

L is the slope length factor;

S is the slope steepness factor; and

C is the cover management factor.

In a geographic information system (GIS) each component of the equation was represented by a raster map file or a constant value. The output computed using USLE loss in tons of soil per acre (A) can then be compared to known soil T-values on a cell-by-cell basis to derive a finite number of risk categories.

II.3.1 GIS Software

The Environmental Systems Research Institute, Inc. ARC/INFO software running on a Sun SPARC Server 1000 Unix system was used for all GIS processing, except for the determination of the LS-factor. The LS-factor processing was completed using the IDRISI GIS and the USLE2D.EXE (Release 2.4) processing software obtained from Desmet and Govers (1996) on a personal computer

(PC) running Windows 3.1.

II.3.2 Sources for the Digital Data

All digital map files used the Universal Transverse Mercator projection, Zone 16, with units of meters, and the North American Datum of 1927. The land cover/land use digital data were obtained from the National Park Service (NPS) and were augmented with the aspen and white birch component of the Michigan Department of Natural Resource's Michigan Resource Information System (MIRIS) digital data. The separate C-factor values for potential road construction and for potential harvest were obtained from the Natural Resources Conservation Service (NRCS) (Carey 1993 and Carey 1997) and were added as separate items in the land cover/land use digital data (refer to Appendix 1).

Parts of nine US Geological Survey (USGS) 7.5-minute Digital Elevation Models (DEMs) were the source for the LS-factor data. Desmet and Govers (1996) used a DEM with a 5-meter posting based on a 2.5-meter contour interval. The USGS DEMs used in this study have a 30-meter posting. Whether the coarser USGS DEMs affect the results, and to what extent, is unknown. The DEMs were mosaiced together and all sinks were filled before processing to determine the LS-factor values. Sinks are depressions in the surface of a DEM that would collect flowing water in an hydrologic model and have no drainage. Sinks are artifacts of generating the DEM and are considered to represent most real topographic surfaces erroneously.

A vector file for soils was obtained from the NPS but the area of coverage was incomplete. To extend the coverage of the soil's data, 8.5" by 14" photocopies of a 1929 soil's map produced by the Michigan Department of Conservation were transferred and drafted by contractors at the Midcontinent Ecological Science Center (MESC) to 1:24,000-scale mylar overlays for USGS quadrangles. The overlays were digitized using the ARC/INFO software. The digital soil's data from the NPS and

III. RESULTS & DISCUSSION

III.1 Lakes

The depth distributions of dissolved oxygen, temperature, and Secchi disk depth for the lakes sampled for over the three years appear in Figures 7-24. The shape of the curve for temperature indicates the position of the thermocline and the thickness of the epilimnion, the layer of water above the thermocline, and the hypolimnion, the layer of water below. The thermocline is defined as the depth where the temperature changes at a rate greater than 1 °C/m. In general when a lake is stratified the two layers will not mix and material will not cross the thermocline. This has the potential for very different physical and chemical conditions which may affect the ecology and distribution of fish and invertebrates in a lake. The depth distribution of the dissolved oxygen concentration is a reflection of the trophic status of the lake. In general oligotrophic lakes, those lakes with low nutrient concentrations and low concentrations of phytoplankton, have high concentrations of dissolved oxygen in their hypolimnia. Their oxygen concentrations do not suffer drastic declines in the hypolimnion, in fact there may even be a layer of algae in the hypolimnion that results in an observed increase in dissolved oxygen due to photosynthesis by a layer of algae.

Secchi disc depth, a measure of the transparency of the water, is highly correlated and has been related to the trophic status of the lake water. The amount of phytoplankton present will directly affect the depth of Secchi disc visibility. If this is the predominant factor affecting the transparency of the water, the Secchi disc depth is proportional to the density of phytoplankton in the water. However, naturally suspended sediments and other induced material also affect the transparency of lake water. Wind induced turbulence will suspend more material in a shallow lake than a deep lake. Lakes with erosion from disturbed watersheds would have less transparent waters that

lakes with undisturbed watersheds. Within a given lake among the three years, the difference in Secchi disk depth was less than among different lakes. However, the variability in Secchi disk depth was due to the interaction of the same factors.

III.1.1 Big Beaver Lake: The temperature profile of this lake indicated weak stratification in 1994 and 1995, with more a pronounced thermocline in 1996 (Figure 7-9). The dissolved oxygen concentration depth gradients were more pronounced in all three years, indicating a hypolimnion with lower oxygen conditions. Secchi disc depth varied between three and five m.

III.1.2 Chapel Lake: The temperature profile of Chapel Lake indicated pronounced stratification with the temperature of the hypolimnion at 4°C (Figure 10-12). The dissolved oxygen concentration decreased gradually with depth but was not strictly associated with the hypolimnion. In fact in 1996 there was an oxygenated layer just below the thermocline, indicating a stratified layer of phytoplankton. The Secchi disc depth varied between 2-3 m among the three years.

III.1.3 Grand Sable Lake: The temperature profile of Grand Sable Lake showed the thermocline at the same general depth all three years (Figure 13-15). The temperature in 1996 appeared to be several degrees warmer than in the previous two years. Dissolved oxygen concentration changed little with depth. Secchi disc depth varied from 2.5 to 4.5. Considering the depth of this lake and high oxygen concentration down through the depth profile, the hypolimnion does not exhibit the reduction in dissolved oxygen of a eutrophic lake.

III.1.4 Legion Lake: The temperature profile of Legion Lake indicated that the depth of the thermocline changed among the three years, becoming substantially shallower in 1996 (Figure 16-18). In all three years the concentration of dissolved oxygen increased abruptly just below the thermocline indicating a layer of phytoplankton 1-3 m thick, before rapidly declining to the bottom. The Secchi

disc depth varied 8.5 to 7.

III.1.5 Miners Lake: Although both temperature and oxygen concentration decreased with depth in Miners Lake, the lake did not show pronounced stratification during the three years (Figure 19-21). Secchi disc depth varied from 1.5-2.75 m

III.1.6 Section 36 Lake: The temperature and dissolved oxygen concentration depth profiles indicated that this lake was not stratified at the time of sampling (Figure 22-24). The dissolved oxygen concentration fell slightly near the bottom in 1994 and 1996. The Secchi disc was visible on the bottom at 3.5 m.

III.1.7 Nitrogen and phosphorus: The critical nutrients nitrogen and/or phosphorus control the production and density of phytoplankton in freshwater lakes. Usually when the ratio of nitrogen to phosphorus is above 15:1 , phosphorus is considered to be the limiting nutrient; below seven the limiting nutrient is considered to be nitrogen. A ratio between seven and 15 both nitrogen and phosphorus are considered potentially co-limiting. Figures 25 and 26 depict the mean concentration of phosphorus and nitrogen averaged over the depths where water samples were collected. In most cases the ratio of N:P indicated that phosphorus was the limiting nutrient. However, several lakes in various years were in the middle, co-limiting range (Chapel Lake, 1994 and 1995; Legion Lake, 1994 and 1995; and Section 34 Lake, 1994). Miners Lake was nitrogen limited 1994-1996.

III.1.8 Trophic status:

A Trophic Status Index (TSI) of lakes can be determined by the analysis of several variables: an estimation of the transparency of the water as measured by Secchi disk depth, the concentration of the limiting nutrients such as phosphorous and nitrogen (Carlson, 1977; Kratzer and Brezonik, 1981) (Table 3).

TABLE 3a. Trophic States Associated With the Trophic Status Index (TSI).

TSI	Trophic State*	Secchi Disc m	Total P (ug/L)	Total N (mg/L)
0	Ultraoligotrophic	64	0.04	0.75
10	Ultraoligotrophic	32	0.12	1.5
20	Ultraoligotrophic	16	0.34	3
30	Oligotrophic	8	0.94	6
40	Oligotrophic	4	2.6	12
45	Mesotrophic	2.8	5	17
50	Mesotrophic	2	7.3	24
53	Eutrophic	1.6	10	30
60	Eutrophic	1	20	48
70	Hypereutrophic	0.5	56	96
80	Hypereutrophic	0.25	154	192
90	Hypereutrophic	0.12	427	384
100	Hypereutrophic	0.06	1183	768

TSI (SD) = 10(6 - ln (SD/ln 2), SD in meters (Carlson, 1977).
TSI (TP) = 10(6 - ln(48/TP)/ln 2), TP in ug/L (Carlson, 1977).
TSI (TN) = 10(6 - ln(1.47/TN)/ln 2), TN in mg/L (Kratzer & Brezonik 1981)
* Approximate trophic states based on trophic indicator values; names assigned by Kratzer and Brezonik (1981), and not by Carlson.

Table 4 shows the TSI calculated for all six lakes using Secchi disc, total phosphorus, and total nitrogen. The values for all lakes range in the oligotrophic to mesotrophic range with except for those values for phosphorus in Miners Lake and Section 36 Lake when nitrogen was the limiting nutrient. These values provide a baseline for long term monitoring of these lakes. The lakes range from oligotrophic to mesotrophic.

Table 3b

Pictured Rocks National Lakeshore
Lake Trophic Indexes 1994-96

	TSI(SD)			TSI(TP)			TSI(TN)		
Lake	1994	1995	1996	1994	1995	1996	1994	1995	1996
BBL	44.70	42.18	41.29	35.03	35.85	40.59	37.43	41.31	37.07
CL	45.69	45.69	48.23	51.15	53.34	37.37	38.56	39.30	39.30
GSL	41.87	41.63	47.17	59.07	58.33	40.59	47.83	44.87	32.92
LL	34.82	36.88	36.69	47.00	46.63	40.59	29.09	32.60	40.29
ML	45.69	51.03	51.45	52.48	55.55	40.59	38.98	40.76	37.07
S36L	----	----	----	57.37	58.96	37.37	41.46	45.55	33.45

III.2 Streams

III.2.1 Substrate size analysis: The principal expected threat to the streams in PIRO is sedimentation due to changes in land use. Increased sedimentation rates from road building and intensive logging would change the substrate size and habitat value of the streams at and downstream of points of impact. In order to provide a baseline the size distribution in a stream substrate was determined for five size fractions of a substrate within each stream sample section. These are depicted in Figures 27, 28, and 29. Depending on the channel form, gravel and cobble substrate may shift to sand/silt with increased sedimentation. For Mosquito the stream sample sections start with one at the mouth and 17 at the highest point in the stream (Figures 1 and 2). For Miners and Hurricane the highest numbered stream sample sections are at the mouth of the river at Lake Superior, while Stream Sample Section 1 is the furthest upstream (Figures 3-6). In general the Mosquito River had the most consistently diverse substrates along its length with three to five substrate types represented at nearly all of the 17 sample sections (Figure 27). Miners River was largely dominated by the sand/ silt substrate type which made up 95-100% of the substrate for 15 of the 20 stream sample sections (Figure 28). The Hurricane River has predominately a sand/silt substrate in its upper five sample sections and then became more diverse at the lower 15 sample sections (Figure 29). These data at GPS referenced stations and are intended as baseline to be used in a monitoring program to detect changes in the physical condition of the stream that may have impact on the biological community. They are also used in the subsequent multivariate analysis with the benthic macroinvertebrate community.

III.2.2 Benthic macroinvertebrates

Samples of the benthic macroinvertebrate community were collected and analyzed at a

selected number of stream sample sections for two summers on the Mosquito, Miners, and Hurricane Rivers. They were not collected at all stream sample stations due to limitations on time and available resources. The purpose for collections over the years was twofold: The same selected stations were collected over two years to get some idea of community variability, and different stations were collected to provide a complete set of collections at all the stream sample sections. A smaller number of ancillary samples were taken one summer on Sullivan and Seven Mile Creeks. Since biological communities have a number of parameters that measure change, the communities collected were analyzed by two methodologies: 1) Integrated multivariate analysis of the physical and biological data was performed using canonical correspondence analysis (CCA), and 2) individual metrics of the various communities were calculated.

III.2.2a Multivariate analysis

In order to further explore the relationship between the variation in structure of the benthic macroinvertebrate communities within stream sample sites on each of the rivers, and substrate types we subjected the data to multivariate analysis using canonical correspondence analysis (CCA). Output from the program CANOCO is shown in Figures 30-32 with supporting statistics in Tables 4, 5, and 6.

The following steps were taken in conjunction with the CCA to test these data. The goal was to provide a depiction of the status of the benthic macroinvertabrates at various stream sample sections within each of the three principal rivers over the course of the three years efforts, and the relationship with the variation in substrate type.

A forward selection process was used with the program CANOCO to determine which environmental variables were significant in explaining the variation of the taxa counts among the

various sites. The first step of this process has particular importance because, in essence, individual CCA's are run using each environmental variable with the taxa counts, and thus the marginal effects of each variable can be determined. The remainder of the forward selection procedure is much like one that would be used for multiple regression: once a variable is included in the model, variables are then subsequently added to the model based on their additional fit. Hence a variable that is marginally significant might be passed by in the forward selection procedure because the variation that it could have explained was accounted for by another variable. Fortunately CANOCO provides methods of incorporating these variables into the results despite the fact that they were not selected in the forward selection process due to their colinearity. The forward selection process was stopped once the permutation test p-value of an additional variable being tested was somewhat higher than 0.05.

An ordination diagram was developed using CCA for the composite invertebrate and environmental data from where the data were collected in common. The environmental data used was size of the substrate was determined by performing Wolman counts. These are also the variables expected to change if impacts due to increased sedimentation are introduced into the rivers sampled at PIRO. To test which environmental variables were associated with the variation in community structure of the benthic macroinvertebrates, each of the environmental variables was run and correlations were developed between sample ordination scores for the first two axes of the composite ordination and the environmental variables in two ways. First the relationship for each individual variable was determined on an individual basis. Second, a stepwise procedure was used to select the best combination of statistical significant environmental variables associated with the first two ordination axes.

The CCA of the Mosquito River data showed strong grouping of the stream sample sections within the ordination diagram (Figure 30) according to size class of substrate. The circles in the diagram represent the scores of the biological information and the year and the stream sample sections. The vectors length represents the strength of association (correlation) of the classification variables within the ordination. The vectors of the substrate classification variables point in the direction of which stream sampling sections they were most associated with. The asterisks indicates which of the vectors (substrate classifications) were significantly associated with the separation of the communities at the various stream sample sections. The CCA of the Mosquito River data indicates that the biological communities found in the various stream sample sections were substantially different from one another and that the sand/silt and the cobble substrate types were highly significantly associated with the statistical separation of these communities. Despite the hiatus of two years between samples, the community structure at the same stream sample sections, as indicates by proximity of scores within the ordinations diagram, were remarkably similar in 1994 and 1996 (Figure 30). Table 4 shows the supporting statistics for the CCA of the data from the Mosquito River. The statistics for the marginal as well as the conditional effects are listed. The percentage of variance of the species-environmental relationship for the first two axes was high: 73.9%. This is also indicated by the significance test of the first and all canonical axes which was highly significant.

The CCA analysis and ordination diagram for the Miners River showed that the variability of community structure of the benthic macroinvertebrates was even more associated with differences in substrate than in the Mosquito River. The classes sand/silt, gravel, cobble, and boulder, were all statistically significant in separating the various stream samples in the ordination

diagram. The association between the years were also highly significantly associated with the statistical separation of these communities. The similarity between the community structure at individual stream sample sections between the two years was very close as indicated by proximity of the scores depicted on the ordination diagram (Figure 31). Table 5 shows the supporting statistics for the CCA of the data from the Miners River. The statistics for the marginal as well as the conditional effects are listed. The percentage of variance of the species-environmental relationship for the first two axes was high: 76.4%. This is also indicated by the significance tests of the first ($p = 0.015$) and all ($p = 0.025$canonical axes which were significant.

The CCA for the Hurricane River was similar to that of the Miners River. The classes sand/silt, gravel, and cobble were all statistically significant in separating the various stream samples in the ordination diagram. The association between the years were also highly significantly associated with the statistical separation of these communities. The similarity between the community structure at individual stream sample sections between the two years was very close as indicated by proximity of the scores depicted on the ordination diagram (Figure 32). Table 6 shows the supporting statistics for the CCA of the data from the Hurricane River. The statistics for the marginal as well as the conditional effects are listed. The percentage of variance of the species-environmental relationship for the first two axes was high: 84.5%. This is also indicated by the significance tests of the first ($p = 0.005$) and all ($p = 0.005$)canonical axes which were highly significant.

These analyses establish the definite link between substrate size at the different stream sample sections and variations in the community structure of the benthic macroinvertebrates in the three principal rivers, Mosquito, Miners, and Hurricane in PIRO.

III.2.2b Community Metrics

The changes in community structure is considered multiparametric, that is, there are a number of attributes of a community that may change due to changes in the natural or anthropogenic variables in the environment. The calculations and use of a series of accepted community metrics was done to establish the status and serve as a baseline. The following community metrics were calculated for the benthic macroinvertebrate communities at each stream sample section where they were collected:

1) Total number of individuals, or simply density,

2) Number of taxa, or taxa richness, simplest measure of diversity,

3) Shannon-Weiner diversity, which is sensitive to changes in dominant species,

4) Simpson's diversity, which is sensitive to changes in rarer species,

5) EPT, number of taxa in the orders Ephemoptera, Plecoptera, Tricoptera, which are considered the taxa most sensitive to environmental stress, and

6)The ETP : taxa richness ratio, a measure of the proportion of sensitive taxa.

Figures 33 to72 show these six indices for the streams samples in 1994-6 in PIRO.

III.2.2.b.1Density: The total number of invertebrates, or density, varied within a stream, between years, and among streams. For the Mosquito River the density varied in 1994 and 1996 from 120 to over 800 (Figures 33 and 34). Miners River exhibited the same degree of difference in density as Mosquito. The Hurricane River had a similar range of values in 1995 (Figure 37), but had two sample sections with values exceeded 2,000 individuals in 1996 (Figure 38). The density of invertebratres in Seven Mile and Sullivan varied from 130 to 450 individuals (Figure 39). The variation in density did not form a pattern that could be attributed completely to type of substrate.

Except for extremes in low or high numbers, by itself variation in the total density of individuals of communities is difficult to interpret. Some invertebrates have long life cycles, up to two years, and populations may be low. Others have life cycles that may be complete within several weeks. For a number of reasons these latter types of invertebrates with short life histories and high growth rates can become very dense with a short period of time. Conversely, a stress could affect longer lived invertebrates with low reproduction rates tho yield extremely low numbers for a period of time.

III.2.2.b.2 Taxa Richness: The number of taxa within a community, taxa richness, is the simplest measure of biodiversity. Over the period of three years in this study 232 taxa of benthic macroinvertebrates were enumerated from the rivers within PIRO. Taxa richness in the Mosquito River was ranged from 28 to 68 identified taxa. There were slightly more taxa found in 1996 than in 1994, however this did not represent a substantial difference (Figures 40 and 41).

The taxa richness in the Miners River varied for extremes of 17 to 58. There was some association of higher taxa richness with stream sample sections with more diverse substrates. There was no differences in the pattern of taxa richness between the two years, 1995 and 1996 for the Miners River (Figures 42 and 43).

For the Hurricane River the taxa richness varied among the stream sample sections from 12 to 60. In general there were few taxa present in the Hurricane River in the 1995 samples than in the 1996 (Figures 44 and 45). The highest number of taxa were found in stream sample section with three to five substrate types and the lowest number of taxa were found in those sites with only sand/silt size fraction in their substrates.

The taxa richness of Seven Mile Creek was 28; Sullivan Creek had 35 (Figure 46). Both

sites on these creeks were within the range of taxa richness on other rivers in PIRO

III.2.2.b.3 Shannon's Diversity: This diversity index considers both the number of taxa and how the total number of individuals are distributed among the taxa. Shannon's H' is most sensitive to large changes in the number of dominant taxa. Value of H' above 2.5 are considered to reflect high diversity; values of H' below 1.5 are indicative of low diversity.

For the Mosquito River, the values of H' were nearly all above the value of 2.5 , with only four stream sample sections having an H' slightly below this value. No consistent pattern of differences between the two, 1994 and 1996 years could be discerned (Figures 47 and 48). Miners River H's were more varied and lowest values were in the central stream sample sections where the substrate was completely dominated by sand. Most of the H's were higher in 96 than in 95, however almost all values were high in both years except those noted (Figures 49 and 50). The Hurricane River had H' values relatively high except in stream sample section in sandy areas near the head of the river (Figure 51 and 52). The H's at the two stream sample sections of Sullivan Creek was slightly higher than those on Seven Mile Creek, but both site show high diversity (Figure 53).

III.2.2.b.4 Simpson's *D*: A second diversity index was calculated that will give another dimension. Simpson's *D* ranges from 0 to 1.0 and is more sensitive to changes in rare species than Shannon's H'.

The diversity as measured by *D* were all near or above 0.9 for Mosquito River for 1994 and 1996 (Figures 54 and 55). There was more variability in the *D* values in Miners River with several values below 0.7 in some of the central stream sample reaches (Figure 56). In 1996 one value of *D* in the Miners River fell below 0.6 (Figure 57). Likewise the Hurricane River had high

values of *D* except for two stream sample sections in the upper part with complete sand substrates. These lower *D* values were found in the same place both years (Figures 58 and 59). Simpson's *D* for the two stream sample stations on Seven Mile and Sullivans Creeks was 0.9, 0.91; and 0.84 and 0.86 respectively (Figure 60).

III.2.2.b.5 EPT: Individual taxa within the insect orders of Ephemeroptera, Plecoptera, and Tricoptera (ETP) are considered to be among the invertebrates most sensitive to environmental stress. The number of taxa within ETP can be put into an index in two ways: the number of taxa present in the EPT, or the ratio of EPT taxa to the total number of taxa present at the stream sample section.

Both the EPT and EPT ratio were high in the Mosquito River in 1994 and 1996 (Figures 61-64). The EPT ranged between 11 to 27, while the EPT ratio ranged from 0.34 to 0.61. Both these indices in the Mosquito River indicate a major proportion of the invertebrate community to be comprised of taxa considered to be sensitive to environmental stress.

The EPT and EPT ratio in the Miners River varied more among stream sample sections than in the Mosquito River (Figures 65-68). The EPT ranged from seven to 26, with the EPT ratio ranging from .32 to .55. This indicate that even through the EPT fell at several stations, the EPT ratio remained relatively high. The sites where the low EPTs were found were in the downstream portion of Miners River where the substrate consisted of shifting sand.

The Hurricane River had ETPs ranging from three to 27 and EPT ratios varying from 0.25 to 0.69 (Figures 69-72). Both the low values of for EPT and EPT ratio were in sand substrate un the upper reach of the Hurricane River. One low EPT also fell at the river's mouth located next to a public campground where the stream receives a great deal of human use by fishermen and

children wading. By late summer, when these collections were made, some impact due to physical disturbance may be the cause of the low EPT on what should have been relatively good habitat for invertebrates.

The ETPs for Seven Mile and Sullivan Creeks were low, but within the range of the of those on the Mosquito, Miners, and Hurricane Rivers. The EPT ratio ranged from 0.34 to 0.50 indication a major proportion of the taxa were from groups sensitive to environmental stress (Figure 73 and 74).

III.3 Fish

Eleven species of fish were collected from the three principal rivers in PIRO. The fish were collected at nine stream sample sections on the Hurricane, four on the Miners, nine of the Mosquito, and each two each on Sullivan Creek and Seven Mile. The sections and their geo-referenced UTM coordinates appear in the data appendix. The population density of the various species and the mean length appear in Figures 75 and 76. Seven Mile Creek and the Mosquito had the highest number of species, with eight and seven respectively. These should be considered baseline data for comparison with future collections

III.4 Development of risk using USLE implemented in a GIS

To derive a risk analysis map of PIRO we used remote sensing data from several sources and applied The Universal Soil Loss Equation (USLE) adapted for use on forested lands (Dissmeyer and Foster, 1984). In a geographic information system (GIS) each component of the equation was represented by a raster map file or a constant value. The output computed using USLE loss in tons of soil per acre (A) was then compared to known soil T-values on a cell-by-

cell basis to derive a finite number of risk categories.

The rainfall and runoff factor (R) was read from an index map of average annual rainfall values for the region (Wischmeier and Smith, 1978). Although the PIRO is most accurately represented by a gradient of values (approximately 71-76 according to Wischmeier and Smith, 1978), a single value of 75 erosion index units ([100 foot tons/acre][inches/hour]) was used in the USLE to calculate A (Figure 77).

The soils file (Figure 78) (containing minimum and maximum K-factor values and T-factor values) and the land cover/land use file (Figure 79), containing C-factor values for potential road construction (Figure 80) and for potential timber harvest (Figure 81), originated in vector format. The vector files were converted to raster format based on the values for the maximum K-factor, T-factor, C-factor for potential road construction and, C-factor for potential timber harvest.

A combined LS-factor value (Figure 82)which includes both the slope-length factor (L) and the slope-steepness factor (S) was computed using the IDRISI GIS, processing software provided by Desmet and Govers (1996), and the DEM files (Figure 83). After the sinks in the DEM file were filled, the DEM was divided into pieces with no more than 600 rows and 600 columns, to meet the processing requirements of the USLE_MUL component of the USLE2D.EXE software. The pieces were then converted from ARC/INFO GRID format to the IDRISI format and moved from the SUN UNIX system to a PC. For each piece, a new grid was created with slope in units of meter per meter. The USLE_MUL program was run with inputs including the DEM elevation data, the slope data in units of meters per meter, and a parcel grid for the entire PRNL. The detailed values option was used rather than using distinct parcel values, since the parcel covered the entire area of the PIRO.

The formula developed by McCool et al. (1987, 1989) was chosen in USLE_MUL to compute the LS-factors. Of the three options for expected rill erosion (1 - no observed or expected rill erosion; 2 - rill erosion from moderate rainfall and runoff rates; and, 3 - rill erosion from high rainfall and runoff rates) option three was used for rill erosion from high rainfall and runoff rates. The USLE_MUL software uses the multiple flow direction algorithm developed by Quinn et al. (1991).

The output files with the LS-factor values were moved back to ARC/INFO GRID format on the Sun Unix system. Before the pieces were mosaiced together, the edges of each piece were removed to reduce the possibility of error introduced by processing along the edge of each grid.

5d. The support practice factor is represented in the USLE by the component P. According to Dissmeyer and Foster (1984) the P-factor is not required for applications on forested (untilled) lands. The P-factor was not used in this application.

Execution of the USLE

The actual execution of the USLE was completed in the ARC/INFO GRID module. The GRID module uses algebraic notation to process raster data on a cell by cell basis.

In this application, the USLE is represented by the following formula:

$$A = R * K * L * S * C$$

where: A is the expected erosion in tons per acre per year;

R is a constant value, 75;

K is represented by a grid, KMAX;

L and S are represented by a single LS-factor grid, LS;

and C is represented by one of two grids, CROAD for C-factors when considering

potential road construction, and CCUT for C-factors when considering potential timber harvest.

The actual implementation of the USLE in GRID is represented by two equations (one based on potential road construction and the other based on potential timber harvest). The two equations are:

$$EROAD = 75 * KMAX * LS * CROAD$$

and

$$ECUT = 75 * KMAX * LS * CCUT$$

where: EROAD is an output grid with values representing expected erosion in units of tons per acre per year based on potential road construction; and ECUT is an output grid with values representing expected erosion in units of tons per acre per year based on potential timber harvest.

Derivation of Risk Categories

Categories of risk are computed by comparing expected erosion (A) to the erosion factor T. "Erosion factor T is an estimate of the maximum average annual rate of soil erosion by wind or water that can occur without affecting crop productivity over a sustained period" (Carey 1993). The T-factor is expressed in units of tons per acre per year (Figure 84). Grigar (1998) suggested that risk categories may be assigned as follows:

Low Risk -	$A <= T$
Moderate Risk -	$A > T$ and $A <= 2.5T$
High Risk -	$A > 2.5T$

The algebraic notation in GRID for determining these three risk categories based on potential road construction is:

RISKROAD = CON (EROAD > TFACTOR, CON (EROAD <= 2.5 * TFACTOR, 2, 3), 1)

and based on potential timber harvest the formula is:

RISKCUT = CON (ECUT > TFACTOR, CON (ECUT <= 2.5 * TFACTOR, 2, 3), 1)

where: RISKROAD and RISKCUT are output grids containing the values 1 (low risk), 2 (moderate risk), and 3 (high risk);

EROAD and ECUT contain expected erosion values;

TFACTOR is a grid containing T-factor values;

CON is a GRID function that evaluates, on a cell by cell basis, one or more conditional if/else statements of the format [condition] [result if condition is true] [result if condition is false].

For example, the formula for computing RISKROAD is interpreted as:

If the condition "EROAD > TFACTOR" is true, then evaluate the condition "EROAD <= 2.5 * TFACTOR", else, if it is false, assign an output value of 1 (low risk). Then, if the condition "EROAD <= 2.5 * TFACTOR" is true, assign a value of 2 (moderate risk), else, if it is false (meaning EROAD > 2.5 * T), assign an output value of 3 (high risk).

This analysis yielded two risk analysis maps, one for road building (Figure 85), and one for timber harvest (Figure 86). Details of these maps for the watersheds for the Mosquito River, Miners River, and Hurricane River are shown in Figures 1-6.

III.5 Monitoring

The following monitoring sampling sites have been chosen based on the Mosquito, Miners, and Hurricane Rivers using analysis maps shown in Figures 1-6, developed from the universal soil loss equation and substrate type (especially critical are cobble/gravel,

mud/silt, and organic). Consideration was given to stream sample sections where substrate analysis and macroinvertebrates had been collected previously. Of the 10 sites chosen for each river, 2-3 are within the Fee Zone (federal ownership) of Pictured Rocks National Lakeshore and 7-8 are within the Inland Buffer Zone of the Lakeshore.

MOSQUITO RIVER

Prioritization No.	Sampling Site No.	Zone
1	15	Inland Buffer Zone
2	11	IBZ
3	17	IBZ
4	6	Fee Zone
5	10	IBZ
6	9	Fee Zone
7	14	IBZ
8	16	IBZ
9	8	Fee Zone
10	13	IBZ

The following field schedule estimates the number of hours it would take a 2 person team to reach the sites, take Wolman Pebble Counts, collect macroinvertebrates from various habitats and sort and preserve them in vials for later identification. The schedule takes into consideration efficiency of field sampling based on the prioritization given above.

Time estimate for monitoring selected sampling sites on the **Mosquito River**:

Sampling Site	No. Hours/Day	Cumulative No. Hours
15 & 17	10	10
11 & 10	10	20
6 & 9	12	32
14	9	41
16	9	50
8	8	58
13	9	67

Total No. Hours = 70 – 90

MINERS RIVER

Prioritization No.	Sampling Site No.	Zone
1	2	Inland Buffer Zone
2	4	IBZ
3	1	IBZ
4	16	Fee Zone
5	18	Fee Zone
6	10	IBZ
7	11	IBZ
8	7	IBZ
9	3*	IBZ
10	14	Fee Zone

* Macroinvertebrates have not been sampled at this site.

Time estimate for monitoring selected sampling sites on the **Miners River**:

Sampling Site	No. Hours/day	Cumulative No. Hours	
2 & 4	10	10	
1	8	18	
16 & 18	10	28	
10 & 11	13	41	
7	8	49	
3	8	57	
14	8	65	Total No. Hours = 70 - 90

HURRICANE RIVER

Prioritization No.	Sampling Site No.	Zone
1	9	Inland Buffer Zone
2	16	IBZ
3	17	Fee Zone
4	8	IBZ
5	12	IBZ
6	10	IBZ
7	19	Fee Zone
8	14	IBZ
9	7	IBZ
10	4	Outside IBZ (State of MI land)

Time estimate for monitoring selected sampling sites on the **Hurricane River**:

Sampling Site	No. Hours/day	Cumulative No. Hours	
9 &16	10	10	
17& 19	12	22	
8 & 12	12	34	
10	8	42	
14 & 7	12	54	
4	5	59	Total No. Hours = 60 – 80

The estimate of the amount of time it would take 2 technicians to monitor all 3 rivers for macroinvertebrates and substrate size is 200 – 260 hours. This work could fit into the August and September time frame (approximately 320 hrs) with some leeway. If the technicians wanted to complete only 1 sampling site per day (8-10 hr days), there would be 32-40 working days in an 8 week period. That still allows leeway in the schedule.

III.5.1 Site analysis

At each site chosen for monitoring substrate size and benthic macroinvertebrates should be collected as in the Materials and Methods section. A recommended sample frequency is every three years, with more frequent *ad hoc* samples taken a sites below disturbance to monitor physical change and community structure. The taxa should be enumerated in as fine a detail as possible. Until a sufficient number of years have established the range in natural variation, a 30% change in particle size or a 30% reduction in an index calculated for the benthic macroinvertebrate communities should be considered a "red flag". This is very important in assessing potential effects from observed impacts to the watershed upstream or instream changes from a variety of

sources.

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Appendix 1. C-factor values for potential road construction and for potential harvest including type of harvest, number of polygons, and the area in acres.

Cover Type	C-Factor for Roads	C-Factor for Harvest	Type of Harvest	Number of Polygons	Area in Acres
Aspen and White Birch	0.450	0.100	Clear Cut	116	10,835
Beach Strand	0.000	0.000	None	229	112
Cedar	0.450	0.038	Selective Cut	98	2,448
Cleared Area	0.450	0.100	Clear Cut	112	1,379
Dunes Plant Communities	0.000	0.000	None	11	1,475
Hemlock	0.450	0.038	Selective Cut	30	149
Jack Pine	0.450	0.100	Clear Cut	47	1,320
Northern Hardwood	0.450	0.038	Selective Cut	301	38,745
Red Pine	0.450	0.038	Selective Cut	38	1,599
Red and White Pine	0.450	0.038	Selective Cut	106	2,508
Red, White, and Jack Pine	0.450	0.038	Selective Cut	2	100
Steep Sand Bluff	0.000	0.000	None	9	274
Water	0.000	0.000	None	122	2,023
Wetland Conifer	0.000	0.000	None	210	3,367
Wetland Shrub	0.000	0.000	None	191	773
Wetland Shrub-bog	0.000	0.000	None	8	31
Wetland Shrub-marsh	0.000	0.000	None	11	42
White Birch	0.450	0.100	Clear Cut	22	147

					67,327

Appendix 2. Minimum and maximum K-factor values and T-factor values (tons per acre per year) for each soil type in the Pictured Rocks National Lakeshore (Carey 1993 and Carey 1997). Only the maximum K-factor values, not the minimum K-factor values, were used in the USLE.

Soil Type	K-factor (Minimum)	K-factor (Maximum)	T-factor
Ad	0.00	0.00	9999*
Al	0.32	0.32	5
AsA	0.15	0.15	4
AuB	0.10	0.10	5
BlB	0.15	0.17	5
BlD	0.15	0.17	5
BlE	0.15	0.17	5
BoB	0.24	0.43	5
BoD	0.24	0.43	5
Bp	0.00	0.00	9999
Bs	0.00	0.00	5
BtA	0.32	0.43	5
Bu	0.37	0.43	5
BwC	0.15	0.24	2
Cb	0.00	0.00	5
Ck	0.32	0.32	5
CmD	0.10	0.24	4
Cn	0.00	0.00	4
CrA	0.15	0.15	5
Dd	0.10	0.24	4
DeB	0.12	0.15	4
DeD	0.12	0.15	4
DlB	0.12	0.17	4
Dn	0.15	0.15	5
DnG	0.15	0.15	5
EcB	0.17	0.17	5
EcD	0.17	0.17	5
EkB	0.17	0.17	5
EkD	0.17	0.17	5
EkE	0.15	0.17	5
Es	0.20	0.32	5
Gl	0.17	0.17	5
Gw	0.00	0.00	5
HaB	0.15	0.15	5
IoB	0.15	0.37	5
Jb	0.15	0.28	4

Soil Type	K-factor (Minimum)	K-factor (Maximum)	T-factor
KaB	0.17	0.17	5
KaD	0.15	0.15	5
KaE	0.15	0.15	5
KaG	0.15	0.15	5
KdB	0.10	0.20	4
KdD	0.10	0.20	4
KdE	0.10	0.20	4
KgC	0.24	0.24	4
KmB	0.15	0.24	5
KmD	0.15	0.15	5
KmE	0.15	0.15	5
KnB	0.15	0.15	5
KnD	0.15	0.15	5
Kr	0.15	0.15	5
Lb	0.00	0.00	9999
McB	0.17	0.17	4
Mh	0.00	0.00	9999
MuB	0.20	0.20	4
MuD	0.20	0.20	4
MuE	0.20	0.20	4
Nh	0.24	0.24	4
Of	0.15	0.15	4
OoE	0.24	0.24	4
OrB	0.24	0.24	4
OrD	0.12	0.24	4
Os	0.20	0.20	5
OtB	0.17	0.17	5
Rc	0.17	0.17	5
RkB	0.15	0.17	5
RuB	0.15	0.15	5
RuD	0.15	0.15	5
RuE	0.15	0.15	5
ShB	0.15	0.15	5
SkB	0.24	0.24	3
Ss	0.15	0.15	2
StB	0.17	0.24	3
StD	0.17	0.24	3
SvA	0.24	0.24	4
SwA	0.17	0.17	4
Ta	0.15	0.15	4

Soil Type	K-factor (Minimum)	K-factor (Maximum)	T-factor
TrB	0.24	0.24	5
TrD	0.24	0.24	5
WaA	0.15	0.15	5
Water	0.00	0.00	9999
YaB	0.15	0.24	4
YaD	0.15	0.24	4

* A T-value of 9999 indicates that no T-factor value has been established for that soil type. A value of 9999 insures that the assigned risk category will be "low".

Appendix 3. Taxa lists for fish and invertebrate fauna.

Fish Name Lookup

Code	Common Name	Scientific Name
BKS	brook stickleback	*Culaea inconstans*
BKT	brook trout	*Salvelinus fontinalis*
BND	blacknose dace	*Rhinichthys atratulus*
COS	coho salmon	*Oncorhynchus kisutch*
FSD	finescale dace	*Phoxinus neogaeus*
LND	longnose dace	*Rhinichthys cataractae*
MSC	mottled sculpin	*Cottus bairdi*
MUW	central mudminnow	*Umbra limi*
NRD	northern redbelly dace	*Phoxinus eos*
RBT	rainbow trout	*Oncorhynchus mykiss*
WS	white sucker	*Catastomus commersoni*

Pictured Rocks National Lakeshore Master Taxa List / Voucher Collection 1994-96

1 COLLEMBOLA

EPHEMEROPTERA

Baetidae

2 *Acentrella turbida*
184 *Acerpenna macdunnoughi*
185 *Baetis armillatus*
141 *Baetis brunniecolor*
186 *Baetis cinctutus*
143 *Baetis flavistriga*
187 *Baetis tricaudatus*
188 *Barbaetis cestus*
159 *Centroptilum* sp.
3 *Baetis* sp.

Baetiscidae

177 *Baetisca* sp.

Ephemerellidae

4 *Ephemerella* sp.
152 *Eurylophella* sp.
5 *Serratella deficiens*
189 *Timpanoga (Dannella) simplex*

Leptophlebiidae

6 *Paraleptophlebia* sp.

Heptageniidae

7 *Epeorus* sp.
156 *Heptagenia* sp.
190 *Leucrocuta* sp.
8 *Stenonema vicarium*

Ephemeridae

9 *Ephemera simulans*
10 *Litobrancha recurvata*

Metretopodidae

11 *Siphloplecton basale*

Ameletidae

12 *Ameletus* sp.

Tricorythidae

13 *Tricorythodes* sp.

Caenidae

191 *Brachycercus* sp.
14 *Caenis* sp.

PLECOPTERA

Pteronarcyidae

15 *Pteronarcys* sp.

Capniidae

16 *Paracapnia* sp.
192 Chloroperlidae

Leuctridae

17 *Leuctra* sp.

Taeniopterygidae

18 *Taeniopteryx* sp.

Nemouridae

19 *Amphinemura* sp.

Perlidae

20 *Acroneuria* sp.
21 *Paragnetina media*

Perlodidae

233 *Clioperla clio*
22 *Isoperla* sp.
23 *Isogenoides* sp.

ODONATA

Calopterygidae

24 *Calopteryx* sp.

Aeshnidae

25 *Boyeria vinosa*

Gomphidae

26 *Ophiogomphus* sp.

Cordulegastridae

27 *Cordulegaster* sp.

Libellulidae

145 *Libellula* sp.

HEMIPTERA

Belostomatidae

28 *Belostoma flumineum*

Corixidae

193 *Hesperocorixa minorella*
29 *Hesperocorixa* sp.
30 *Sigara* sp.
31 *Trichocorixa* sp.

Gerridae

32 *Aquarius remigis*

Nepidae

154 *Ranatra fusca*

Veliidae

33 *Microvelia* sp.

TRICHOPTERA

Brachycentridae

34 *Brachycentrus americanus*
147 *Brachycentrus americanus* PUPA
181 *Brachycentrus numerosus*
35 *Micrasema* sp.

Glossosomatidae

36 *Glossosoma* sp.
36-A *Glossosoma* sp. PUPA
146 *Protoptila* sp.
149 *Protoptila* sp. PUPA

Hydropsychidae

195 *Diplectrona modesta*
194 *Hydropsyche betteni*
37 *Hydropsyche morosa*
38 *Hydropsyche slossonae*
39 *Hydropsyche sparna*
196 *Hydropsyche* sp. PUPA
153 *Parapsyche* sp.

Hydroptilidae

180 *Hydroptila* sp.
140 *Oxyethira* sp.

Lepidostomatidae

40 *Lepidostoma* sp.
197 *Lepidostoma* sp. PUPA

Leptoceridae

176 *Mystacides* sp.
41 *Oecetis* sp.

Limnephilidae

135 Glyphopsyche irrorata
42 *Goera* sp.
42-A *Goera* sp. PUPA
175 *Hesperophylax designatus*
43 *Hydatophylax argus*
44 *Ironoquia* sp.
161 *Limnephilidae* PUPA
150 *Limnephilus* sp.
182 *Nemotaulius hostilis*
45 *Neophylax* sp. ADULT
199 *Neophylax* sp. Larvae
198 *Onocosmoecus unicolor*
148 *Psychoglypha subborealis*
46 *Pycnopsyche* sp.

Molannidae

47 *Molanna* sp. LARVA

Odontoceridae

48 *Psilotreta indecisa*

Philopotamidae

137 *Chimarra* sp.
49 *Dolophilodes distinctus*
49-A *Dolophilodes distinctus* PUPA

Phryganeidae

50 *Oligostomis ocelligera*
51 *Ptilostomis* sp.

Polycentropodidae

52 *Neureclipsis* sp.
53 *Phylocentropus* sp.
54 *Polycentropus* sp.

Psychomyiidae

55 *Lype diversa*
56 *Psychomyia flavida*

Rhyacophilidae

57 *Rhyacophila fuscula*
200 *Rhyacophila fuscula* PUPA
201 *Rhyacophila* sp.

LEPIDOPTERA

58 Lepidopteran PUPA
59 Tortricidae LARVA

MEGALOPTERA

Corydalidae

60 *Nigronia* sp.

Sialidae

61 *Sialis* sp.

Pictured Rocks National Lakeshore Master Taxa List / Voucher Collection 1994-96

COLEOPTERA
- Curculionidae
  - 62 *Lixus* sp. ADULT
- Dryopidae
  - 63 *Helichus* sp. ADULT
- Elmidae
  - 64 *Dubiraphia* sp. LARVA
  - 65 *Dubiraphia minima* ADULT
  - 66 *Macronychus glabratus* ADULT
  - 67 *Optioservus* sp. LARVA
  - 68 *Optioservus fastiditus* ADULT
  - 69 *Stenelmis* sp. LARVA
  - 70 *Stenelmis crenata* ADULT
- Dytiscidae
  - 205 *Agabus* sp. LARVA
  - 71 *Agabus* seriatus ADULT
  - 72 *Hydroporus* sp. ADULT
  - 73 *Liodessus affinis* ADULT
  - 202 *Oreodytes* sp. LARVA
  - # 179 *Nebrioporus rotundatus* ADULT
- Gyrinidae
  - 203 *Gyrinus latilimbus* ADULT
  - 174 *Gyrinus lecontei* ADULT
- Haliplidae
  - 204 *Haliplus immaculicollis* ADULT
  - 74 *Haliplus* sp. LARVA
- Hydrophilidae
  - 172 Crenitis digesta ADULT
  - 75 *Helophorus* sp. ADULT
  - 76 *Hydrobius* melaenus ADULT and LARVA
  - 164 *Paracymus sp.* ADULT
  - 77 *Sperchopsis tesselata* ADULT
  - 163 *Sperchopsis tesselata* LARVA
  - 78 *Tropisternus* sp. ADULT
  - 79 Staphylinidae ADULT
  - 80 Staphylinidae LARVA

DIPTERA
- Athericidae
  - 81 *Atherix variegata*
  - 82 Ceratopogonidae
  - 206 *Atrichopogon* sp.
  - 83 *Bezzia* sp.
- Chironomidae LARVA
- Diamesinae
  - 84 * *Diamesa* sp.
  - 85 * *Pagastia* sp.
  - 169 * *Potthastia gaedii* group
  - 207 * *Potthastia longimana* group
- Prodiamesinae
  - 86 * *Odontomesa* sp.
  - 87 * *Prodiamesa* sp.
- Orthocladiinae
  - 88 *Brillia* sp.
  - 160 * *Cardiocladius* sp.
  - 162 *Corynoneura* sp.
  - 90 * *Cricotopus* sp.
  - 168 * *Cricotopus trifascia* group
  - 91 * *Epoicocladius* sp.
  - 92 * *Eukiefferiella* sp.
  - 165 * *Heterotrissocladius* sp.
  - 208 * *Limnophyes* sp.
  - 209 * *Lopescladius* sp.
  - 93 * *Nanocladius* sp.
  - 183 * Orthocladiinae sp. C
  - 166 * *Orthocladius (Symposiocladius) lignicola*
  - 155 * *Parachaetocladius* sp.
  - 89 * *Parametriocnemus* sp.
  - 210 * *Paraphaenocladius sp.*
  - 138 * *Rheocricotopus* sp.
  - 211 * *Synorthocladius* sp.
  - 94 * *Thienemanniella* sp.
  - 95 * *Tvetenia* sp.
  - 96 * *Xylotopus* sp.
- Chironominae
  - 97 * *Cladotanytarsus* sp.
  - 139 *Cryptochironomus* sp.
  - 158 *Dicrotendipes* sp.
  - 212 * *Micropsectra* sp.
  - 98 *Microtendipes* sp.
  - 171 * *Paracladopelma* sp.
  - 167 * *Phaenopsectra* sp.
  - 99 * *Polypedilum* sp.
  - 100 * *Rheotanytarsus* sp.
  - 101 * *Robackia* sp
  - 102 * *Stempellina* sp.
  - 103 * *Stenochironomus* sp.
  - 173 * *Stictochironomus* sp.
  - 104 * *Tanytarsus* sp.
  - 170 * *Zavrelia* sp.
  - * Tanypodinae
  - 213 * *Ablabesmyia* sp.
  - 178 * *Apsectrotanypus* sp.
  - 105 * *Brundiniella* sp.
  - 151 * *Macropelopia* sp.
  - 214 * *Natarsia* sp.
  - 106 * *Procladius* sp.
  - 215 Tanypodinae PUPA
  - 107 * *Thienemannimyia* group
  - 108 * *Trissopelopia* sp.
- Chironomidae PUPA
  - 109 *Diamesa* sp. PUPA
- Chironomidae ADULT
  - 216 Empididae
  - 110 *Chelifera* sp.
  - 144 *Hemerodromia* sp.
  - 217 *Hemerodromia* sp. PUPA
  - 157 *Trichoclinocera* sp.
  - 218 Psychodidae
- Ptychopteridae
  - 111 *Bittacomorpha* sp.
  - 112 *Ptychoptera* sp.
- Simuliidae
  - 113 *Simulium* sp. LARVA
- Tabanidae
  - 114 *Chrysops* sp.
- Tipulidae LARVA
  - 115 *Antocha* sp.
  - 116 *Dicranota* sp.
  - 117 *Hexatoma* sp.
  - 220 *Ormosia* sp.
  - 118 *Pedicia* sp.
  - 119 *Pilaria* sp.
  - 120 *Prionocera* sp.
  - 121 *Tipula* sp.
  - 219 Tipulidae PUPA

221 NEMATODA

222 NEMATOMORPHA

*123 OLIGOCHAETA
- 223 * Enchytraeidae
- 225 * Lumbricidae
- 224 * Tubificidae

HIRUDINEA
- 136 Erpobdellidae
- 142 Nephelopsis obscura
- Glossiphoniidae
  - 125 *Glossiphonia complanata*
  - 234 *Helobdella stagnalis*

ARANEAE

HYDRACARINA
- Hygrobatidae
  - 226 *Atractides* sp.
  - 227 *Hygrobates* sp.
- Lebertiidae
  - 228 *Lebertia* sp.

AMPHIPODA
- Gammaridae
  - 134 *Gammarus lacustris*
- Hyalellidae
  - 128 *Hyalella azteca*

DECAPODA
- 229 Cambaridae

GASTROPODA
- Ancylidae
  - 129 *Ferrissia* sp.
- 130 Lymnaeidae
  - 230 *Pseudosucinnea columella*
  - 231 *Stagnicola sp.*
- Physidae
  - 131 *Physella* sp.
- 132 Planorbidae

BIVALVIA
- Sphaeriidae
  - 133 *Pisidium* sp.
  - 232 *Sphaerium* sp.

 # 179 Retained, C.P. Gillette Museum of Arthropod Diversity, Colorado State University

*** denotes slide mount**

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74. Ratio of EPT Taxa:Total Taxa, 7 Mile and Sullivan River, 1996.
75. Fish Length by River and Species.
76. Fish Population Density by River and Species.

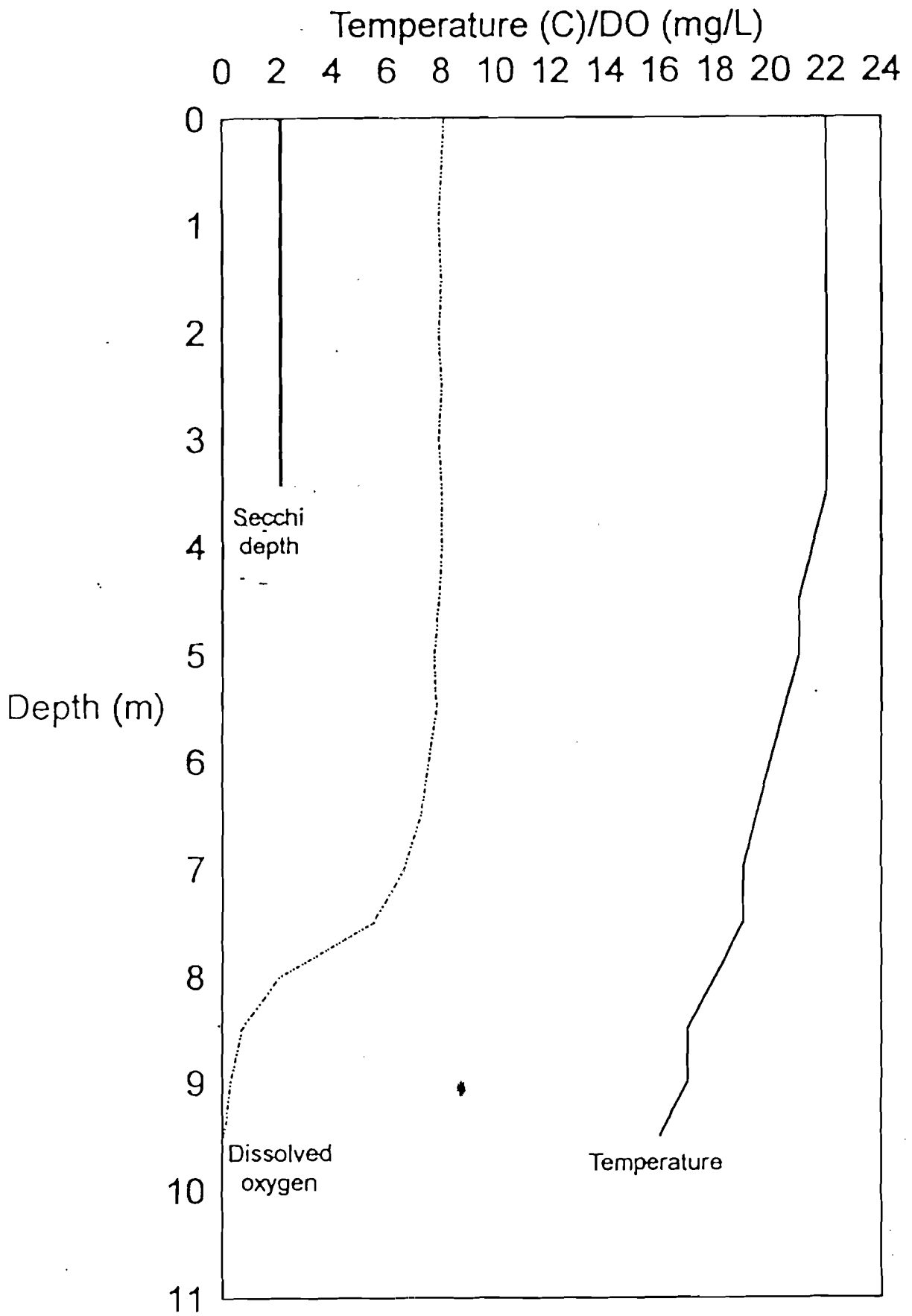


Figure 7. Big Beaver Lake 1994

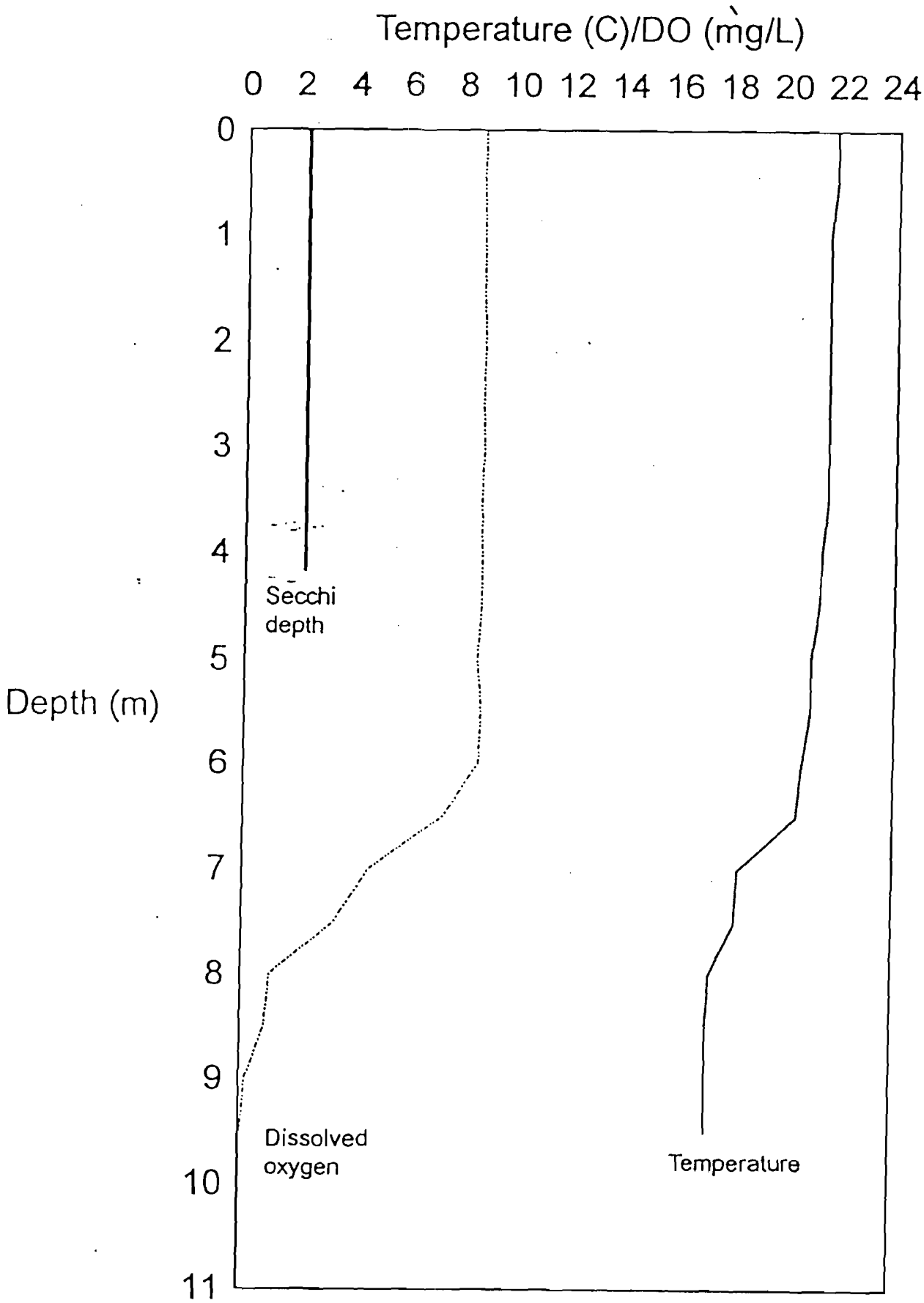


Figure 8. Big Beaver Lake 1995

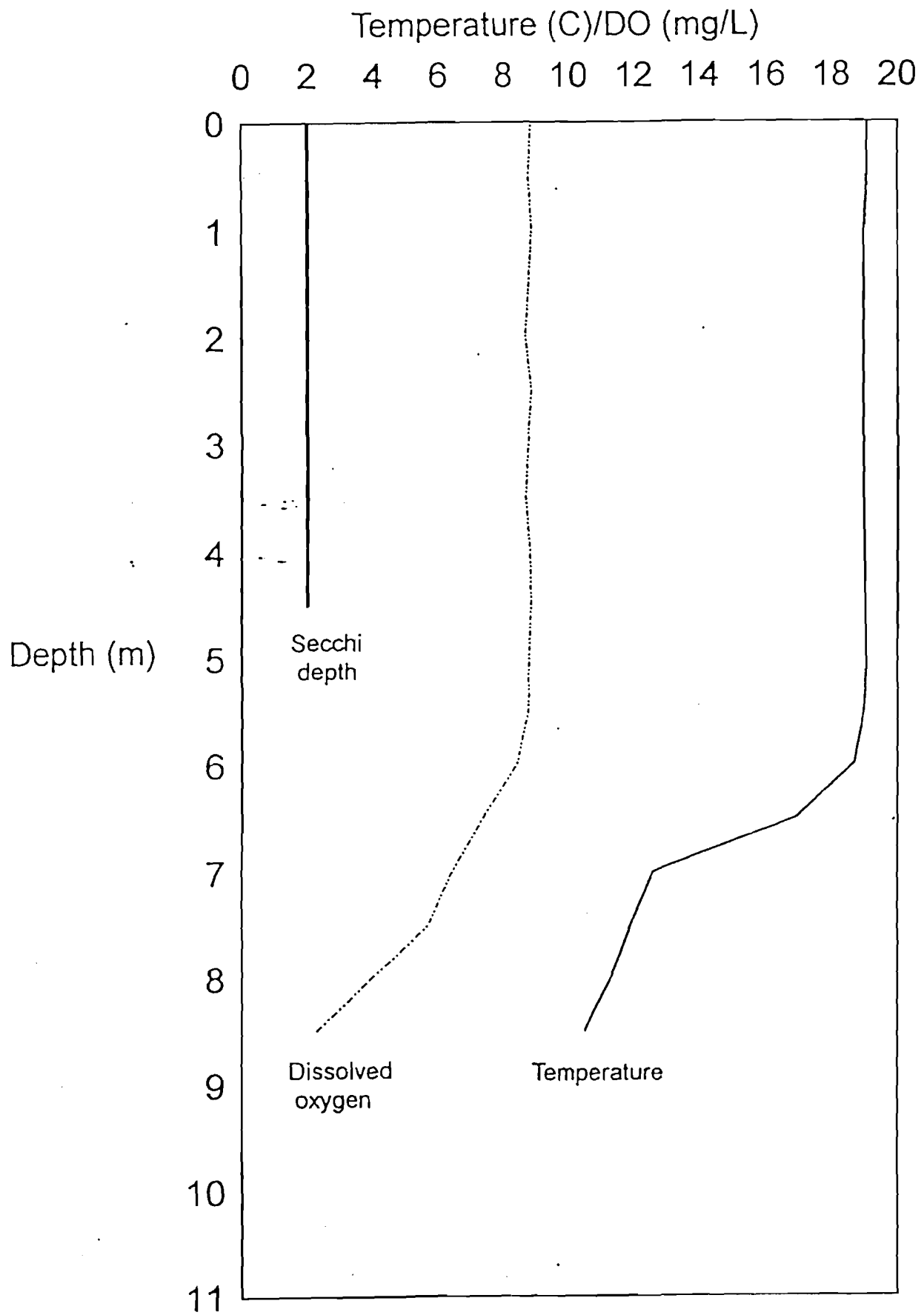


Figure 9. Big Beaver Lake 1996

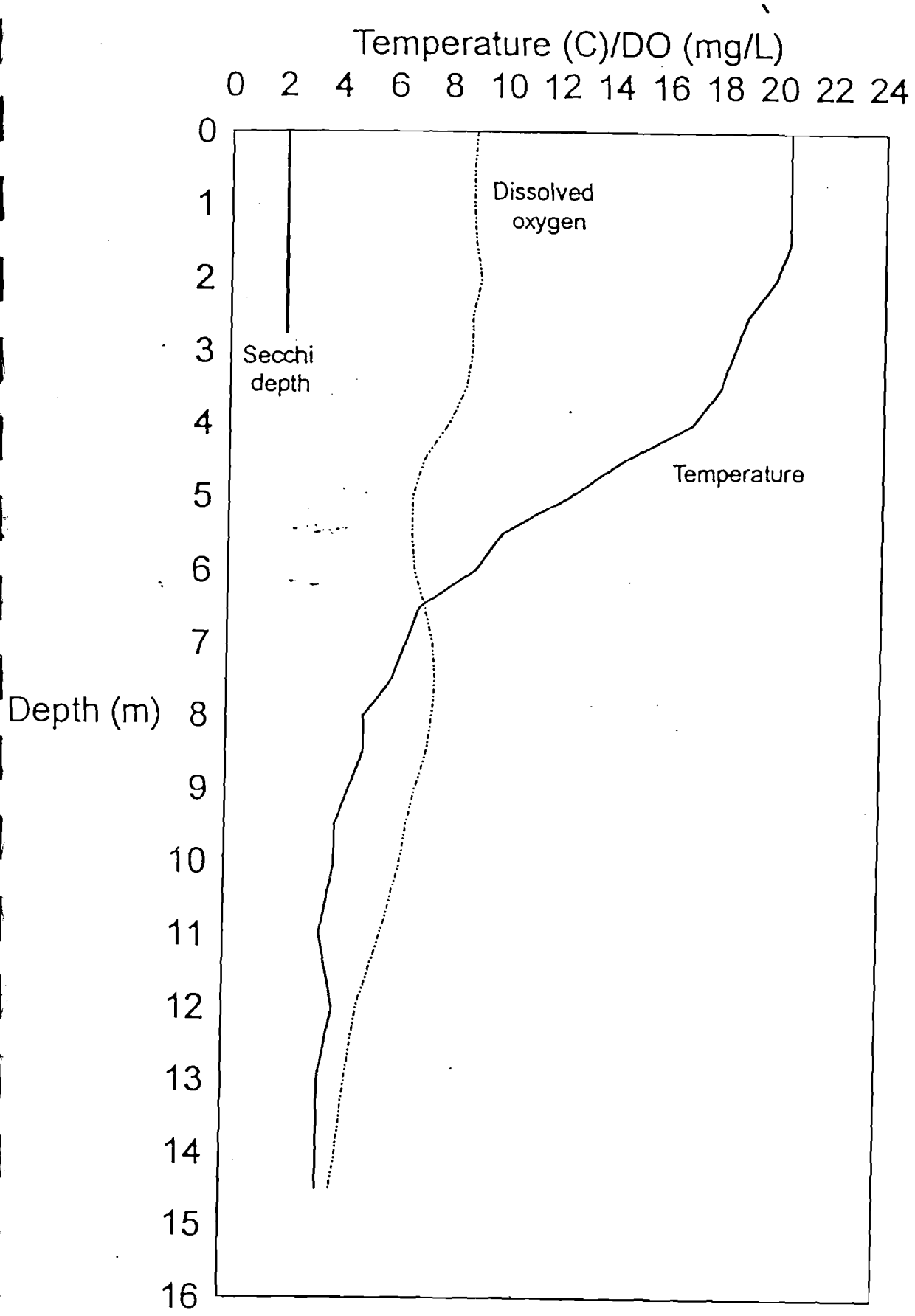


Figure 10. Chapel Lake 1994

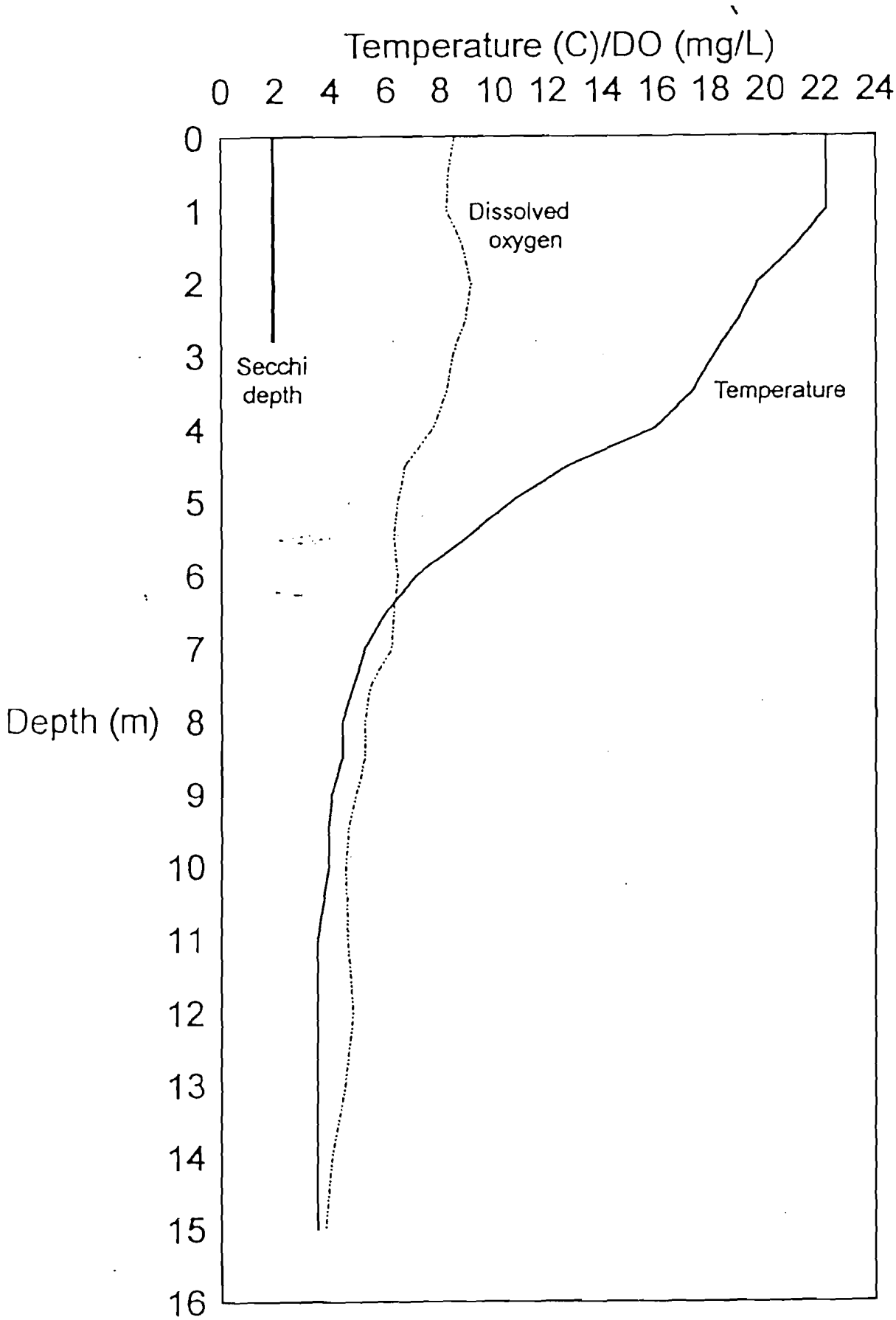


Figure 11. Chapel Lake 1995

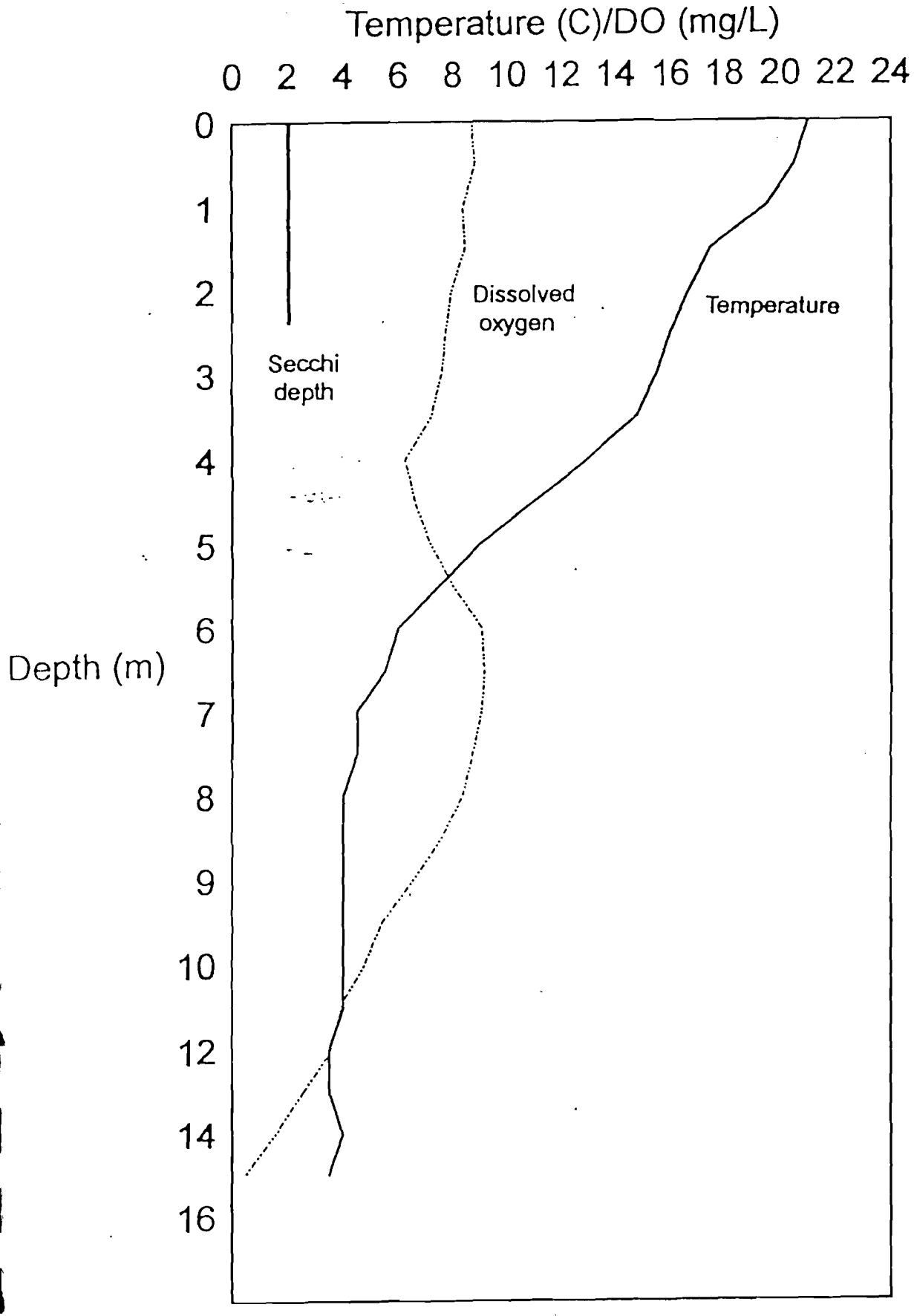


Figure 12. Chapel Lake 1996

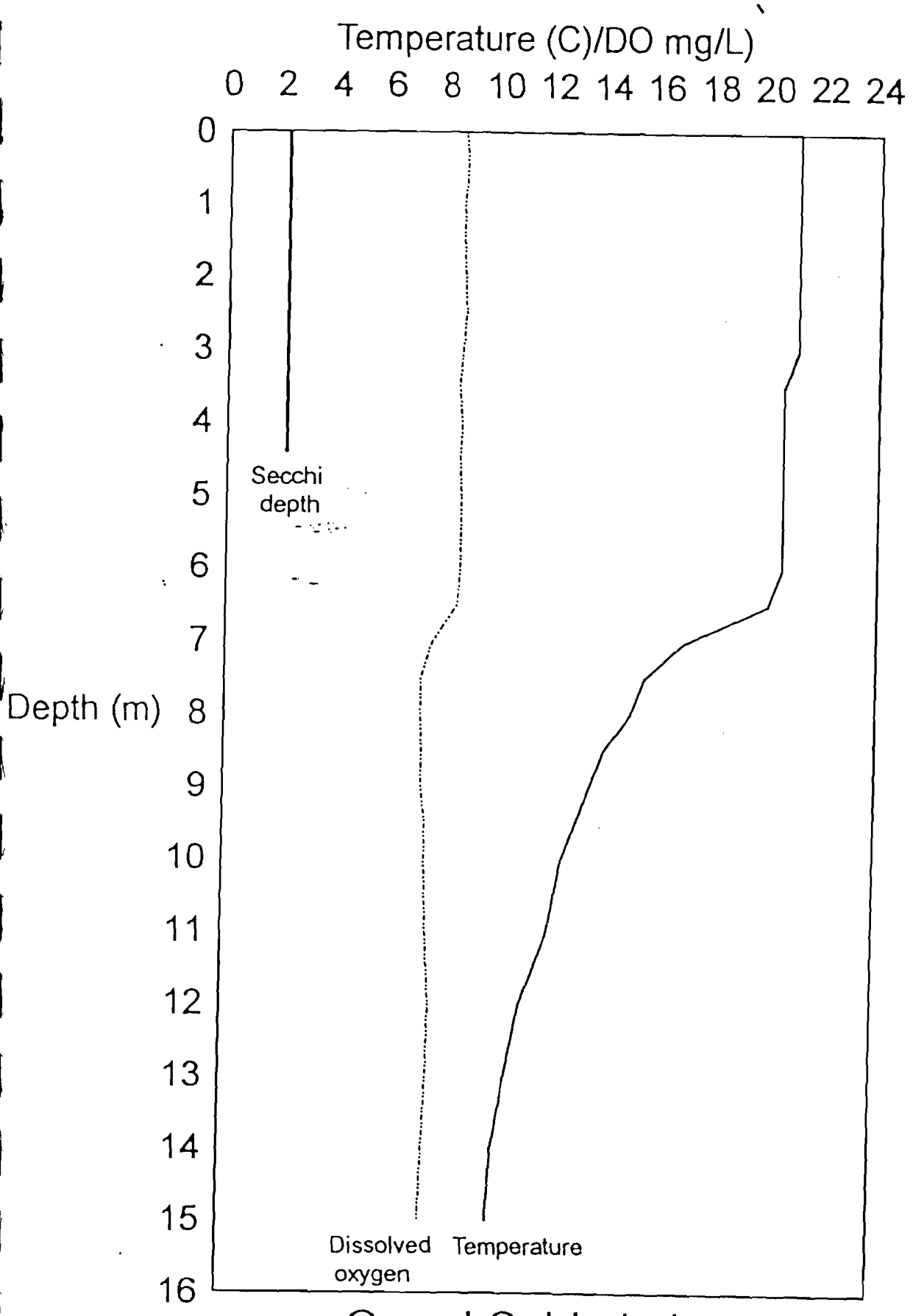


Figure 13. Grand Sable Lake 1994

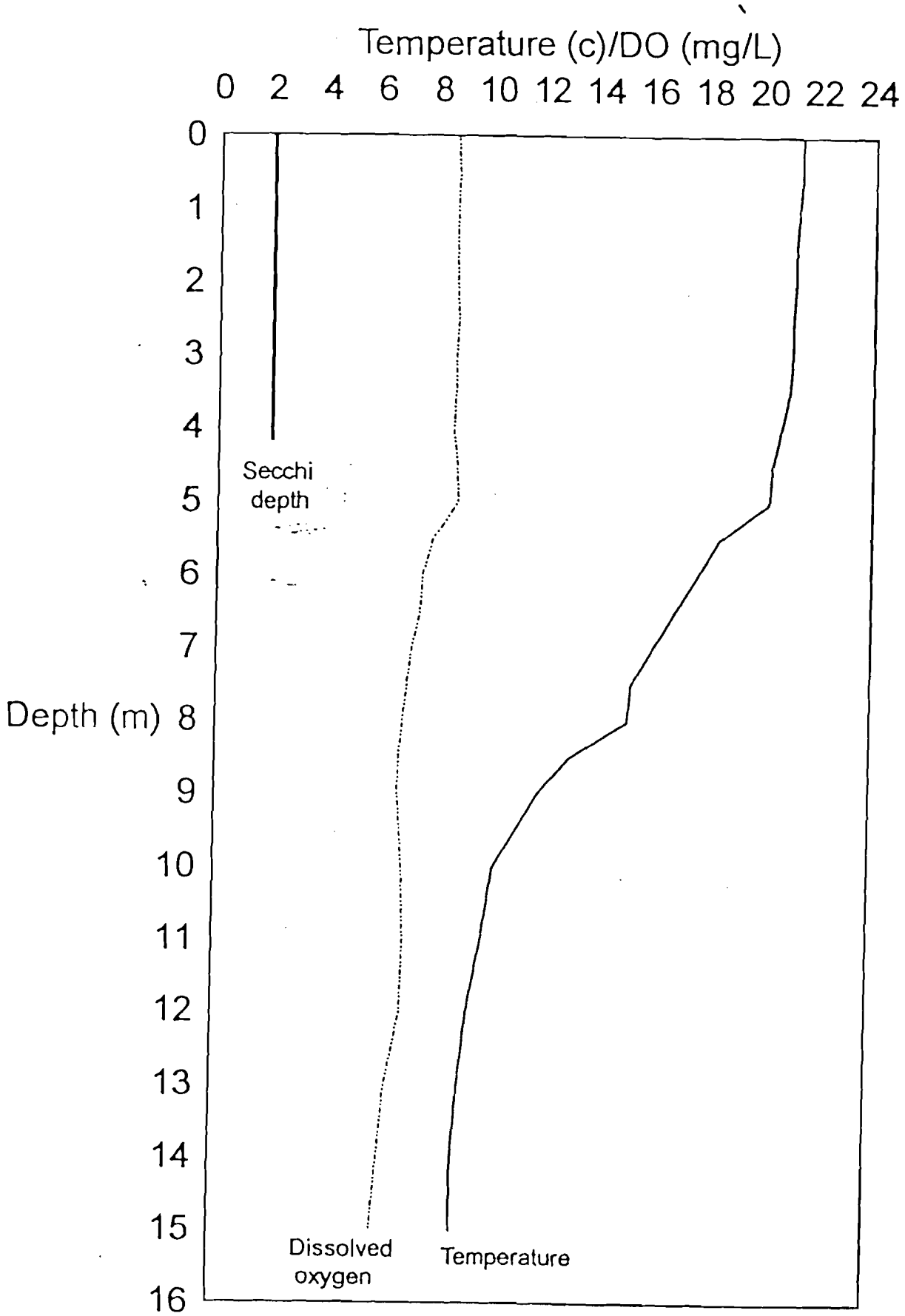


Figure 14. Grand Sable Lake 1995

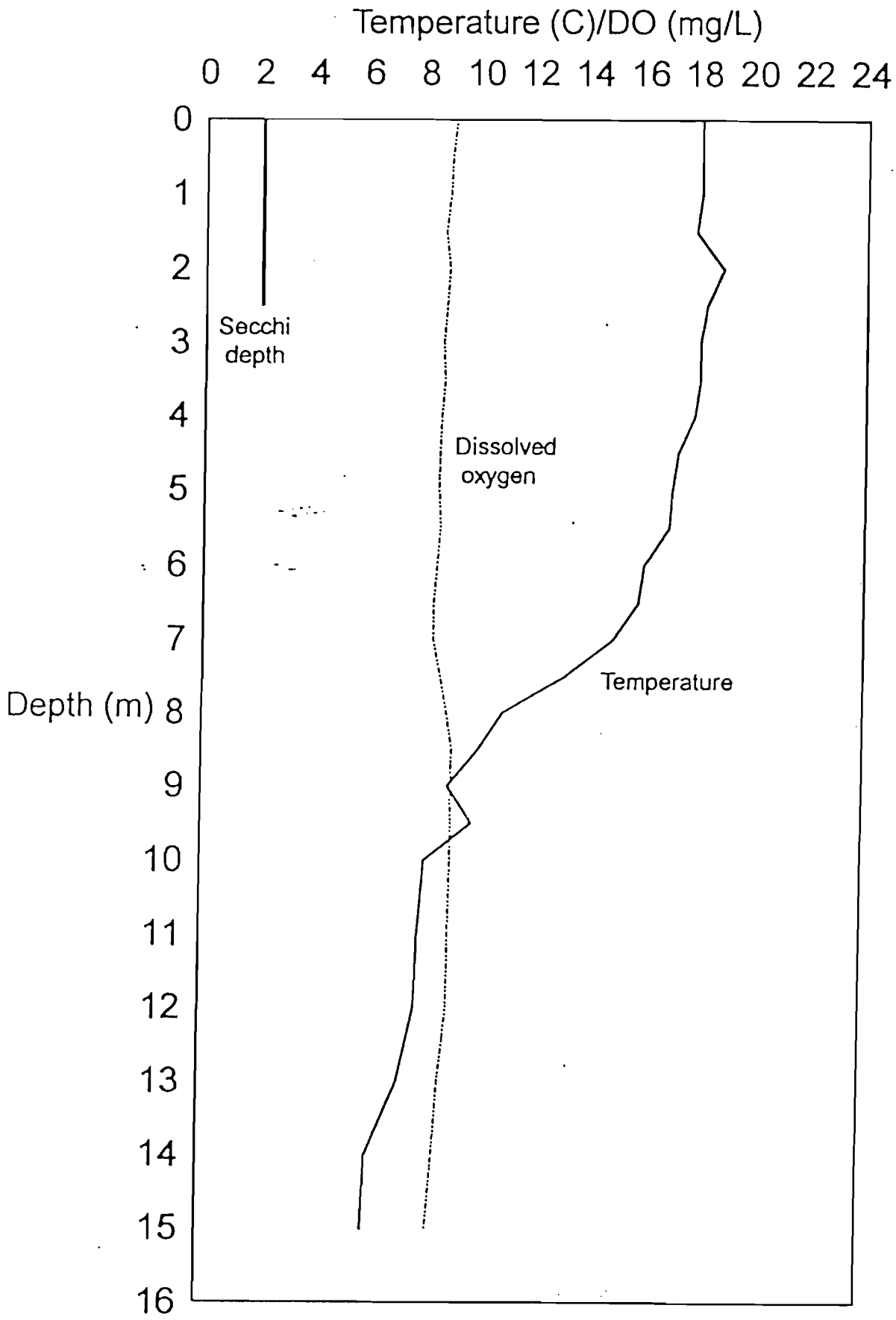


Figure 15. Grand Sable Lake 1996

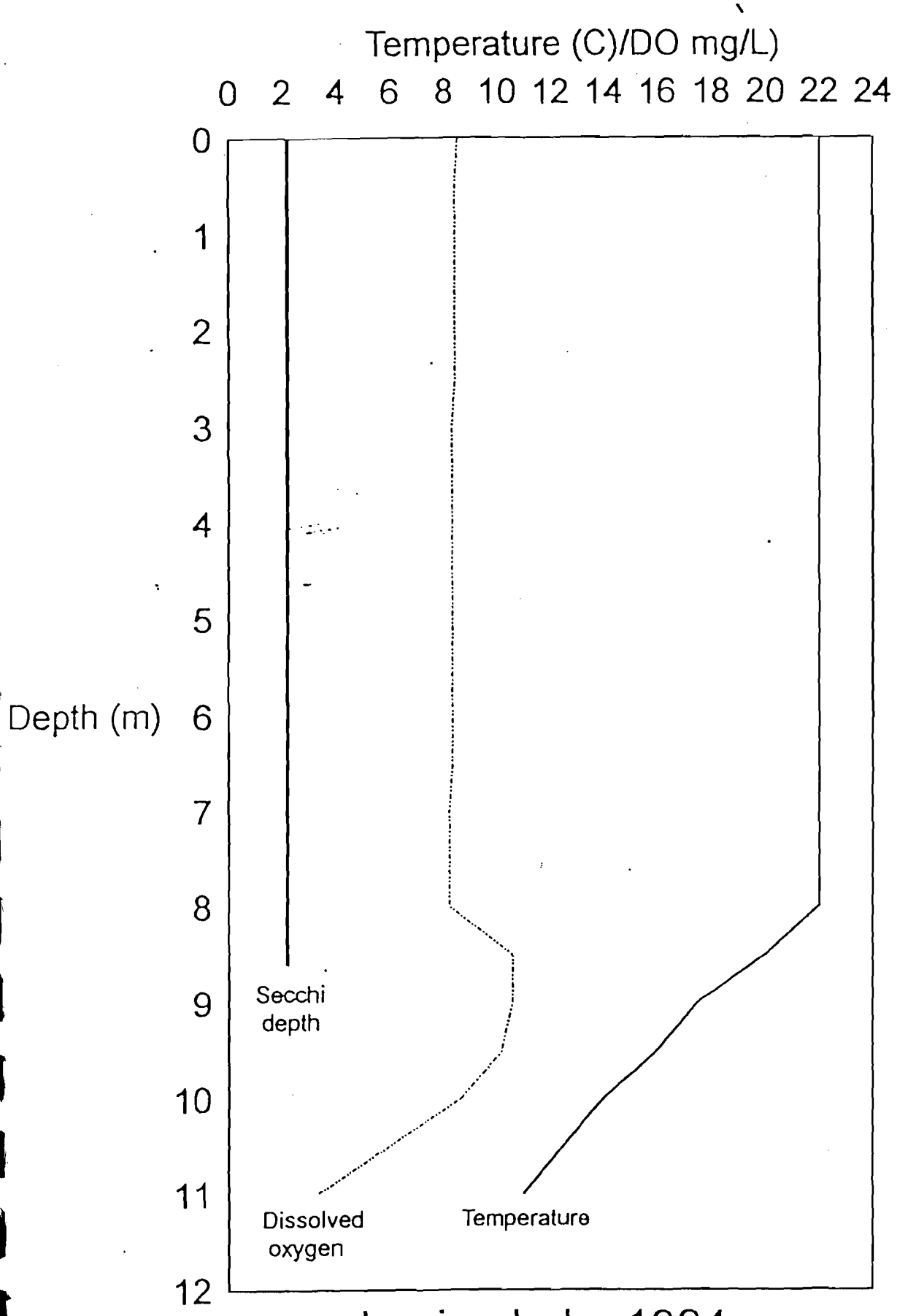


Figure 16. Legion Lake 1994

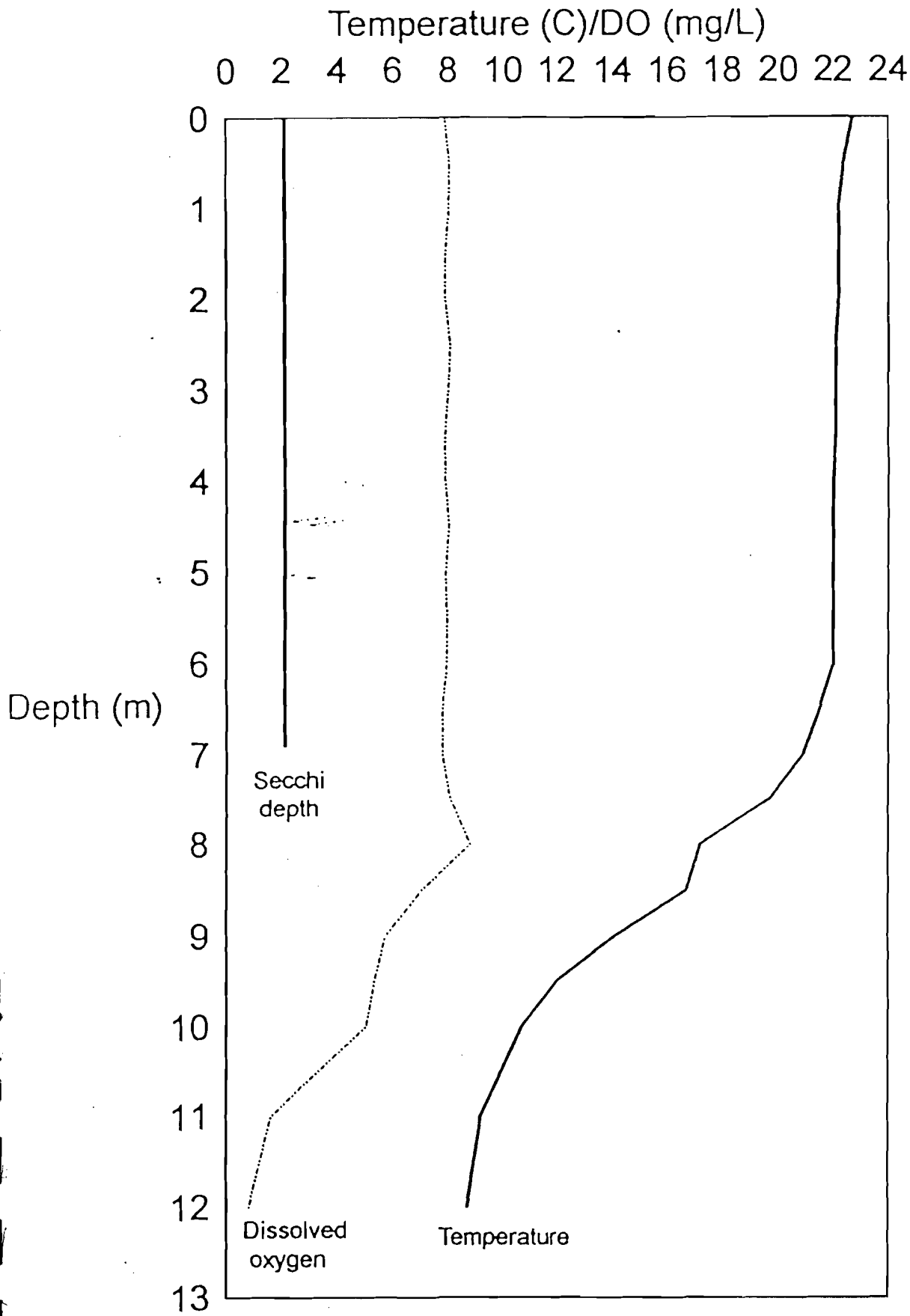


Figure 17. Legion Lake 1995

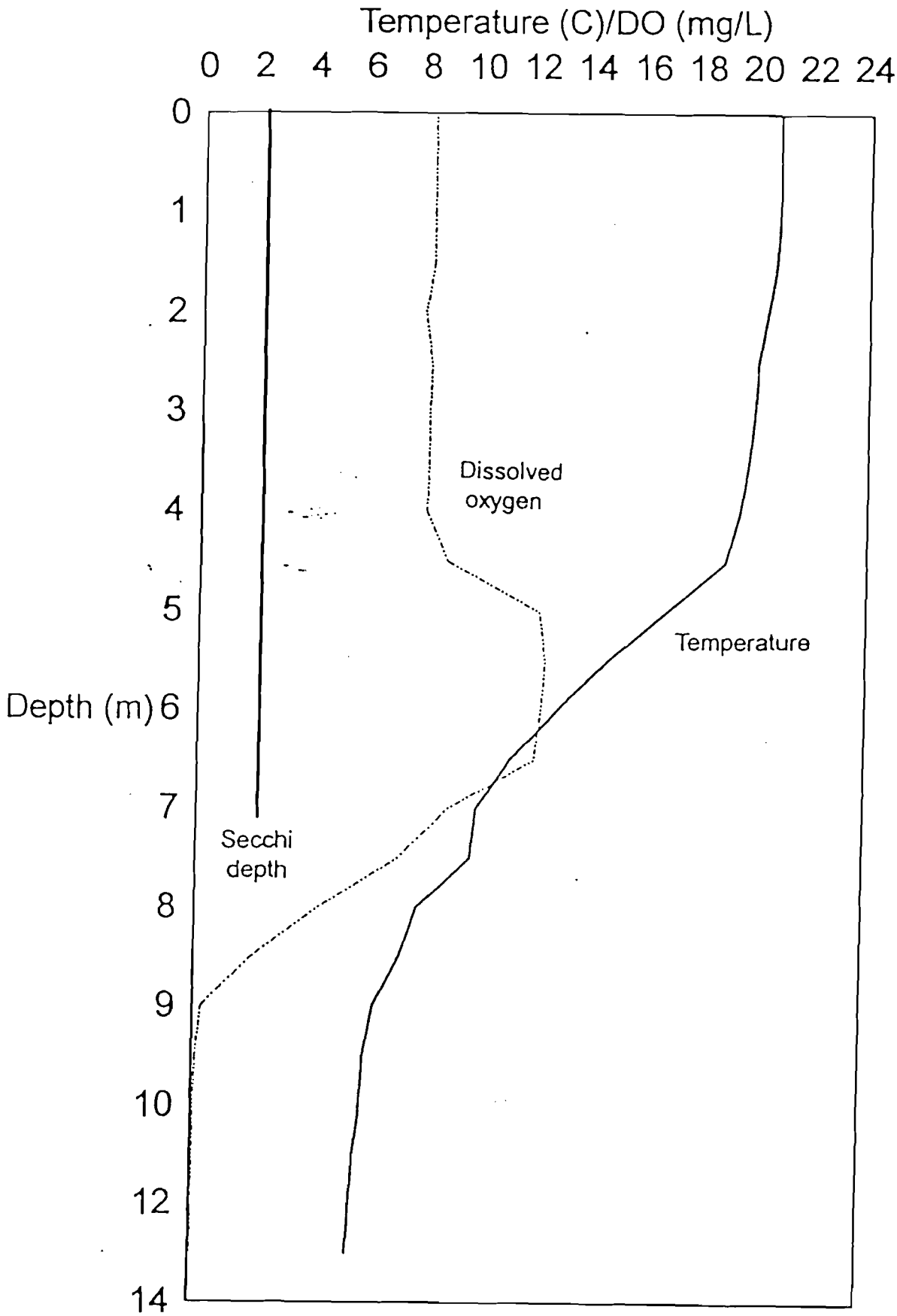


Figure 18. Legion Lake 1996

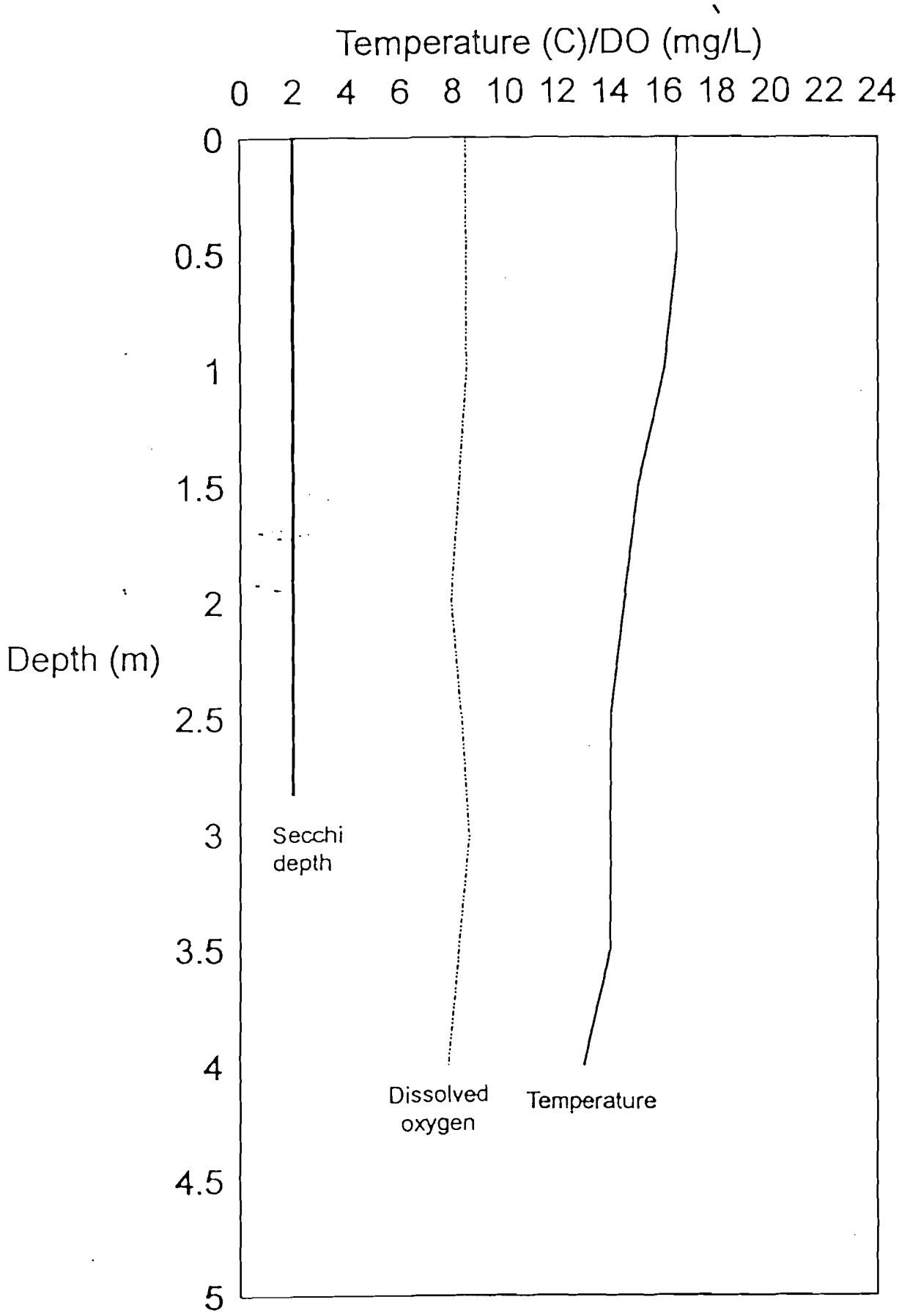


Figure 19. Miners Lake 1994

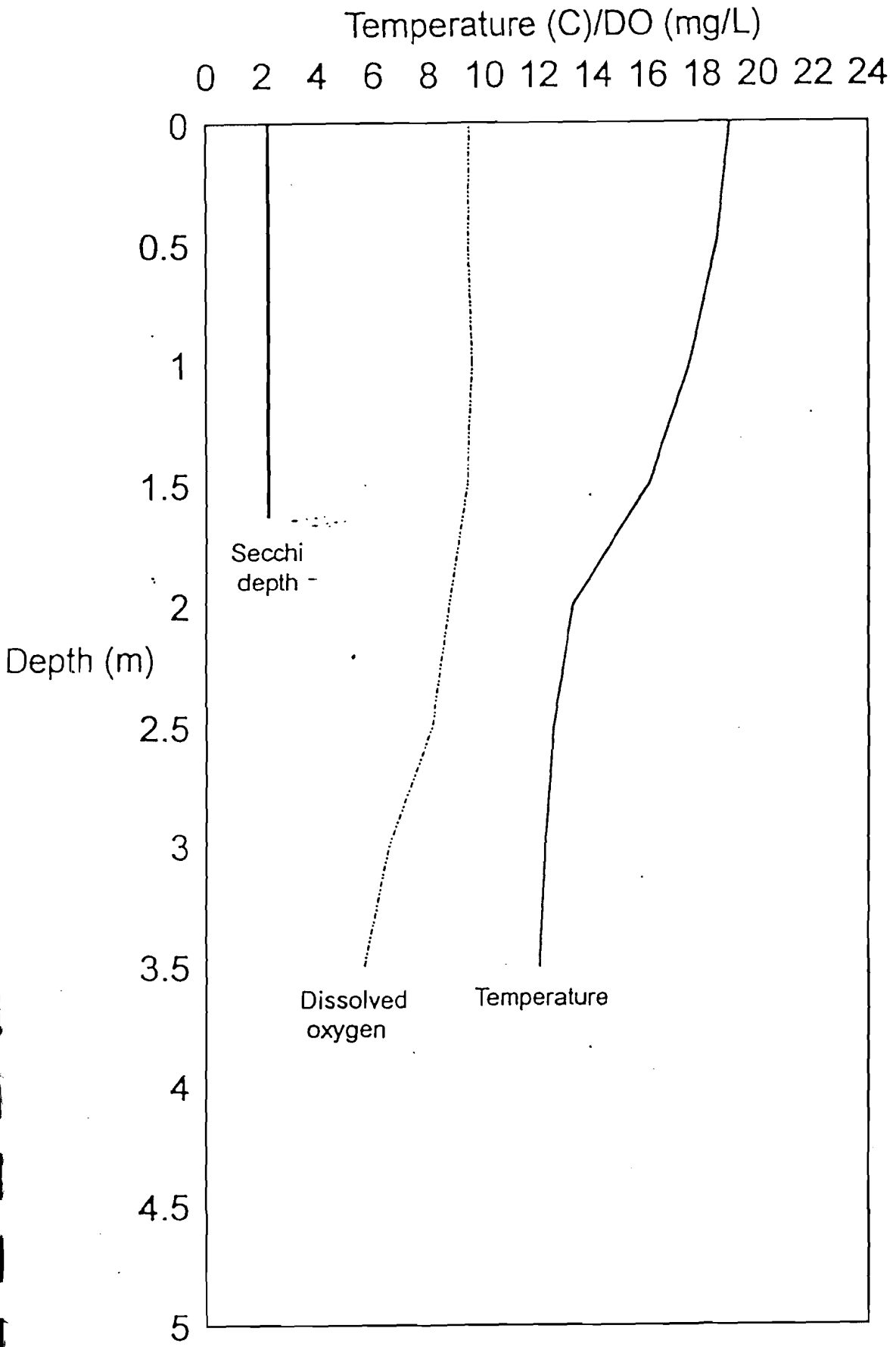


Figure 21. Miners Lake 1996

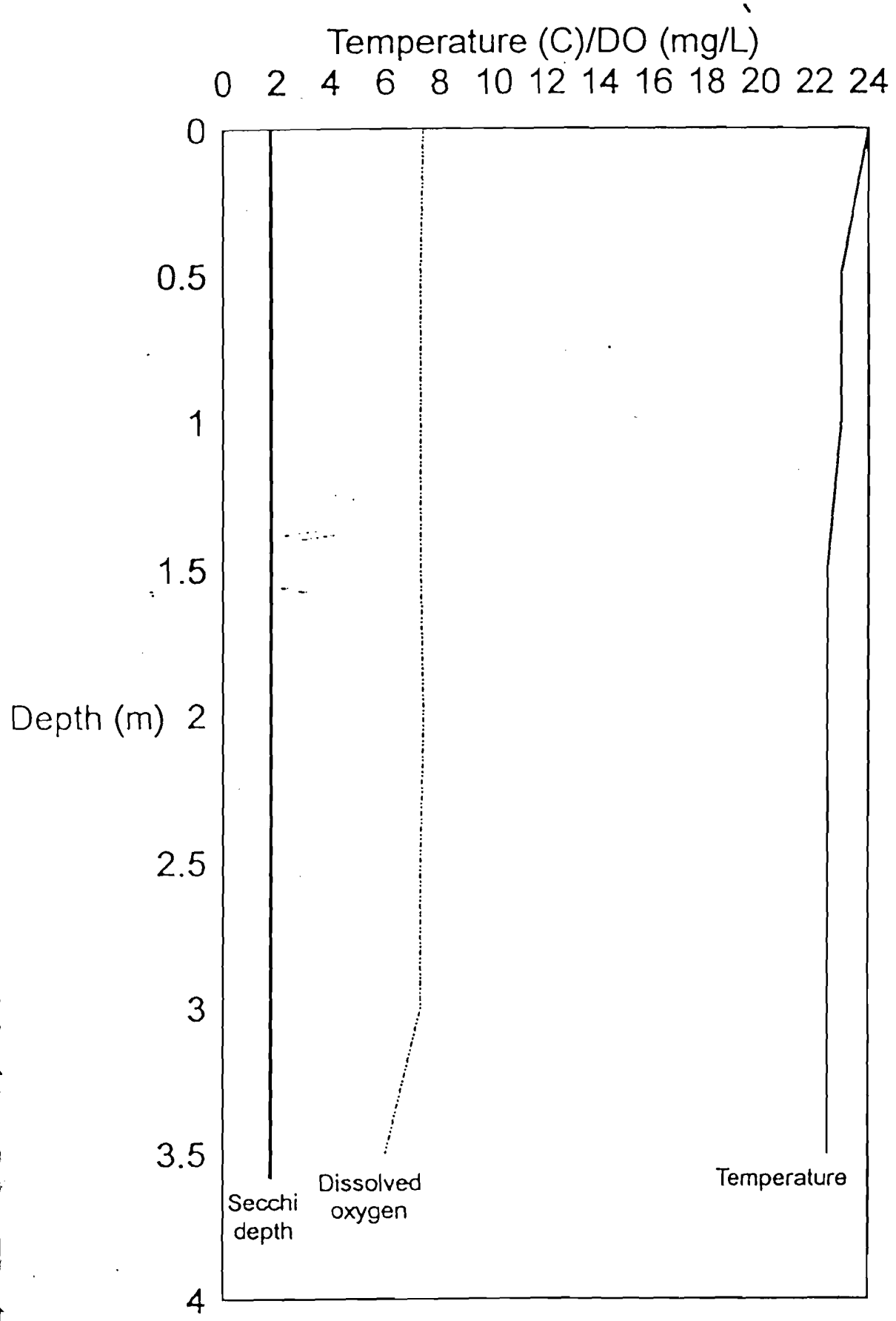


Figure 22. Section 36 Lake 1994

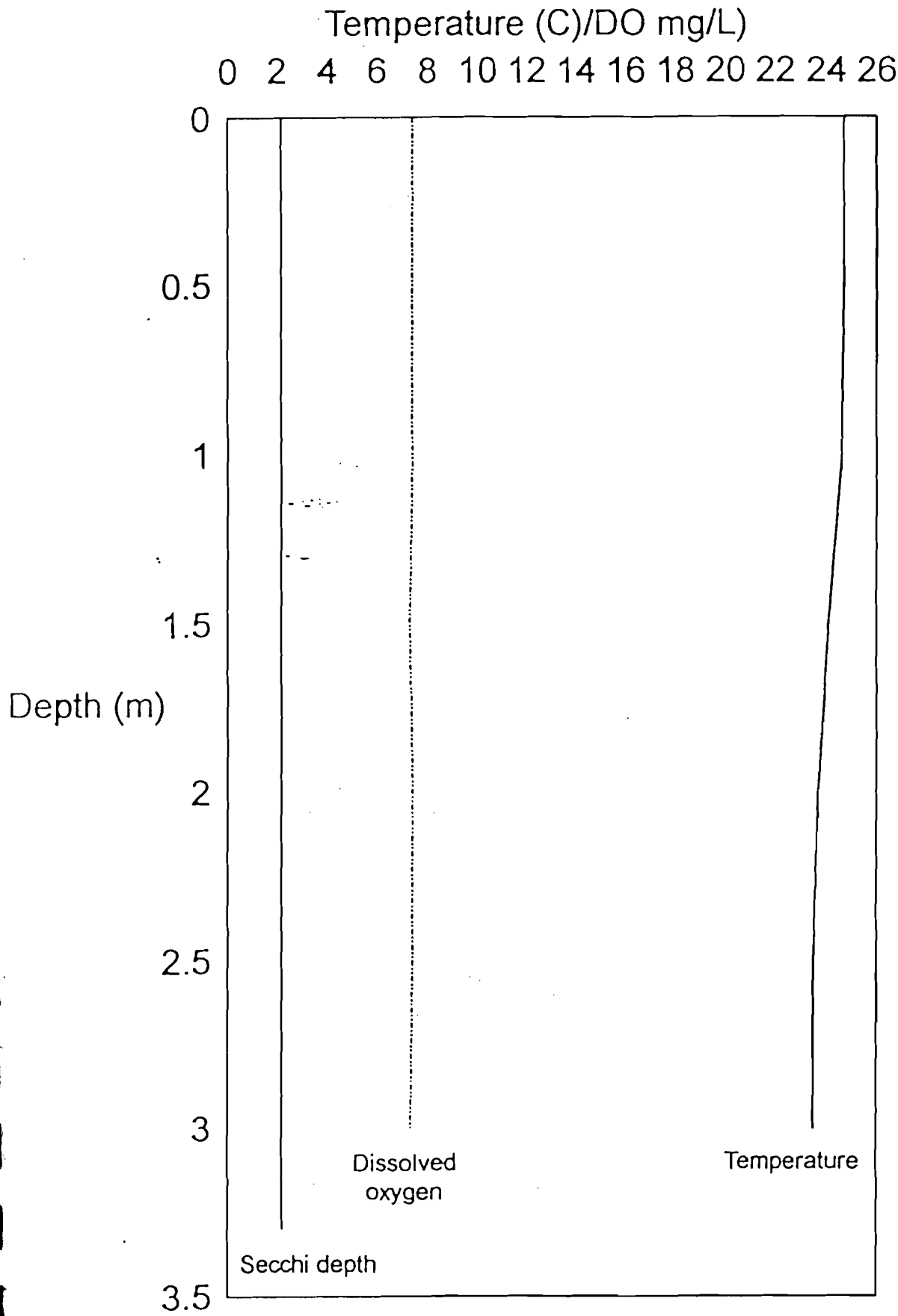


Figure 23. Section 36 Lake 1995

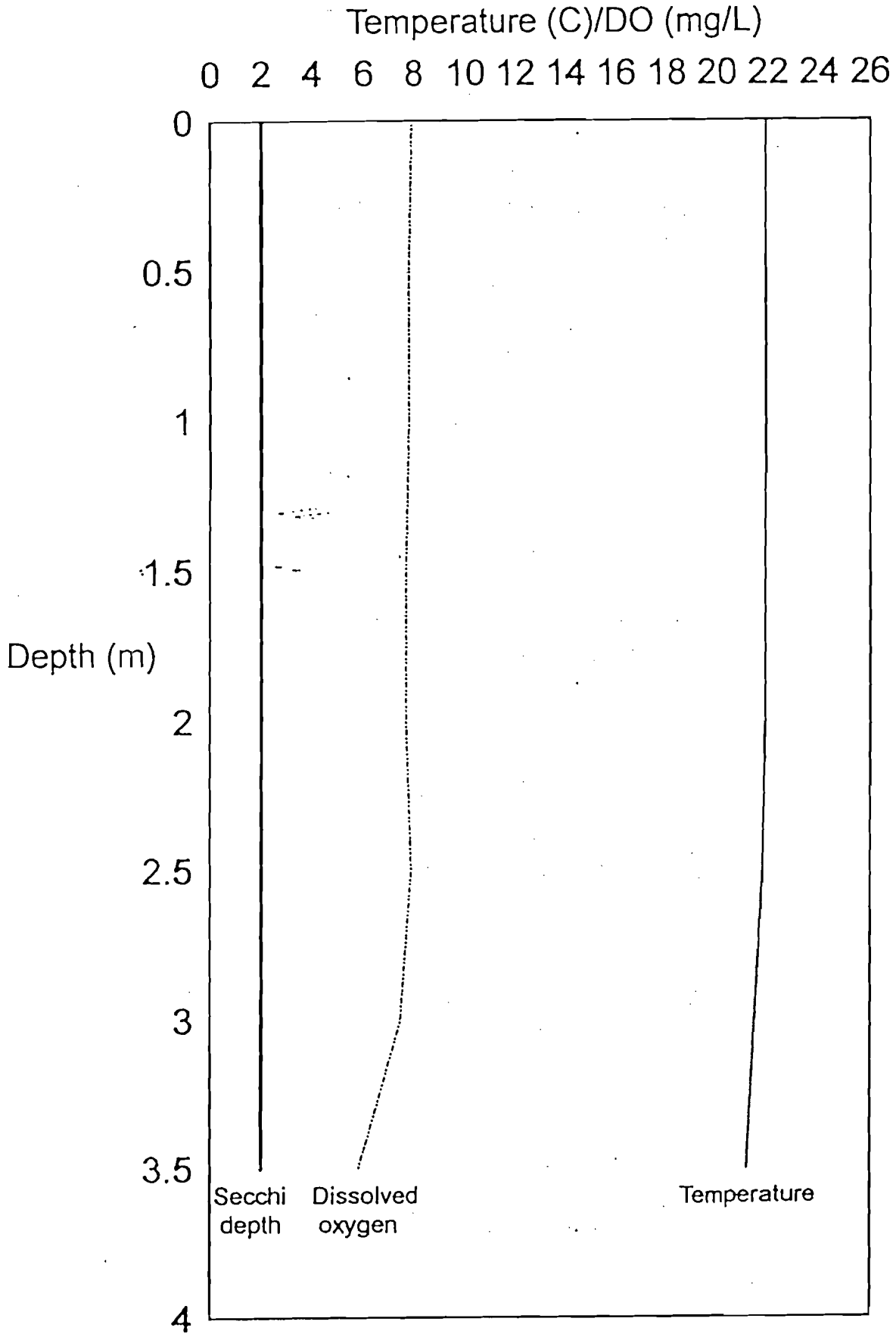


Figure 24. Section 36 Lake 1996

Figure 25. Average Total Nitrogen by Lake

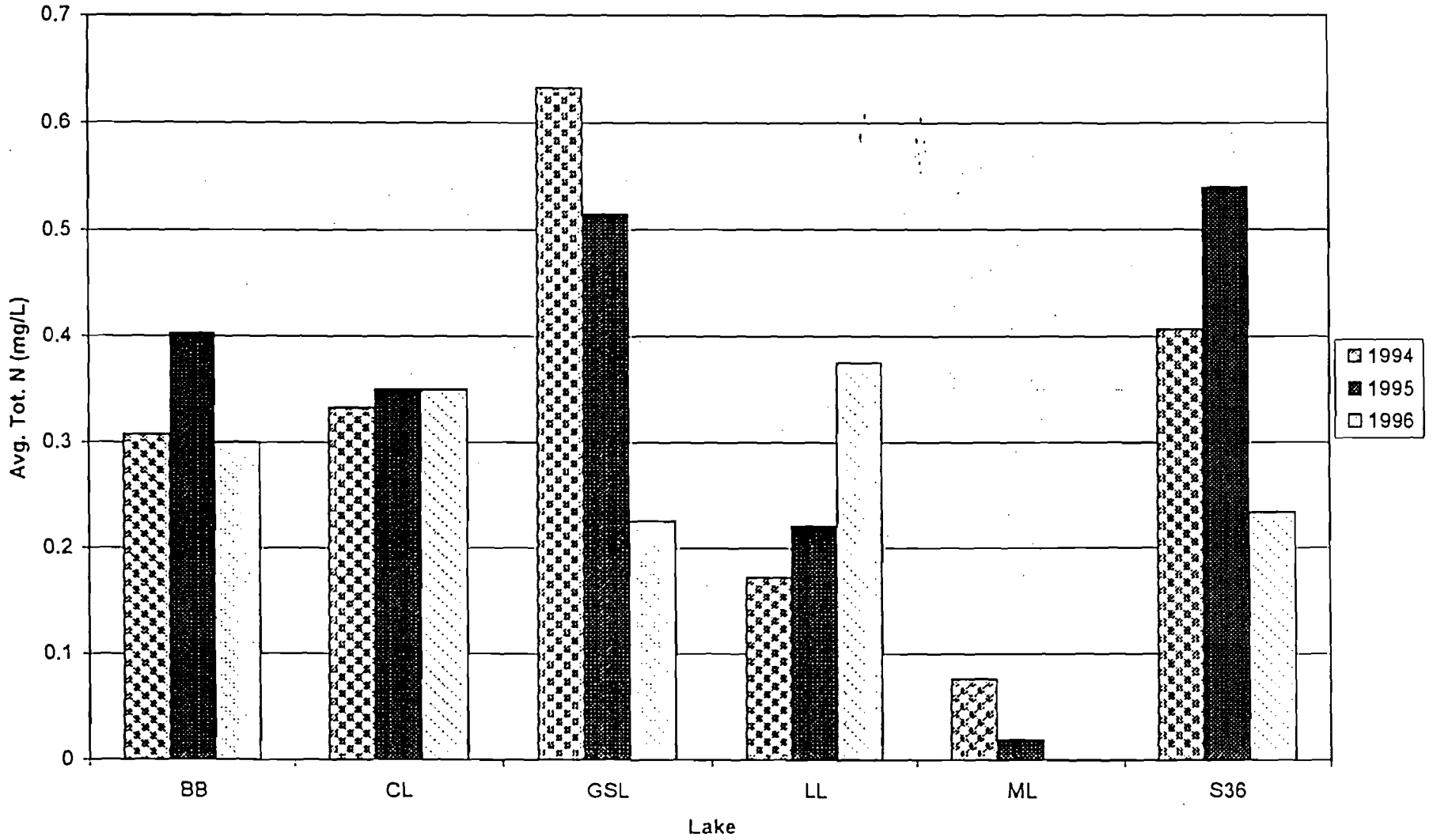


Figure 26. Average Total Phosphorus by Lake

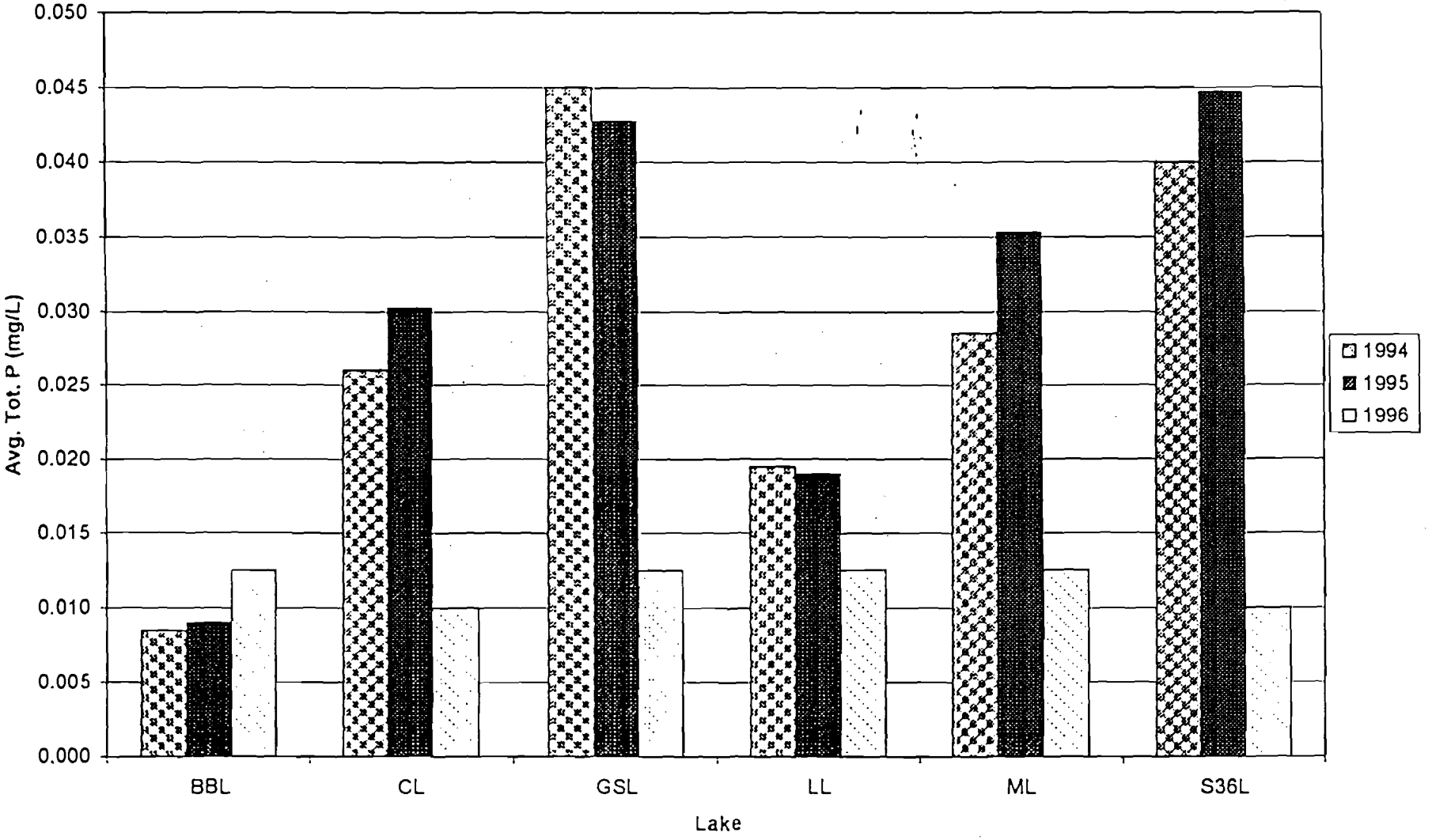


Figure 27. Mosquito River

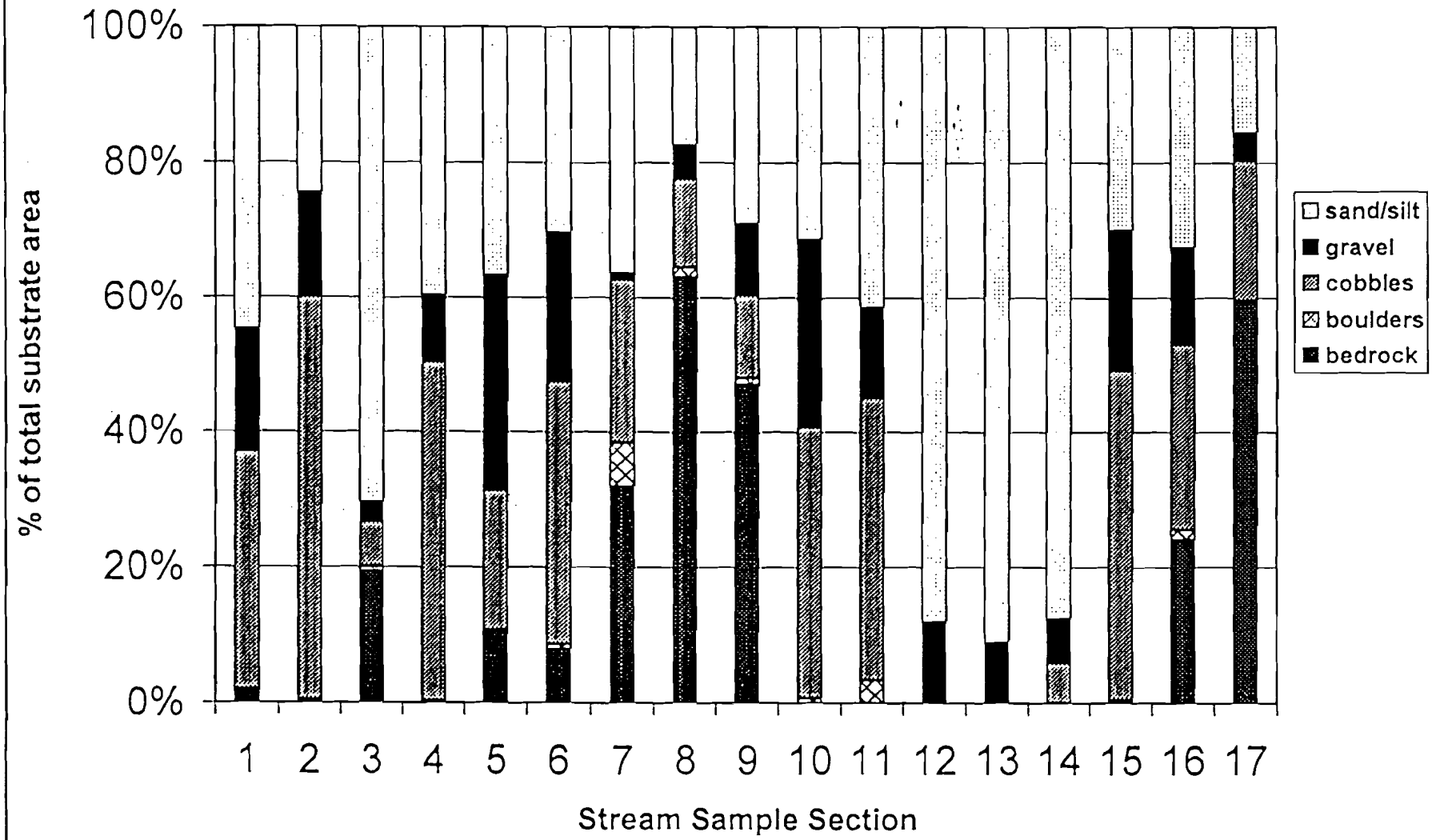


Figure 28. Miners River

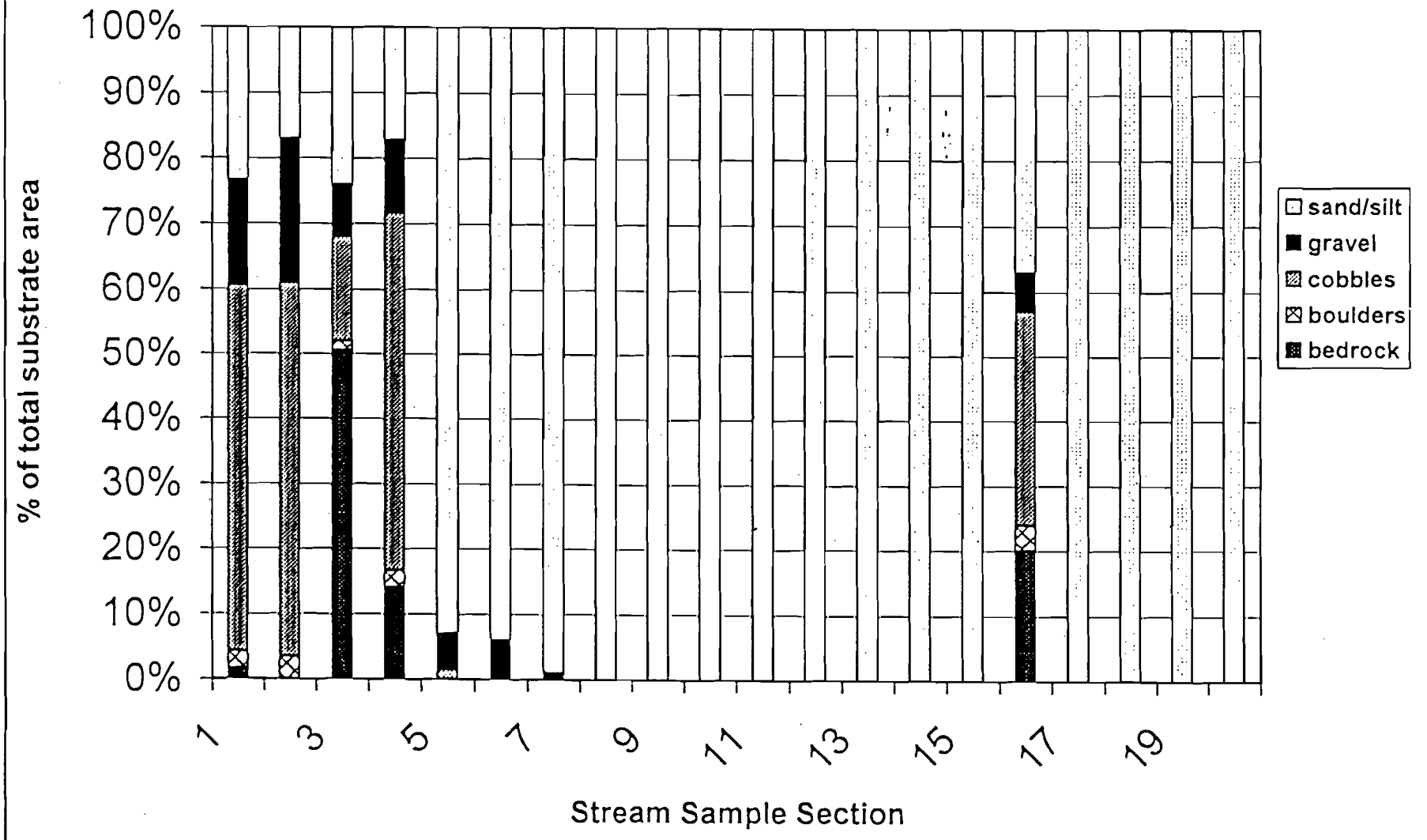
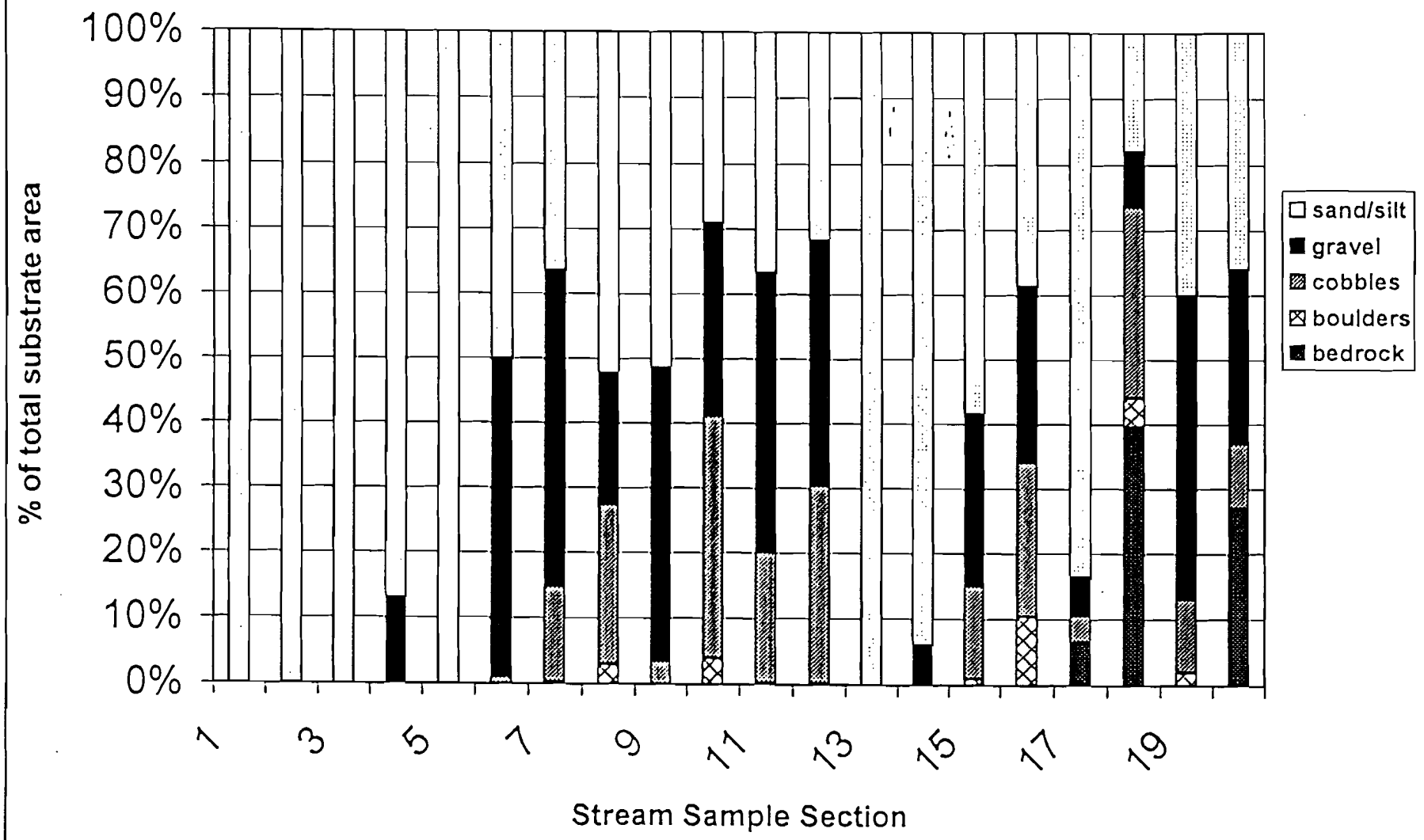


Figure 29. Hurricane River



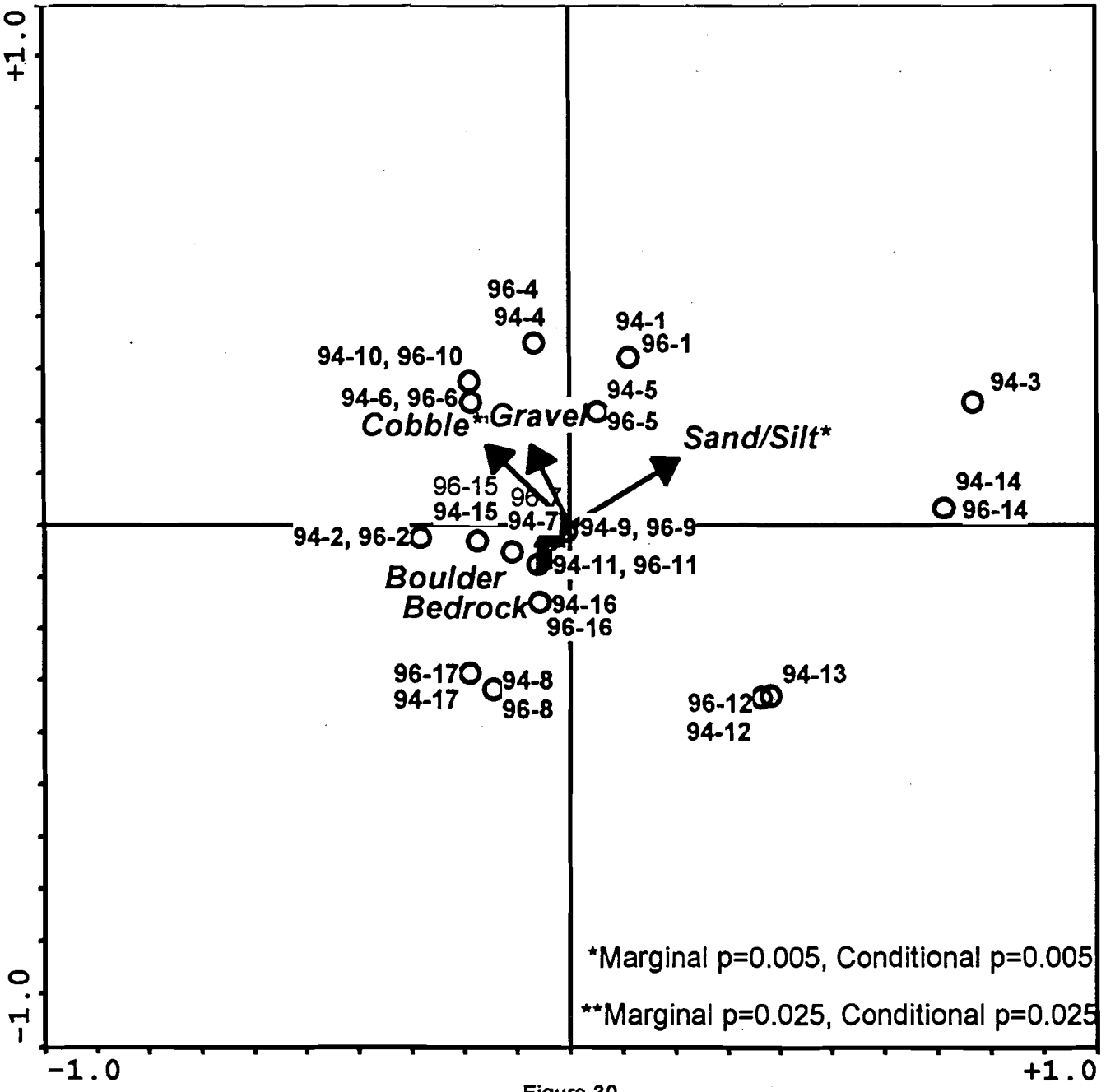


Figure 30.

CCA of Mosquito River Invertebrate Data (94&96) by Substrate Size Class for each Section Sampled

Table 4.
Summary of CCA for 1994 and 1996 Mosquito River Data.

Marginal Effects

Variable	Var.N	Lambda1	p-value
sand.sil	5	0.24	.0050
cobbles	3	0.20	.0250
gravel	4	0.13	.1550
bedrock	1	0.11	.2200
boulders	2	0.06	.7250

Conditional Effects

Variable	Var.N	LambdaA	P	F
sand.sil	5	0.24	0.005	2.69
cobbles	3	0.19	0.025	2.31
bedrock	1	0.10	0.280	1.18
gravel	4	0.05	0.900	0.59
boulders	2	0.05	0.915	0.54

Axes	1	2	3	4	Total inertia
Eigenvalues :	.280	.183	.088	.041	2.877
Species-environment correlations :	.846	.802	.722	.717	
Cumulative percentage variance					
of species data :	9.7	16.1	19.2	20.6	
of species-environment relation:	44.7	73.9	88.0	94.6	

Sum of all unconstrained eigenvalues 2.877
Sum of all canonical eigenvalues .626

Test of significance of first canonical axis: eigenvalue = .280
F-ratio = 2.801
P-value = .0150

Test of significance of all canonical axes : Trace = .626
F-ratio = 1.448
P-value = .0100

Sum of all unconstrained eigenvalues 2.877
Sum of all canonical eigenvalues .626

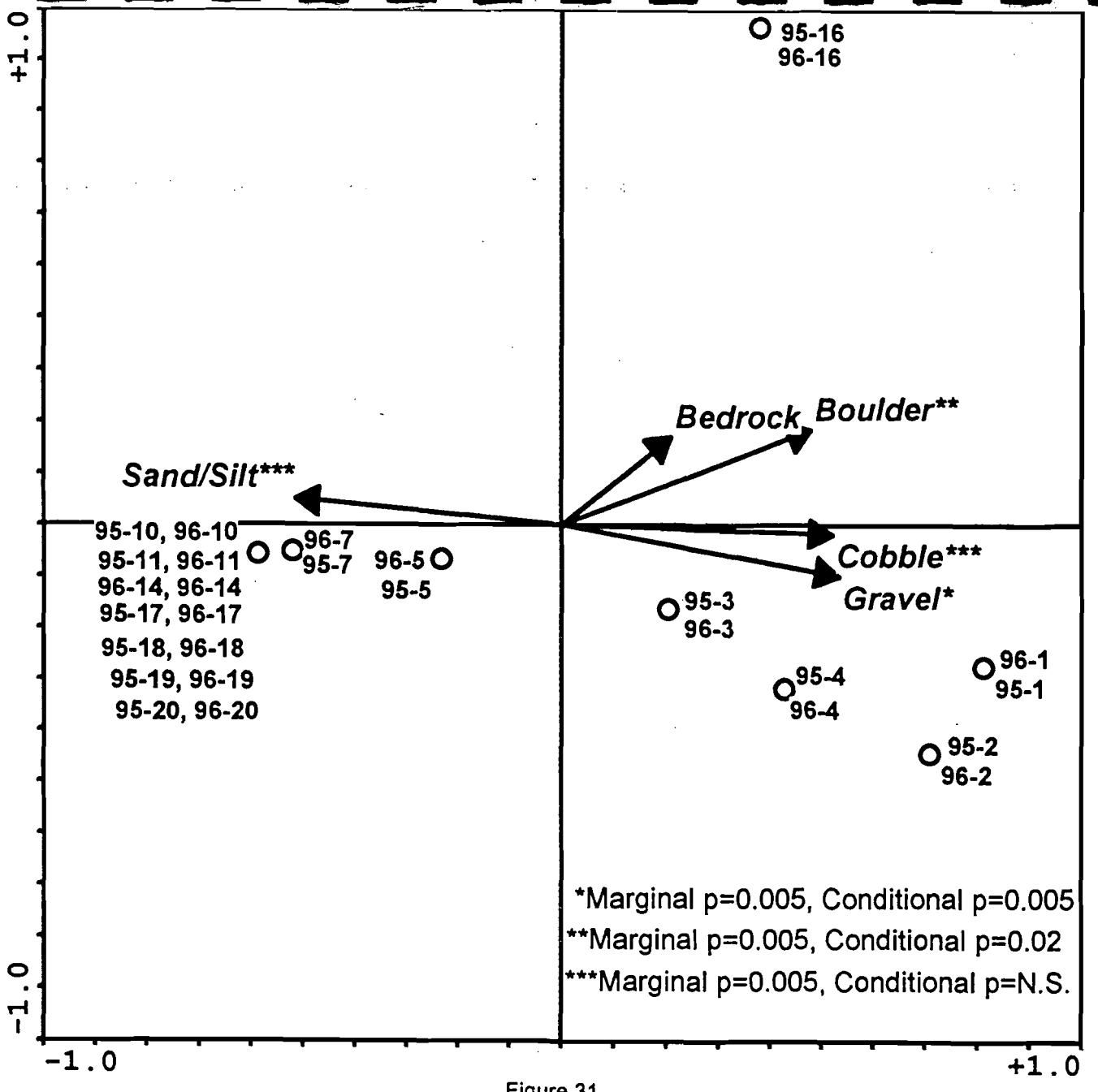


Figure 31.

CCA of Miners River Invertebrate Data (95&96) by Substrate Size Class for each Section Sampled

Table 5.
Summary of CCA for 1995 and 1996 Miners River Data.

Marginal Effects

Variable	Var.N	Lambda1	p-value
gravel	4	0.46	.0050
cobbles	3	0.43	.0050
sand.sil	5	0.43	.0050
boulders	2	0.41	.0050
bedrock	1	0.17	.1450

Conditional Effects

Variable	Var.N	LambdaA	P	F
gravel	4	0.46	0.005	3.74
boulders	2	0.25	0.020	2.12
sand.sil	5	0.10	0.500	0.89
bedrock	1	0.08	0.800	0.66
cobbles	3	0.07	0.855	0.57

Axes	1	2	3	4	Total inertia
Eigenvalues :	.483	.252	.114	.062	3.650
Species-environment correlations :	.949	.918	.885	.535	
Cumulative percentage variance					
of species data :	13.2	20.1	23.3	25.0	
of species-environment relation:	50.2	76.4	88.2	94.7	

Sum of all unconstrained eigenvalues 3.650
Sum of all canonical eigenvalues .962

Test of significance of first canonical axis: eigenvalue = .483
F-ratio = 3.353
P-value = .0150

Test of significance of all canonical axes : Trace = .962
F-ratio = 1.575
P-value = .0250

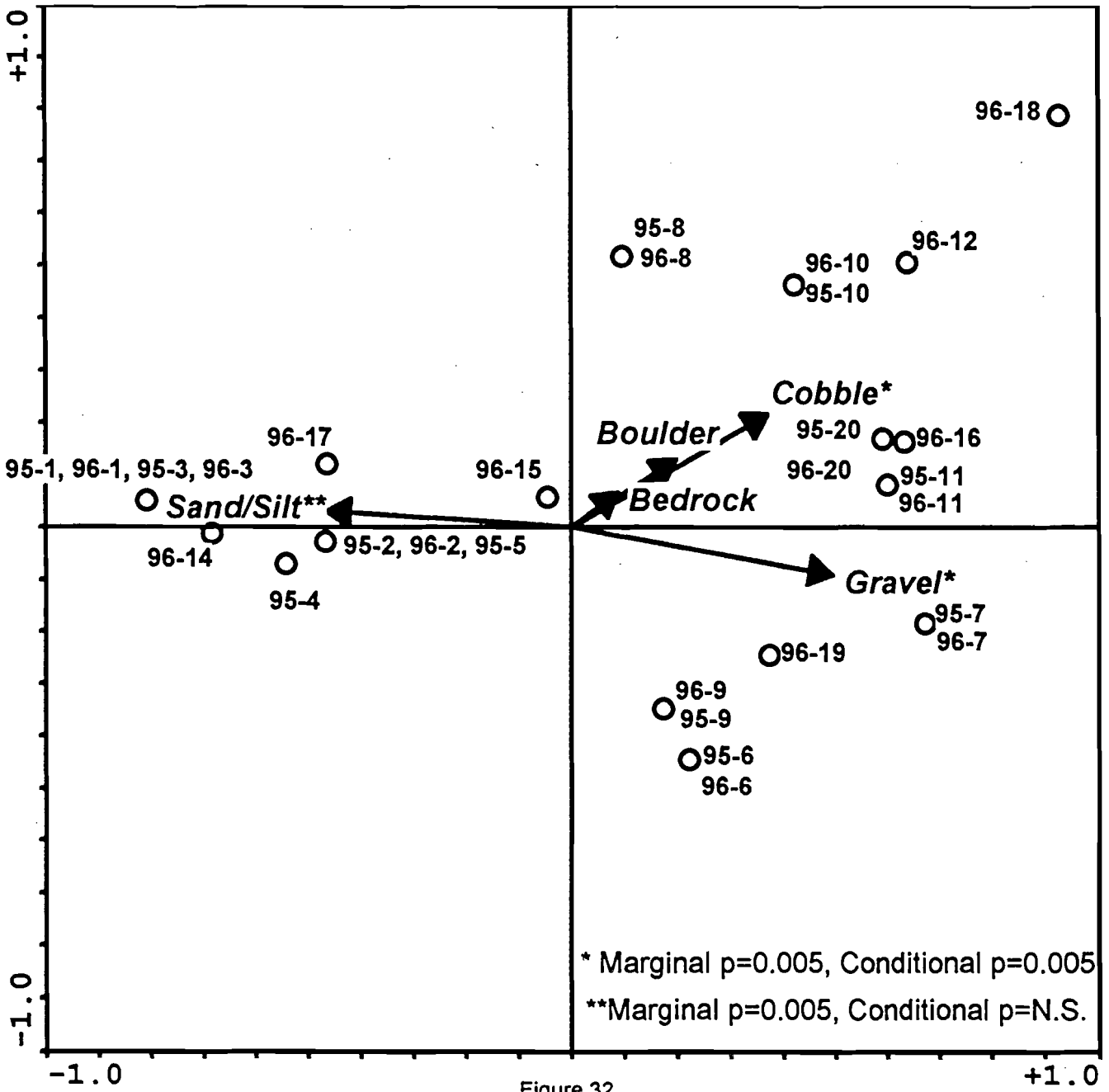


Figure 32.

CCA of Hurricane River Invertebrate Data (95&96) by Substrate Size Class for each Section Sampled

Table 6.
Summary of CCA for 1995 and 1996 Hurricane River Data

Marginal Effects

Variable	Var.N	Lambda1	p-value
gravel	4	0.52	.0050
sand.sil	5	0.45	.0050
cobbles	3	0.38	.0050
boulders	2	0.14	.1800
bedrock	1	0.08	.5850

Conditional Effects

Variable	Var.N	LambdaA	P	F
gravel	4	0.52	0.005	5.97
cobbles	3	0.23	0.005	2.75
sand.sil	5	0.09	0.255	1.14
bedrock	1	0.07	0.415	0.93
boulders	2	0.05	0.745	0.58

Axes	1	2	3	4	Total inertia
Eigenvalues :	.620	.193	.071	.049	2.871
Species-environment correlations :	.892	.717	.702	.786	
Cumulative percentage variance					
of species data :	21.6	28.3	30.8	32.5	
of species-environment relation:	64.4	84.5	91.9	97.0	

Sum of all unconstrained eigenvalues 2.871
Sum of all canonical eigenvalues .963

Test of significance of first canonical axis: eigenvalue = .620
F-ratio = 6.332
P-value = .0050

Test of significance of all canonical axes : Trace = .963
F-ratio = 2.320
P-value = .0050

Figure 33. Total of Invertebrates
Mosquito River, 1994

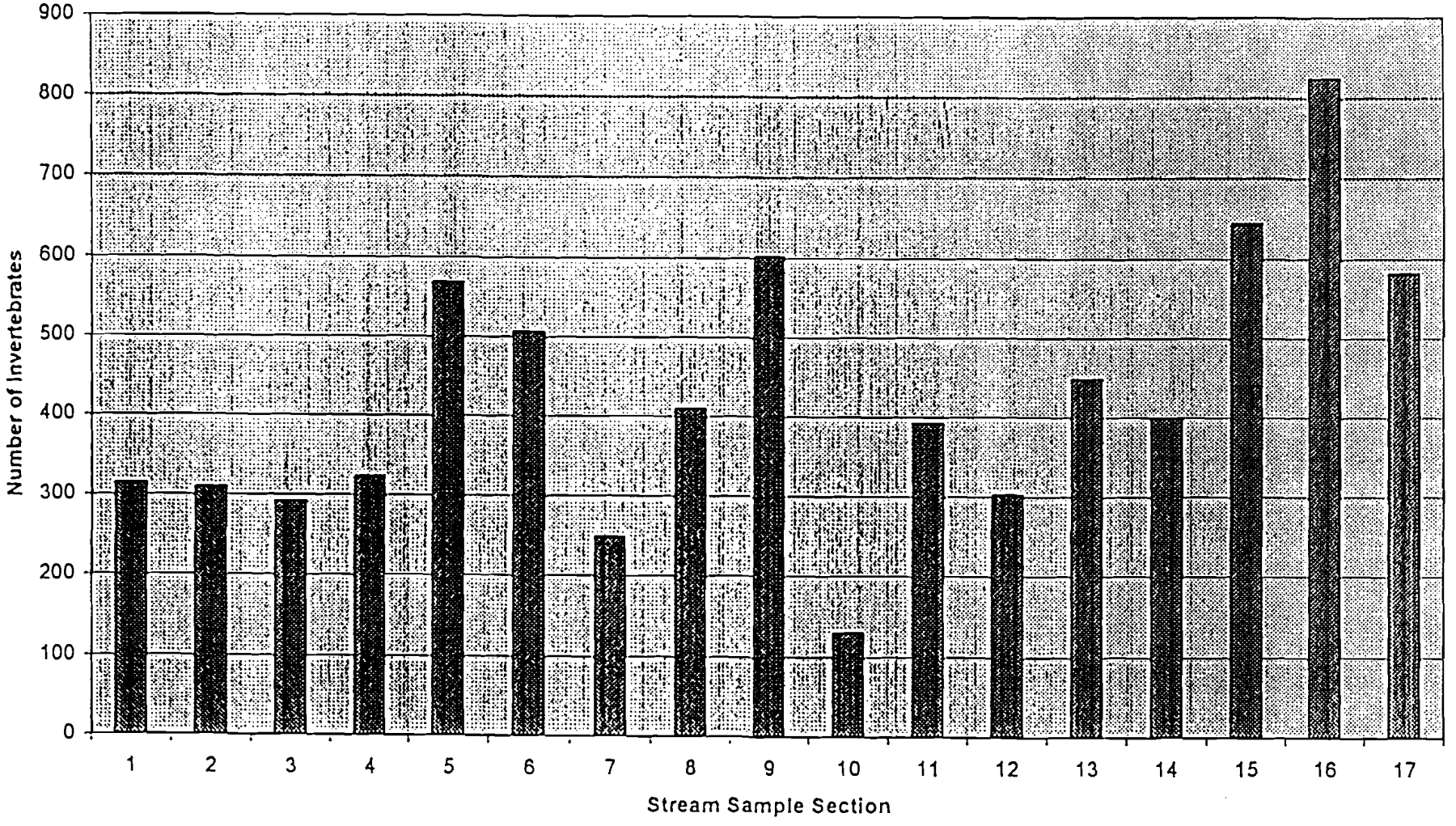


Figure 34. Total of Invertebrates
Mosquito River 1996

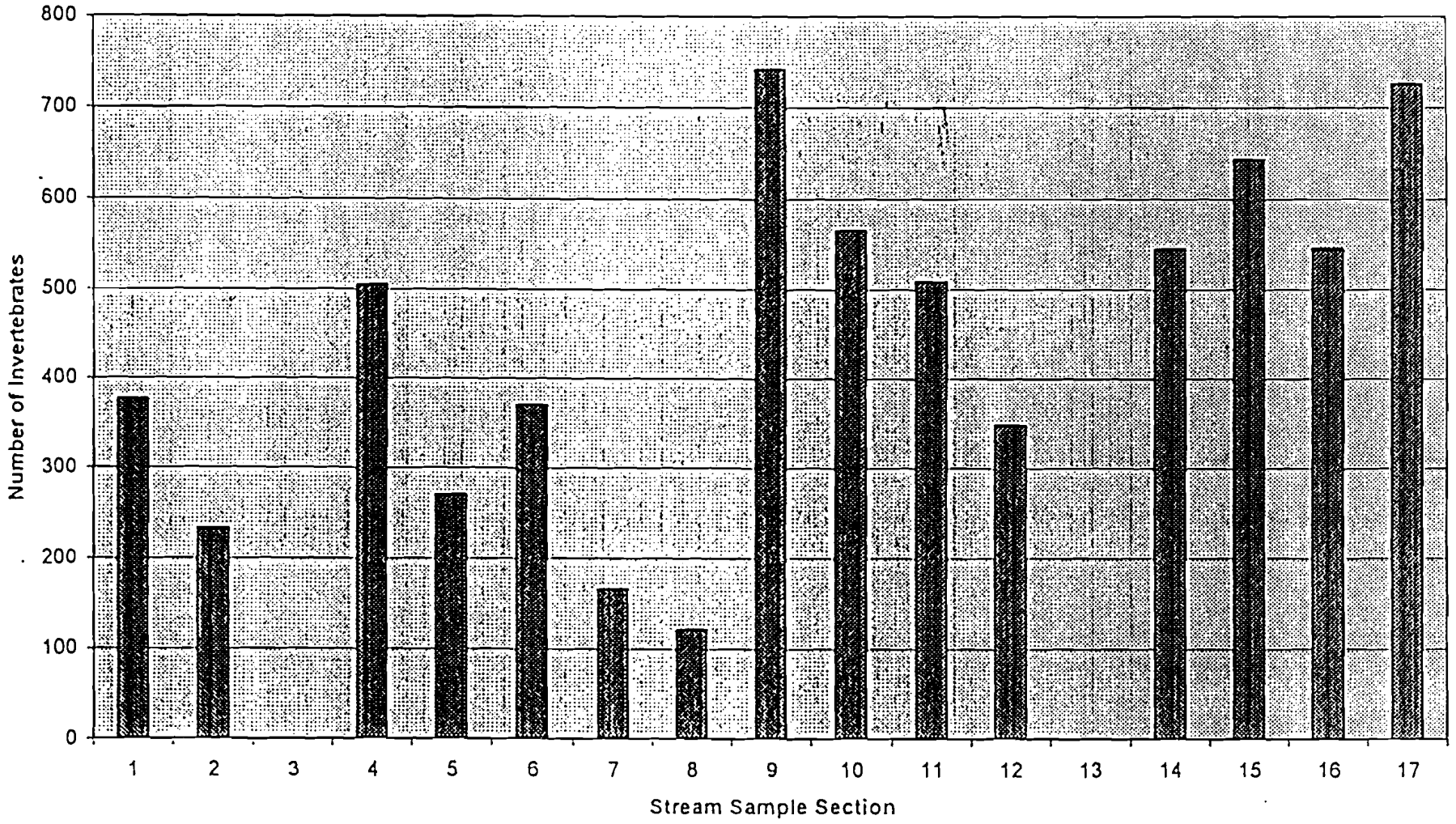


Figure 35. Total of Invertebrates
Miners River, 1995

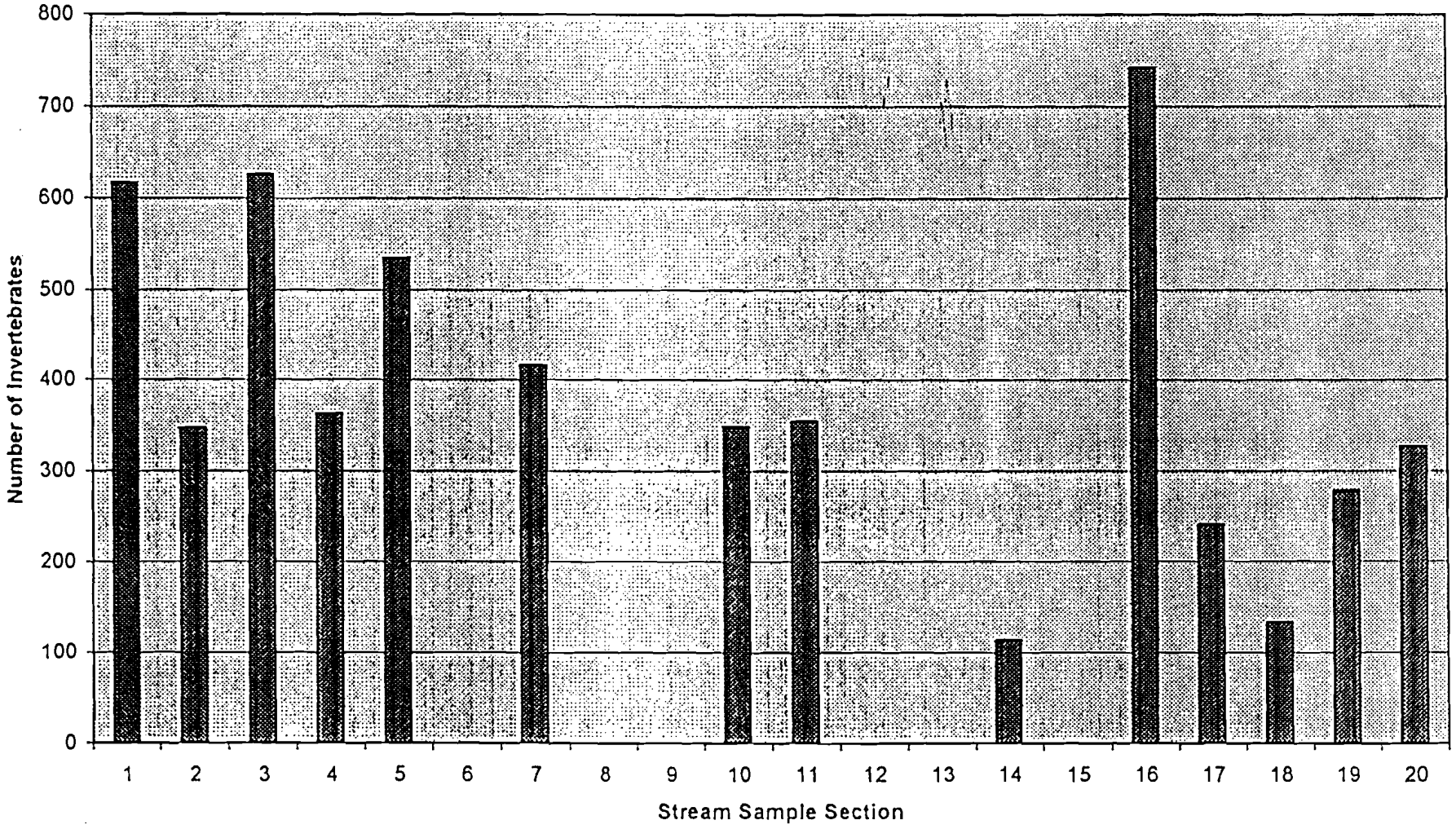


Figure 36. Total of Invertebrates
Miners River, 1996

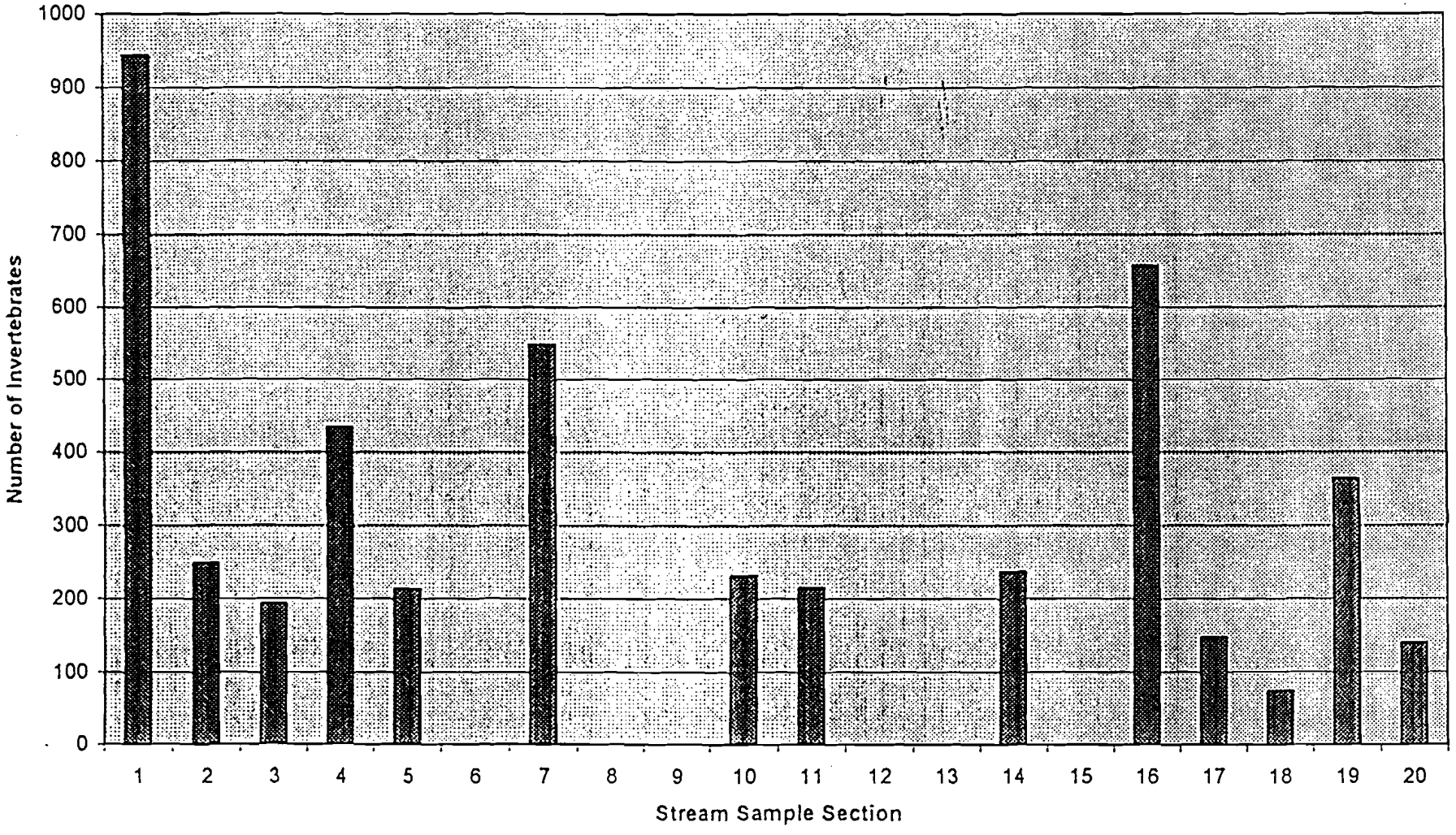


Figure 37. Total of Invertebrates
Hurricane River, 1995

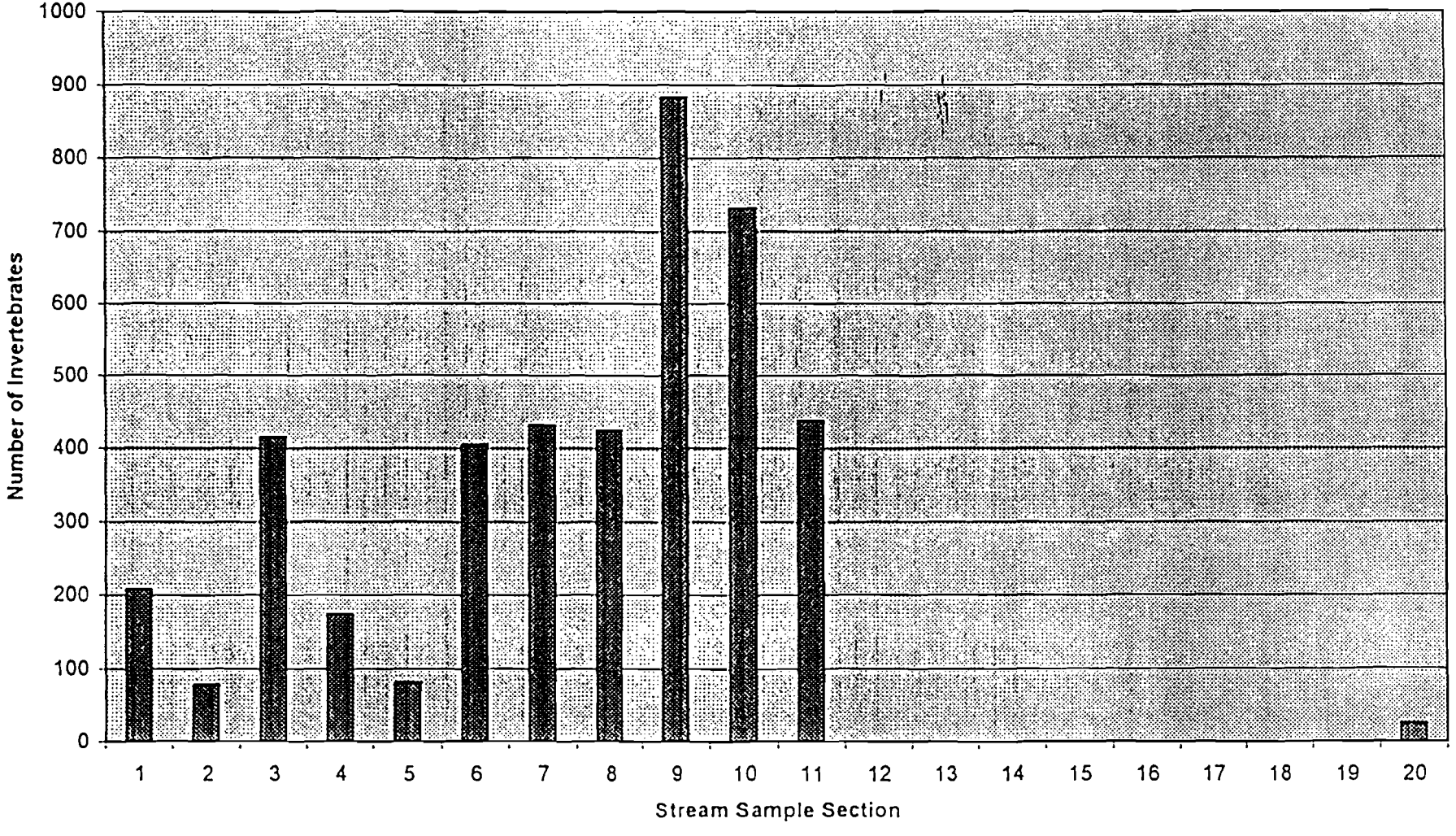


Figure 38. Total of Invertebrates
Hurricane River, 1996

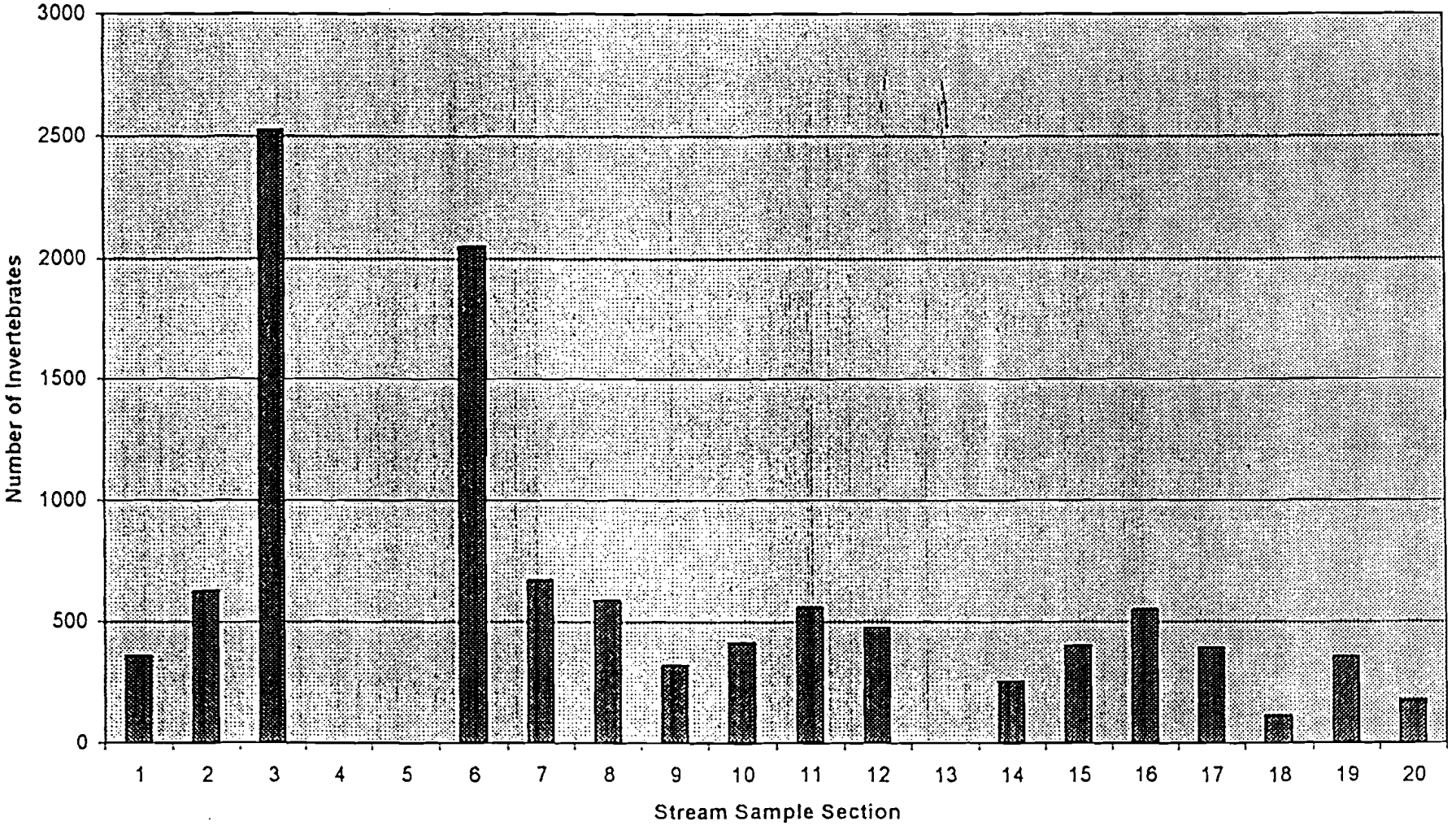


Figure 39. Total of Invertebrates
7 Mile and Sullivan River, 1996

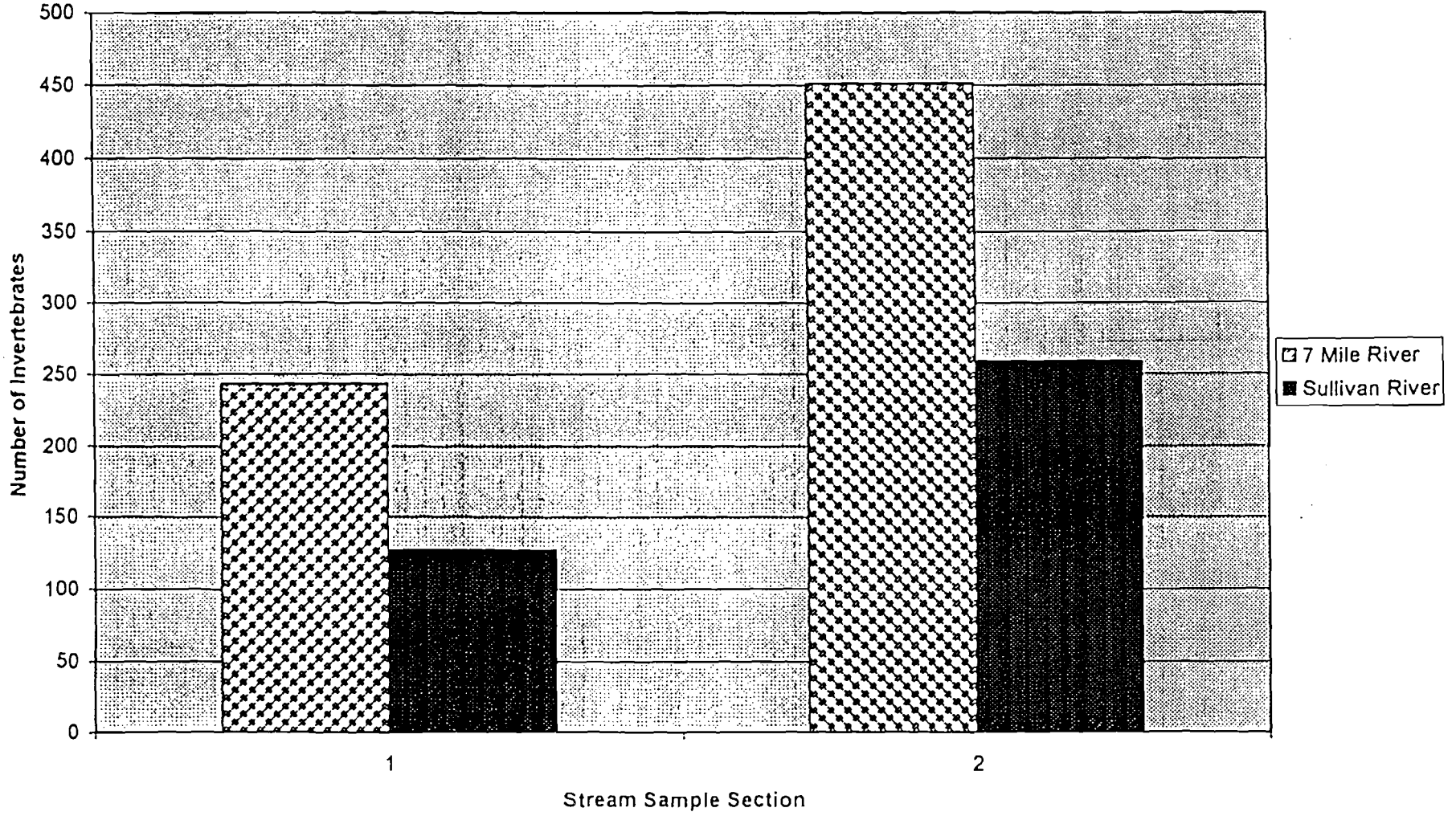


Figure 40. Number of Taxa by Stream Section
Mosquito River, 1994

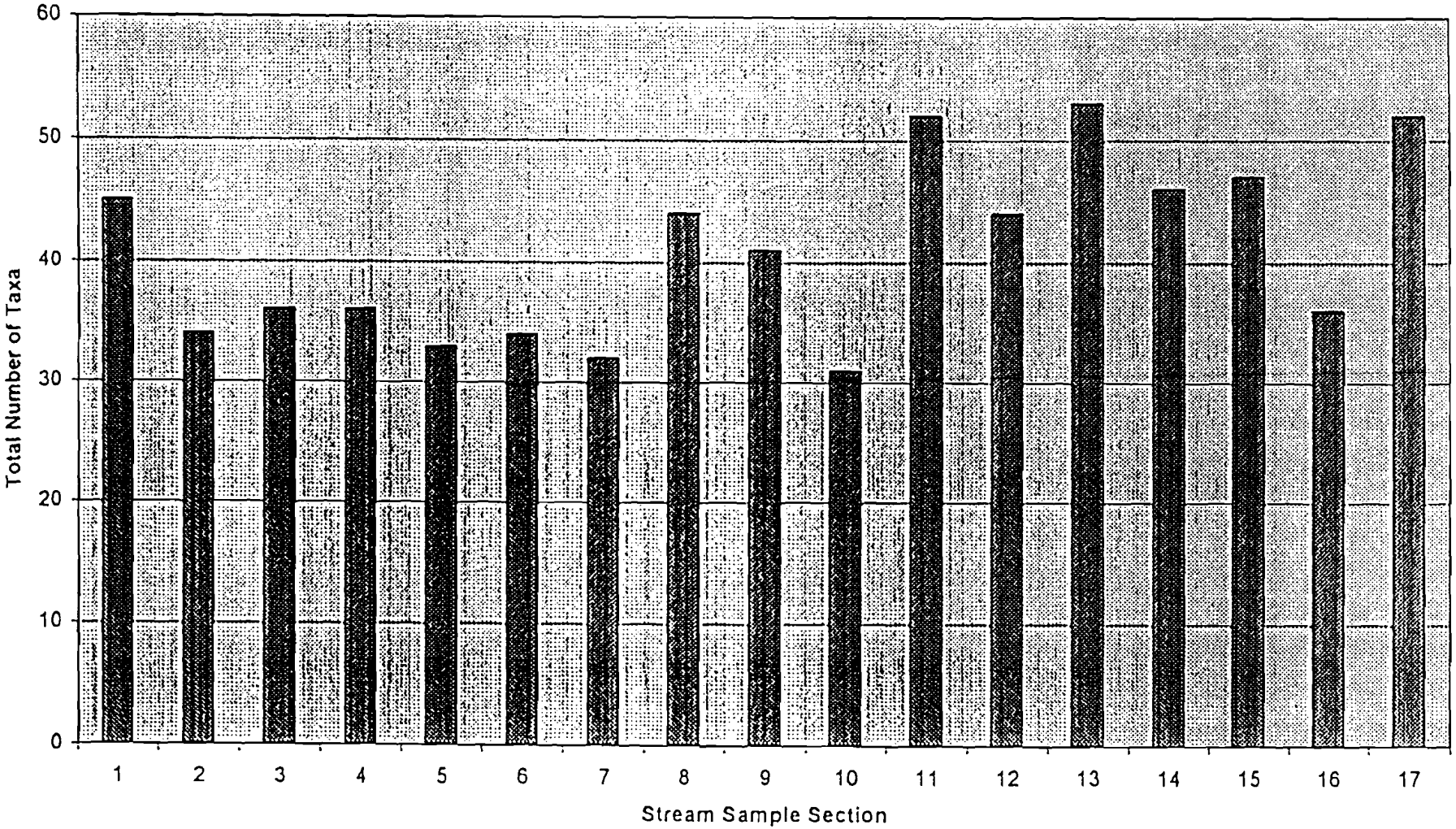


Figure 41. Number of Taxa by Stream Section
Mosquito River, 1996

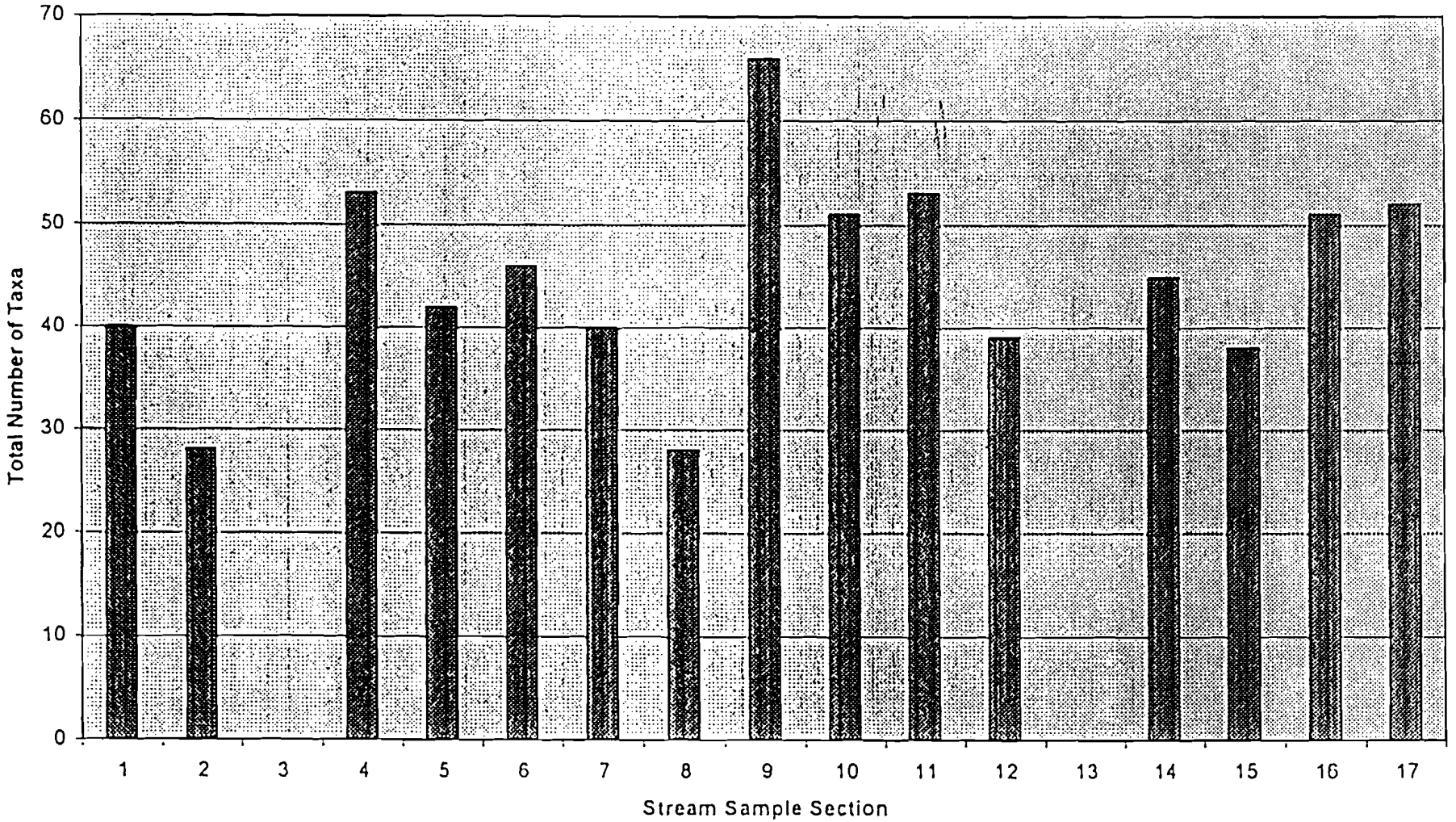


Figure 42. Number of Taxa by Stream Section
Miners River, 1995

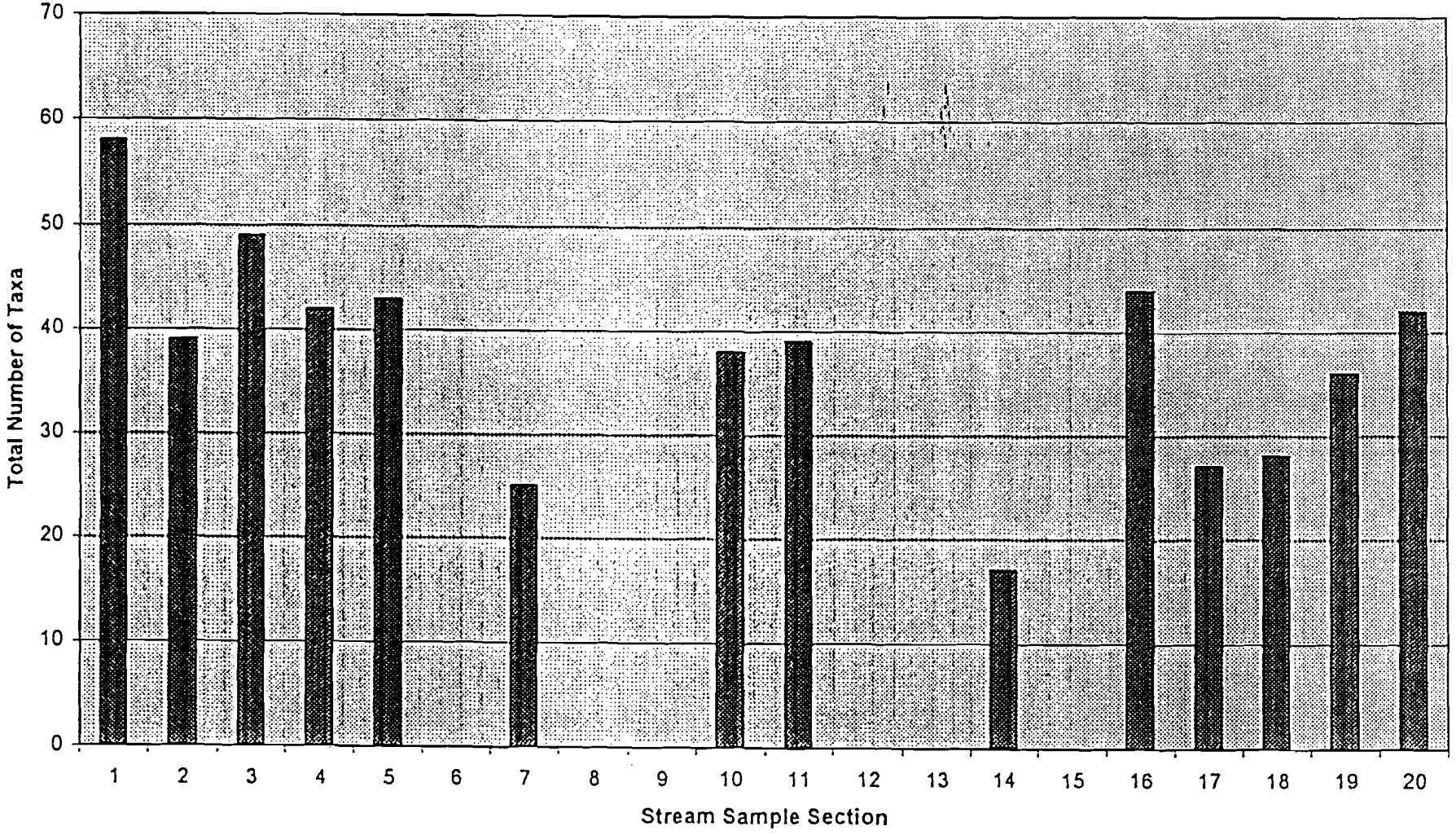


Figure 43. Number of Taxa by Stream Section
Miners River, 1996

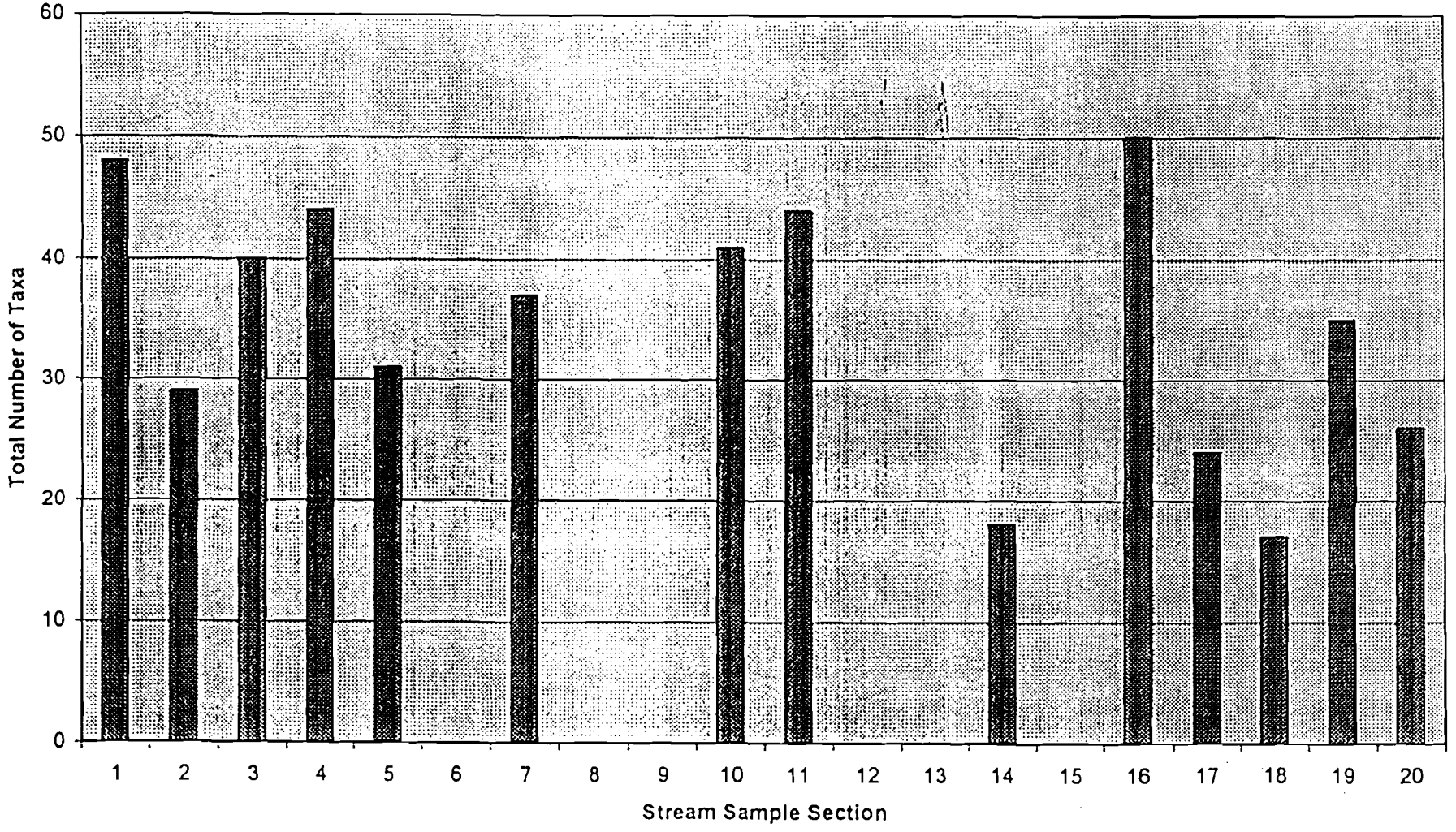


Figure 44. Number of Taxa by Stream Section
Hurricane River, 1995

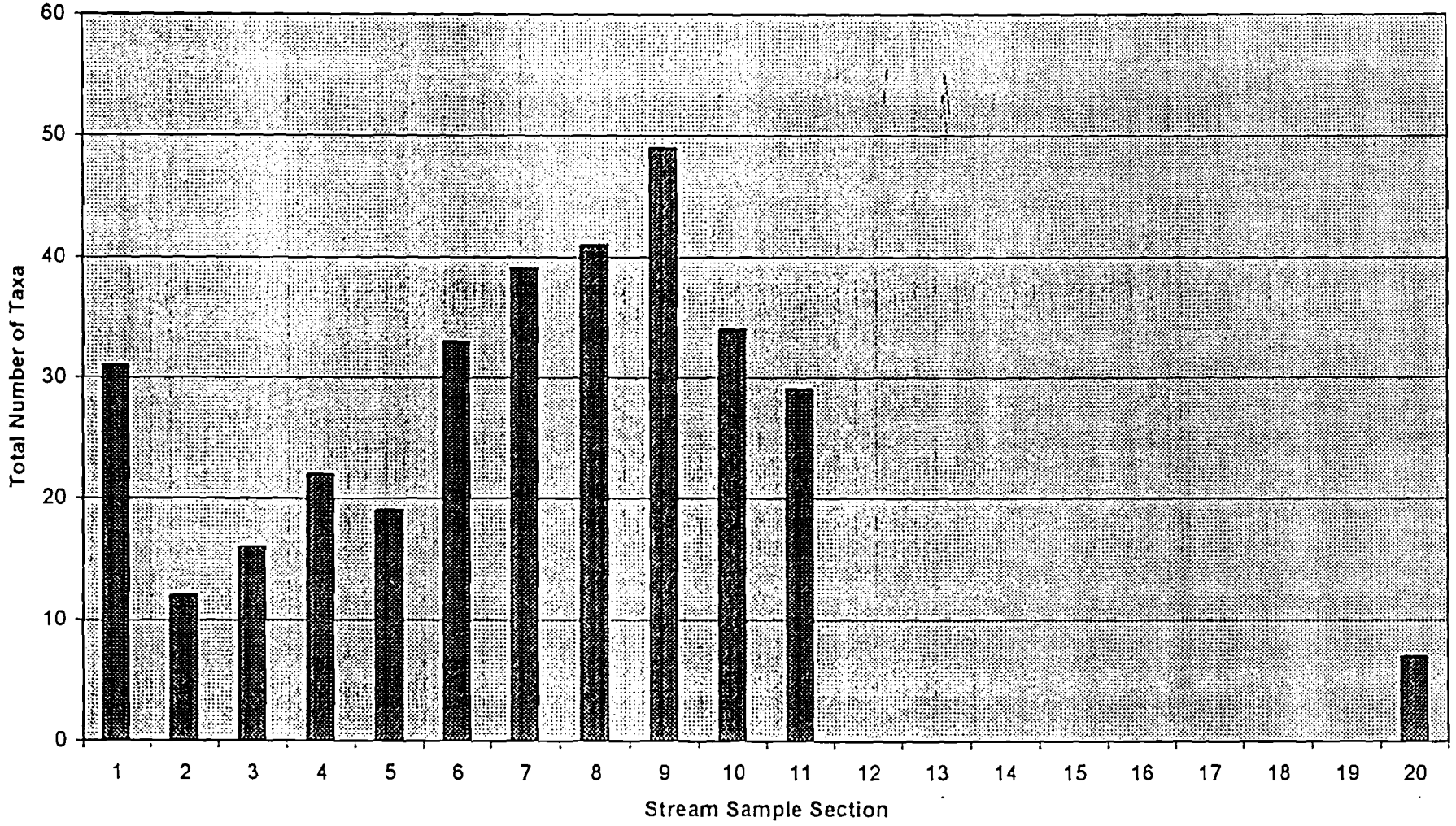


Figure 45 Number of Taxa by Stream Section
Hurricane River, 1996

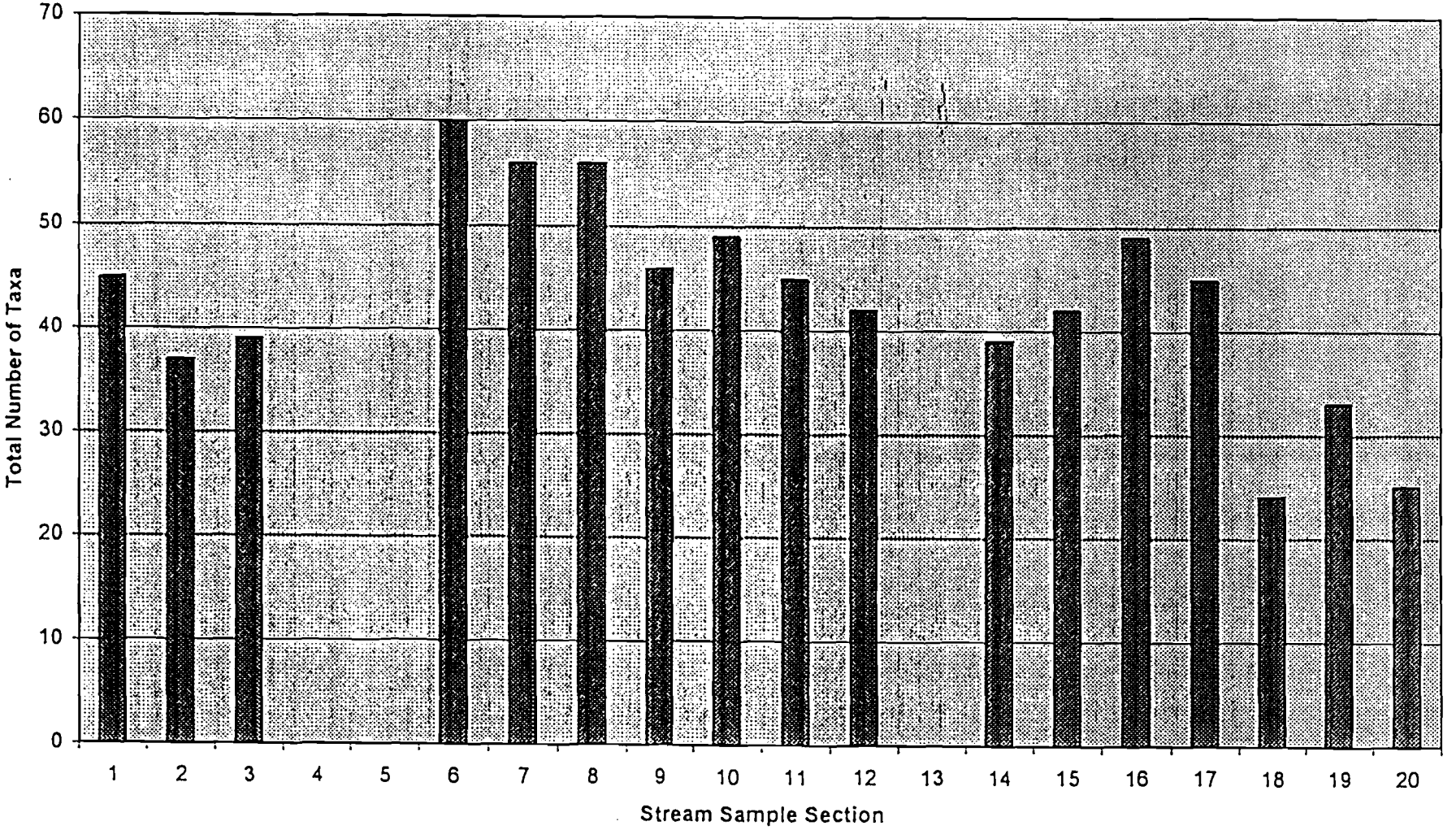


Figure 46. Number of Taxa by Stream Section
7 Mile and Sullivan River, 1996

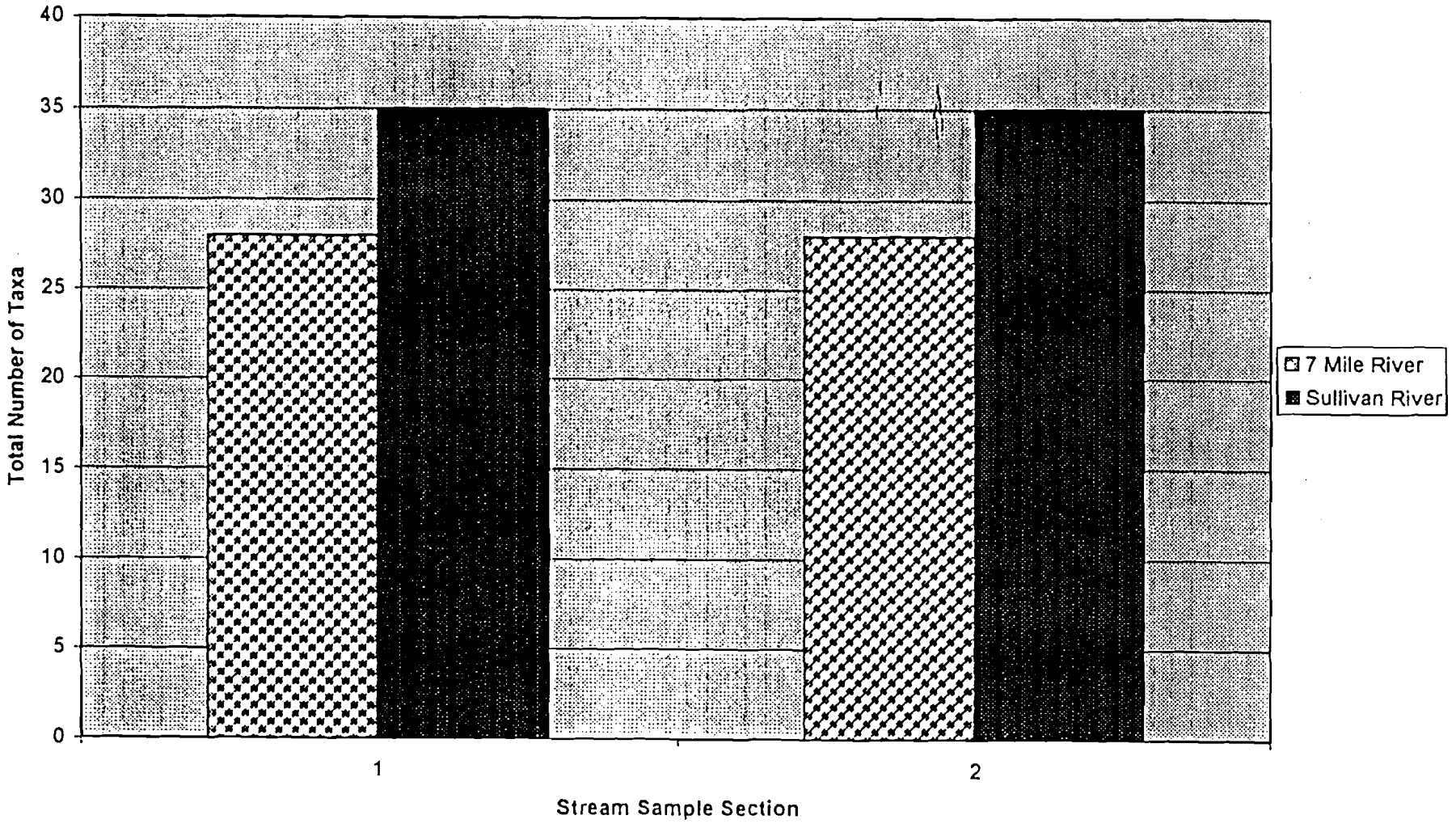


Figure 47. Shannon's H' Diversity
Mosquito River, 1994

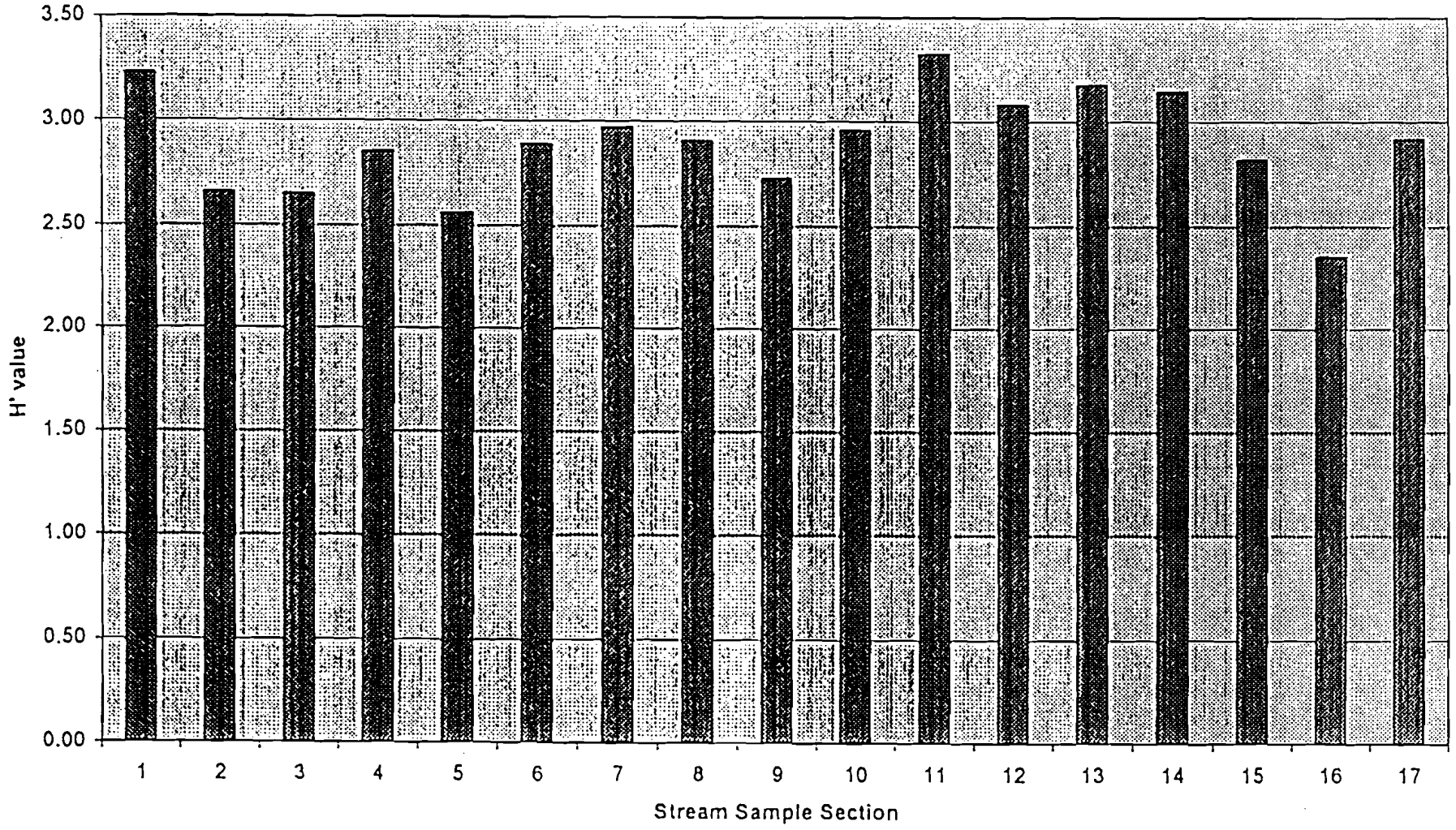


Figure 48. Shannon's H' Diversity
Mosquito River, 1996

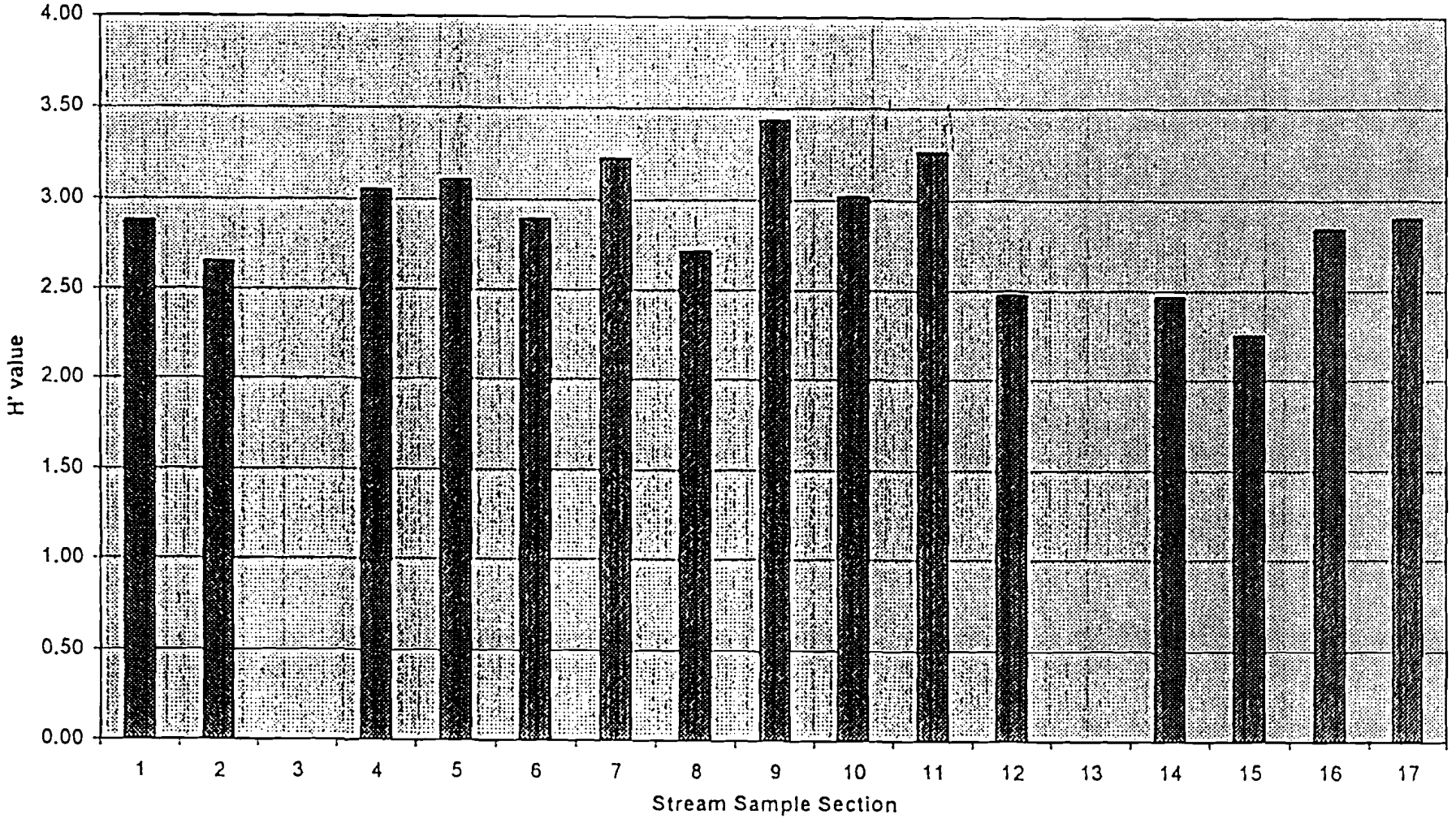


Figure 49. Shannon's H' Diversity
Miners River, 1995

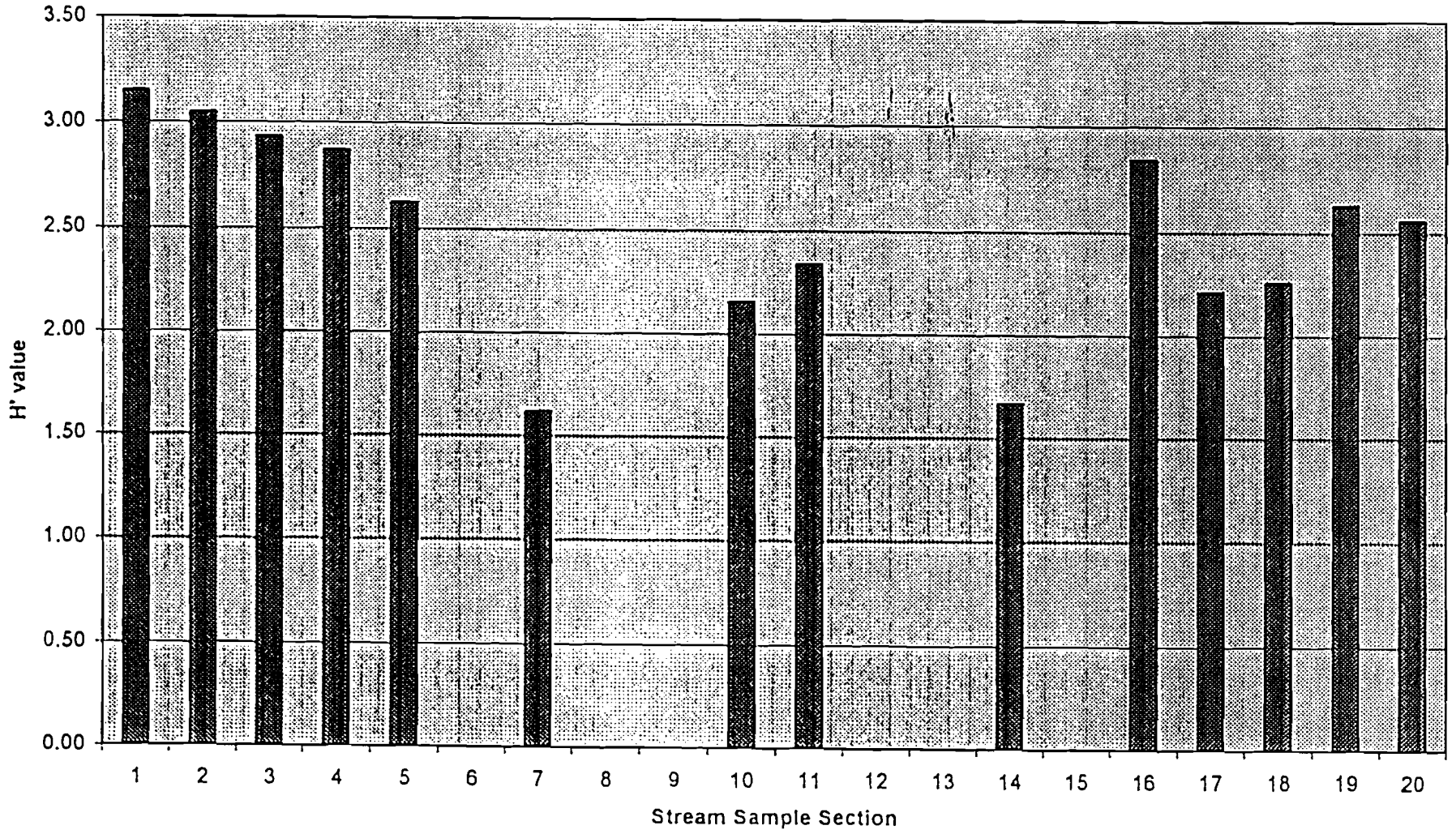


Figure 50. Shannon's H' Diversity
Miners River, 1996

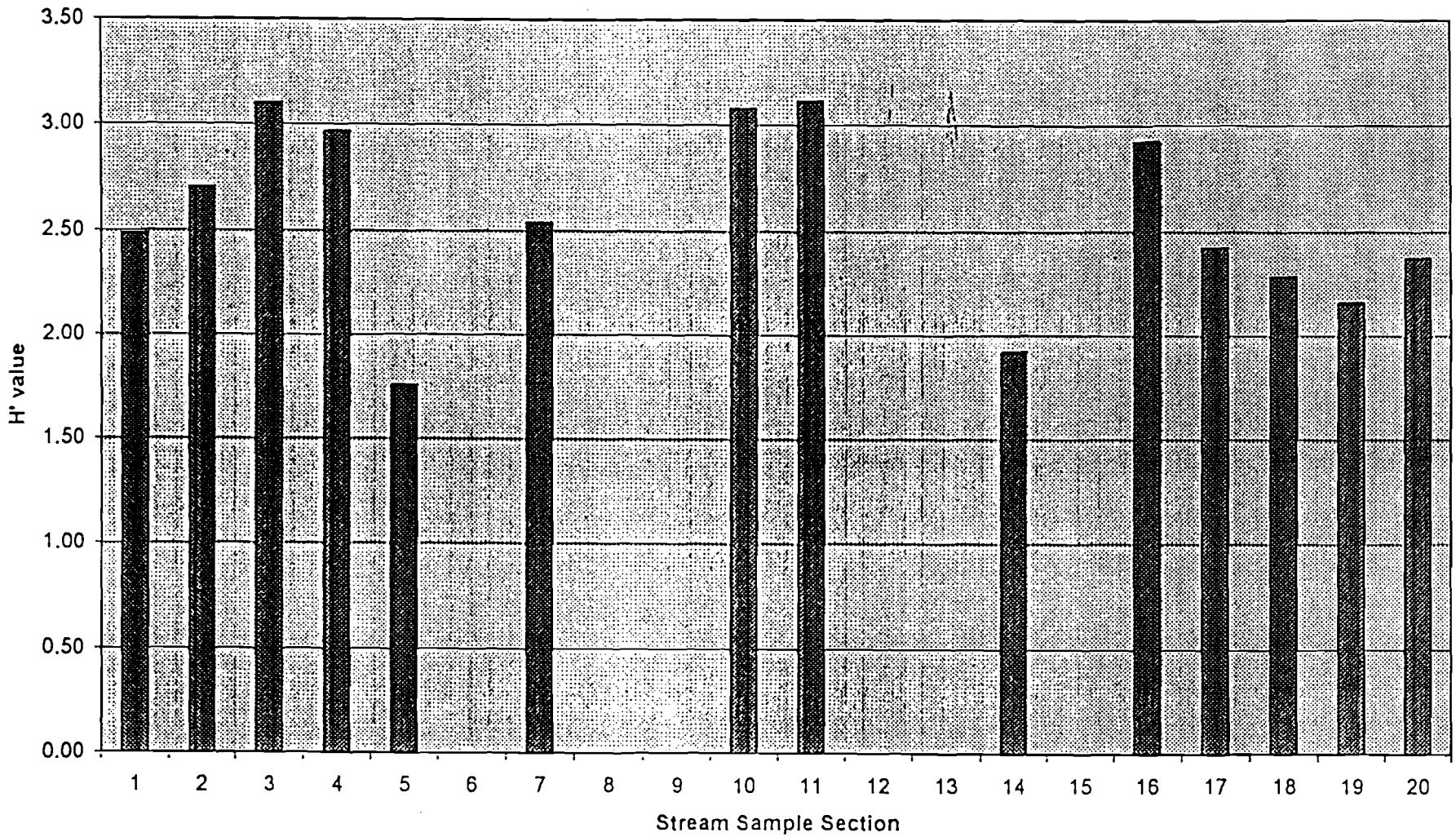


Figure 51. Shannon's H' Diversity
Hurricane River, 1995

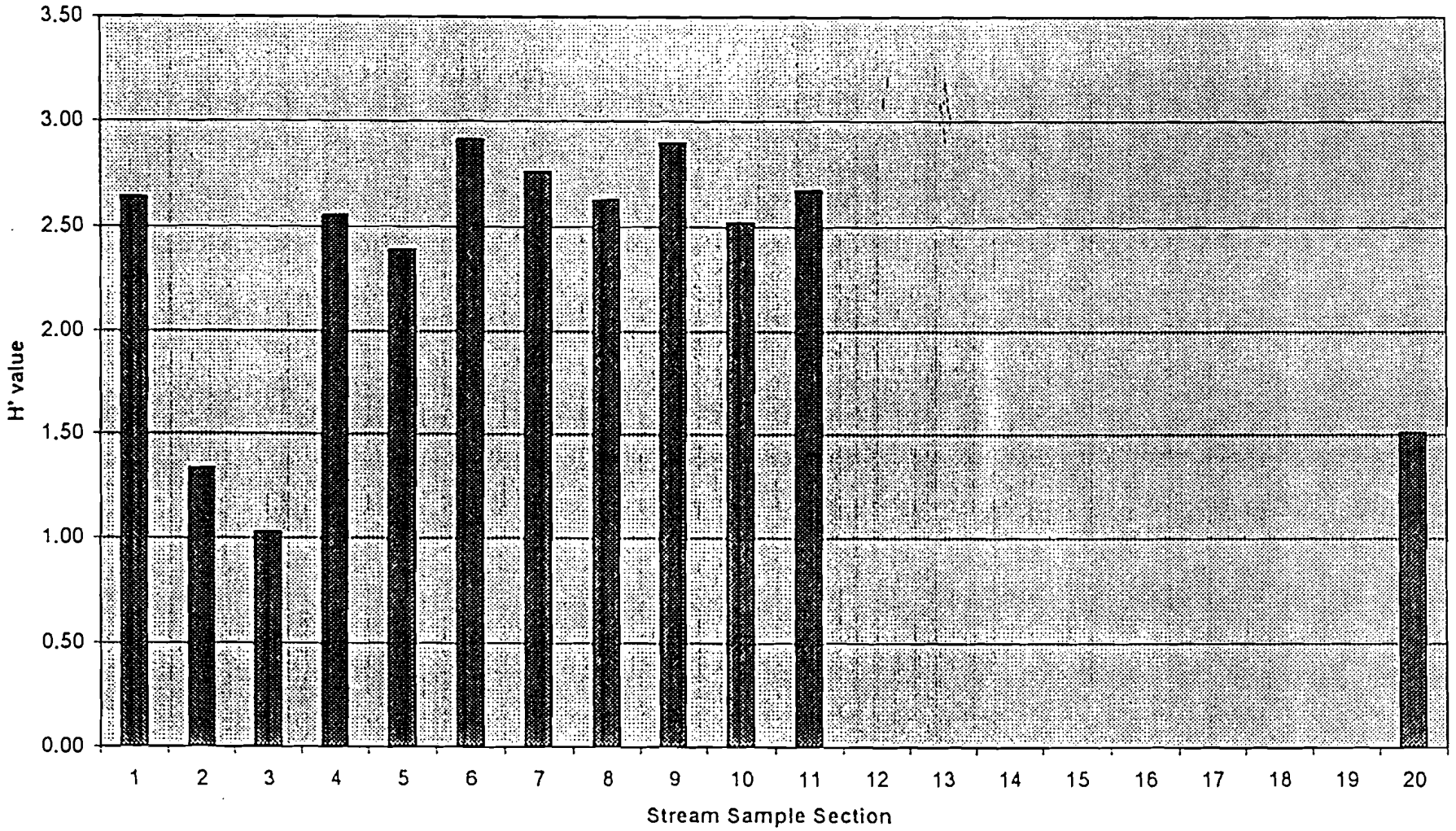
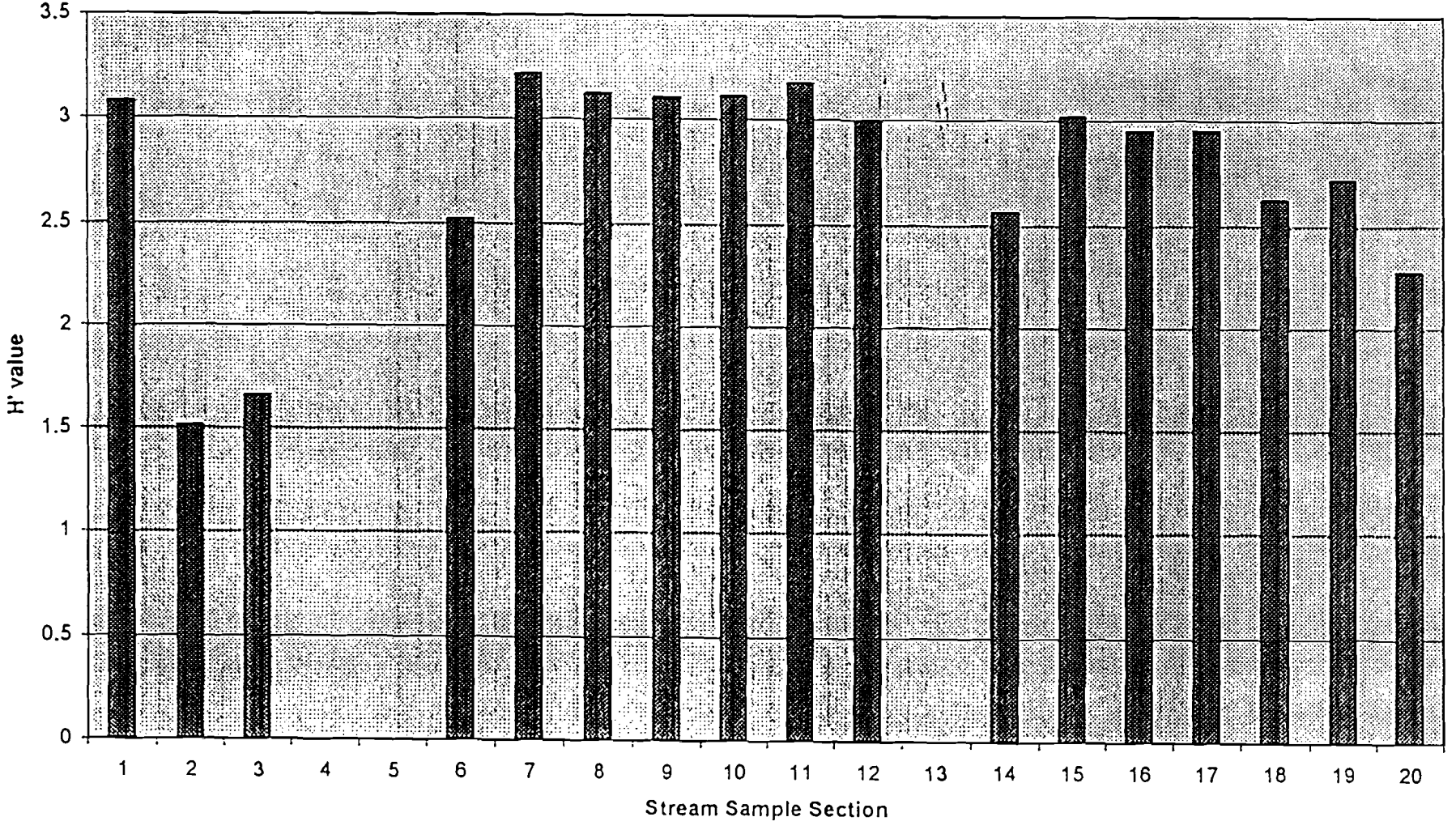


Figure 52. Shannon's H' Diversity
Hurricane River, 1996



Fiugre 53. Shannon's H' Diversity
7 Mile and Sullivan River, 1996

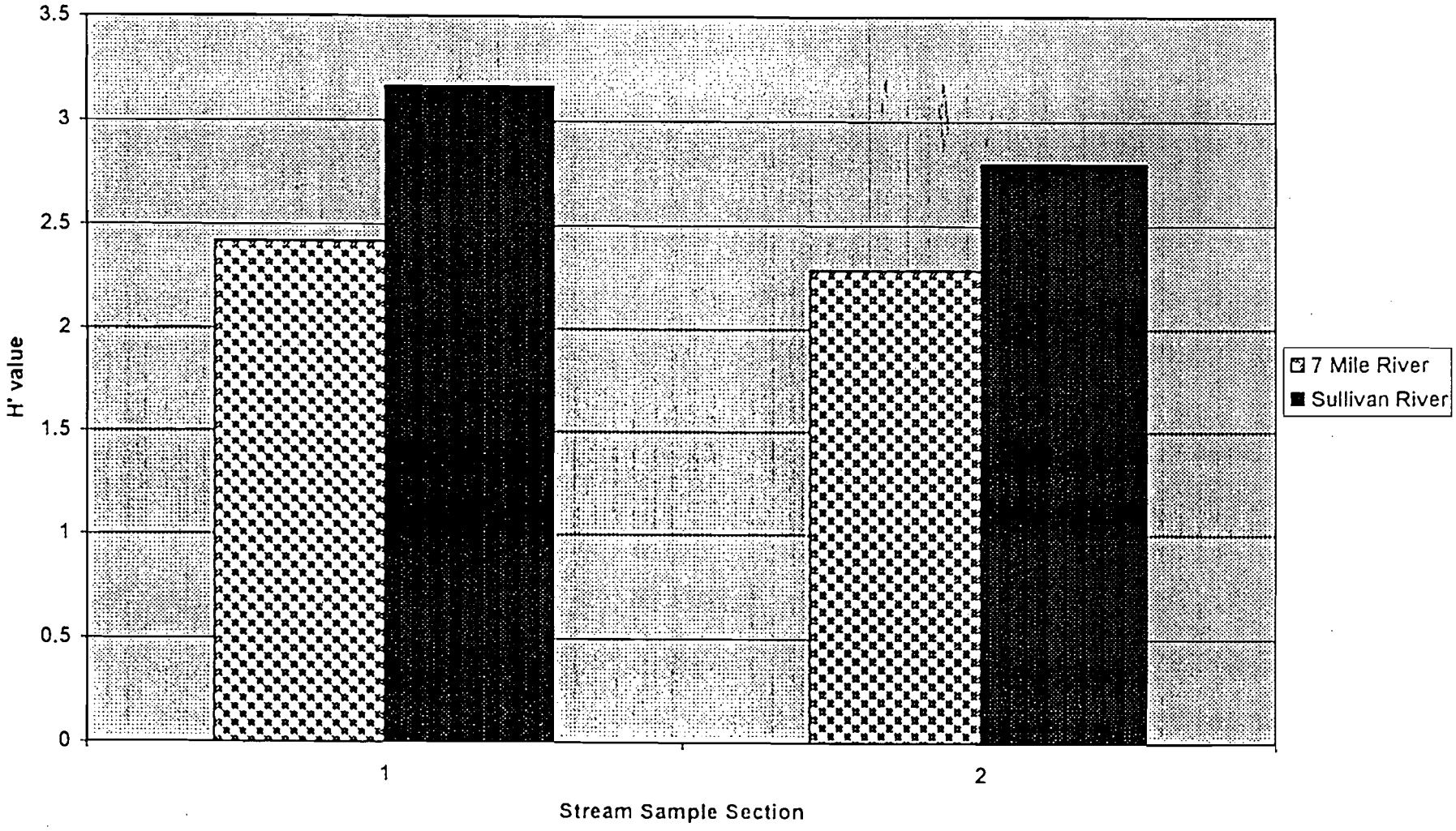


Figure 54. Simpson's D Diversity
Mosquito River, 1994

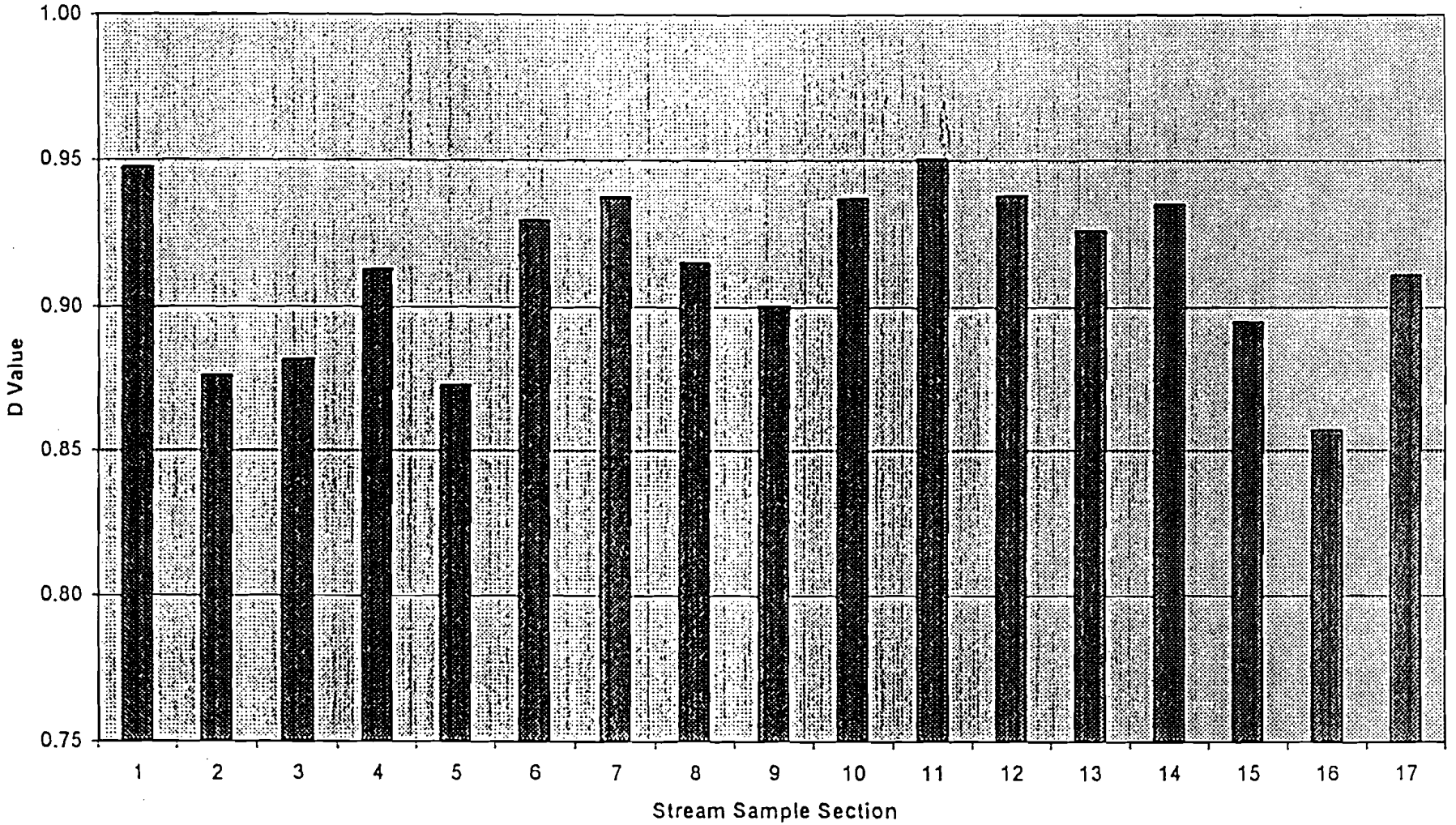


Figure 55. Simpson's D Diversity
Mosquito River, 1996

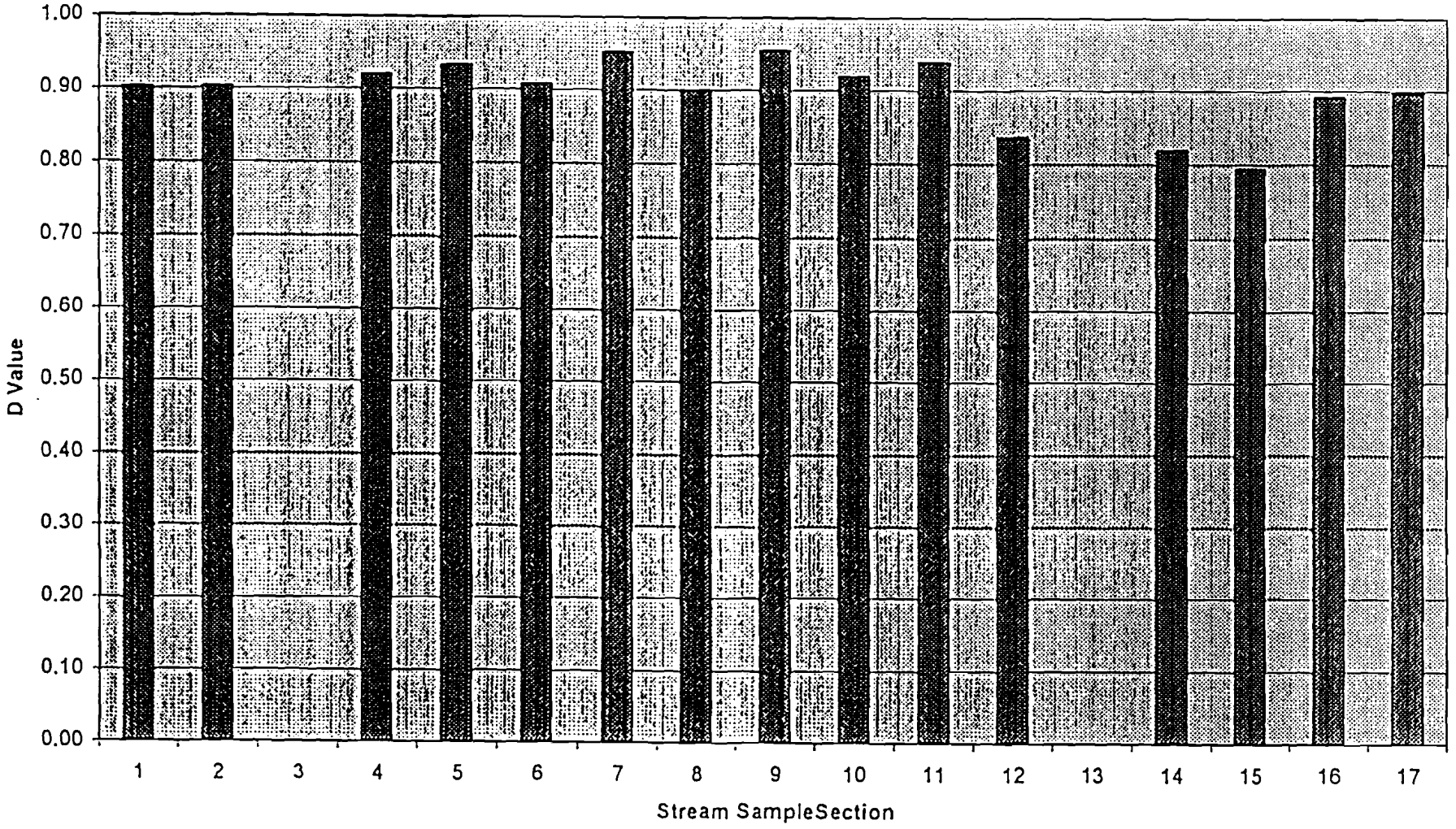


Figure 56. Simpson's D Diversity
Miners River, 1995

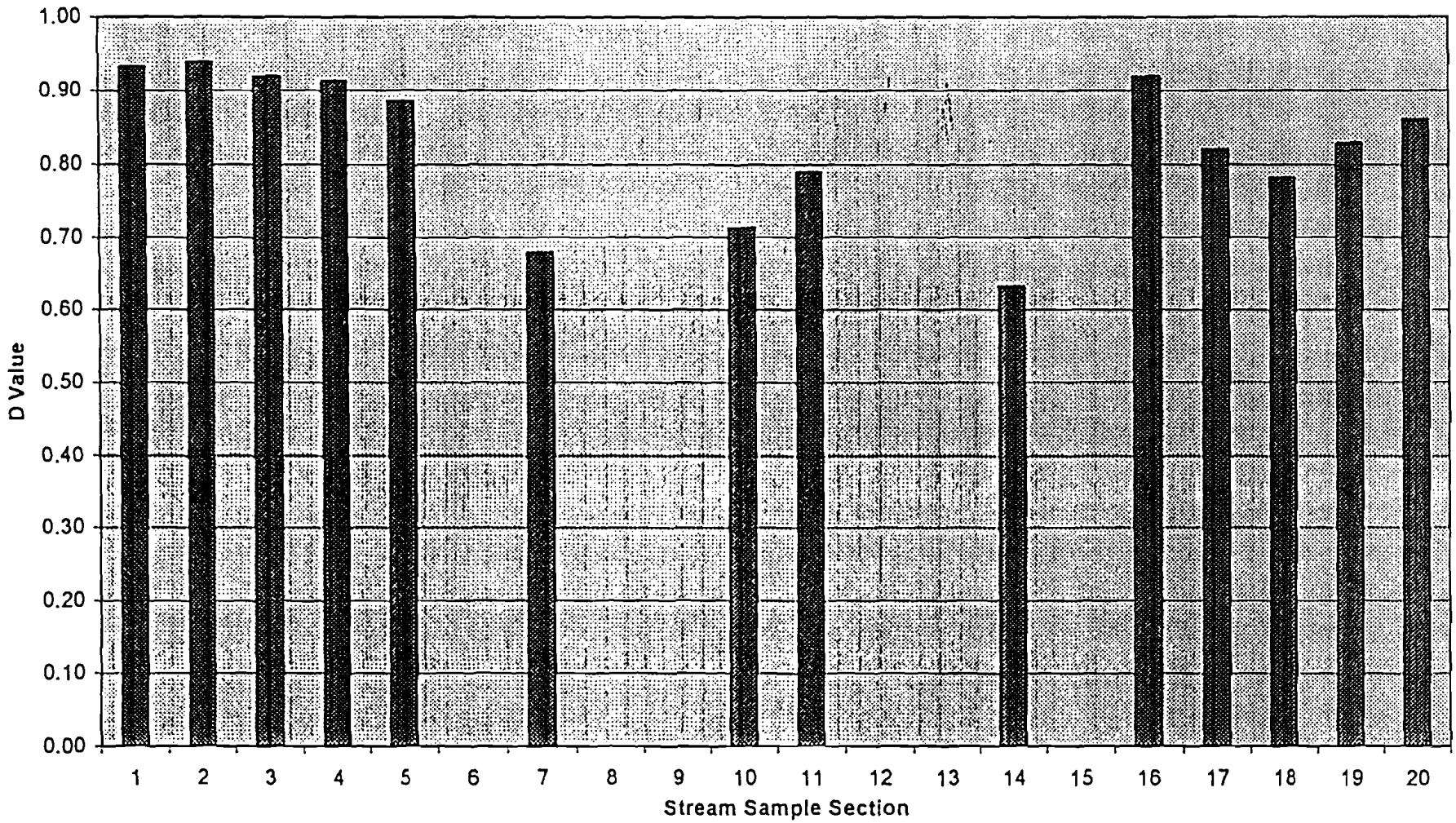


Figure 57. Simpson's D Diversity
Miners River, 1996

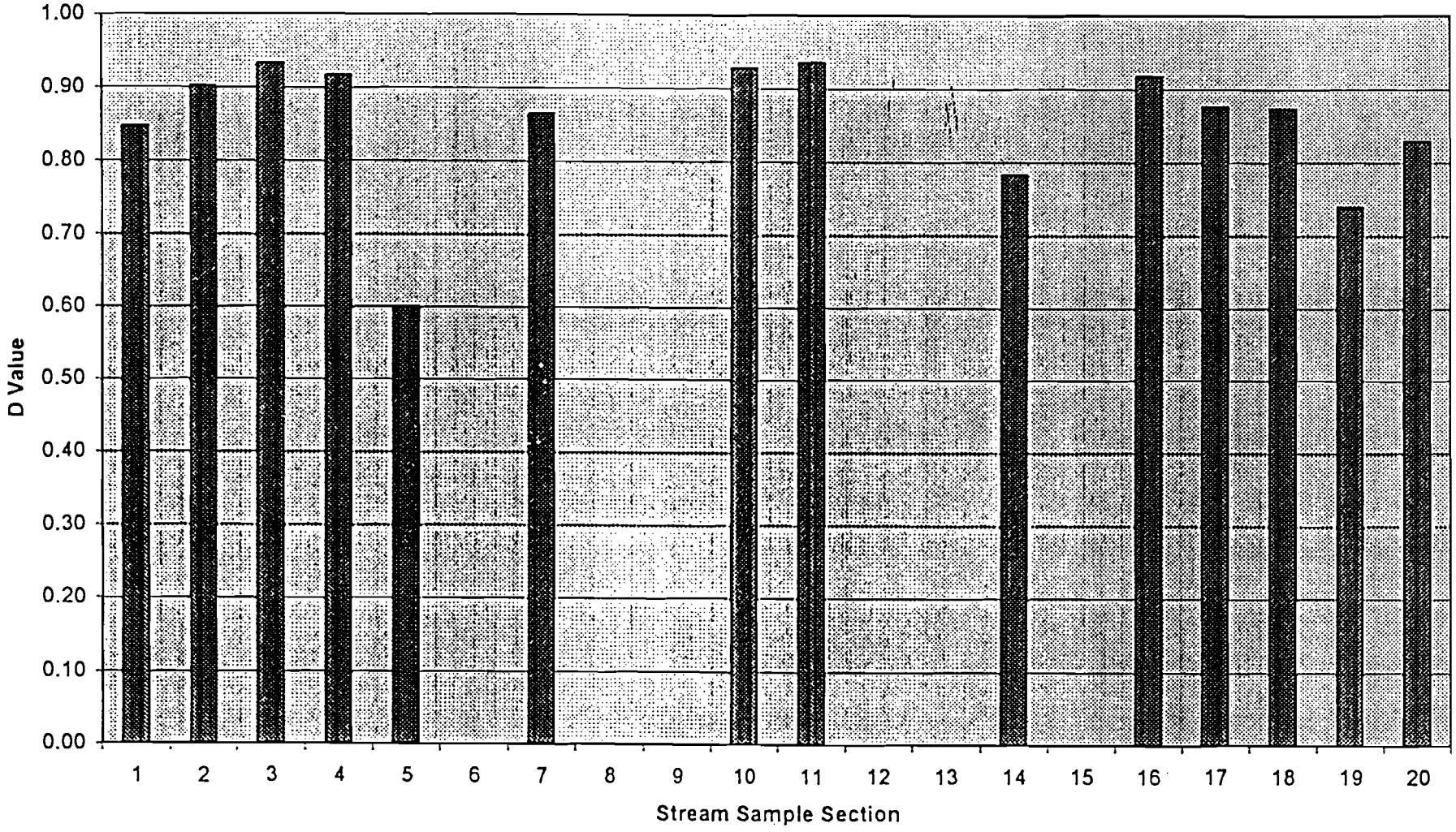


Figure 58. Simpson's D Diversity
Hurricane River, 1995

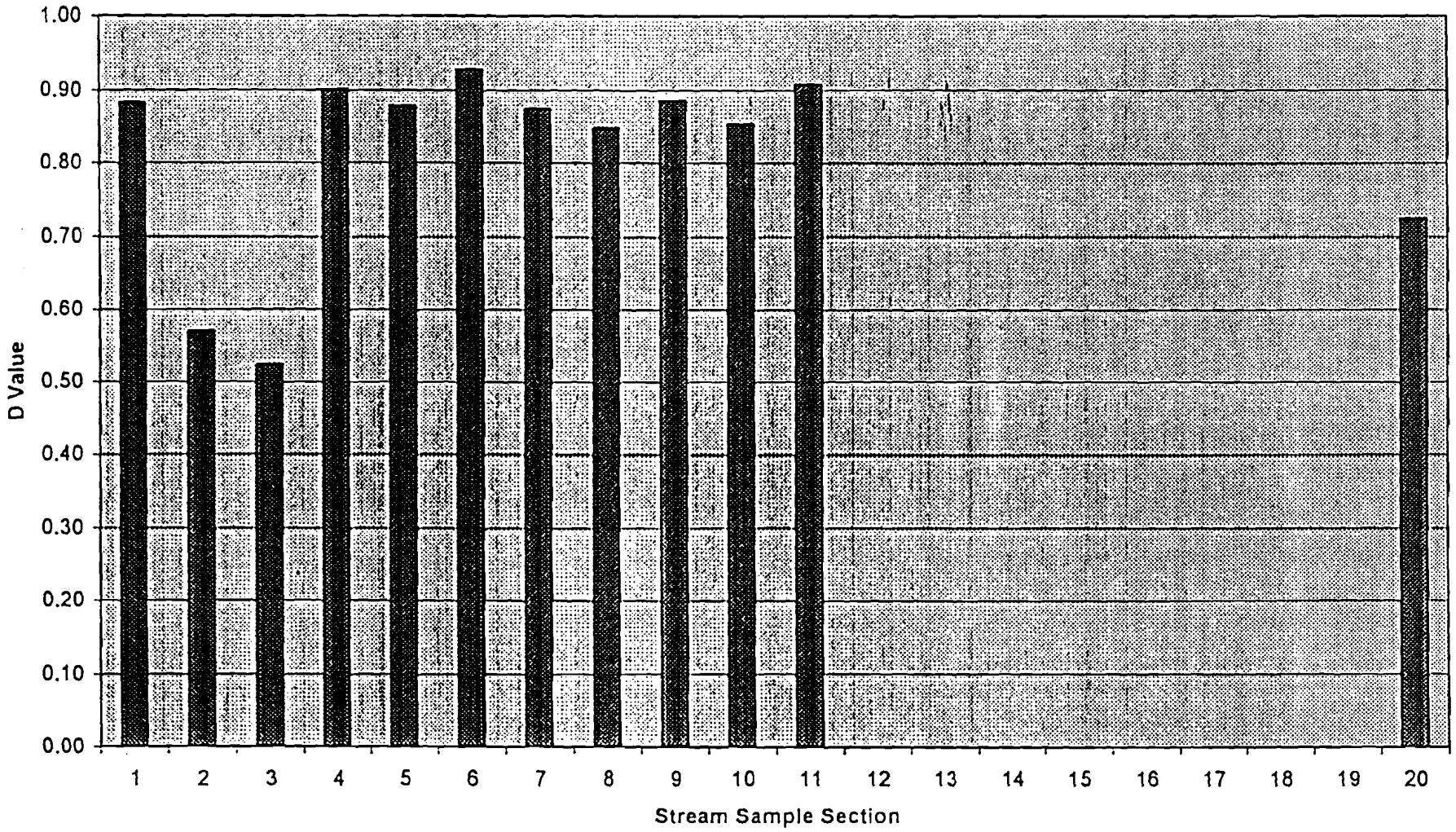


Figure 59. Simpson's D Diversity
Hurricane River, 1996

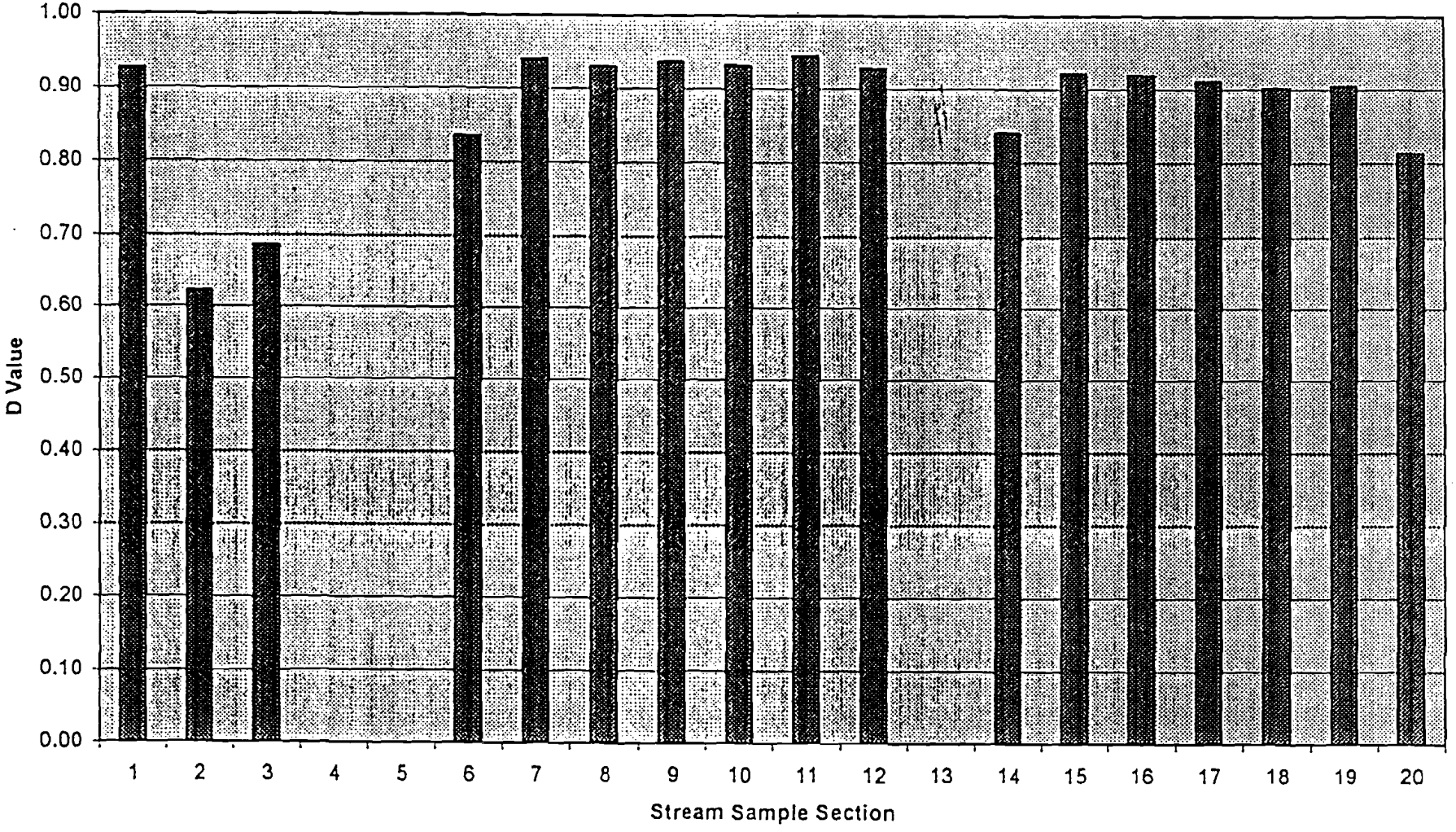


Figure 60. Simpson's D Diversity
7 Mile and Sullivan River, 1996

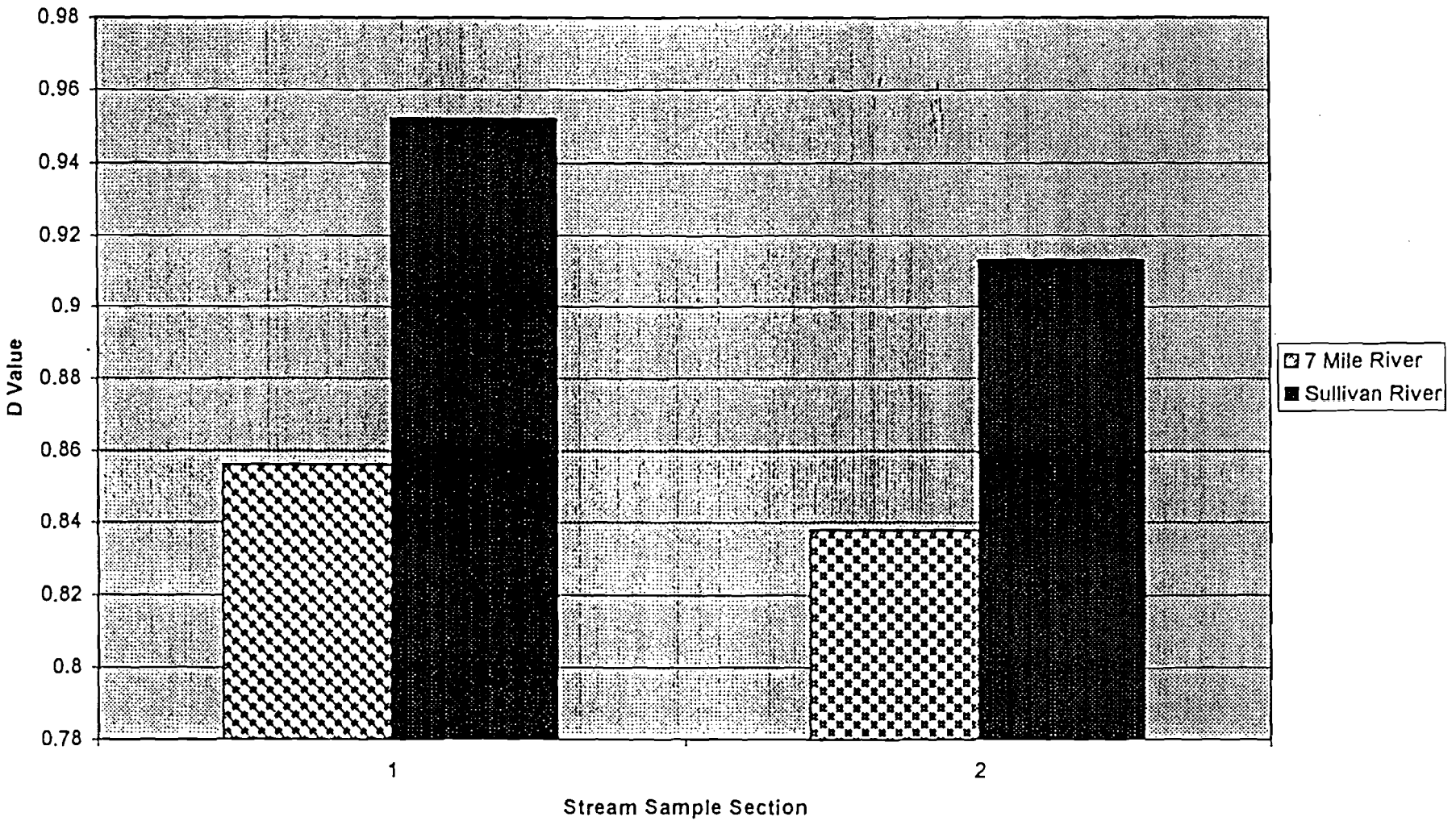


Figure 61. Number of EPT Taxa by Stream Section
Mosquito River, 1994

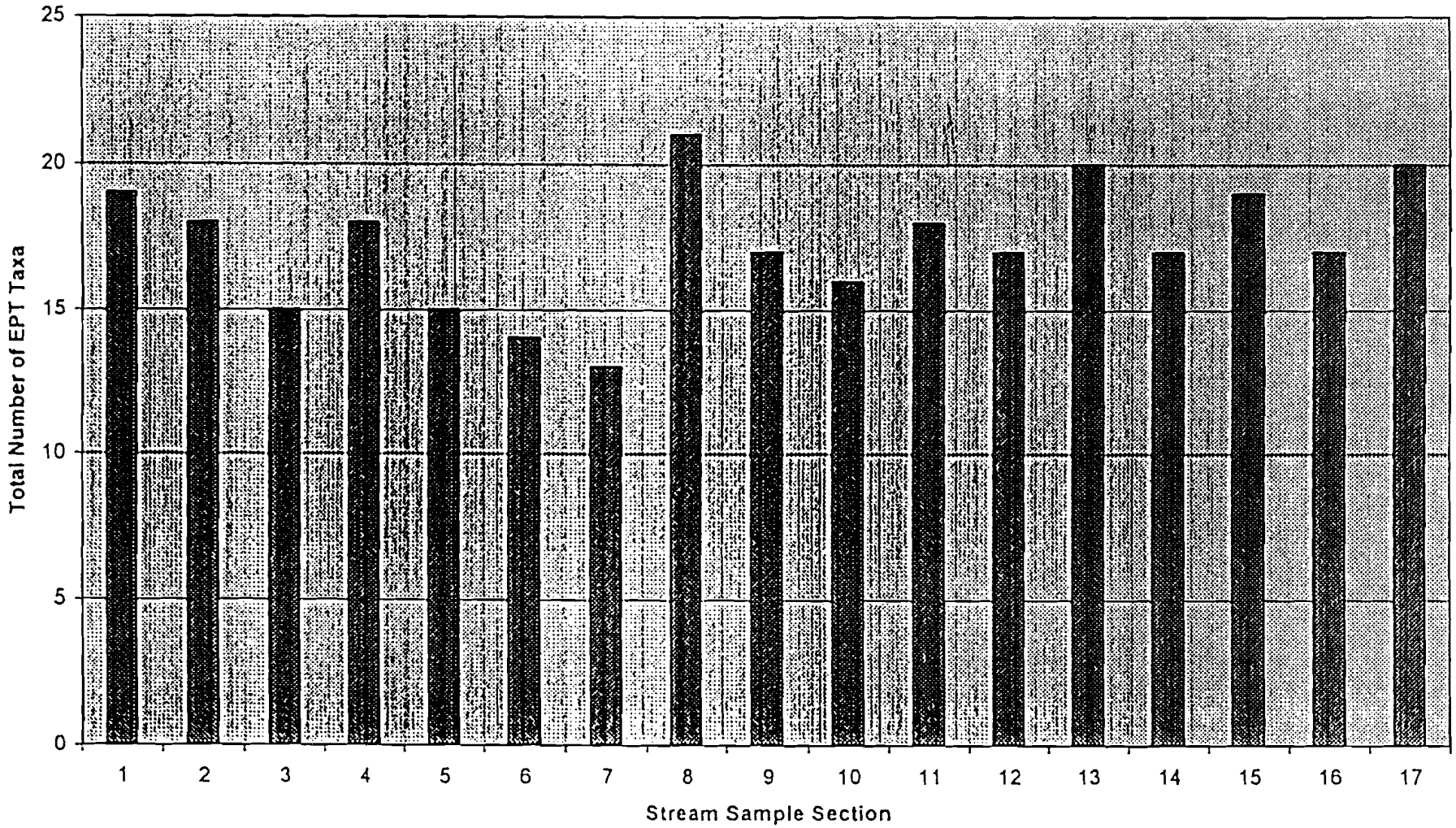


Figure 62. Ratio EPT Taxa:Total Taxa
Mosquito River, 1994

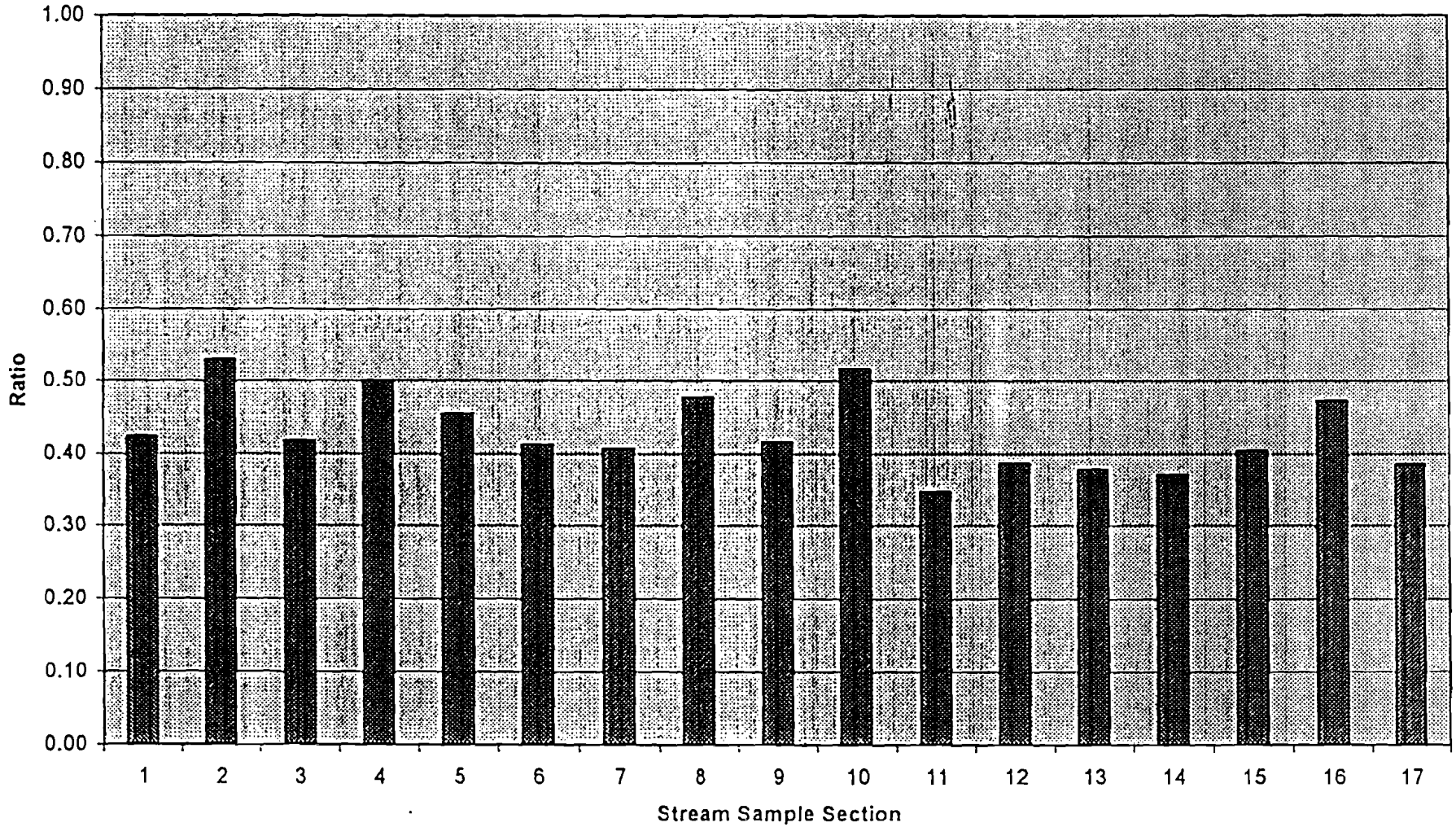


Figure 63. Number of EPT Taxa by Stream Section
Mosquito River, 1996

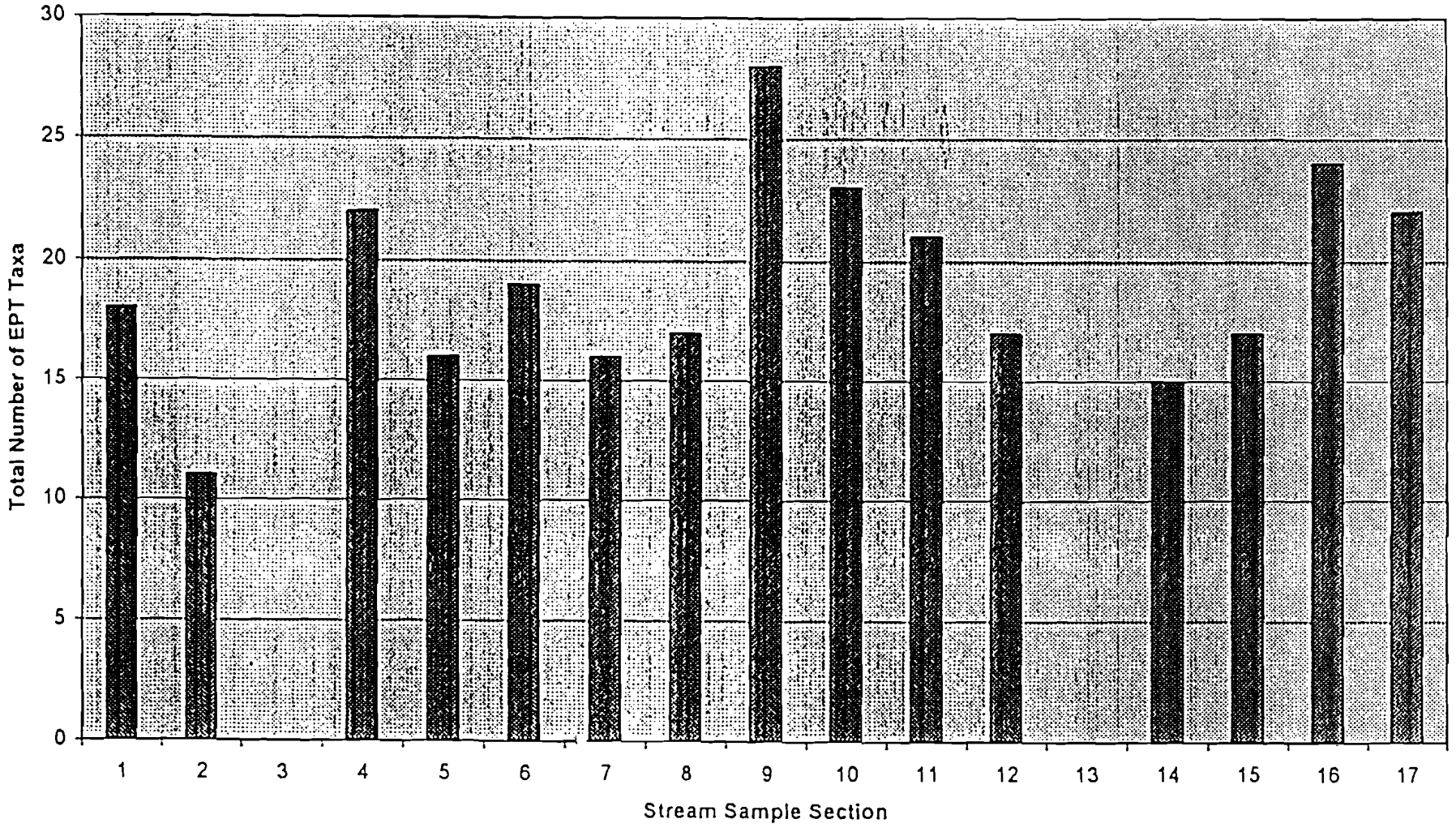


Figure 64. Ratio EPT Taxa:Total Taxa
Mosquito River, 1996

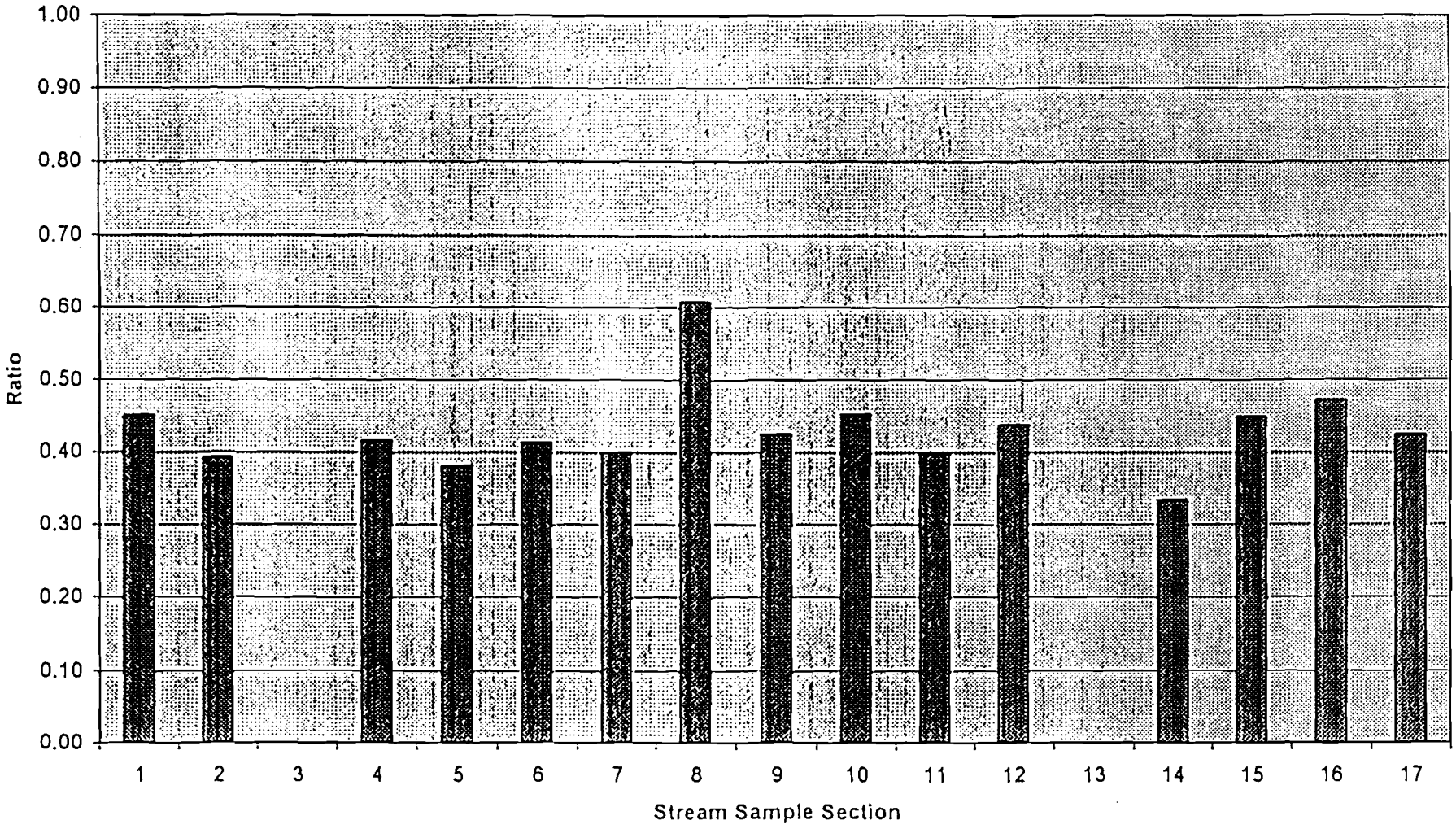


Figure 65. Number of EPT Taxa by Stream Section
Miners River, 1995

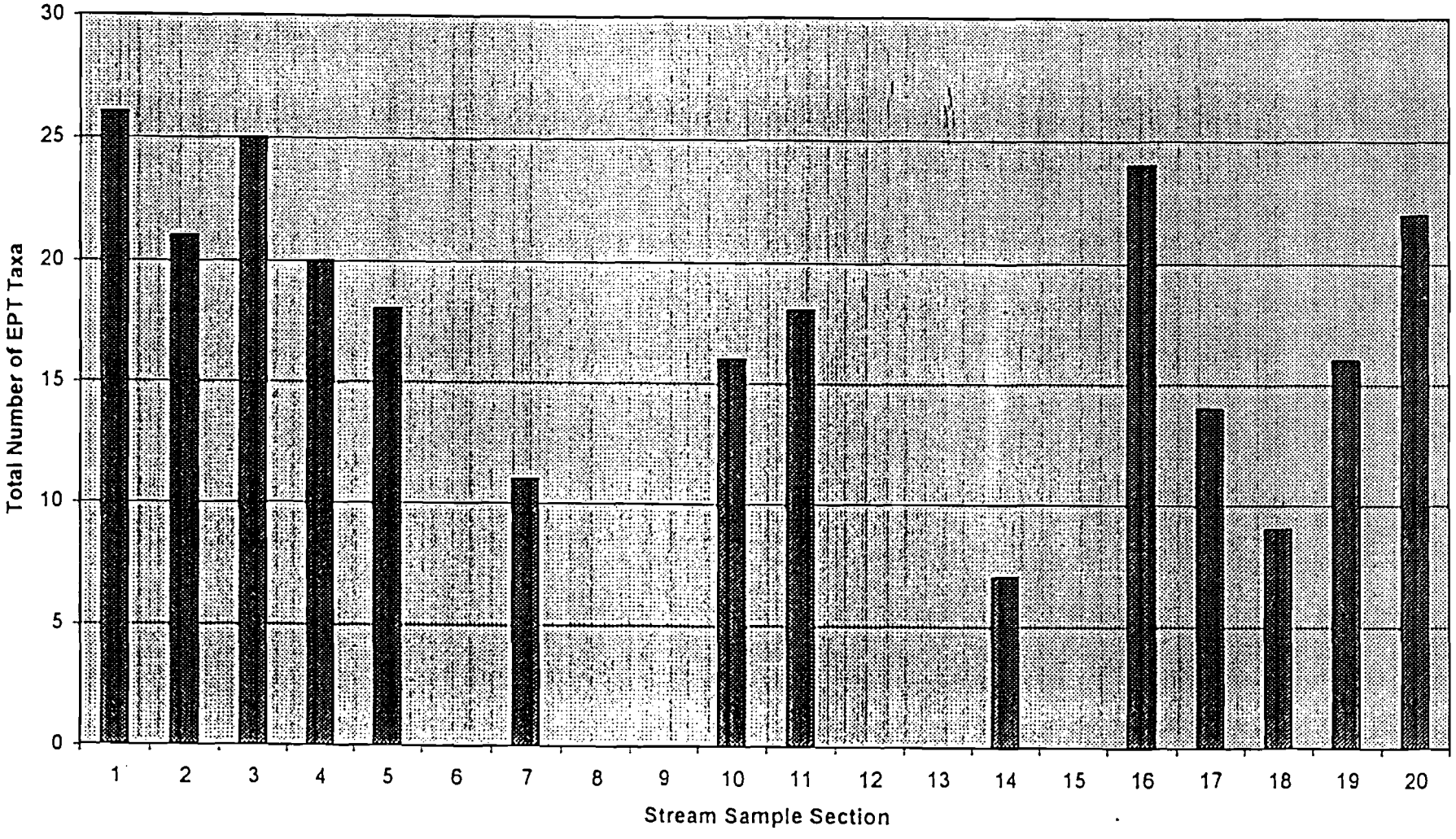


Figure 66. Ratio EPT Taxa:Total Taxa
Miners River, 1995

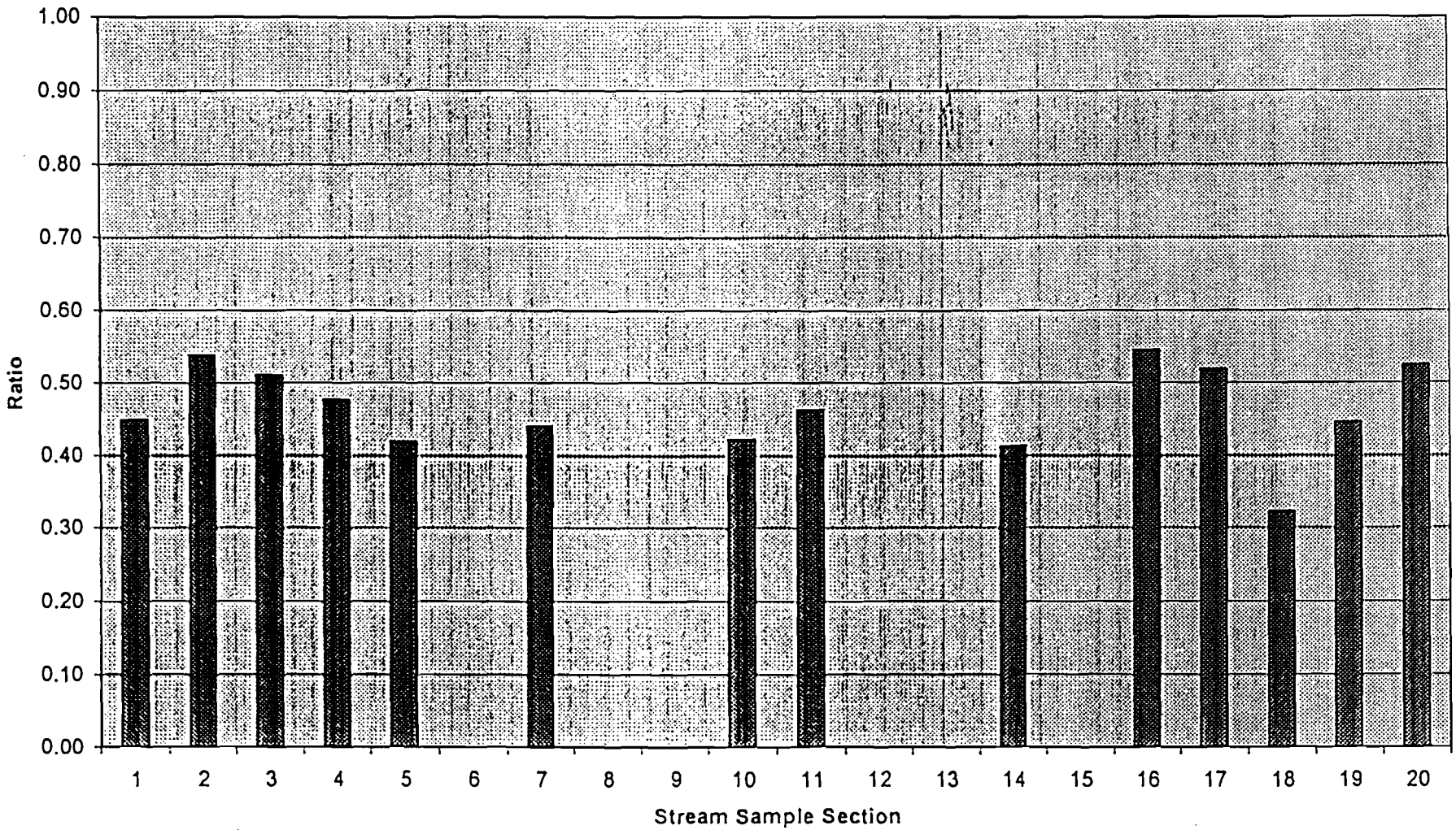


Figure 67. Number of EPT Taxa by Stream Section
Miners River, 1996

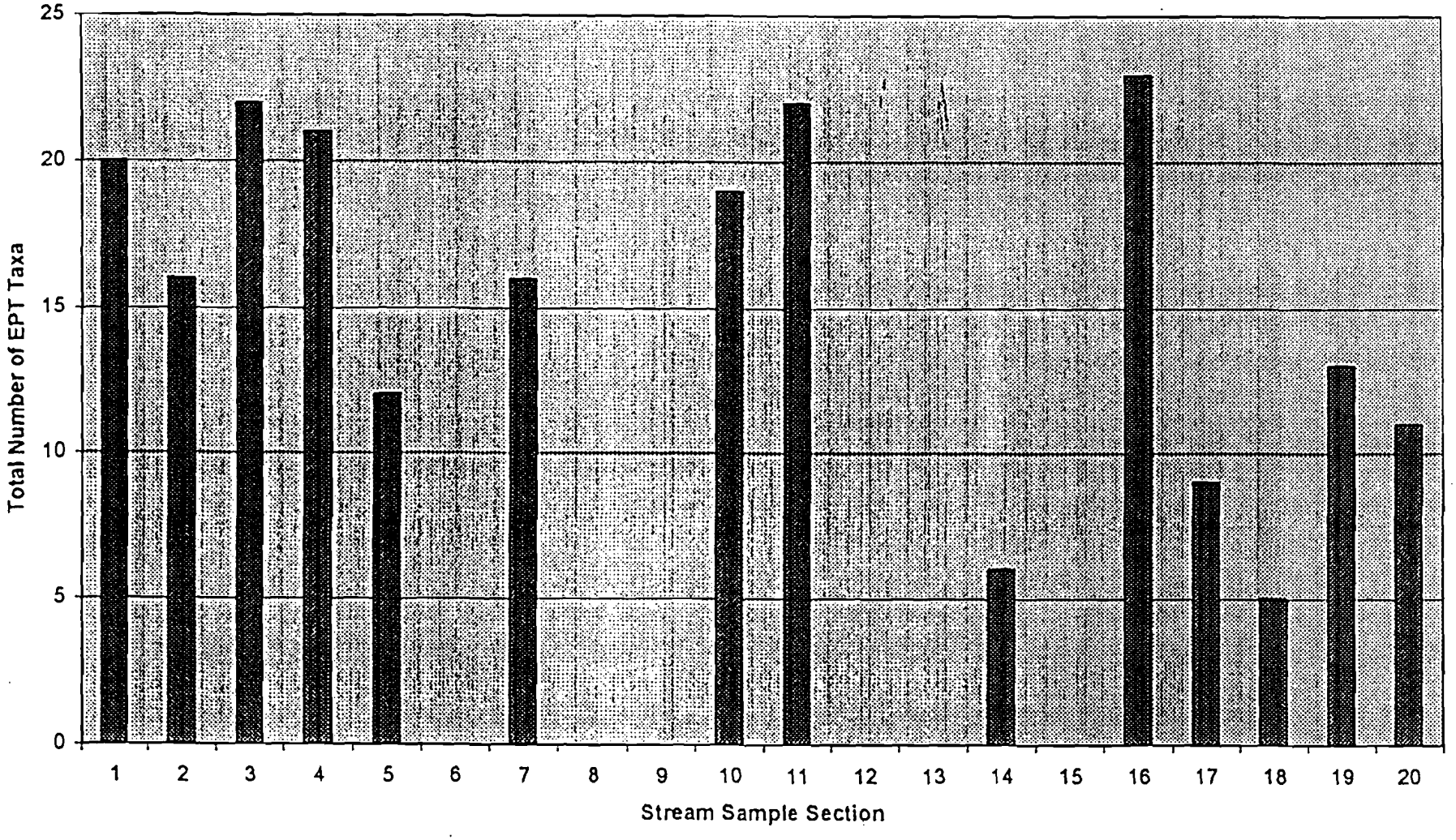


Figure 68. Ratio EPT Taxa:Total Taxa
Miners River, 1996

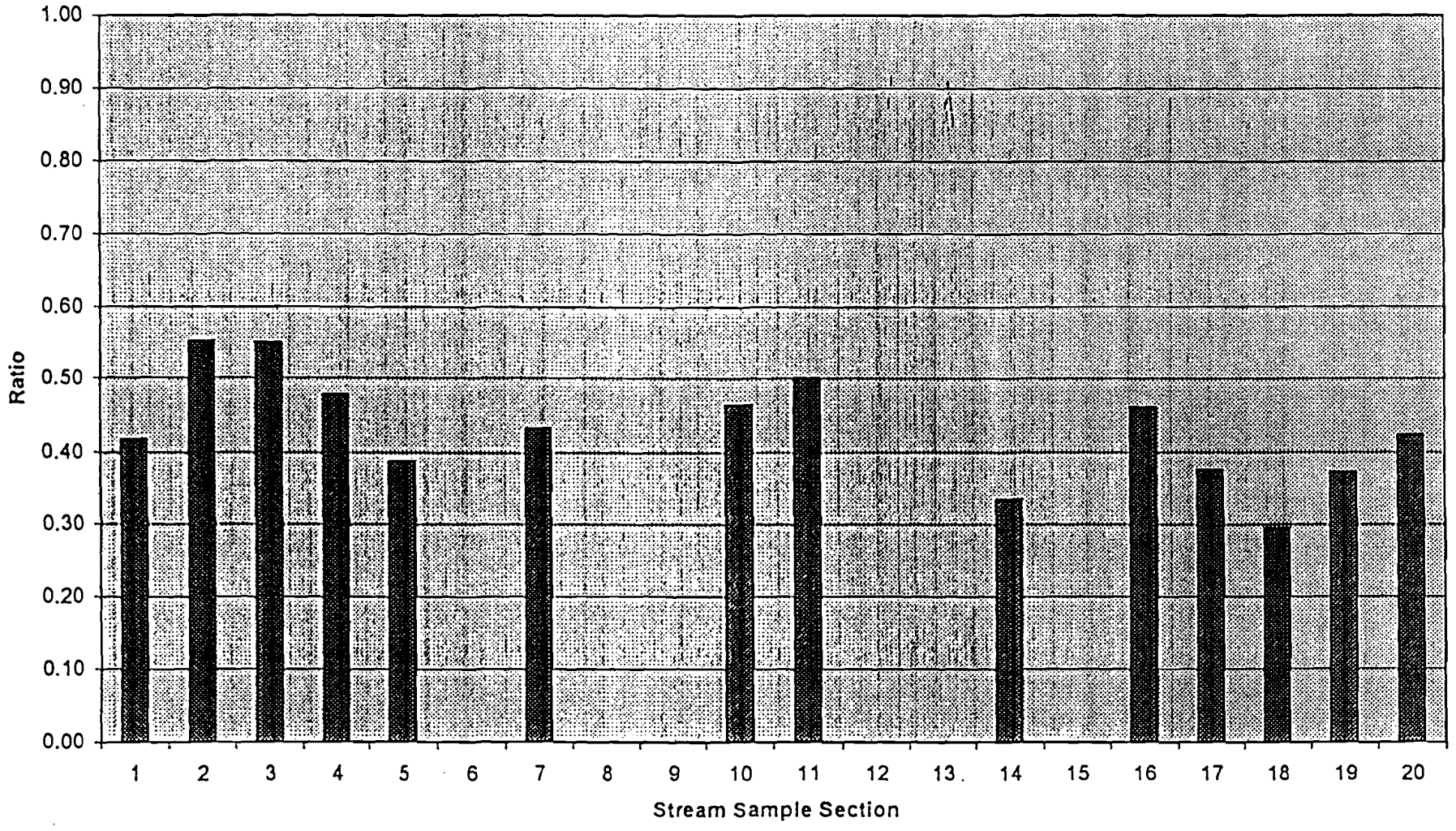


Figure 69. Number of EPT Taxa by Stream Section
Hurricane River, 1995

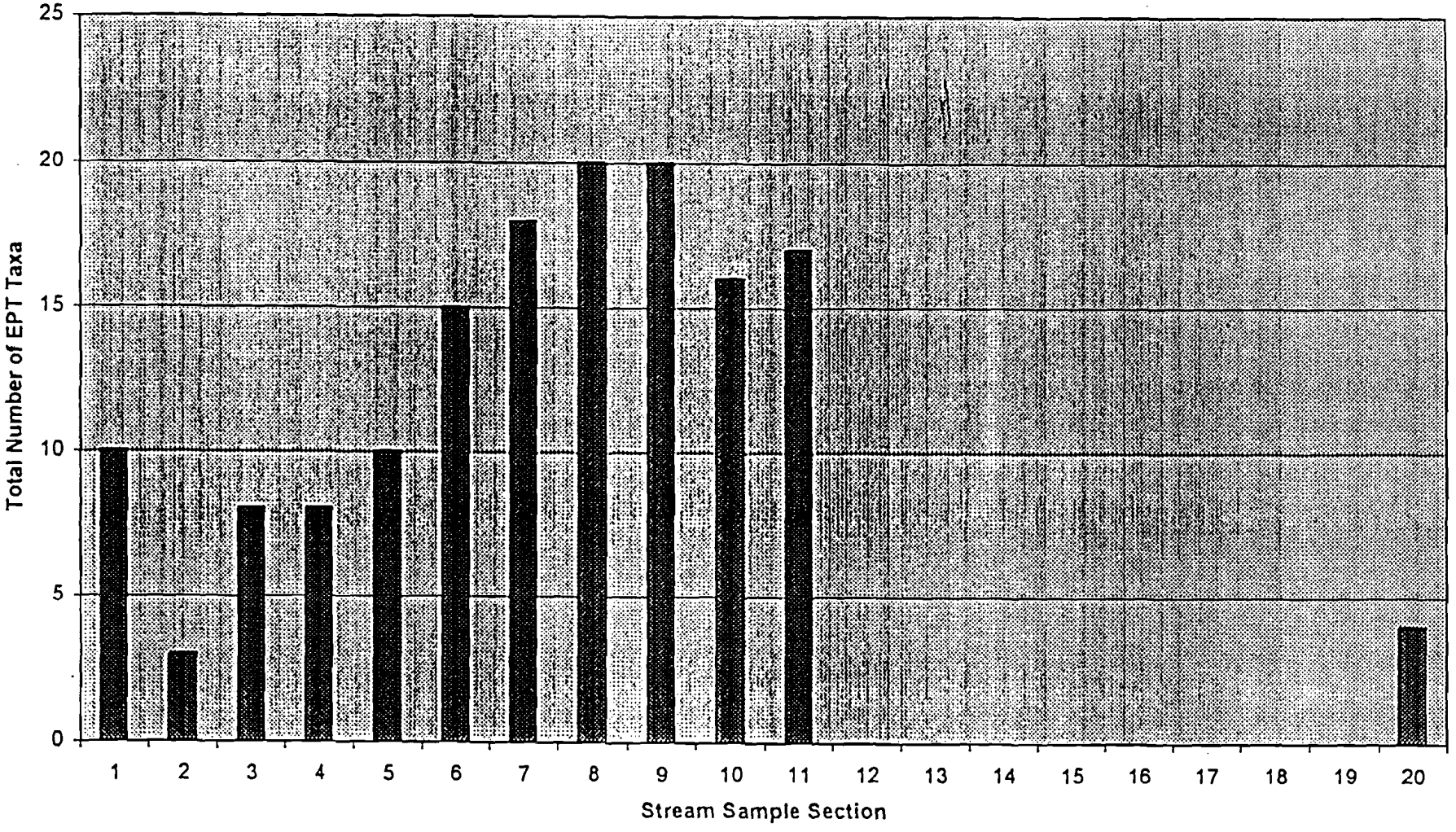


Figure 70. Ratio EPT Taxa:Total Taxa
Hurricane River, 1995

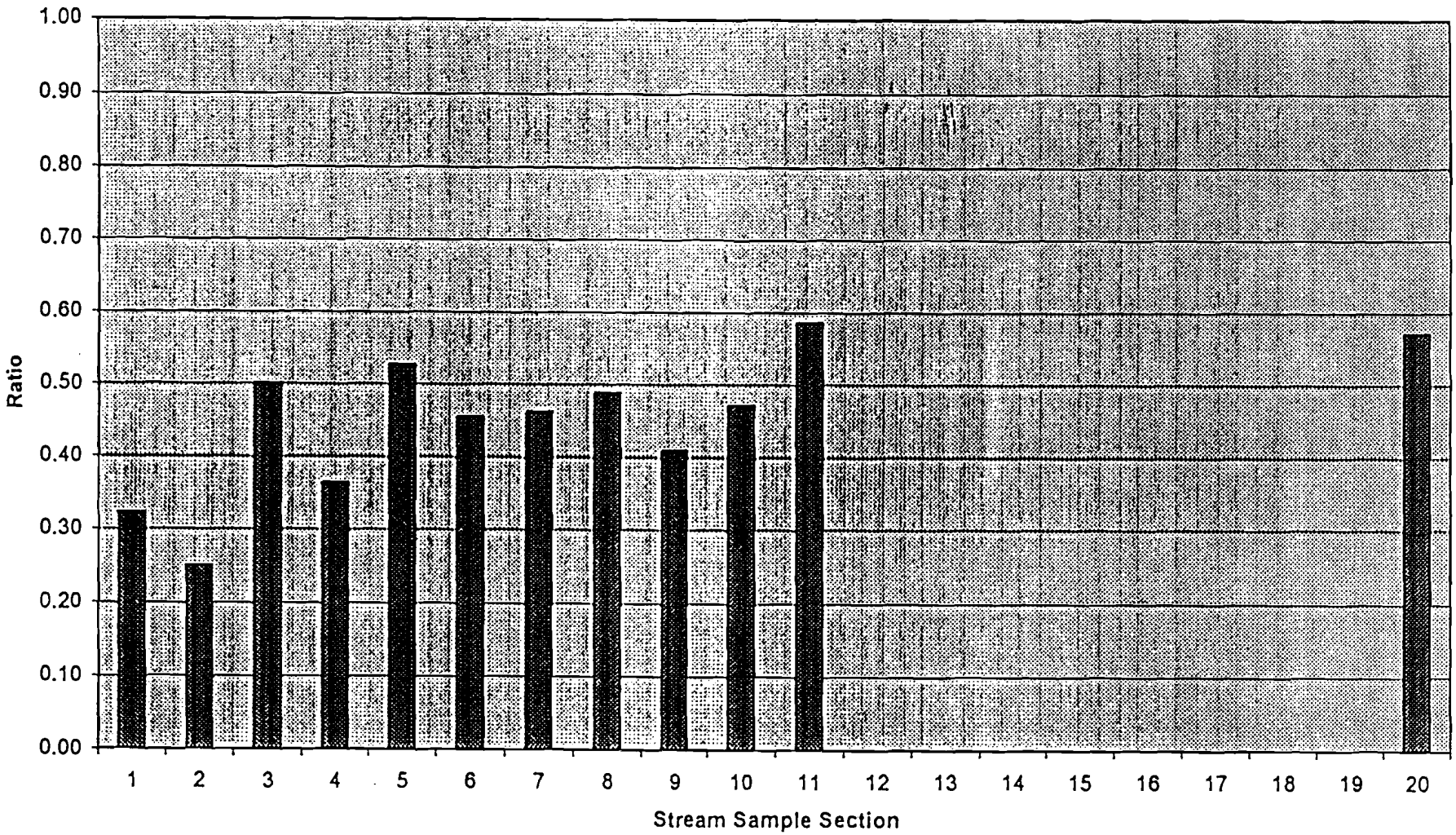


Figure 71. Number of EPT Taxa by Stream Section
Hurricane River, 1996

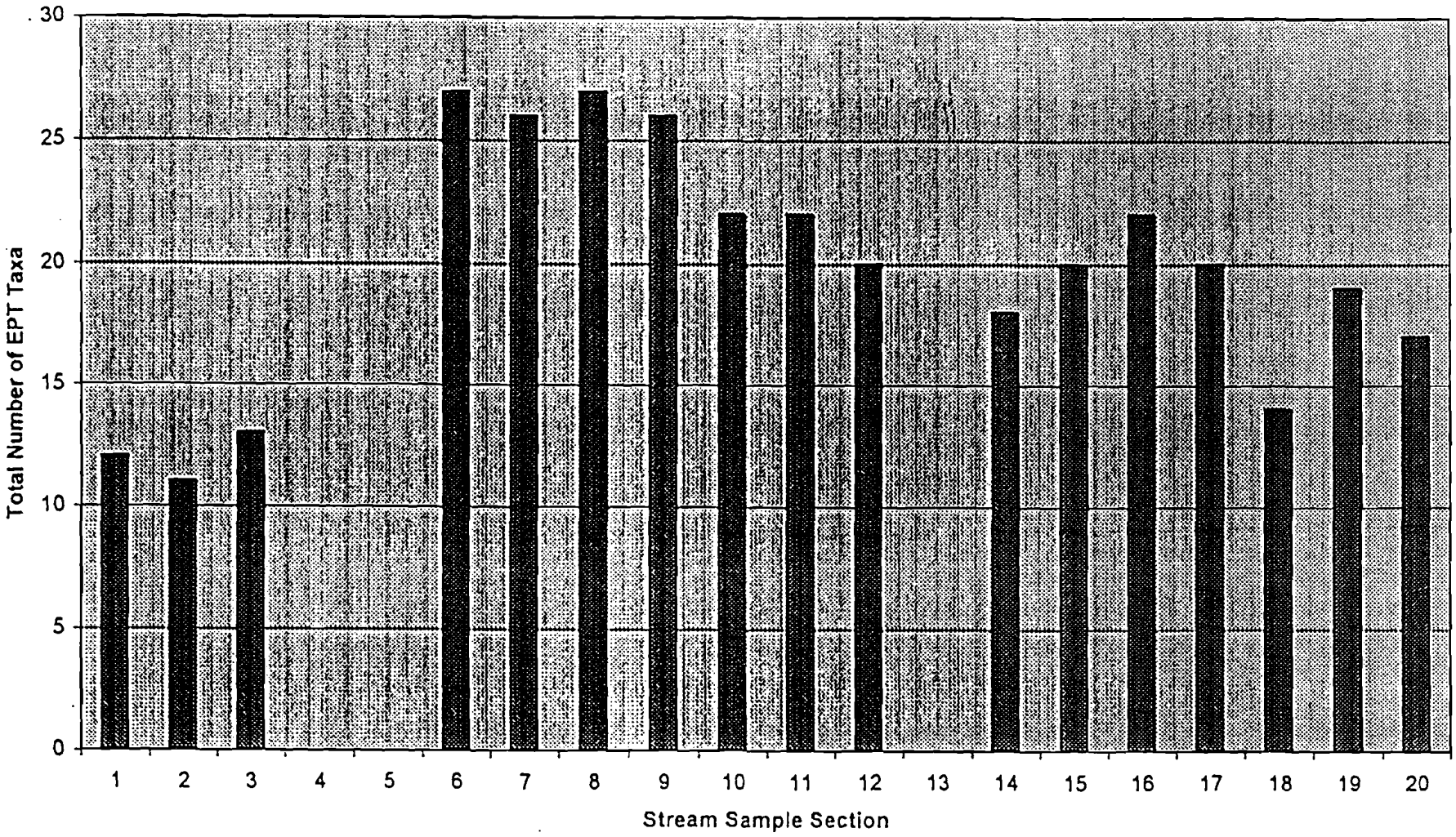


Figure 72. Ratio EPT Taxa:Total Taxa
Hurricane River, 1996

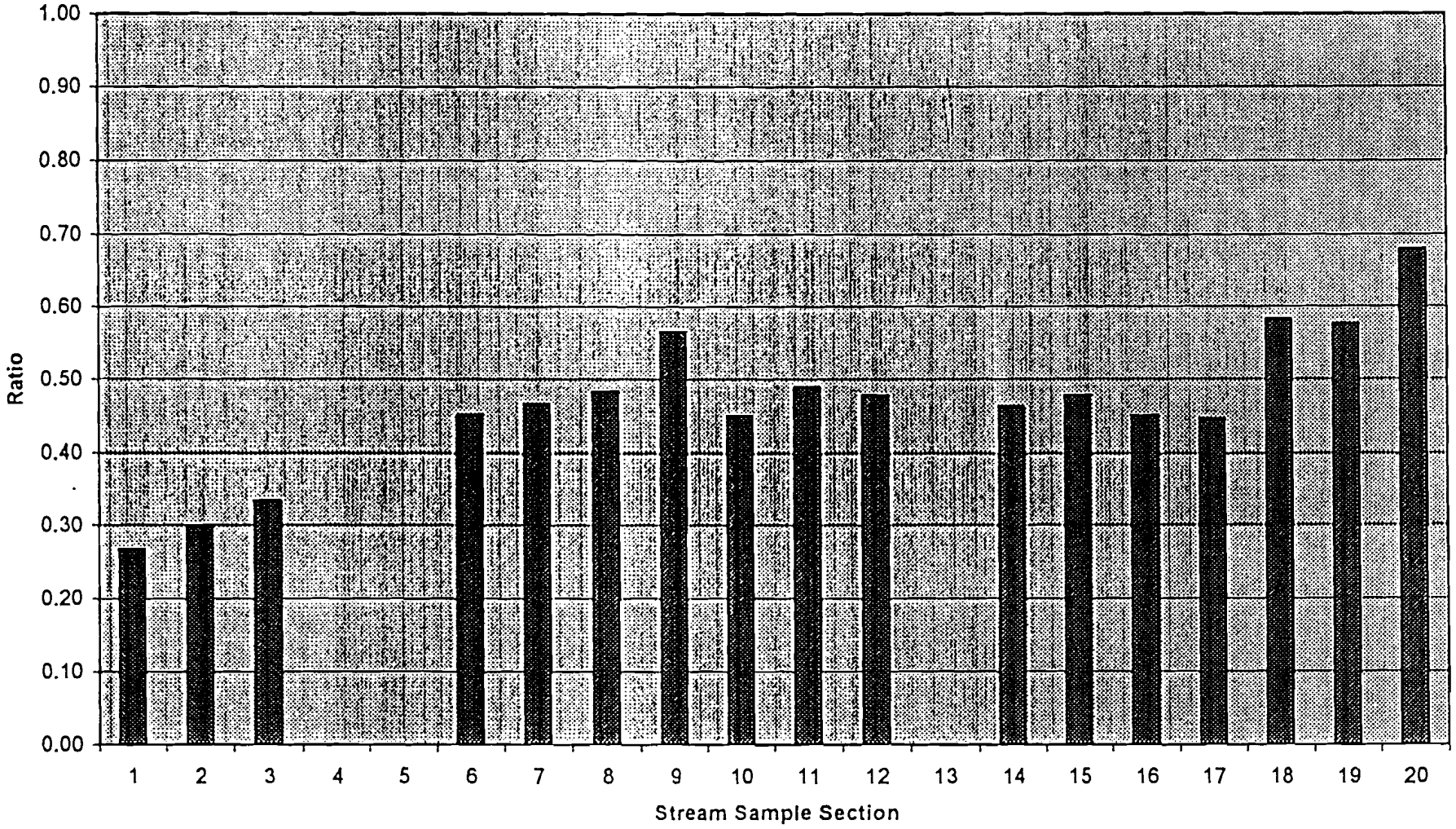


Figure 73. Number of EPT Taxa by Stream Section
7 Mile and Sullivan River, 1996

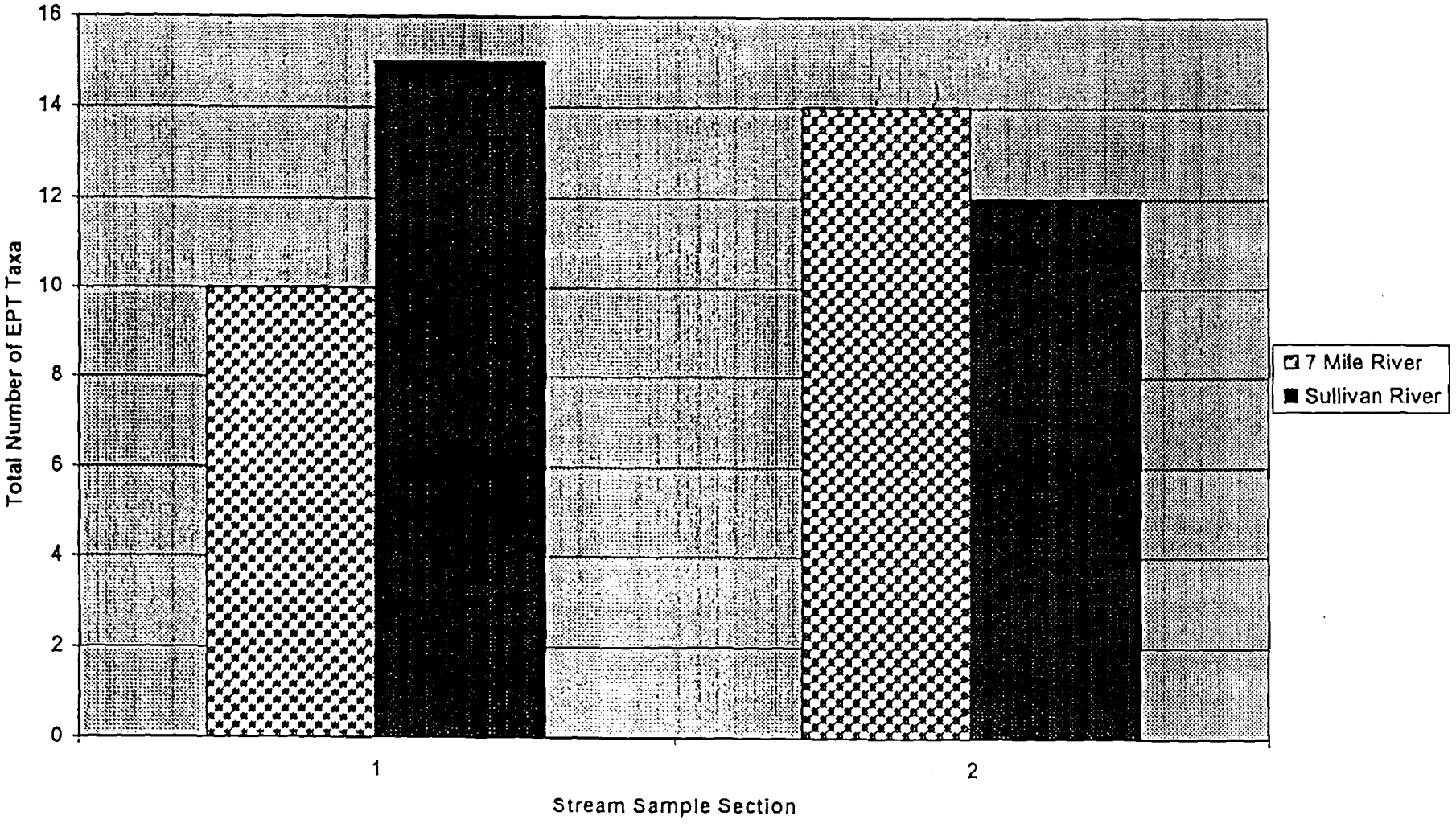


Figure 74. Ratio EPT Taxa:Total Taxa
7 Mile and Sullivan River, 1996

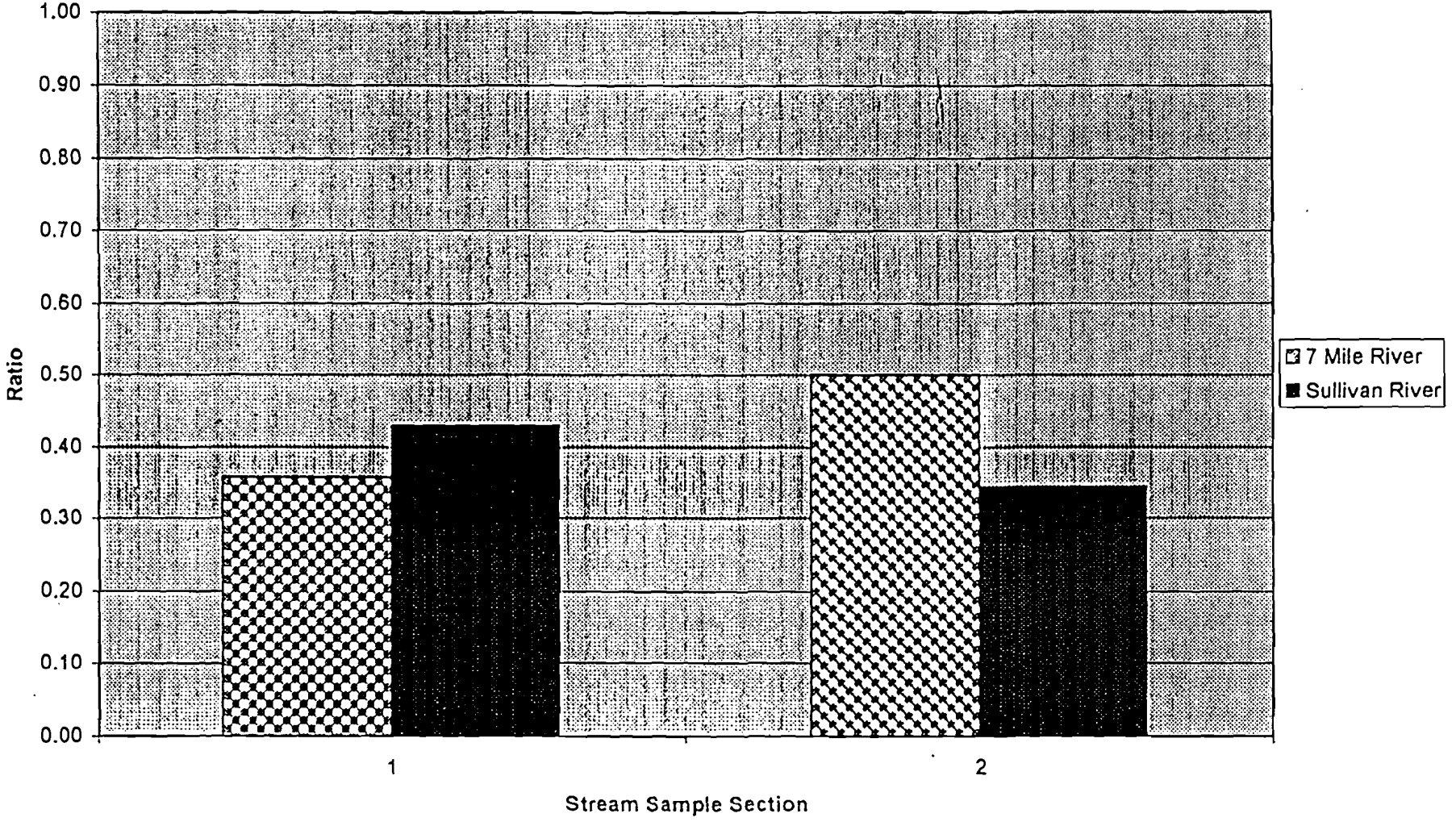


Figure 75. Fish Length

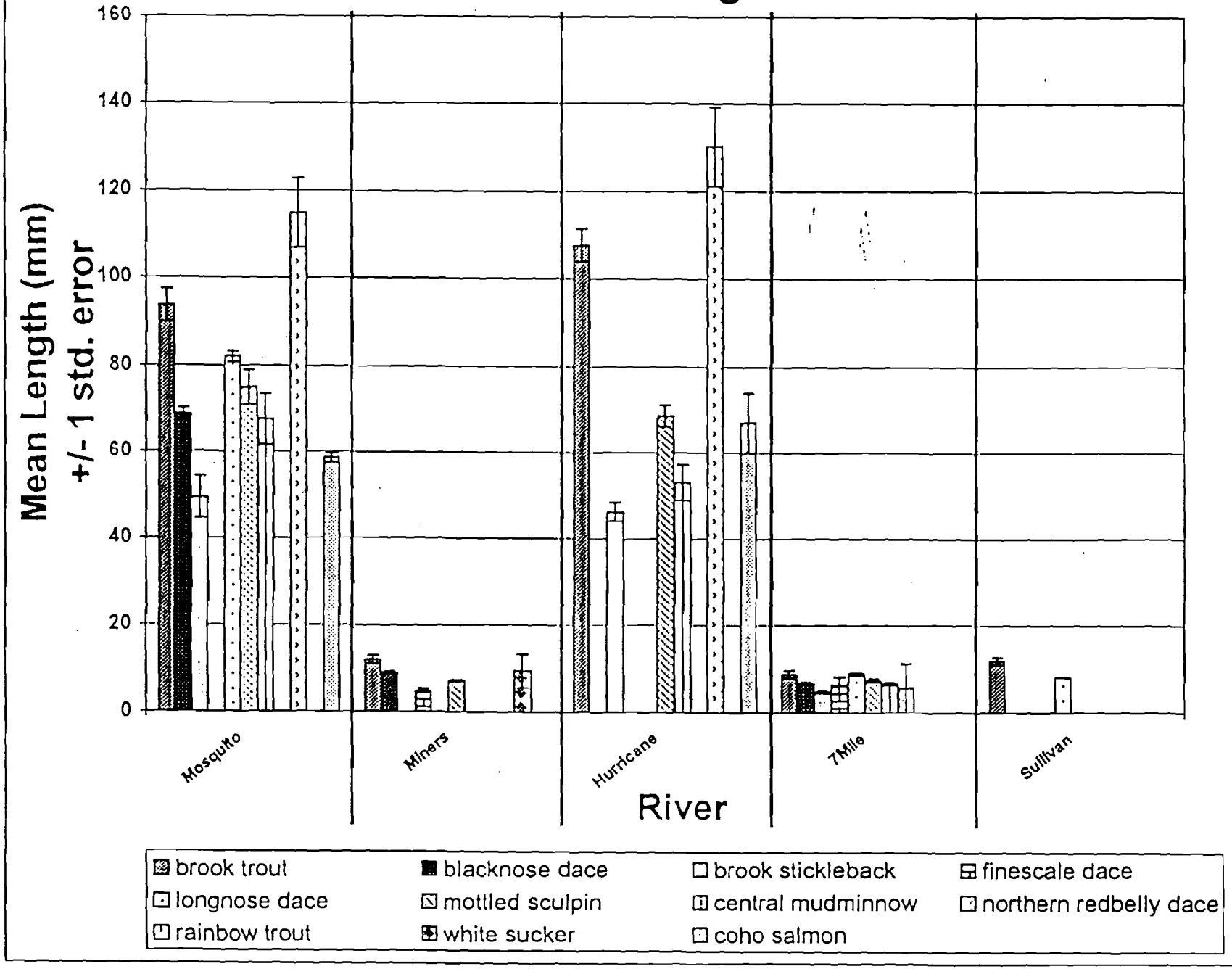
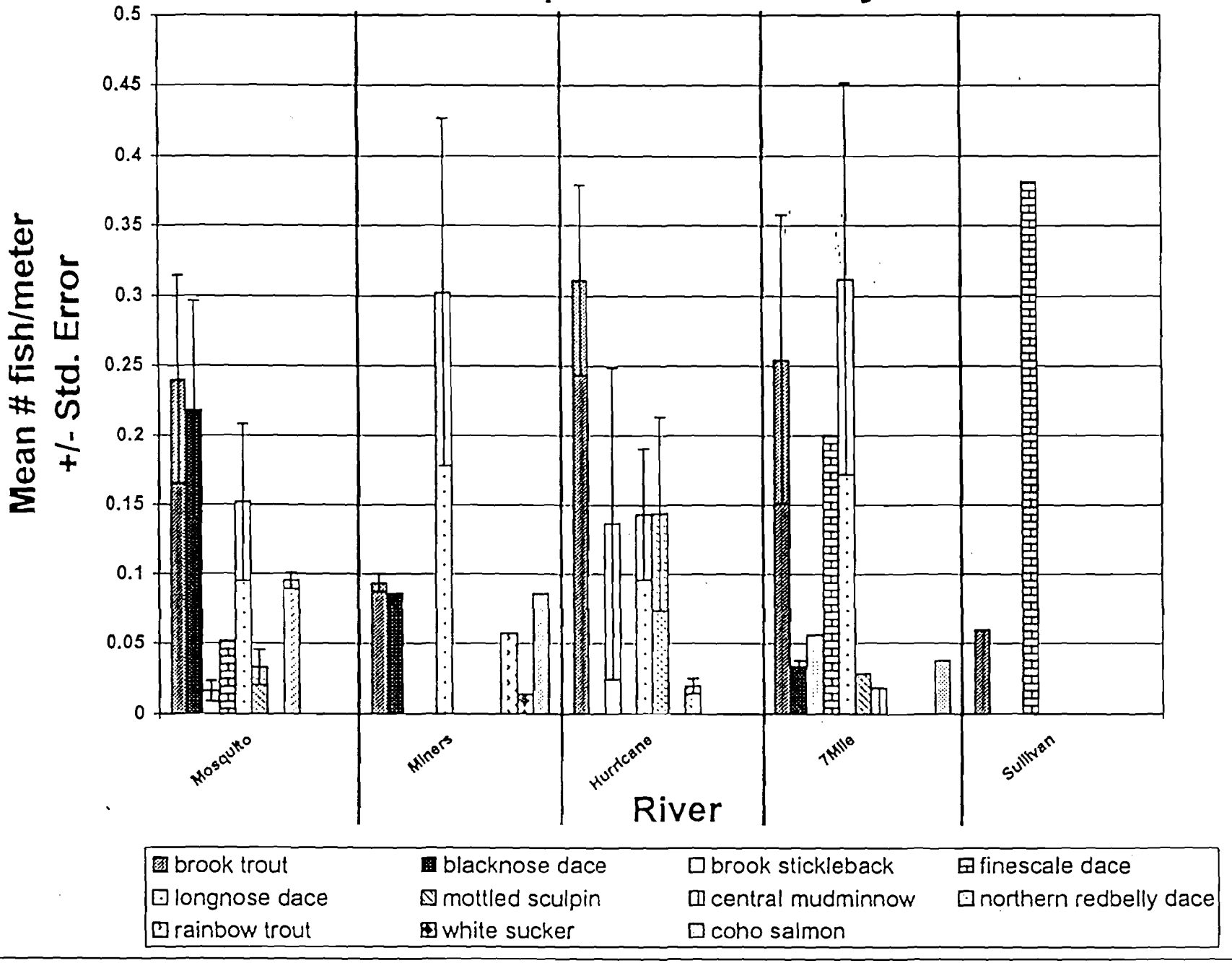



Figure 76. Fish Population Density